Prosthodontics at a Glance

Irfan Ahmad
Prosthodontics at a Glance
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Prosthodontics at a Glance

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BDS
The Ridgeway Dental Surgery
Middlesex
UK
For my caring wife, Samar, my shining children Zayan and Zaina, and my loving father Mansur Ahmad
What good’s a disease that won’t hurt you?  

Lou Reed
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In a Utopian context, a tooth should survive throughout life, unscathed by disease or trauma. However, in the real world, a tooth endures vicissitudes, often necessitating clinical intervention for ensuring its viability. Assuming a pessimistic stance, from nascence to its final demise, a tooth may undergo the following pathological sequelae: incipient fissure or proximal caries, intracoronal decay, pronounced multi-surface caries, endodontic involvement, extracoronal restoration, intra- and periradicular compromises with or without periodontal involvement leading to extraction, and eventual replacement by either a denture (removable or fixed) or dental implants. On an optimistic note, it is not a fait accompli that these events are inevitable; clinical intervention at any stage can prevent progression to the next, more destructive, eventuality. All these aforementioned stages require some form of clinical intervention for salvaging or replacing lost teeth. This is the basic premise of prosthodontics.

Prosthodontics is defined as restoring and/or replacing missing teeth. At times, the line dividing restorative dentistry and prosthodontics can be vague. As a generality, restorative dentistry is concerned with restoring teeth directly, involving a single visit, while prosthodontics is restoring or replacing teeth indirectly, invariably involving multiple visits, usually with impression and employing a dental laboratory. Furthermore, prosthodontics is a multidisciplinary subject, involving specialties such as periodontics, endodontics, orthodontics, implantology and oral surgery.

Besides resolving pathology, another factor requiring consideration is vanity. In an ever-increasing appearance-conscious society, elective cosmetic dental treatment is burgeoning. Although, at times, this type of treatment may be questionable, the communication revolution has created immense patient awareness leading to an escalating demand for patient-driven treatment planning. Hence, cosmetic or aesthetic treatment is now a major part of prosthodontics.

The purpose of this book is to describe the main concepts of prosthodontics. Its aim is to act as a platform for further reading on a chosen aspect of prosthodontics. The ordered format of the ‘At a Glance’ series accelerates learning, ensures relevance to daily clinical practice, and avoids the tedium and frustration of a verbose text.

Irfan Ahmad
Acknowledgements

There are innumerable friends and colleagues who have, directly or indirectly, helped with the fruition of this project, and at the outset my apologies if I do not mention each person by name. Instead, I offer ‘a big thank you’ to all those who have supported and inspired me during the four years it has taken to write this book.

However, the protagonists that come to mind are my family, relatives and close friends; Karl-Wilhelm Theis for his rock-solid unflagging moral support, Horst-Wolfgang and Christian Haase for creating an aura for global belonging, aesthetic dentistry icon Claude Rufenacht et Madame for showing me a world of art that I never knew existed, Nairn Wilson for pointing me in the right direction regarding topics in this book, Stephen Hancocks for his charismatic persona, Alan Sidi for his continuing help, Federico Ferraris, Angelo Putignano, Francesco Mangani, Antonio Cerutti, Carlo Zappala, Lauro Dusetti, Dinos and Mary Kontouras, Dimitrios Kapagionmidis and Alex Grous for being wonderful company at conferences where we have lectured, Mauro Fradeani for his comprehensive teaching methods, direct composite artists Didier Dietschi, Roberto Spreafico and Newton Fahl, Serhiy and Vera Radlinsky for their entrepreneurial skills, Meshari Al-Otaibi for their continuing encouragement, Giulio Rasperini for his vivacious gregariousness, Ann-Louise Holding for her warm friendship, forward-looking clinician Egle Kunciuviene, Douglas Terry for his unrivalled enthusiasm, Rich Groves for his comradeship, critical thinking Graeme Beresford, Stephen Chu for his ongoing advancements in cutting-edge clinical research, living dental legend Denis Tarnow for being an exceptional role model, and Hina Robinson for ‘being there’.

Image acknowledgements:
• Ami Smidt (Figs. 11.6, 32.7–32.9, 39.18, 39.20 and 39.21)
• Ilan Gilboa (Figs. 26.4 to 26.6)
• Giulio Rasperini (Figs. 52.10 to 52.12)
• Alan Sidi (Figs. 19.3, 19.4, 19.11, 19.12, and 51.11)
• Patrick Holmes (Figs. 19.9a to 19.10, 52.1 to 52.6, 55.11 to 55.13, 55.18 to 55.20 and 55.22)
• Dorina van der Merwe (Figs. 10.2, 10.3, 39.1 to 39.3, 47.3 and 47.4)

I would like to extend a special and warm thanks to Manuela Brusoni for her friendship, kindness, and belief in my work. Ciao Manuela!

Finally, my gratitude goes to Sophia Joyce and her team at Wiley-Blackwell for their patience in enduring the lapsed deadlines for this book. Thanks for waiting!

Irfan Ahmad
1 Overview: rehabilitation of natural teeth

Black’s cavity classification

<table>
<thead>
<tr>
<th>Class I</th>
<th>Class II</th>
<th>Class III</th>
<th>Class IV</th>
<th>Class V</th>
<th>Class VI</th>
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<tr>
<td>L</td>
<td>B/L</td>
<td>B/L</td>
<td>F</td>
<td>F/L</td>
<td>B/L</td>
</tr>
</tbody>
</table>

Key: B (buccal), L (lingual), F (facial)

Inlay

Preoperative

Preparation

Impression

Fabrication

Postoperative

PLV

Preoperative

Wax-up

Preparation

Impression

Fabrication

Postoperative

Crowns

Preoperative

Preparation

Temporary

Impression

Fabrication

Postoperative

Post-crown

Preoperative

Preparation

Impression

Fabrication

Postoperative
An indirect restoration requires taking an impression and employing a dental laboratory to fabricate the prosthesis. Conversely, a direct restoration is carried out chair-side, usually in a single visit, without using a dental laboratory. Dental prostheses can either be intra- or extracoronal.

**Indirect intracoronal prostheses**

Intracoronal prostheses are defined as those surrounded by one or more natural tooth surface(s). This categorisation is broadly based on Black’s cavity classification:

- **Class I**: lesions of pits and fissures of all teeth, predominantly in premolars and molars;
- **Class II**: lesions on the proximal surfaces of posterior teeth, referred to as MO (mesial-occlusal), DO (disto-occlusal), and MOD (mesial-occlusal-distal);
- **Class III**: lesion in the anterior teeth, similar to a class II lesion, the class III lesion typically appears at the contact point;
- **Class IV**: the class IV lesion is a class III lesion including the incisal corner of an anterior tooth;
- **Class V**: typically occurs at the cervical margins on the buccal, rather than the lingual, aspect of any tooth;
- **Class VI**: not originally in Black’s classification, but has become accepted as an additional lesion that occurs on the tips and cusps of posterior teeth, or along the biting surfaces of the incisors.

Three developments have made Black’s cavity classification redundant. First, research has elucidated biological mechanisms such as demineralisation/remineralisation and the role of fluoride ion, and removal of infected and affected dentine is no longer a prerequisite. Second, new restorative materials such as resin (plastic)-based adhesives and filling materials, and therapeutic filling materials, which are both bacteriostatic and bactericidal, avoid removing vast amounts of tooth. Third, improved and sophisticated techniques such as adhesive protocols allow restorations of small lesions, preventing progression to larger cavities. All these advances preserve more of the natural tooth, and Black’s classification is therefore used today as a notation, rather than as a basis for restoring decay. Whereas, in the past, cavity design was geometric (dictated by the restorative material), it is now amorphous (dictated by the extent of disease).

Smaller lesions are restored by a direct approach, while larger Class II or Class IV are restored indirectly with inlays or onlays (extracoronal), when a direct approach is mechanically or aesthetically inferior. Inlays and onlays are fabricated in a dental laboratory using a variety of materials including composite resins, ceramics and cast gold alloys.

**Indirect extracoronal prostheses**

Extracoronal prostheses are defined as those surrounding one or more natural tooth surface(s). The indications for extracoronal restorations are:

- Restoring structurally compromised teeth;
- Improving function (e.g. altering occlusal vertical dimension – OVD);
- Improving aesthetics (e.g. anterior maxillary and mandibular sextant);
- Abutments for a fixed partial denture (FPD).

Extracoronal prostheses are categorised as:

- **Inlays and onlays** – the difference between an inlay and an onlay is the extent of tooth loss requiring replacement. Broadly speaking, an inlay ‘fits into’, while an onlay incorporates cuspal coverage and ‘fits onto’ the tooth;
- **Porcelain laminate veneers (PLV)** – the principal use of PLVs is improving anterior aesthetics by altering tooth morphology and colour. PLVs are the least invasive of extracoronal restorations, usually involving the buccal surfaces of anterior teeth. If the underlying tooth colour is acceptable, only minimal tooth reduction is necessary (0.3–0.8 mm) for improving shape and colour with a thin porcelain laminate fabricated in a dental laboratory. PLVs are the most prescribed type of restoration for purely cosmetic reasons. However, it should be remembered that preparing vital healthy teeth for PLVs with little aesthetic improvement is contentious, especially if similar results are achievable with less invasive protocols such as bleaching or composite resin fillings;
- **Partial coverage crowns** – partial coverage crowns are an extension of PLVs. They occupy a midpoint between full coverage and the minimally invasive PLV. Many configurations are possible, e.g. ½, ¾, ⅞, etc. The rationale for partial coverage is retaining as much natural tooth substrate as possible, and hence preserving pulp and structural integrity;
- **Full coverage crowns and fixed partial dentures (FPD) or bridges** – a full coverage, 360° crown is indicated for severely broken-down teeth, abutments for FPDs, or rarely for elective aesthetic treatment. Various materials are used for fabricating crowns depending on the clinical scenario, e.g. cast metal, metal-ceramic, all-ceramic, composite and acrylic. For vital teeth, a crown can be supported either by coronal dentine or a core build-up. For endodontically treated teeth a post-and-core complex may be necessary. Intra-radicular posts are available in many materials, designs, configurations and sizes. A core can be fabricated directly in the mouth using amalgam or composite, or indirectly in a dental laboratory using cast metals or ceramics. The sole purpose of a post-and-core complex is supporting the eventual extracoronal crown. Posts and cores do not reinforce or strengthen teeth, but weaken an already compromised root and the remaining coronal dentine. A ferrule effect is highly desirable for cores (with or without posts);
- **Combination prostheses** – depending on the extent of the clinical requirements, any intra- and extracoronal restoration can be combined into a single entity, e.g. inlay + onlay or PLV + inlay (veneerlay).

**Key points**

- A direct restoration is carried out chair-side, while an indirect restoration requires using a dental laboratory.
- Black’s classification, although redundant, is useful for describing the site of a lesion.
- Intracoronal restorations are surrounded by tooth surface(s).
- Extracoronal restorations surround tooth surface(s).
- Inlays are examples of intracoronal prostheses.
- Onlays, PLVs and crowns are examples of extracoronal prostheses.
Overview: rehabilitation by artificial teeth

Removable partial denture: tissue and tooth supported

Partially Edentulous

Fixed partial denture, e.g. Rochette bridge

Fixed partial denture (conventional fixed-fixed), using natural tooth abutments

Total Edentulous

Exclusively tissue-borne full denture

Tissue-borne combined with implants and/or root supported overdentures

Established clinical and laboratory protocols
• Irreversible destruction to abutment teeth
• Possible endodontic and/or periodontic complications of abutment teeth
• Bone loss at pontic site(s)
• Difficult oral hygiene procedures

Minimally invasive
• Poor retention
• Frequent dislodgment
• Bone loss below pontic site(s)
• Technique sensitive

Minimally invasive
• Poor retention
• Frequent dislodgment
• Bone loss below pontic site(s)
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Minimally invasive
• Poor retention
• Frequent dislodgment
• Bone loss below pontic site(s)
• Technique sensitive
Oral rehabilitation of *missing teeth* is achieved with *removable* or *fixed prostheses*. The distinction between the two is that removable prostheses are supported by both soft tissues and teeth and/or implants, whereas fixed prostheses are exclusively supported by teeth and/or implants. Before deciding to replace missing teeth, the shortened arch concept should be considered.

**Removable full dentures (RFD)**

Edentulous rehabilitation is either with *full/full dentures*, totally supported by the alveolar ridges, or with *overdentures* supported by strategically placed implants and/or retained natural tooth roots for additional stability.

**Removable partial dentures (RPD)**

An RPD relies on support from both soft tissues and adjacent or surrounding natural teeth or implants. These dentures can be fabricated entirely from acrylic resins, or in combination with cast metal frameworks. Clasp, rests and precision attachments are often incorporated into the denture design for additional retention and stability. A variation of RPDs are overdentures, retained by tooth roots or mini implants.

**Fixed partial dentures (FPD)**

Before dental implants, fixed partial dentures were the state-of-the-art prostheses for replacing missing teeth, but involve gross tooth preparation of supporting abutments. More conservative FPDs, with minimal or no preparation, include Maryland, Rochette or fibre-reinforced bridges. While the advantages of minimal preparation are obvious, these types of bridge are less retentive, requiring frequent recementing and are often used as transitional prostheses, e.g. during the surgical healing phase following bone grafting or implant placement. Other uses include splinting periodontally compromised mobile teeth, or as an interim restoration while awaiting a more permanent restoration.

Conventional FPDs require preparation of abutment teeth for supporting the final prosthesis incorporating pontic(s) for replacing missing tooth or teeth. Numerous FPD configurations are possible, e.g. fixed-fixed, cantilever, telescopic, with or without precision attachments for stress relief for long spans. FPDs have a cast metal substructure, which is subsequently veneered with porcelain. Newer all-ceramic FPDs use dense ceramic frameworks, e.g. of zirconia or alumina, for supporting the veneering porcelain. Although conventional FPDs using natural teeth as abutments are destructive, they still have a place in prosthodontics where local anatomy contraindicates surgery or implant placement. Besides natural tooth abutments, implants can also act as abutments for FPDs.

**Dental implants**

Dental implants are titanium root forms placed into alveolar bone. Following osseointegration, the implants are prosthetically restored with a variety of artificial prostheses including RFD, RPD and FPD. Implants are extremely versatile and used for replacing a single missing tooth, or as abutments for FPDs for replacing several missing units. In addition, implants offer many advantages compared to conventional prostheses including:

- Improved stability for implant supported RFDs and RPDs;
- Preventing mechanical, periodontal and endodontic insult of supporting teeth associated with RPDs (e.g. by clasps or occlusal rests);
- Occlusal rehabilitation of edentulous areas;
- Greater bite force compared to exclusively tissue-borne prostheses, improving masticatory performance and therefore allowing a wider choice of foods;
- Avoiding tooth preparation of natural teeth bounding missing spaces, e.g. for conventional FPDs, reducing possibilities of endodontic and periodontal complications;
- Preventing further bone loss (due to bone stimulation by the implants in edentulous areas);
- Immunity from secondary caries of natural tooth abutments used for conventional FPD.

Although implants offer numerous advantages compared to conventional treatment modalities, detailed planning, clinical training, experience and meticulous execution are mandatory for avoiding complications and failures. Before deciding whether the patient is a suitable candidate for dental implants, an initial MAP (medical, anatomy, prognosis) assessment is necessary:

- Medical considerations – age, race, gender, compromised immune system, diabetes, osteoporosis, bisphosphonate therapy, radiotherapy, psychological stress, pregnancy;
- Anatomy – soft tissue volume, dental biotype, bone quality and quantity, aesthetics (site: anterior or posterior regions of mouth), reduced vascularity from previous surgical traumas (e.g. apicectomies), proximity to vital structures (nerves, blood vessels, sinuses), occlusal clearance, parafunctional habits (e.g. bruxism);
- Prognosis – not only for an implant, but also for conventional treatment options depending on prevailing clinical situation such as:
  - What is the survival rate of a tooth with periodontitis following periodontal surgery?
  - What is the success of endodontic re-treatment?
  - What is the longevity of an apicectomised tooth with a post crown?

A risk assessment is essential before deciding whether to pursue conventional treatment options, or consider implants at the outset. The cost implications of conventional vs implant treatment are also worth consideration. If the prognosis for conventional treatment is poor, it is futile spending time and money which could be better allocated for treatment that has greater long-term predictability.

**Key points**

- Missing teeth can be replaced by fixed or removable prostheses.
- Exclusively tissue borne removable prostheses, e.g. RFD or RPD, are economical and have established protocols, but are a compromise for long-term oral rehabilitation.
- Conventional FPD are highly destructive, but obviate the need for bone and soft tissue surgical procedures.
- Implant-supported single or multiple units are the state-of-the-art treatment modality for oral rehabilitation, but require specialist training and experience for successful outcomes.
European Medical Risk Related History (EMRRH) questionnaire

1. Do you experience chest pain upon exertion (angina pectoris)? If so, (II)
   Are your activities restricted? (III)
   Have the complaints increased recently? (IV)
   Do you have chest pain at rest? (V)
2. Have you ever had a heart attack? If so, (II)
   Are your activities restricted? (III)
   Have you had a heart attack in the last 6 months? (IV)
3. Do you have a heart murmur, heart valve disease, or an artificial heart valve? (II)
   Have you had heart disease or vascular surgery within the last 6 months? (II)
   Have you ever had rheumatic heart disease? (III)
   Are you activities restricted? (IV)
4. Do you have heart palpitations without exertion? If so, (IV)
   Are you short of breath, pale or dizzy at these times?
5. Do you suffer from heart failure? If so, (II)
   Are you short of breath when lying down? (III)
   Do you need two or more pillows at night due to shortness of breath? (IV)
6. Have you ever had high blood pressure? (II)
7. Do you have a tendency to bleed? If so, (II)
   Do you bleed more than one hour following injury or surgery? (III)
   Do you suffer from spontaneous bruising? (IV)
8. Have you ever suffered a cerebral congestion? If so, (II)
   Have you suffered from one in the last 6 months? (III)
9. Do you have epilepsy? If so, (II)
   Is your condition getting worse? (III)
   Do you continue to have attacks despite medication?
10. Do you suffer from asthma? If so, (II)
    Do you use any medication and/or inhalers? (III)
    Is your breathing difficult today? (IV)
11. Do you have other lung problems or a persistent cough? If so, (II)
    Are you short of breath after climbing 20 steps? (III)
    Are you short of breath while getting dressed? (IV)
12. Have you ever had an allergic reaction to penicillin, aspirin, latex or anything else? If so, (II)
    Did this require medical or hospital treatment? (III)
    Was it during a dental visit? (IV)
    What are you allergic to?
13. Do you have diabetes? (II)
    Are you on insulin? If so, (III)
    Is your diabetes poorly controlled at present? (IV)
14. Do you suffer from thyroid disease? If so, (II)
    Do you have an underactive thyroid? (III)
    Do you have an overactive thyroid? (IV)
15. Have you now or in the past had liver disease? (II)
16. Do you have a kidney disease? (II)
    Are you undergoing dialysis? (III)
    Have you had a kidney transplant? (IV)
17. Have you ever had cancer or leukaemia? (IV)
    Have you received drug therapy or had a bone marrow transplant for this? (III)
    Have you ever had X-ray treatment for a tumour or growth in the head or neck? (IV)
18. Do you suffer from any infections at present? (II)
    If so, which is it?
19. Do you suffer from hyperventilation? (II)
20. Have you ever fainted during dental or medical treatment? (II)
21. Do you have to take antibiotics before dental treatment? (II)
22. Are you on any medication at present? (II)
23. Women only, please: are you pregnant? (II)

The ASA rating is stated in blue parentheses, no abnormality is rated as I. The higher the number, the greater the risk of medical complication for dental treatment.

Medical emergency drugs commonly found in a dental practice

Cardiac problems are the most frequent form of medical complications affecting dental treatment. A knowledge of CPR and readily available oxygen can avert fatal consequences.
**History taking** is the first stage before embarking on dental treatment. Recent medical advances have prolonged life expectancy, and age-related and chronic illness treated with long-term medication influences an individual’s medical status. Furthermore, the ever increasing elderly population retain more of their natural teeth, requiring regular dental maintenance. Collating a patient’s history is not confined to **medical anamnesis**, but also takes account of **familial medical traits** and **social habits**. All these factors can, and may, affect dental procedures.

**Family medical history**

There is widespread consensus among physicians that many diseases have a **genetic origin**, and a sibling may harbour genes which may or may not manifest as an eventual ailment. Also, many diseases are **multi-factorial**, and even if a given gene for a specific disease is possessed, it is not a foregone conclusion that disease will follow. For example, having a gene for cardiac problems does not mean that a myocardial infarction is inevitable. If diet, smoking and lassitude are controlled, an individual with a cardiac family history may never suffer a heart attack. The same is applicable with a family history of chronic periodontitis.

However, knowing the family medical background helps **risk assessment** and **tailoring treatment plans** unique for each patient. For example, an individual with a family history of diabetes and periodontitis will require more frequent periodontal maintenance to prevent activation of the offending gene(s) leading to periodontal destruction.

**Social history**

Many patients are reticent to divulge social practices since they do not perceive that this will influence their dental care. A caring and sympathetic approach is necessary, combined with detailed explanations, to obtain this information. For example, **smoking**, **drug addiction** or **alcohol abuse** affect many dental procedures and their prognosis. Another increasingly prevalent dental ‘disease’ is **tooth wear**, which is non-infectious loss of tooth substrate (**erosion, attrition and abrasion**) due to lifestyle choices such as drinking effervescent acidic beverages or stress-related occlusal grinding.

Gauging the **persona** of a patient is more difficult and takes time, especially when treatment is protracted. A patient’s personality, expectations and wishes may be irrelevant for simple procedures or for alleviating pain, but are decisive for certain **esthetic** or cosmetic treatment outcomes.

**Personal medical history**

Medical history taking involves completing a **questionnaire**, a **medico-legal** document, which is regularly updated, reflecting the patient’s changing health status. Diligent questioning is necessary to establish all medical history and medication, especially if the patient does not realise the relevance of divulging this information for dental care. The choice of medical questionnaire lies between a form bespoke for a given practice, a proprietary form purchased from dental stationers, the Medical Risk Related History (MRRH) or the European Medical Risk Related History (EMRRH) form. The bespoke and proprietary are both non-standardised questionnaires and the risk assessment is piecemeal, depending on the prevailing medical conditions. The MRRH and EMRRH forms are an attempt to standardise **risk assessment**, using the American Society of Anesthesiologists (ASA) scale for rating the severity of medical complications for easier assessment of the state of the patient’s health.

**Medical complications**

A significant proportion of the population have medical histories or medication that affects numerous dental procedures. Furthermore, some diseases can **place the dental team at risk** of contracting illness or exposure to pathogenic organisms. The most significant systemic diseases affecting dentistry are summarised below.

- **Cardiovascular diseases** include hypertension, ischaemic cardiovascular disease (angina), myocardial infarction, congestive cardiac insufficiency, valvopathy and cardiac arrhythmias (with or without a pacemaker). A practical knowledge of cardiopulmonary resuscitation (CPR) is essential.
- **Allergies** can either be constitutional, e.g. asthma, or drug induced. The most common **anaphylactic** reaction is due to penicillin, but can also be precipitated by many other drugs. The symptoms are usually apparent within 15 minutes of taking the offending drug. Other allergies that may complicate dental treatment are **latex gloves**, **local anaesthesia** or dental materials, especially alloys containing **nickel**.
- **Diabetes mellitus** is not only a debilitating systemic disease, but may also increase the severity of periodontal destruction and complicate surgical or implant procedures. **Type I** diabetes is insulin dependent, while **type II** diabetes is controlled by diet. Many patients are oblivious to their condition until symptoms appear, and if detailed questioning arouses suspicion, referral to a medical practitioner for further tests is advisable.
- **Infectious diseases**, e.g. **hepatitis A, B, C, HIV** and **tuberculosis**, do not contraindicate dental care, but stringent cross-infection control is mandatory.
- **Epileptic** convulsions are controllable by medication in the majority of cases, but the dental surgery environment may cause stress and trigger an epileptic attack.
- **Tendency to bleed** may be due to haemophilia or anticoagulant therapy. In both situations, a medical consultant’s report is essential before embarking on deep scaling or surgical procedures.
- **Drug-related complications** are secondary effects that may interfere with certain treatment; for example, antidepressants interacting with local anaesthetics, or bisphosphonate therapy causing osteonecrosis following soft tissue or implant surgery.
- **Other conditions** include pregnancy, thyroid disease, radiotherapy, kidney disease, stroke and carcinomas.

**Key points**

- A detailed family, social and personal medical history is essential before starting dental treatment.
- Gauging a patient’s persona is helpful for aesthetic treatment outcomes.
- A standardised MRRH or EMRRH questionnaire with an ASA rating is useful for assessing severity of medical complications.
- A working knowledge of dealing with medical emergencies is essential.
Diagnostics: initial consultation

Extra-oral facial assessment: frontal
Extra-oral facial assessment: profile

Photographs of the face are an excellent method for studying in detail extra-oral pathology, variations and asymmetries that affect treatment planning. For example, the parallelism of the interpupillary line with the incisal plane is essential for aesthetic approval.

Computer-generated dental and periodontal charting

Dental software allows a comprehensive dental and periodontal charting, which can be readily reviewed and modified.

Oral carcinoma
Early detection of cancerous and pre-cancerous lesions can be life saving

Asymmetrical gingival zeniths
Uneven gingival margins detract from ‘pink’ aesthetics, especially with a high lip line

Angle’s Class II (ii)
Angle’s Class II(ii) anterior relationship is associated with a steep anterior guidance

Tooth wear
Tooth wear is non-infectious loss of enamel and dentine, e.g. due to attrition
The initial consultation is to assess the patient’s current dental status and determine which, if any, detailed investigations or referral are necessary before arriving at a diagnosis.

**Initial complaint**
The first point to ascertain is the reason for attending, which can be pain, dissatisfaction with previous dentists, referral, coercion by family, friends and colleagues regarding poor dental health and/or appearance, second opinion, or a personal desire to improve dental health and aesthetics.

**Dental history**
Dental history taking includes the following:
- **Attitude** to oral health;
- **Regular or occasional** attender;
- **Dental records**, models, photographs and radiographs from previous dentist(s);
- **Dental phobias**;
- **Hobbies** or habits that affect the dentition, e.g. playing a wind instrument;
- **Sports, occupational hazards**, or other risky activities;
- **Persona** and expectations about dental treatment;
- **Financial** status.

**Extra-oral examination**
The extra-oral examination consists of a **visual and tactile** assessment. The skeletal structure, tegumental (skin) structure and the musculature are scrutinised, and deviations from the norm or pathological changes are noted.
- **Skeletal**: facial shape (ovoid, tapering, rectangular or square), facial profile (class I, II or III base), zygomata (prominent, receding), angle of mandible (prominent, receding), temporomandibular joint (TMJ) (deviation and/or clicking during movement, hypo- and hyperplasia of condyles) and maxilla (parallelism, prominent, receding, canting).
- **Tegumental**: swellings, lacerations, bruising, scarring (e.g. healing of previous disease or surgery, or result of facial cosmetic procedures), indelible tattoos, suppuration, pathological pigmentation and hirsutism, loss of tonicity, prominent facial grooves and ridges (e.g. nasolabial). Other soft tissues to consider are the shape and size of the nose, lips and chin. **Facial asymmetries** are assessed during musculature stasis and contraction (e.g. conversing, smiling and laughing).
- **Musculature**: paralysis, hypertrophy and twitching. In addition, palpation of the oral muscles is performed including temporalis, masseter, medial and lateral pterygoids. During this tactile examination, tenderness or trigger points that elicit pain or spasm are recorded. Lastly, the degree of mouth opening and trismus is noted.

**Intra-oral examination**
As well as a visual and tactile assessment, intra-oral examination is expedited by using diagnostic adjuncts to elucidate and confirm clinical findings (see Chapter 5).

**Soft tissues**
The areas to examine are the oral mucosa, buccal mucosa, palate, uvula, floor of the mouth, the tongue (especially the lateral aspects, together with **tongue thrust**), and, in children, habits such as **thumb or dummy sucking**. Any abnormality or findings are recorded, especially pathological, **cancerous** and **precancerous** lesions. Finally, impediment to **phonetics** is ascertained with sounds such as ‘M’, ‘F’, ‘V’, ‘S’ and ‘TH’.

**Dental charting**
Nowadays, most dental charting is performed using **computer software**, which prompts the user with specific items to record, thereby avoiding omissions. The charting should include DMF score (decayed, missing and filled teeth), diastemata, imbrications, tooth wear (erosion, attrition, abrasion, abfraction), **primary caries** (in virgin teeth) and **secondary caries** (around restorations or prostheses), **direct restorations** (amalgam or composite), **indirect prostheses** (veneers, crowns, inlays, bridges), **defective margins**, **discolouration** (intrinsic and extrinsic), **fractures** (tooth, restorations or cuspal), **tooth vitality**, **removable prostheses** (acrylic, metal dentures, mouthguards, bleaching trays), **implant-supported prostheses** and **fixed** or **removable orthodontic retainers**.

**Periodontal charting**
Computer-aided charting also expedites periodontal charting and avoids omissions. The items to record are **halitosis**, **inflammation**, **suppuration**, plaque score, **calcus**, **bleeding on probing**, **pocket measurements**, location of the cemento-enamel junction (CEJ), gingival recession (class I, II, III, IV), mobility (class I, II, III, IV), width of attached gingivae, passive eruption, furcation involvement (class I, II, III), pronounced gingival embrasures (‘black triangles’), degree of maxillary gingival exposure during a relaxed and exaggerated smile (norm is <3 mm), and the gingival aesthetic line (GAL), for assessing the maxillary anterior sextant gingival zeniths.

**Occlusion**
The basic occlusal examination includes **arch shape** (narrow, wide, oval, square), **Angle’s classification** (class I, II(i), II(ii), III), **measurement of overjet** and **overbite**, slide from centric relation (CR) to centric occlusion (CO), lateral contacts (canine guidance, group function), anterior guidance (steep, normal, shallow), **fremitus**, occlusal interferences, parafunctional activity (e.g. bruxism), TMJ dysfunction, trauma from occlusion and loss of occlusal vertical dimension (OVD).

---

**Key points**
- Enquire about initial complaint or reason for attending.
- Obtain dental history and dental records from previous dentists.
- Extra-oral examination assesses the facial skeleton, tegument and muscles.
- Intra-oral examination includes soft tissues, dental charting, periodontal charting and occlusal assessment.
- The initial consultation determines whether to start treatment, carry out further investigations and tests, or refer to a specialist for further advice or treatment.
Diagnostic adjuncts

Transillumination
Useful for detecting cusp and restorative material fractures

UV illumination
Using a fluorescent disclosing agent, allows visualisation of plaque biofilm with UV light

Dental loupes
As well as choosing the magnification factor, it is important to select the correct working distance to ensure correct posture and prevent musculoskeletal strain. A fibreoptic cable can also be attached for shadow-free illumination

Operating microscope
Although the learning curve is more challenging than for loupes, a microscope offers innumerable benefits such as dual binocular vision for both the clinician and dental assistant

Traumatised teeth
Transient paraesthesia gives a false-negative result when vitality of traumatised teeth is tested using thermal or electrical stimulation

Leukoplakia
Besides visual and tactile examination, many conditions and lesions require specific tests and adjuncts to elucidate findings and confirm diagnosis.

**Illumination**

The typical illumination in a dental practice is the operatory light which delivers incident light that is suitable for most examinations. However, other types of illumination allow visualisation of features that may be missed by traditional light sources, e.g. transillumination via a fiberoptic cable emphasises fractures (tooth and restorations), defective restorative margins and caries. In addition, ultraviolet (UV) illumination is useful for detecting plaque biofilm (with fluorescent disclosing solutions) or porosity in ceramic restorations.

**Magnification**

Visual enhancement is not limited to specific specialties such as endodontics, but is invaluable in many dental disciplines such as prosthodontics and periodontics, and in detecting lesions that may be ‘invisible’ to the unaided eye. Magnification elevates visual acuity using loupes, intra-oral cameras, operating microscopes and projection stereomicroscopes using 3-D video technology. Loupes offer magnification from \( \times 2 \) to \( \times 5 \), while microscopes have the capability for \( \times 20 \) or greater levels of reproduction.

The advantages of magnification are:
- Enhanced visual access to detail;
- Improved precision;
- Increased efficacy;
- Compensate for presbyopia;
- Comfortable ergonomics, avoiding musculoskeletal injuries.

The disadvantages of visual aids are:
- Limited field of view (beyond \( \times 2.5 \));
- Reduced depth of field (with extreme magnifications \( \gg \times 10 \));
- Cross-infection concerns;
- Damage to optics (by dental debris, or air abrasion procedures);
- Learning curve (especially with microscopes).

**Oral precancer and cancer lesions**

Oral and oropharyngeal cancer accounts for 3% of all malignancies, with a 50% mortality rate for oral cancer. Early detection and management are therefore essential for increasing survival rates and minimising recurrence. The aggressiveness of squamous cell carcinoma depends on its location, which includes vermillion border of lower lips, ventral surface of the tongue, floor of mouth, palate, buccal mucosa and oropharynx.

Examples of precancerous lesions are leukoplakia (dysplasia ranging from 3% to 18%) and erythroplakia (high incidence of dysplasia at clinical detection). The early stages of cancer are asymptomatic, while the late stages (carcinoma in situ) show ulceration and bleeding accompanied by pain, dysphagia and lymphadenopathy. Visual inspection is insufficient for diagnosis and must be investigated with active stains (toluidine blue), oral cytology (scrapping and brush biopsy) and scalpel biopsy. However, staining and scrapings may be inconclusive, and a brush biopsy is useful for lesions that do not heal in 10 days. Differential diagnoses include lichen planus, frictional keratoses, leukoedema, nicotinic stomatitis, white sponge naevus, etc., where a cause cannot be elucidated. The gold standard for definitive diagnosis is a scalpel biopsy and histology examination.

**Vitality testing methods**

Methods to determine pulp vitality include thermal, electrical, drilling cavities into dentine, anaesthesia, laser Doppler flowmetry, dual wavelength spectrophotometry and pulse oximetry. The most commonly used are thermal and electrical stimuli that are subjective, while pulse oximetry is objective.

Thermal and electrical tests measure neural responses and are erratic and inconclusive, especially when used in children. Heat stimuli are less reliable than cold liquids (e.g. 1,1,1,2 tetrafluoroethane). In addition a false-negative result is often obtained with traumatised teeth due to transient paraesthesia of nerve fibres. Conversely, a false-positive result is elicited when necrosis of the pulpal vascular tissues has occurred, leaving vital nerve fibres, which are more resilient. Both of these situations delays diagnosis and treatment of the affected tooth, often leading to root absorption.

Pulse oximetry is objective, measuring the blood oxygen saturation levels or circulation within the pulp. The pulse oximeter consists of light emitting diodes (LED) of two wavelengths (red light, 640 nm and infrared light, 940 nm) and a receptor which records the spectral absorbance of the oxygenated and deoxygenated haemoglobin in the tooth pulp. A computer calculates the percentage of oxygen saturation levels, which are approximately 75% to 80% for vital teeth, compared to values at the fingers or ear lobes of 98%. The saturation levels of teeth are lower than soft tissues due to the dentine and enamel enclosing the pulp, which scatters the LED light.

**Other diagnostic methods**

Other methods used for diagnosis include:
- Caries detection and periodontal assessment (Chapter 6);
- Radiography (Chapter 7);
- Computed tomography (CT) (Chapter 8);
- Dental photography (Chapter 9);
- Occlusal analysis (Chapter 10);
- Plaster casts and additive diagnostics (Chapter 11).

**Key points**

- Transillumination is used for detecting caries, fractures and deficient restorative margins.
- Magnification facilitates diagnosis, using loupes or operating microscopes.
- Precancerous lesions such as leukoplakia and erythroplakia that do not heal in 10 days should be biopsied.
- Frequently used tests for tooth vitality include thermal, electrical and pulse oximetry.

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Diagnostic adjuncts 1  Chapter 5  19
Methods of diagnosing periodontal disease

<table>
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<th>Level</th>
<th>Process</th>
<th>Diagnostic tools</th>
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</thead>
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<td>Clinical</td>
<td>Attachment and bone loss</td>
<td>Periodontal probing, radiographs</td>
</tr>
<tr>
<td>Tissue</td>
<td>Apical migration of epithelial attachment, connective tissue and bone loss</td>
<td>Histomorphometry, immunohistochemistry</td>
</tr>
<tr>
<td>Cellular</td>
<td>Presence of inflammatory cells (neutrophils), osteoclast activation</td>
<td>ELISA, immunohistochemistry</td>
</tr>
<tr>
<td>Molecular</td>
<td>Activation of receptors for endotoxins: CD-14, toll-like receptors</td>
<td>Polymerase chain reaction, DNA-DNA hybridisation, laser-capture microdissection</td>
</tr>
</tbody>
</table>

Quantitative laser fluorescence (QLF)
QLF is an objective method for detecting caries

Bitewing radiographs
Bitewing radiographs are an excellent method for detecting inter-proximal (smooth) carious lesions

Digital score | Clinical interpretation
--- | ---
0 – 9 | Sound enamel or early enamel lesion
10 – 17 | Enamel caries
18 – 99 | Dentine caries

Michigan-O manual perio probe
Spring-loaded probe (Click-Probe)
Florida electronic probe and digital display
Saliva assay for detecting biomarkers
Caries detection

Dental caries is the most prevalent lesion in the oral cavity that is diagnosed and treated in a dental practice. Caries describes both the lesion and disease process, and its incidence in industrialised countries has decreased over the last three decades. Specifically, interproximal or smooth surface caries has shown a greater decline than occlusal lesions. Consequently, occlusal caries presents a greater challenge for early detection and treatment to prevent progression into larger cavities. Ideally, caries diagnostic tests should fulfil the following criteria:

- Sensitivity – ability to truly determine presence of caries;
- Specificity – ensure that sound tooth is registered as negative;
- Accuracy – number of positive and negative tests should sum to the total examined tooth surfaces.

Methods for caries detection include the following.

- Histology – remains the gold standard for evaluating caries, but is obviously impractical in the dental surgery. Its use is limited to research, especially of the primary dentition following exfoliation or extraction.
- Visual inspection – most common method for caries diagnosis, e.g. using the International Caries Detection and Assessment System (ICDAS), but is affected by operator experience and subjectivity.
- Enhanced visual inspection includes:
  - Magnification – using loups or operating microscope;
  - Fibreoptic illumination – widely used for detecting interproximal caries, but can also be used for occlusal lesions, e.g. FOTI (fibreoptic transillumination) and DIFOTI (digital imaging fibreoptic transillumination). Sound enamel appears translucent, enamel caries appears grey and opaque, and dentine caries casts an orange/brown or bluish shadow;
  - Enamel porosity (Ekstrand method) – assesses difference of refractive indices between air, water and enamel;
  - Combination of fibreoptics and enamel porosity.
- Electrical conductance measurements (ECM) – measures electrical resistance of teeth. Intact enamel has greater resistance than carious lesions, which are porous and have a higher water content. Dentine has lower resistance than enamel, and therefore allows differentiation between dentine and dentin lesions.
- Tactile – explorer probes suffer from subjectivity and clinical experience, and should be used with caution to avoid piercing non-cavitated enamel (possibly reversible) carious lesions.
- Bitewing radiographs – the most popular method, especially for interproximal lesions. In addition, digital radiography allows image manipulation for highlighting salient lesions.
- Caries detection dyes – stain carious dentine, especially useful for deep caries excavation and avoiding inadvertent pulpal exposure.
- Tuned aperture computed tomography (TACT) – reconstruction of anatomical ‘slice’ images to form a pseudo- or true 3-D representation of a tooth, known as a pseudohologram.
- Tooth staining and hydration – produce erratic values.
- Fluorescence – either quantitative laser fluorescence (QLF) using a diode fluorescence device that illuminates the tooth with a pulse light of wavelength 290–450 nm or DIAGNOdent that uses infra-red light of wavelength 655 nm. The emitted fluorescence correlates with the extent of enamel and dentine demineralisation, e.g. a digital scale representation from 0 to 99. This is an objective assessment, but intrinsic or superficial tooth stains or hypomineralisation create variable light scattering and therefore unpredictable readings.

Periodontal assessment

The crucial factor for periodontal disease is host genetic susceptibility. Individuals who are susceptible to severe chronic periodontitis should be screened and identified as genotype positive, which helps with treatment planning and monitoring. Periodontal disease is diagnosed at the clinical, tissue, cellular and molecular levels.

The clinical assessment of periodontal disease is the most popular method for ascertaining destruction caused by previous episodes of disease, or the effectiveness of recent periodontal therapy. This includes recording bleeding on probing (BOP), pocket depth (PD) and clinical attachment level (CAL) using periodontal probes of the following types.

- Manual, e.g. Michigan-O or Williams. The degree of reproducibility varies with the type of probe and there are conflicting reports on whether a manual or electronic probe is more reliable. Manual probing is convenient and expedient but measurements may be erratic due to prevailing inflammation, presence of plaque, calculus, over-contoured restorations, tooth location and angulation, patient compliance, probe diameter, angulation and pressure, and visual recording errors.
- Spring loaded, e.g. Brodontic Probe (Prima, Byfleet, UK) and Click-Probe (KerrHawe SA, Switzerland). Unlike manual probes, these varieties deliver a predefined consistent force (0.2–0.5 N probe force or 255 N/cm² probing pressure), but are also prone to recording errors.
- Electronic or computerised pressure-sensitive, e.g. Florida Probe (Florida Probe Company, Gainesville, FL, USA) and Jonker Probe (Jonkers Data, Staphorst, Netherlands). These offer the advantage of delivering a constant probing pressure and electronic recording or displaying data using appropriate software. However, the probing pressure in many probes is less than 250 N/cm², which is necessary to enter periodontal pockets deeper than 5 mm.

At the tissue, cellular and molecular levels, biomarkers are useful diagnostic indicators for assessing periodontal disease. Biomarkers include microbial factors, host response factors and connective tissue breakdown products, bone resorption factors (e.g. ICTP; type I collagen carboxyterminal telopeptide), and their levels found in plaque biofilm, gingival crevicular fluid or saliva are diagnostic markers for periodontal disease activity and its progression. Future developments may allow oral fluid analysis for biological markers with chair-side assay.

Key points

- Although dental caries incidence has declined, caries remains the most prevalent disease treated in the oral cavity.
- Subjective caries detection includes visual, tactile and enhanced visual inspection.
- Objective caries detection includes radiography and QLF.
- Periodontal probing is the most popular and convenient method for detecting, charting, and monitoring periodontal disease.
A dental X-ray unit allows the operator to select the kV, resolution, and time of exposure depending on specific requirements.

Extra-oral panoramic dental X-ray equipment

Larger dental X-ray units allow extra-oral radiographs such as panoramic and lateral cephalometric images.

Bitewing radiograph

Lateral cephalometric radiograph

Panoramic radiograph

Radiation monitor badge

Digital CCD sensor

Manipulated dental radiograph
Besides a clinical examination, **projection dental radiography** is the most frequently used diagnostic tool in dentistry. Its uses range from detecting caries to more elaborate findings such as gross pathologies of the jaws. Cone beam computed tomography (CBCT, discussed in Chapter 8), is the latest radiology tool, offering enhanced and sophisticated visualisation of dentomaxillofacial anatomy.

**X-ray tube**

The production of X-rays has changed very little since they were discovered by Röntgen in 1895. X-rays are produced when electrons are accelerated to strike a metal target. A contemporary dental X-ray tube for producing radiation is housed in a casing and has an appropriately sized collimator to restrict the emitted beam. The typical setting for intra-oral dental radiography is 60 kVp, 7 mA, with varying distance of 15–32 cm. The exposure time is selected according to tooth, age and the physical build of the individual.

**Radiation safety and precautions**

X-rays are part of the electromagnetic spectrum classified as ionising radiation, which are potentially hazardous for living organisms, causing irreversible ailments such as cancer, sterilisation and gene mutation. The aims of radiation safety are:

- **Justification** for its use, i.e. risks vs benefit;
- **Optimisation** of protection using the lowest possible dosage, e.g. for a periapical exposure the limit is 2.3 mGy;
- **Limitation** of exposure by conforming to recommended limits as specified by law. In the UK, **Ionising Radiation Medical Exposure Regulations 2000** guidelines must be observed for all types of radiographic examination.

Radiation protection is for the operator, patient, ambient environment and third parties (other patients and staff members in the practice). Precautions include regular equipment testing and maintenance, thyroid lead aprons, monitoring devices/badges, and restricted areas of operation.

Finally, **operator training** is essential in the taking and interpreting of radiographs, thereby avoiding the need to repeat exposures unnecessarily.

**Conventional dental radiography**

Film or conventional radiography is similar to conventional photography. A cellulose acetate sheet (film) is coated with X-ray-sensitive chemicals which react when exposed to radiation. Subsequently, the film is processed with chemicals (developer and fixer) to create a black-and-white indelible image on the cellulose acetate sheet. The processing can be performed manually in tanks of appropriate chemicals, or in an automated processing unit, which also dries the film ready for storage.

The films are available in various sizes for taking intra-oral periapical, bitewing, occlusal, as well as extra-oral lateral cephalometric or panoramic views. In addition, radiation dosages can be reduced by using films of varying sensitivities (high film speeds) or intensifying screens in film cassette holders (panoramic and lateral cephalometric).

The major advantage of film radiography is familiarity with established protocols. The drawbacks are a relatively higher radiation dose (compared to digital radiography), the need for visual magnification for proper analysis, environmentally toxic chemicals, and the inability to store and transmit images electronically.

The two main methods for intra-oral periapical radiographs are the **parallel** and **bisection angle** techniques.

**Digital dental radiography**

Similar to digital photography, **digital dental radiography** has revolutionised dental radiology. The **advantages** are instantaneity, no chemical processing, reduced radiation dosage, ability to manipulate and enhance images for improved and accurate diagnosis, electronic storage, and transmission via the Internet. The **disadvantages** are the initial capital outlay for equipment purchase and training, which are rapidly offset by the innumerable benefits mentioned above.

With digital radiography, the film is substituted with a **sensor**. Currently three types of sensor are available, CCD (charge-coupled device), CMOS (complementary metal oxide semiconductor) and SPP (storage phosphor plate). Each type of sensor has advantages and limitations regarding altering the exposure time, signal-to-noise ratio or image resolution. For accurate diagnosis the resultant image resolution is paramount. Image resolution is determined by spatial resolution expressed as pixel size, dots per inch (dpi) or line pairs per millimetre (lp mm\(^{-1}\)). For example, a high resolution CCD sensor is 15–20 lp mm\(^{-1}\), while an SPP system is 8 lp mm\(^{-1}\). The required resolution depends on the diagnostic requirements, e.g. medium resolution is sufficient for detecting caries or gross pathology, while high resolution is beneficial for discriminating minute tooth or root fractures and for locating root canal anastomoses during endodontic treatment. However, high resolution images create larger files, requiring increased computer hard drive storage capacity, and present a challenge for transmission via email.

The process of digital radiography is as follows. After exposing the sensor to radiation from an X-ray unit, an analogue/digital (A-D) converter converts the analogue signal to digital data that is processed by either a dedicated or generic software for displaying as an image on a computer monitor. The radiograph image can be manipulated by altering magnification (best method for enlargement is bicubic convolution), gamma curve, density, contrast, brightness or applying filters (e.g. polarising) for emphasising or enhancing pertinent detail.

**Key points**

- Projection dental radiography is the commonest diagnostic tool in dentistry.
- A dental X-ray unit produces potentially hazardous ionising radiation.
- An X-ray detector can either be analogue (film) or digital (sensor).
- Radiation safety and appropriate training are paramount for preventing irreversible damage to health.
- Digital radiography offers innumerable advantages compared to X-ray films.
Computed tomography

<table>
<thead>
<tr>
<th>Type of image</th>
<th>Effective radiation dose, E (µSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full-mouth periapical examination</td>
<td>13 – 150</td>
</tr>
<tr>
<td>Single panoramic</td>
<td>3 – 11</td>
</tr>
<tr>
<td>Conventional CT of mandible</td>
<td>1320 – 3324</td>
</tr>
<tr>
<td>Conventional CT of maxilla</td>
<td>1031 – 1420</td>
</tr>
<tr>
<td>Cone beam CT</td>
<td>37 – 558</td>
</tr>
</tbody>
</table>

Dosimetry with different radiographic imaging methods

cCT axial image

CBCT axial plane

CBCT sagittal plane

CBCT coronal plane

CBCT Oblique planar reformation

CBCT Serial transplanar reformation

CBCT Maximum intensity projection (MIP)
Computed tomography (CT) is a radiology-based imaging system for evaluating skeletal structures of the body. CT imaging is one method used for scanning the maxillofacial region. However, depending on the symptoms and clinical findings, alternative methods of imaging can be considered including digital radiography, magnetic resonance imaging (MRI) and ultrasonography (ultrasound imaging).

Conventional CT
Conventional CT (cCT) imaging uses a rotating helical fan beam X-ray unit and detector to scan the patient’s maxillofacial region. The ensuing digital slice-by-slice images, usually in the axial plane, are combined to create a 2-D representation. The scan can either be a single-slice or multiple detector CT (MDCT), which substantially reduces the radiation dosage. CT scans are usually limited to hospitals or specialist centres due to their prohibitive cost, large size, and the requirements for periodic maintenance, training of operating staff and adherence to strict radiation controls.

Cone beam CT
Unlike the layered (or slice) images produced with cCT scans, cone beam CT (CBCT) scans are based on volumetric tomography. The 3-D cone beam X-ray source makes a 360° scan of the patient’s head, which is held static with an appropriate holder. The digital information obtained is in the form of 3-D cuboid blocks known as voxels or volume pixels (similar to pixels in a digital camera), representing the intensity of X-ray absorption at a particular point on the image. At predefined intervals, ‘basis’ images are acquired (usually 300–600 per scan) and subsequently reformatted with algorithms using computer software to yield 3-D images in the axial, coronal and sagittal orthogonal planes. This process is termed multiplanar reformation (MPR). As well as images in various planes, other types of possible MPR images include the following:

* Oblique planar reformation – 2-D non-axial images useful for assessing the temporomandibular joint (TMJ) and impacted molars;
* Curved planar reformation – similar to panoramic radiographs but without distortion or superimposition of the cervical spine;
* Serial transplanar reformation – a series of images (1 mm thick, with 1 mm separation) derived from oblique and planar reformations for assessing alveolar bone height and width, relation of nerve canals and sinuses, and shape of the condyles for determining TMJ pathologies;
* Multiplanar volume reformation – formed by increasing the number of voxels of a slice for ‘thicker’ panoramic (25–30 mm) or cephalometric (130–150 mm) images;
* Maximum intensity projection (MIP) – isolates the highest value voxels to form a pseudo-3-D structure of surface morphology. A true 3-D representation is also possible by adding shading effects with appropriate software to create the desired degree of 3-D. Furthermore, user interaction allows the skeletal structures to be visualised in ‘real time’ in any orientation from limitless angles.

Clinical applications of CBCT
The applications of CBCT are ever expanding. The technology is useful for many disciplines in dentistry such as implant site assessment, oral surgery, oral medicine, TMJ dysfunction, periodontology, endodontics, prosthodontics, orthodontics. The recent introduction of a larger, 12-inch field of view (FOV) enables CBCT images to substitute for conventional panoramic and cephalometric radiographs. A further application is in monitoring pathology and the efficacy of therapy.

Advantages of CBCT
CBCT technology has rapidly evolved due to the reduced cost and size of X-ray tubes, development of high-quality digital sensors, and the introduction of powerful personal computers. These factors have made CBCT equipment more accessible, and within reach of many practitioners as a worthwhile and affordable investment.

As with digital photographs or radiographs, image manipulation is relatively easy, e.g. zoom, magnification, isolation, cropping, altering contrast and brightness, adding ‘false colours’ for visual enhancement of specific structures, cursor-driven measurements, image pointers (arrow, lines) and text annotations to emphasise relevant details. Another invaluable advantage is transmission of CBCT images by the Internet to specialists for remote diagnosis, and to dental laboratories for prosthetic assessment. Moreover, CBCT imaging offers numerous benefits compared to cCT scans or digital radiographs, including:

* Collimated X-ray beam adjustment – for altering FOV and concentrating on regions of interest (ROI), for example, root canal number and location within an individual tooth;
* Image accuracy – reduced distortion, no magnification factor;
* Image quality – superior due to isotropic voxels, less than 1 mm (compared to anisotropic voxels of 1–2 mm with cCT);
* Faster scan time than cCT – 10–70 s depending on equipment;
* Reduced dosimetry – compared to cCT, but higher than digital radiography;
* Soft tissue rendering – allows assessment of soft tissues profiles, especially useful for orthodontic therapy;
* Fabrication of surgical stents – exporting data to remote proprietary or dental laboratories;
* Reduced image artefacts – using sophisticated software.

Disadvantages of CBCT

* Increased radiation dosage compared to digital radiography;
* Misuse by inexperienced operators may cause excess dosage;
* Radiation burden for children, if used for periodic orthodontic monitoring;
* Irradiation of vital organs – pituitary gland, salivary glands, eyes, skin, bone marrow, breast, reproductive organs;
* Training for interpretation is mandatory for gaining maximum diagnostic value;
* Caries detection is unreliable;
* Scatter from metals, e.g. amalgam, casting alloys or gutta-percha;
* Evolving technology – obsolescence of equipment and software.

Key points

* cCT produces 2-D axial images with higher dosage compared to CBCT.
* CBCT is a 3-D volumetric representation with many distortion-free views.
* CBCT is becoming accessible and affordable.
* CBCT dosimetry is greater than digital radiography.
* CBCT is a rapidly evolving technology, requiring continual capital investment and intensive training.
Stage 1: The object is captured by a digital sensor composed of pixels.

Stage 2: The analogue signal is processed by converting into digital data.

Stage 3: An image is displayed from the processed digital data.

**Capture**

**Process**

**Display**

**Camera and flashes**

**Portrait**

**Intra-oral**

**SET-UPS**

**Exposure**: The lens aperture, or opening, controls light intensity, while the duration is controlled by the shutter speed. The aperture size is calibrated in f-stop numbers; the larger the number, the smaller the lens opening. The shutter speed is the length of time the shutter remains open when the shutter release is activated, expressed in fractions of a second, e.g., 1/125s is faster than 1/60s.

**Over-exposure**

**Correct exposure**

**Under-exposure**

**White balance (WB)**: Setting the appropriate colour temperature to match the illumination. Photographic daylight (electronic flashes) have a colour temperature of 5500K. If the colour temperature is too high, the image will have a bluish tint. Conversely, a low colour temperature will render an image that is reddish/orange.

**High colour temp**

5500 K

**Low colour temp**

**Depth of field**: is the zone of in-focus objects, from front to back, or the range of distance (or objects) that are acceptably sharp within a photograph. Depth of field varies inversely with the aperture opening, i.e., a wide-open lens with an aperture of f2.8 has little depth of field; if stopped down to f22, almost everything from front to back will be sharply in focus.

F 2.8

F 5.6

F 22
Dental photography is increasingly becoming an integral part of a modern dental practice, for improved patient care. Its uses extend far beyond documentation, e.g. during the treatment process (planning, progress and outcome), education (patient and staff), communication (with patients, staff, ceramists and specialists), marketing (practice literature and brochures) and dento-legal records (particularly for elective therapies such as bleaching or aesthetic/cosmetic dentistry). The digital revolution has made analogue (film) photography almost redundant, and therefore this chapter concentrates exclusively on digital dental photography.

**Principles of digital photography**
Digital photography offers the following benefits:
- **Instantaneity and convenience;**
- **Flexibility** (edit, crop and disseminate images);
- **Environmentally friendly** (no toxic processing chemicals);
- **Long-term economy;**
- **Using existing computers** for image display and manipulation.

The **basic principles** of digital photography can be summarised by the acronym CPD:
- **Capture;**
- **Processing;**
- **Display.**

The heart of a digital camera is a sensor composed of tiny, light-sensitive units called **pixels**, which replace the film emulsion of film cameras. The pixels, which can be as small as 5µm, are arranged in pixel squares representing the three primary colours, **red, green and blue**. The number of pixels on a sensor is expressed as millions of pixels or **megapixels**. Although most digital cameras are marketed according to the number of megapixels, it is important to note that the **number of pixels** represents the **image size, not quality**. The two most popular sensors are the **CCD** (charge-coupled device) and **CMOS** (complementary metal oxide semiconductor). Once stimulated by light entering the camera lens, the pixels produce an electrical voltage. This process of obtaining an image with a sensor is termed **image capture**.

The voltage produced by the pixels is an analogue signal, which is digitised by an **analogue/digital** (**A-D**) converter. The digital signal is further processed by software either within the camera, or by a computer using photo-editing software, e.g. Adobe® PhotoShop®.

After processing, the image is displayed on an LCD screen on the camera back, or transferred to a computer for manipulation, printing, dissemination and storage. The entire sequence of CPD is completed within a few seconds.

The photographic images can be stored on various **storage media** (computer hard drives, CD, DVD, memory sticks or cards). The choice of **file format** depends on the intended use of an image.

Some popular file formats are **RAW** (unadulterated image), **TIFF** (tagged image file format), **DNG** (digital negative graphic), **JPEG** (joint photographic experts group), **PDF** (personal document file) and **EPS** (encapsulated post script).

**Equipment**

The requirements of a camera for dentistry are two-fold: first for taking **portraits**; and second for **close-up** or **macro images**. Numerous cameras are available satisfying these criteria including instant Polaroid, range-finders or digital single-lens reflex (DSLR). The most versatile and appropriate choice for dental photography is the DSLR camera. In addition, the following are necessary for a dental photographic set-up:
- **Macro-telephoto lens** – for portraiture and close-up intra- and extra-oral images;
- **Electronic flashes** – studio flashes for full face, and compact flashes (either **ring** or **bilateral** units) for close-up intra- and extra-oral images;
- **Tripod** – for mounting camera and flashes;
- **Remote foot release** – for hands-free operation and cross-infection control;
- **Cheek retractors** – preferably the plastic variety for comfort;
- **Front-coated intra-oral mirrors;**
- **Moisture control** – saliva ejectors, cottonwool rolls and rubber dam, warm air from 6-in-1 dental syringe;
- **Cross-infection measures** – routine procedures in a dental practice, e.g. disinfection, disposable paper and plastic drapes for covering photographic equipment;
- **Patient consent** – for intended use of their pictures.

**Camera settings**

Most contemporary cameras are automated, requiring minimal or no user input. However, for dental photography, certain settings require attention:
- **Exposure** – combination of the lens aperture and the shutter speed.
- **Ideal settings** for dental photography are **f 22** to ensure sufficient depth of field and **1/250s** to prevent camera shake. Using dedicated flash systems and **TTL** (through-the-lens) metering, the camera controls the duration and intensity of the flash(es) for ensuring a correctly exposed image;
- **White balance** – setting the **colour temperature** of the illumination, usually **5500 K** (Kelvin) if using electronic flash;
- **Other settings should have default levels**, e.g. contrast, brightness, colour domain, sharpness, colour space, etc. as photo-editing software can be used, if required, for image manipulation.

**Dental photographic set-ups**

Two basic set-ups are required, extra- and intra-oral. The **extra-oral set-ups** include:
- **Full face portraits** – frontal and profile views;
- **Dento-facial perspective concentrating only on the lips and teeth**;
- **Plaster casts and dental prostheses**.

The **intra-oral set-ups** are the most frequently used for photographing teeth and surrounding soft tissues, for example:
- **Full arch** – frontal and occlusal;
- **Quadrant occlusal, lingual (or palatal) and lateral**;
- **Magnification views** for areas of interest, e.g. a few teeth or specific regions of the oral mucosa.

**Key points**

- Digital photography can be summarised by CPD.
- The ideal camera for dentistry is a DSLR with ring or bilateral flashes.
- Extra-oral views include facial and dento-facial compositions.
- Intra-oral views are achieved using cheek retractors and photographic mirrors.
Occlusal analysis consists of 3 stages: gathering occlusal data; setting up an articulator; and analysis.

Plaster casts, facebow registration (shown) and articulator parameters are part of gathering occlusal data.

Plaster casts are mounted onto an articulator using occlusal records and necessary settings.

Occlusal analysis, e.g. anterior guidance.

Articulators

Hinge type

Semi-adjustable

Virtual 3-D

Occlusal analysis

Skeletal base
Class III

Cross-bite

Loss of OVD

Erratic aesthetic plane

Bruxism

Curve of Spee

Curve of Wilson

Centric occlusion (CO or MIP)

Canine guidance

Group function

Protrusion

Trauma from occlusion
Occlusal analysis assesses dysmorphology and dysocclusion and is a prerequisite before starting prosthodontic treatment, ensuring correct function and satisfactory occlusal schemes that are essential for aesthetics and long-term harmony of the stomatognathic system. This chapter is an introduction to occlusion, which is further elaborated in chapters 14 to 17. It should be remembered that there are numerous occlusal philosophies, with varying subjectivity and bias.

**Occlusal data registration**

To diagnose a patient’s occlusal status, and formulate a treatment plan, information needs to be transferred from the patient to an extra-oral simulating device, which can either be a mechanical or virtual articulator. Dental articulators are devices to visualise both static and dynamic occlusion. The data required depends on the chosen type of articulator and includes:

- **Plaster casts** – poured from accurate impressions of the maxillary and mandibular arches;
- **Facebow transfer** – locating the maxillary arch to the condylar hinge axis;
- **Occlusal records** – locating the mandibular cast to the maxillary cast. Check bite records, using wax or rigid addition silicone impression materials; may be required for centric occlusion (CO), centric relation (CR) and anterior and lateral excursions;
- **Articulator parameters** – Bennett and condylar angles, intercondylar distance and spacial relationships of craniomandibular geometry;
- **Mandibular movements** – instrumental measurements using pantographs, Gothic arch tracing or computer-assisted jaw-tracking systems;
- **Articulator-related registration** – rather than transferring data from the patient to an articulator, articulator registration works the opposite way. The articulator geometry is virtually transferred to the patient, using an electronic recording system, and the articulator adjusted accordingly.
- **Digital scans** – digitising the dentition using a 3-D scanner, and subsequently outputting the data into appropriate computer software for analysis.

**Mechanical articulators**

Numerous types of dental articulators are available with varying complexity:

- **Hand-held or hinge** – suitable for single tooth restorations that integrate with the existing occlusal status;
- **Fixed condylar path** – similar to hinge types, for single tooth restorations and maintaining the existing occlusal status quo;
- **Semi-adjustable with fixed or average parameters (condylar and arcon types)** – suitable for most full-arch rehabilitation requiring a change of occlusal status;
- **Fully adjustable** – for complex analysis of jaw movements, occlusal equilibrium and a diagnostic aid for temporomandibular disorders (TMD), assuming there is no muscular spasm or TMJ pathology.

**Virtual articulators**

Presently, mechanical articulators are the most prevalent device for occlusal analysis and treatment planning. However, these devices are limited in their applications and do not represent dynamic occlusion. Furthermore, the influence of mobile teeth, deformation of the mandible during function, and the influence of the soft tissues and muscles cannot be simulated. Other shortcomings are technique-sensitive methods for collating data, and errors in laboratory protocols that contribute to decreased accuracy for representing the clinical situation.

With the sophistication of computer hardware and software, it is now possible to create a 3-D virtual articulator. The process involves attaching ultrasound transmitters to the jaws for recording jaw motion, and scans of the maxillary and mandibular arches. The information is combined by the computer software to create a 3-D virtual articulator, which offers the following advantages:

- **Sectional slices** of individual teeth for assessing flowing and sliding contacts and interferences;
- **Protrusive and lateral** movement analysis;
- **Dynamic occlusion** assessment by animations of jaws in ‘real time’, e.g. simulated mastication;
- **Designing restorations** with correct cuspal and ridge inclines that ‘fit’ into a patient’s occlusion;
- **Fabricating CAD/CAM restorations** by transferring data to a milling machine;
- **Discovering TMJ pathologies** during functional movements;
- **Avoiding** facebow transfer, plaster casts and measuring articulator parameters;
- **Communicating information** with patient, laboratory and specialists;
- **Plug-in modules** for orthodontics, tooth wear and holo-perspective display environment for virtual teaching via the Internet.

**Occlusal analysis**

A systematic occlusal analysis should consider the following items:

- **Skeletal and dental bases** – classes I, II or III;
- **Cross-bites**;
- **Occlusal vertical dimension (OVD)** – e.g. loss of vertical dimension due to tooth wear;
- **Functional and aesthetic occlusal planes**;
- **Vertical or horizontal chewing patterns** (evidence of bruxism);
- **Curve of Spee** – arrangement of teeth in the anteroposterior plane;
- **Curve of Wilson** – arrangement of teeth in the lateral plane;
- **Curve of Monson** – 3-D combination of curves of Spee and Wilson;
- **Centric occlusion (CO)** – maximum intercuspation (MI);
- **Centric relation (CR)** – mandible anteriorly and superiorly located in condyles (independent of tooth contact);
- **Lateral excursions** – group function, canine protected (guidance), working and non-working (balancing) contacts;
- **Protrusive excursions** – steep or shallow anterior guidance;
- **Trauma from occlusion** – e.g. fractured fillings and/or teeth, or increased tooth mobility.

**Key points**

- Occlusal analysis is essential for successful treatment.
- The choice of articulator depends on complexity of the proposed treatment.
- Mechanical articulators are limited for detailed occlusal analysis.
- Virtual articulators offer promise for detailed occlusal analysis and will eventually replace mechanical devices.
Plaster casts and additive diagnostics

Dental plaster casts
Dental plaster casts allow visualisation of the teeth from all angles

Simulations
A diagnostic wax-up is a more realistic simulation of what is clinically achievable, compared to a 2-D computer graphic manipulation

Uses of diagnostic wax-ups

Preoperative Wax-up Silicone index Vacuum stents

Preoperative Wax-up Template for direct resin fillings

Digital study casts

Preoperative Wax-up Surgical stent
Dental casts, often referred to as study models, are pivotal for diagnosis and prosthodontic treatment planning. They provide essential information regarding tooth number, alignment and morphology as well as arch form and relation of the dentition to adjacent soft tissues and the jaws.

**Dental casts**

Dental casts are produced by making an impression and pouring plaster to recreate the dental arches and surrounding anatomy. It is customary to incorporate bases for ease of manipulation and storage.

Unmounted casts (without an articulator) serve as essential pre-treatment documentation. In addition, teeth can be visualised from all angles, which is usually difficult during an intra-oral examination. Hand-held pairing of the maxillary and mandibular casts permits a limited assessment of occlusion, and a thorough analysis is only possible when the casts are mounted on a dental articulator.

Mounted casts are an ideal method for carrying out a detailed analysis of static occlusion, and dynamic occlusion by simulating mandibular movements in various excursions. The type of articulator on which to mount the casts depends on the extent of analysis and complexity of the treatment. For most purposes, a semi-adjustable articulator is the recommended choice.

**Diagnostic wax-ups**

After performing an occlusal and aesthetic analysis, treatment options can be prepared and discussed with the patient. A useful method for visualising proposed restorative prostheses is simulation in wax or composite, referred to as additive diagnostics (wax-up or composite-up), depending on the material used. Waxes are available in various colours, and tooth-coloured varieties are ideal for anterior teeth simulations, which are useful for communicating with and educating the patient, emphasising the improvements possible with contemporary dental treatment modalities.

For aesthetic dentistry, concerned primarily with the anterior regions of the mouth, wax-ups have a major advantage over computer simulations. It is of course expedient to use computer software to show patients the immediate aesthetic improvements of their anterior teeth. However, the proposed ‘virtual’ treatment may not be clinically feasible because little information regarding arch form or occlusion is incorporated into a 2-D computer photo manipulation. On the other hand, a wax-up on mounted casts is a more realistic indication of what is clinically possible.

Diagnostic wax-ups can restore the curves of Spee and Wilson to their correct inclinations, to ensure a smooth and uninterrupted mandibular disclusion. A worn incisal plane can be restored with correct tooth proportions (width/length ratio) and morphology. Also, eccentric and harmful tooth contacts during excursions can be eliminated with correct cusp ridge inclinations. Finally, teeth can be added to or removed from the wax-up (e.g. prior to a full arch rehabilitation) to help discussion about various treatment options, before any irreversible procedure is carried out in the mouth.

**Uses of wax-ups**

Diagnostic wax-ups have many uses including:
- **Documentation** of the proposed therapy;
- **Ability to discuss different treatment options** before irreversible treatment is initiated;
- **Communication** – between patient, ceramist and specialists for multidisciplinary collaboration;
- **Vacuum stents** – made of transparent acrylic for intra-oral composite mock-ups for aesthetic approval, chair-side temporary restorations for assessing occlusal scheme changes, e.g. increasing the occlusal vertical dimension (OVD);
- **Silicone indices** of the wax-up for guided tooth preparation to ensure sufficient and precise tooth preparation and prevent inadvertent removal of tooth substrate, and retaining enamel that is crucial for adhering porcelain laminate veneers;
- **Surgical stents** – with or without cone beam computed scans (CBCT) for guided implant placement;
- **Laboratory-fabricated provisional restorations** – for resilient long-term restorations;
- **Template for definitive restorations** – copying the morphology and alignment of the wax simulation for the permanent restorations;
- **Templates for direct composite fillings** – using silicone index of a wax-up for restoring a fractured tooth (e.g. class IV cavity) with a direct composite restoration.

**Digital study models and simulations**

Although plaster casts are the most popular diagnostic aids for treatment planning, they are insufficient for many disciplines such as orthodontics and dental aesthetics because the dentition is unrelated to extra-oral features such as lips, eyes or the face. Furthermore, root morphology and angulation cannot be ascertained. However, with the burgeoning of CBCT technology, plaster casts will eventually be superseded by digital study models.

A digital study model is produced from CBCT data, which is processed by algorithms to create a 3-D representation of the teeth which can be viewed on a computer monitor. In addition, absent items such as roots, facial skeleton and soft tissue profiles can be incorporated and related to the dentition. Another benefit with virtual diagnostic wax-ups is obviating the need for impressions, pouring plaster models and building up with wax or composite. This allows positioning teeth correctly, by orthodontics and/or using artificial prostheses, that are harmoniously integrated with surrounding soft tissues and facial features. In addition, a virtual occlusal analysis is feasible, ensuring that the proposed restorations are compatible with surrounding and antagonist teeth. Finally, using prototyping technologies the data from scans can be transferred to computer-aided manufacturing (CAM) machines for fabricating conventional casts using appropriate materials such as acrylic resin.

**Key points**

- Dental casts of teeth are essential for diagnosis and treatment planning.
- A diagnostic wax-up is useful for proposing treatment options, and has many other uses in prosthodontics.
- Digital study models offer advantages of visualising tooth roots, facial skeleton and soft tissue profiles for enhanced diagnosis and treatment planning.
Does the treatment fulfil scientific criteria?
Does the treatment fulfil the HFA triad?
What is the success and survival rate of the treatment?
Is the treatment ethical?

Does the operator have the knowledge?
Does the operator have the skill?
Does the operator have the experience?

Can the patient afford the treatment?
Can the patient endure the treatment?
Does the patient want the treatment?
After arriving at a diagnosis from the information gathered by an examination and requisite tests, the next stage is preparing treatment option(s) for therapy. Ideally, the proposed treatment should sequentially restore health, function and aesthetic (the HFA triad). The HFA triad is a sequence, where health is the primary goal, followed by function and aesthetics. Therefore, if conditions are not optimal, achieving health is the priority, at the sacrifice of function and aesthetics. However, in reality, achieving this Utopian goal is challenging and often a compromise may be the best possible outcome. It is essential to recognise and communicate compromises to the patient at the onset of treatment, rather than when complications arise.

Evidence-based (EB) treatment planning is not only a sound scientific model, but also a systematic approach to decision-making. EB of treatment, rather than when complications arise. To recognise and communicate compromises to the patient at the onset of treatment resides with the clinician. However, when marketing and cosmetic) treatment is frequently apparent when a patient requests elective aesthetic (or cosmetic) treatment planning is not only a sound scientific approach. Ultimately, the decision to provide or refuse treatment resides with the clinician. However, when marketing and actively promoting cosmetic dentistry, it is worth remembering that there is a fine line between persuasion and coercion.

Key points
- EB treatment planning avoids a haphazard approach at the treatment planning stage.
- EB treatment has three constituents: scientific credence, clinical erudition and patient needs and wants.
- It is advisable to inform patients of compromises before starting treatment, especially that involving aesthetic or cosmetic dentistry.

Scientific credence
Before considering a specific treatment option, it is important to arrive at a definitive diagnosis. If the diagnosis is incorrect, the therapeutic options will also be incorrect. In some circumstances, there may be more than one treatment option, and each choice should be assessed to ensure there is sufficient research and clinical trials evidence to support its long-term efficacy.

Besides scientific validity, the patient should be informed of the likely survival or success rate of each treatment option. Survival and success rates are not synonymous. Survival implies that a restoration of prostheses has endured, but may be functionally and aesthetically inadequate. For example, a crown with defective margins causing periodontal inflammation together with tooth mobility is neither aesthetic nor functional. Conversely, success implies that a treatment option has not only endured, but is also fulfilling all the intended requirements.

The next item to consider is ethics, which comprises:
- Nonmalfeasance – ‘doing no harm’ (the Hippocratic principle);
- Beneficence – well-being of patients;
- Autonomy – veracity in clinician–patient relationships;
- Justice – fairness.

At times the clinician is faced with the dichotomy of clinical necessity and the patient’s desires for a particular treatment. This scenario is frequently apparent when a patient requests elective aesthetic (or cosmetic) treatment. Ultimately, the decision to provide or refuse treatment resides with the clinician. However, when marketing and actively promoting cosmetic dentistry, it is worth remembering that there is a fine line between persuasion and coercion.

Clinical erudition
The second part of EB treatment planning is operator factors (both clinician and ceramist, if using a dental laboratory).

The first aspect to consider under this heading is knowledge. Knowledge is acquired, not innate or possessed. To learn any technique or procedure requires a certain degree of knowledge to perform a given task. As well as undergraduate education, postgraduate training is essential for gaining insight of a particular discipline. Attending conferences, reading journals and participating in hands-on courses is mandatory to keep abreast of recent scientific research and updates on new techniques.

Besides attaining knowledge, it is essential to possess the skill and manual dexterity to perform a procedure. Knowledge alone is insufficient for clinical practice. Furthermore, clinical self-deprecation is paramount for delivering successful treatment. If the proposed treatment plan is beyond one’s capabilities, it best to refer to a specialist at the beginning, before embarking on procedures that may end in failure. Referral as a last resort is not only embarrassing, but can result in justified litigation.

Having gained knowledge and skills does not automatically equate to success. In addition, experience is prerequisite for ensuring predictability. Experience is the result of making and learning from mistakes. It is an entity that develops over time and as a result of repetition. Experience is also important for making judgements regarding specific treatment options. A protocol or material that works for one clinician may be a disaster for another.

Patients’ needs and wants
Often, an elaborate treatment is rejected by the patient, not because it is scientifically unsound or from lack of trust or confidence in the practitioner, but because of financial constraints. However, offering alternative treatment options that achieve only health may be at a fraction of the cost compared to a treatment plan that ideally achieves function and aesthetics. Sometimes a compromise is the only option that a patient can afford.

Another reason for rejecting treatment is a protracted treatment plan spanning several months or years. This is especially true for medically compromised or infirm elderly patients. Dental phobias or simply indifference to oral health are other reasons for reluctance to accept dental treatment, and counselling and educating is the ideal way forward.

Finally, aesthetic dentistry is a unique clinical situation. As opposed to other forms of treatment modalities, the success of aesthetic or cosmetic dentistry involves patient participation. Even if all clinical procedures are executed meticulously, adhering to sound scientific principles, the patient may judge the treatment outcome a failure. Dental aesthetics is fraught with subjectivity, and it is imperative to understand the patient’s desires before starting therapy. It is also important to clarify and discuss foreseeable compromises, because failure to do so will inevitably be costly and disappointing.
Caries presenting as hard lesions can be left in situ and monitored. It may be possible to leave caries-infected soft dentine, if a peripheral enamel/filling seal is achievable. Assuming health can be restored to 10 anterior occluding teeth (SDA concept) the molars do not need replacing for oral health and comfort. If the lower canines and premolars can be replaced (e.g. with implants), the mandibular molars do not need to be replaced for the SDA concept.

Reposition teeth to:

- Create space for prosthetic unit
- Close diastema
- Create space for restorations by intrusion

Upright roots to create space for implants.
Decision-making is crucial at the treatment planning stage. When presented with oral disease (of the hard or soft tissues), the options available are:

- **Review** – e.g. caries or periodontal disease;
- **Reconsider** – e.g. retain edentulous spaces (shortened dental arch concept);
- **Reposition** – orthodontic appliances for realignment, closing or gaining space;
- **Restore** – with direct or indirect restorations, root canal therapy, etc.;
- **Replace** – replace existing restorations, or close edentulous space(s) with removable, fixed or implant-supported prostheses;
- **Remove** – extract, with or without bone and soft tissue grafting;
- **Refer** – to specialist for advice or treatment.

Very often, a combination of the above is indicated to arrive at a treatment plan with a multidisciplinary approach. Many of the options listed above are discussed in subsequent chapters. This chapter concentrates on a few issues that should be addressed during the planning process.

**Review (monitor) caries**

Traditional teaching is dogmatic about removing all carious lesions, whether they present as hard or soft enamel/dentine lesions. However, research has shown that **hard lesions** can be left in situ and monitored for progression before considering a filling. For example, non-cavitated occlusal caries can either be fissure sealed, or periodically coated with chlorhexidine/fluoride varnish to arrest the lesion or allow remineralisation.

Similarly, a shift in attitude is beginning to emerge regarding caries that presents as **soft dentine lesions**. The **conventional approach** is that caries-infested **soft dentine** be ‘completely’ removed until sound or **hard dentine** is reached, and restored with a suitable filling. The **new approach** is that infected soft dentine can be left, and the cavity restored with a filling. The **rationale** for this is that it is impossible to remove all bacteria from a lesion, and attempting to do so may result in pulpal exposure. So long as the cavity margins have intact enamel (decay-free and not hypocalcified), a hermetic margin seal with a dentine bonding agent and a composite resin filling will deprive any remaining bacteria of nutrients and retard their proliferation. This allows time for formation of a secondary dentine barrier to protect the dental pulp. Although considered heretical by some at present, further research may confirm the validity of this protocol.

**Shortened dental arch (SDA)**

Contrary to popular belief, it is not always necessary to restore a partially edentulous dentition to a full complement of teeth, the so-called ‘28-tooth syndrome’. The SDA concept, although not without its critics, states that **10 occluding pairs of teeth** (six anterior teeth and usually the four premolars), are sufficient to ensure oral aesthetics and function. Both **cross-sectional and longitudinal studies** have concluded that the SDA concept is within the **adaptive capacity** of the stomatognathic system, with little variability (compared to a full dentition) in **masticatory ability**, signs of TMD, **tooth migration**, **periodontal disease** and **general oral comfort**. The ethos of the SDA is that efforts should be directed at **saving and maintaining the incisors, canines and premolars** at the expense of the molars. Also, providing removable dentures for **bilateral free-end saddle** to restore occlusal function may introduce **iatrogenic insult**, e.g. root caries. Furthermore, restoring **missing molars** with implants may be **clinically superfluous and scientifically unsound**.

However, to adopt the SDA concept, certain criteria are essential:

- **Aesthetic and functional** demands are satisfied;
- The remaining teeth are **periodontally sound**;
- **Absence of pathological tooth surface loss** (wear);
- **No pre-existing TMD symptoms**;
- **No anterior open bite, class III** or deep class II malocclusions;
- The clinical situation should be **monitored** and regularly reviewed so that the above criteria are maintained.

**Reposition**

In some instances repositioning teeth to a favourable position may be all that is required for achieving aesthetic and functional objectives, and will minimise irreversible restorative procedures. Orthodontics movement(s) can be used to **realign** teeth and roots, **close diastemata**, **create space** for prosthetic units, **reduce open** and **deep overbites** (levelling the curve of Spee), rectify dental **cross-bites**, expand **arches** and relieve **crowding**. The basic movements include **tipping, rotation, translation, root torque**, **extrusion**, **intraoral and arch expansion**.

The drawbacks of orthodontics are **protracted** treatment times, **poor patient compliance**, root **absorption** and indefinite **retention** following therapy.

The choice of orthodontic appliance depends on the complexity of treatment and the type of desired movement. Orthodontic appliances are categorised as follows:

- **Removable** – full-arch acrylic appliances with wires, brackets, screws and springs. Ideal for tipping movements, intrusion/extrusion (**Dahl appliance**), arch expansion, but limited for complex positioning or root torquing;
- **Fixed** – wires, springs, elastic bands, etc. held with steel or plastic brackets bonded onto labial or lingual surfaces of teeth. These varieties of appliance are state-of-the-art for the majority of tooth movements;
- **Clear aligners** – full-arch acrylic appliances generated from a computer virtual diagnostic set-up. Using software simulation, the teeth are positioned to an ideal position, and a **series of clear aligners** constructed on computer-generated models. As tooth movement progresses, the successive appliance in the series is worn until treatment is complete. A wide range of movements are possible, especially in combination with fixed appliances. The use of clear aligners is relatively new, introduced in 1999; future developments in this emerging technology may allow more complex movements.

**Key points**

- Decision-making is summarised as review, reconsider, reposition, restore, replace, remove or refer.
- Recent paradigm shifts should be considered and incorporated into treatment planning options, e.g. removal of caries, SDA concept and repositioning teeth.
### Occlusion: terminology and definitions

**Centric occlusion (CO)**
A position of the mandible when there is maximum intercuspation of the maxillary and mandibular teeth

**Centric relation (CR)**
A position of the mandible dictated by the shape of the TMJ and the mandibular condyles. This is the only reproducible position of the mandible and is used for complex occlusal rehabilitation

**Curves of Wilson**

**Axial and non-axial forces**
- Axial forces directed through the long axes of teeth are better managed by the stomatognathic system than non-axial (lateral or oblique) forces

**Curves of Spee**

**Guidance**
Anterior guidance involves the incisors (within envelope of function), while lateral guidance can be either by the canines alone (canine guidance), or a combination of posterior teeth (group function)

**Interferences**
A non-working side interference may cause cross-arch pivot opening of the working side. The initial tooth contact in CR should be eliminated if the tooth is to be restored
There are few topics in dentistry that are more shrouded in mystery than the subject of occlusion. The major reason is that our knowledge and understanding of occlusion is incomplete. There has been much speculation and various theories have been put forward, but opinion remains fragmented. However, there are basic principles that are undisputed, and this chapter covers these points, offering a practical approach for prosthodontic treatment.

Curves of Spee, Wilson and Monson

Viewed from the lateral aspect, i.e. the sagittal plane, the curve of Spee is defined as an anteroposterior curve touching the incisal edges and cusps of the dentition and passing through the mandibular condyle. The curve of Spee was originally proposed with a radius of 2.5 inches. A similar curve exits in the bucco-lingual plane, termed the curve of Wilson. The curve of Monson is a 3-D representation of the curves of Spee and Wilson, depicted by a sphere with a radius of 4 inches contacting all incisal edges and cusps of the mandibular and maxillary teeth. The significance of these curves is that, in an unworn dentition, the anteroposterior and bucco-lingual curvature allows unimpeded mandibular lateral and protrusive excursions. However, disruption of these curves due to tooth wear, migration or tooth loss causes occlusal disharmonies, which require addressing to re-establish these curves.

Centric occlusion

Centric occlusion (CO) is apparent when antagonist teeth are in a position of maximum intercuspation position (MIP). CO is influenced by tooth shape as well as neuromuscular ‘memory’. In CO, the occlusal forces are in an ideal vertical direction, directed through the long axis of the teeth and subsequently dissipated by the periodontal ligament and alveolar bone. In the majority of circumstances, most restorations are tailored to ‘fit’ this occlusal status quo.

Centric relation

Centric relation (CR) is when the mandibular condyles are maximally seated in their fossae (hinge axis position). This is an anatomically determined position, not influenced by the dentition. At this position there is usually initial tooth contact, and then a lateral or anterior slide to CO. In the minority of the population (10%), CR and CO are coincident, without any slide (or deflective contacts) from CR to CO.

Without clinical symptoms, a slide from CR to CO is not detrimental to health, and occlusal adjustments to eliminate defective contacts are unjustified. The relevance of CR is important in the following situations:

- When the tooth to be restored is the initial contact at CR;
- If anterior teeth require restoration and there is a substantial shift in CR against the teeth that require artificial restorations;
- If occlusion is to be altered, e.g. when a new occlusal vertical dimension (OVD) is planned;
- Establishing a new OVD following tooth wear. Tooth wear is accompanied by alveolar compensation, leaving insufficient interocclusal space to accommodate restorative materials to restore the incisors. Two methods are available to create interocclusal clearance. The first is to reposition the mandible in CR using an anterior deprogrammer (assuming there is a horizontal shift from CR to CO). The rationale for this is that tooth wear causes the mandible to reposition itself in an anterior and superior direction. An anterior deprogrammer, e.g. Lucia jig, helps relocate the mandible to its original CR position, i.e. posterior and inferior directions, and thereby creating interocclusal clearance for the restorative materials. The second method is using a Dahl orthodontic appliance, allowing periodontal overeruption of the posterior teeth and intrusion of the anterior teeth.

Guidance

During excursions, the mandible is guided by the teeth. In theory, any teeth can guide the mandible. The forces generated in excursions are oblique and not along the long axis of a tooth. Hence, these lateral forces (non-axial loading) are more detrimental than the vertical forces observed in CO, a point worth remembering when restoring guiding teeth with artificial restorations. Mutual protection is when the posterior teeth contact in CO to protect the anterior teeth, and the anterior teeth and canines disclose the mandible in protrusion and lateral excursions, respectively, to protect the posterior teeth.

In protrusion, the incisors act as the guiding teeth. The so-called anterior guidance can be steep or shallow depending on the degree of overbite. This is significant when choosing restorative materials for restoring anterior teeth, i.e. a steep anterior guidance places greater stress on an artificial material, requiring a more resilient restoration, e.g. metal as opposed to all-ceramic. The posterior guidance of the mandible is limited by the shape of the temporomandibular joints (TMJ).

In lateral excursions the guiding teeth are the canines in isolation (canine protected or canine guidance), or the canines in combination with other teeth, usually the premolars (group function). Group function allows lateral forces to be distributed among several teeth, placing less demand on the restorative material.

Interferences

Any contact that impedes mandibular excursions or reaching CO is termed an interference. A working side interference is on the side to which the mandible is moving, while a non-working side interference is on the opposite side. Most interferences are insignificant, since the stomatognathic system adapts or deliberately avoids them during function. However, interferences become relevant when considering prosthodontic treatment. For example, a non-working side contact may cause cross-arch pivot, lifting the teeth on the working side. Ideally, non-working side interference should be eliminated before starting tooth restorative treatment, while new interferences should not be introduced by the artificial prostheses.

Key points

- The items to consider are curves of Spee, Wilson and Monson, CO, CR, guidance and interferences.
- There is no justification for indiscriminate pursuit of occlusal equilibrium in order to achieve an ‘ideal occlusal scheme’.
- Occlusal adjustments before prosthodontic therapy are justified in order to avoid compromising new artificial prostheses.
Occlusion: clinical procedures

A visual and tactile examination requires the above items:
- Shimstock foil (8 µm)
- Coloured articulation papers (40 µm)
- Photographic documentation
- Study casts

A detailed occlusal analysis requires the items below:
- Accurate impressions
- Occlusal record in CO, CR, protrusive and lateral
- Articulator (semi-adjustable)
- Facebow transfer
Even if an occlusal status quo is envisaged, a preoperative occlusal assessment is worthwhile. Furthermore, it is instructive to know the patient’s occlusal status so that the treatment provided does not disturb the existing occlusal equilibrium. This chapter describes the salient clinical procedures of an occlusal examination.

**Centric occlusion**

To observe centric occlusion (CO), the patient is asked to bite on their posterior teeth, so that maximum intercuspation position (MIP) is achieved. In this position there should be maximum contact between opposing teeth, which is dependent on tooth shape and neuromuscular ‘memory’.

**Centric relation**

Centric relation (CR) is a predictably reproducible anatomical position. In order to place the mandible in CR, a transient neuromuscular amnesia is necessary so that the mandible can be freely guided into its most posterior and superior location, rather than its habitual CO. Methods to place the mandible in CR include:

- Bimanual mandibular manipulation;
- Anterior deprogramming with a jig;
- Gothic arch tracing.

**Visual and tactile inspection**

A visual examination requires the following armamentarium: photographic documentation, Shimstock foil, articulation paper and study casts to view the teeth from the lingual perspective.

Placing the mandible in CR allows the initial tooth contact to be observed, and subsequent slide (if any) into CO. Articulation paper of one colour is used to mark tooth contact in CO. Another paper of a different colour is used to superimpose contacts during various mandibular excursions. This allows clear distinction between CO and guiding contacts, as well as discriminating eccentric contacts or interferences. The supporting cusps in both arches are verified, i.e. palatal cusps of maxillary teeth and buccal cusps of mandibular teeth. The visual inspection should also detect degree of mandibular movement, trismus, wear facets and shifts and clicking of the TMJs (temporomandibular joints). Finally, the curvature of the occlusal planes is noted, and whether these conform to the curves of Spee, Wilson and Monson.

Tactile examination includes palpation of the major muscles of mastication, i.e. masseter, temporalis, and medial and lateral pterygoids. The TMJs are also palpated for tenderness or eliciting a painful response, especially if the patient reports a history of temporomandibular disorders (TMD). Differential diagnosis of TMD includes symptoms arising from bruxism, of myogenous or articular origin. Palpation is also useful for ascertaining the degree of tooth mobility and fremitus during mandibular movements.

**Impressions**

Accurate and precise full arch impressions and subsequent mounted plaster casts are essential for extra-oral visual inspection. It is recommended that addition silicone impression materials are used rather than alginites, which have poor dimensional stability and distort if there is a prolonged delay in pouring the models.

**Occlusal records**

It is important to decide at which occlusal vertical dimension (OVD) the casts are to be mounted, irrespective of whether they are mounted in CO or CR. Usually, the casts are mounted to the OVD at which the patient is to be restored. If CO is obvious, and the treatment relatively simple, occlusal records are superfluous, since they may prevent accurate location of the opposing model. If CO is not obvious, the casts must be mounted in CR at the chosen OVD.

Many materials are available for recording occlusal positions, e.g. wax, acrylic, zinc-oxide eugenol or addition silicone bite registration formulations. It is advisable to use similar materials for impressions and occlusal records, since differences in material accuracies may prevent accurate location of the bite records onto the plaster casts.

**Articulators**

The choice of articulator is determined by the complexity of treatment (see Chapter 10). If an articulator is required, the most widely used is a semi-adjustable articulator, with average articulator parameters, i.e. Bennett and condylar angles, intercondylar distance and spacial relationships of craniomandibular geometry are pre-set to average values. Although not a true representation of the clinical situation, this device is satisfactory for the majority of prosthodontic treatment.

If a fully adjustable articulator or articulator-related registration devices are chosen, further parameters are required, and greater adjustment possible, e.g. intercondylar distance, condylar and Bennett angles, upper and lower rear wall inclinations and fossae morphology.

**Facebow transfer**

A facebow transfers the orientation of the maxillary arch relative to the condylar hinge axis. The facebow can be either an earbow or a kinematic type, depending on the chosen articulator device. The basic elements of a facebow are:

- Bite fork to register the cusp tips and incisal edges of the maxillary teeth;
- Two posterior reference points, e.g. external auditory meati for orientation of the transverse condylar axis. If the right and left external auditory meati vary in height, it is better to align the facebow (earbow type) so that its horizontal plane coincides with the interpupillary line to avoid canting of the maxillary cast when mounted onto the articulator;
- One anterior reference point, e.g. the ala-tragus line or an arbitrary point 43 mm superior to the maxillary lateral incisor.

**Key points**

- An occlusal inspection can be limited to visual, tactile and study casts, or involve mounting casts onto an articulator.
- Items necessary for mounting casts are full arch impressions of both arches, occlusal records and a facebow transfer.
- For the majority of prosthodontic treatments, a semi-adjustable articulator with pre-set average values is adequate.
Occlusion: laboratory procedures

**Impressions**

- Plaster casts
- Bite registration
- Shimstock contacts

**Facebow registration**

- Facebow transfer (lateral view)
- Mounted casts (lateral view)

**Occlusal record**

- Lateral excursion
- Protrusion

**Photographs**

Clinical items necessary for mounting casts and setting dental articulator parameters

Occlusal analysis and uses of articulator-mounted casts
The laboratory process involves mounting casts onto a simulating device for reproducing, in three spatial planes, the occlusal situation of the patient’s mouth. The degree of sophistication to which this is achieved depends on the chosen type of articulator, and the meticulous steps taken to avoid introducing errors at each stage of the mounting process. As discussed in Chapters 10 and 15, hinge and fixed value articulators assume no semblance to the relationship of the jaws, while fully adjustable types allow a wider range of adjustable values that are more representative of jaw movements. For most prosthodontic treatment, the most popular type of articulator is the semi-adjustable Denar with accompanying earbow type of facebow transfer. In this chapter the Denar articulator is described for its use in occlusal analysis and treatment planning.

Pouring casts
The first stage is pouring casts from the impressions using high-quality, minimum distortion hard plaster. Any aberration of tooth anatomy will seriously distort the clinical scenario, leading to misleading interpretations and incorrect treatment planning.

Maxillary cast location
The facebow transfer, with the bite fork, locates the maxillary cast within the articulator to the hinge axis and ensures its orientation to the horizontal plane (external auditory meati or interpupillary line of the patient). The anterior reference pointer, 43 mm above the maxillary lateral incisor, ensures that the reference plane is adjusted accordingly.

Mandibular cast location
The mandibular cast is located to the maxillary cast in either CO or CR, at the chosen occlusal vertical dimension (OVD) using the occlusal records.

Mandibular excursions
After both casts of the arches are correctly and accurately mounted, protrusive and lateral excursions can be assessed. Photographic documentation showing articulation paper marks are useful for the technician to verify initial contact in CR, slide from CR to CO, non-working side interferences and guiding teeth in protrusion and lateral excursions, i.e. canine guidance or group function.

Adjusting contacts and OVD
Depending on the treatment plan and clinical prescription, any trial selective occlusal adjustments can be performed on the casts, and analysed, before carrying out irreversible adjustments in the mouth. Similarly, the OVD can be increased, and either an occlusal splint or a temporary prosthesis fabricated to the new OVD for assessing intra-oral occlusal tolerance.

Anterior diagnostic wax-up
If anterior aesthetics are to be restituted, additive diagnostic procedures such as diagnostic wax-ups are invaluable for assessing appearance and gaining the patient’s acceptance. From the diagnostic wax-up, a vacuum stent can be made, which serves as an excellent template for intra-oral mock-ups with composite resins for assessing aesthetic parameters such as:
• Degree of tooth display at rest;
• Amount of the tooth display during smiling;
• Parallelism of maxillary incisal plane with curvature of mandibular lip during a relaxed smile;
• Shade assessment;
• Tooth morphology.

In addition, the diagnostic wax-up can be used to fabricate surgical stents (with or without CBCT scans) for precise placement of implant fixtures.

Broadrick flag
If the posterior dentition requires rehabilitation, a diagnostic wax-up can be carried out using the Broadrick flag to restore the curves of Spee, Wilson and Monson, thereby allowing posterior tooth disclusion during mandibular excursions.

Using the Broadrick flag technique assumes correct functional and aesthetic position of the mandibular incisors. An anterior survey point is chosen, usually the mandibular incisors, and using a compass (opened 4 inches), an arc is drawn on the ‘flag’. The posterior reference point is either a molar, or if none is present, the condylar part of the articulator is selected, and another arc drawn to intersect the first. Using the two arcs as reference curves, wax is curved to restore the occlusal plane in three dimensions (curve of Monson). The completed wax-up can be used in a similar manner to the anterior wax-up as a template for temporary prostheses, and vacuum and surgical stents.

Custom incisal guidance table
A custom incisal table is used to copy either the preoperative or the proposed anterior guidance to the temporary or definitive restorations. Cold cured acrylic resin is placed on the guide table, and the articulator is moved in all excursions until the material has set to create a record of mandibular movements. When the working cast of the definitive restorations is mounted on the articulator, the table acts as a guide to shape the palatal surfaces of the restorations to conform to the mandibular movements.

Key points
• A semi-adjustable articulator is the most convenient and commonly used device for occlusal analysis and prosthodontic treatment.
• Mounting casts involves a facebow transfer with registration using interocclusal records at the correct OVD.
• Anterior wax-ups are an ideal method for aesthetic scrutiny without irreversible tooth preparation.
• The Broadrick flag technique is used for restoring the 3-D curve of Monson.
• A custom incisal table is used for copying anterior guidance for the definitive restorations.
Occlusion: adjustment and splints

Equilibrium
- Occlusal stabilisation is questionable, and may be negated by neuromuscular adaptation

Adjust contacts
- Removing non-working, CR, interfering and iatrogenic contacts before treatment

Clearance
- Ensuring sufficient space for restorative materials in all excursions, especially for guiding teeth

Relieve stress
- On implant-supported prostheses, periodontally involved and endodontically treated teeth, fractured teeth or restorations

Michigan splint
- Stabilising the occlusion and relieving symptoms

Bite raising appliance
- Increasing the OVD

Dahl appliance
- Altering the OVD by orthodontic movement

On implant-supported prostheses, periodontally involved and endodontically treated teeth, fractured teeth or restorations.
After analysing the occlusion by performing a clinical examination and laboratory assessment, the next step is deciding whether any occlusal adjustment or occlusal splints are necessary before starting prosthetic therapy.

**Occlusal stabilisation**

Occlusal stabilisation by occlusal adjustment (OA) is a controversial topic. Before discussing opposing theories, if TMD (temporomandibular disorder) is suspected, differential diagnosis is essential to elucidate whether TMD symptoms originate due to myogenous or bruxism origins, or pathology of the mandibular articular region. If the latter is suspected, occlusal adjustment is futile.

However, if TMD problems originate from myogenous or bruxism causes, OA may or may not alleviate symptoms. There are two schools of thought regarding OA. The first states that neuromuscular feedback will adapt to any adjustments and therefore negate its effect. The second opinion is that OA can stabilise the occlusion, removing interferences that impede physiological mandibular excursions, and hence provide symptomatic relief. Whichever opinion one holds, in order to prevent irreversible occlusal destruction, it is probably prudent to avoid OA until further conclusive research is forthcoming.

Besides TMD reasons, selective OA is justified before starting restorative treatment. Preoperative adjustments can be invaluable in saving time and avoiding disappointment as treatment progresses, especially at the cementation stage to ‘grind in’ the restoration(s), for example:

- Removing non-working side interferences causing lifting of the mandible on the working side;
- Ensuring sufficient occlusal clearance for restorative materials in all excursions (particularly for guiding teeth);
- If the tooth to be restored is the initial contact in CR;
- Eccentric contact(s) preventing closure in CO;
- Extruded teeth;
- Preventing undue stress on implant-supported prostheses;
- Relieving occlusal stress on fractured teeth or restorations;
- Eccentric contacts exacerbating bruxism;
- Iatrogenic interferences introduced by existing artificial prostheses;
- Relieving periodontal trauma due to occlusion;
- Reducing stress on endodontically treated teeth that are more susceptible to occlusal bite forces.

**Occlusal stabilising splints**

Various designs of splint are advocated depending on the clinical manifestations. The most popular is the full arch splint, e.g. Michigan, normally worn at night. The construction is of heat-cured acrylic, 2mm in thickness, with either anterior or canine disclusion. The important factor is that the interocclusal device be periodically adjusted until symptoms subside, or the treatment objective is achieved. Other varieties include partial coverage types that are contraindicated because they permit unwanted orthodontic tooth movement, while the soft varieties (or vacuum-formed splints) are less efficacious than the Michigan type. The disadvantage of splints is lack of patient compliance, which diminishes the potential beneficial effects of these appliances.

Innumerable studies have confirmed the efficacy of occlusal stabilising appliances for reducing parafunctional and electromyographic activity in conjunction with mandibular repositioning. Occlusal splints are prescribed for a variety of reasons including:

- Tooth wear and bite raising appliances (see below);
- Protecting fragile or susceptible restorations (especially all-ceramic restorations);
- Retainers following orthodontic or periodontal therapy;
- Differential diagnosis of TMDs (myogenous, bruxism or articular origin);
- Reducing clenching, bruxism, cheek biting, fractured teeth/restorations;
- Controlling stresses on implant-supported prostheses, trauma from occlusion;
- Tempering bruxism coexisting with comorbid syndromes (e.g. Parkinson’s disease);
- Supportive treatment for secondary otalgia associated with clenching;
- TMJ derangement, clicking, locking, arthralgia, arthritis and myalgia;
- Symptomatic relief in certain types of migraine;
- Relief of smarting symptoms associated with burning mouth syndrome (BMS) using lingual splints.

**Bite raising appliance**

Tooth wear is accompanied by compensatory growth of the alveolus, termed alveolar compensation, that maintains the OVD but leaves little, or no interocclusal space for replacing the lost enamel and dentine. One method for gaining interocclusal clearance is using a bite raising appliance for assessing whether the patient can tolerate an increase in the OVD, before providing reparative restorations.

**The Dahl appliance**

The principle of the Dahl orthodontic appliance is to allow periodontal growth of the posterior denition and intrusion of the anterior teeth, thereby creating room in the anterior region for restorative materials to replace the lost tooth substrate at a new OVD. This was originally achieved by a removable palatal bite-raising platform on the anterior teeth, causing posterior disocclusion, and allowing overeruption of the posterior teeth (periodontal growth) for re-establishing the bite. However, to overcome poor patient compliance, fixed restorations (either temporary or permanent), can instead be cemented onto the palatal surfaces of the anterior teeth to achieve a similar objective, with better outcomes.

### Key points

- Occlusal stabilisation by occlusal adjustment (OA) is contentious.
- Selective OA before starting treatment is prudent and avoids future complications.
- Occlusal splints are inexpensive and non-invasive treatment modalities.
- Occlusal splints can alleviate parafunctional habits and reduce muscular spasms.
- Bite raising or Dahl appliances are useful for establishing a new OVD by interocclusal clearance for restorative materials following tooth wear.
Superficial anatomy

Bone sounding for BW dimension

Attached gingiva

FGM

Sulcus

Epithelial attachment

Connective tissue attachment

Alveolar mucosa

Mucogingival junction

CEJ

Sulcus

Epithelial attachment

Connective tissue attachment

Superficial anatomy

Cross-section dentogingival apparatus landmarks

Bone sounding for BW dimension

BW variations: is smaller around anterior teeth

BW variations: apical location of BW on left lateral due to defective crown

BW variations: passive eruption (short clinical crowns)

BW variations: long EA

Sulcus

0.69 mm
(0.26–6 mm)

Epithelial attachment

0.37 mm
(0.3–3.3 mm)

Connective tissue attachment

1.07 mm
(0.29–1.84 mm)

Biologic width

2.04 mm
(variable)

Alveolar mucosa

Mucogingival junction

CEJ

Sulcus

Epithelial attachment

Connective tissue attachment

Biologic width

2.04 mm
(variable)
Periodontal health is essential for successful prosthodontic treatment outcomes. This chapter describes basic periodontal aspects requiring analysis before embarking on restorative treatment.

Superficial anatomy

Viewed from the facial or buccal aspect, the soft tissue envelope around the teeth is distinguished into the gingiva and alveolar mucosa. Starting from the tooth junction, the gingiva is further divided into the free gingival margin (FGM) and attached gingiva, terminating apically at the mucogingival junction with the alveolar mucosa. The attached gingiva is keratinised, tenacious and resilient to withstand masticatory function, while the alveolar mucosa is unattached and non-keratinised.

The dimensions and texture of the attached gingiva vary enormously, not only between individuals, but also around specific teeth. The width (apico-coronal dimension) varies from 0.5 mm to 8 mm, and the average thickness (bucco-lingual dimension) is 1.4 mm. The function of the attached gingiva is to protect the soft tissues during oral function, and its absence, especially around implants, has been shown to increase the propensity to inflammation.

Dentogingival apparatus

In cross-section, the dentogingival apparatus can be divided into three components: epithelium, connective tissue and bone. In a healthy periodontium, the sulcus starts at the FGM and ends at the epithelial attachment (EA). The depth of the sulcus (or gingival crevice) varies from 0.3 mm to 6 mm depending on numerous factors such as location on the tooth (deeper sulcus interproximally). The EA extends apically from the sulcus to the cemento-enamel junction (CEJ), ranging from 0.3 mm to 3.3 mm. The connective tissue attachment (CTA) is apical to the EA and terminates at the alveolar bone crest (ABC) housing the teeth. The CTA shows the least variance of the dentogingival apparatus, i.e. 0.3 mm to 1.8 mm. The combined linear measurements of the EA and the CTA is termed the biologic width (BW), averaging 2.04 mm.

Biologic width

The frequently quoted measurement of the biologic width (BW) as 2.04 mm is based on average measurement of the dentogingival apparatus from cadavers:

- Sulcus depth = 0.69 mm;
- EA = 0.97 mm;
- CTA = 1.07 mm;
- EA + CTA (biologic width) = 2.04 mm.

The significance of the BW is that it is nature’s approach to protecting the most important part of the dentogingival apparatus, i.e. the periodontal ligament and the ABC, which ensures survival of a tooth. This soft tissue shield guards against mechanical and bacterial insult. However, as for any shield, its efficacy is diminished if violated or damaged, placing the tooth (together with any restorations) in a precarious situation.

The salient points about the BW can be summarised as follows:

- Present around every tooth;
- Nature’s soft tissue shield for ensuring tooth survival;
- 2.04 mm is an average dimension, not applicable to every patient or every tooth;
- It is essential to preserve the BW and prevent its violation during clinical procedures;
- Differential diagnosis is necessary for variations of BW.

BW variations

The biologic width is a physiological 3-D concept, sometimes referred to as the biologic space. At present, the minimum dimension of the BW for health is unknown; it can be as small as 0.6 mm. The dimension of the BW varies depending on the type of tooth and the location around a tooth; some differences are listed below:

- **Type of tooth**
  - Incisors and canines = 1.75 mm;
  - Premolars = 1.97 mm;
  - Molars = 2.08 mm.

- **Population variations**
  - 85% normal relationship of ABC and EA to CEJ;
  - 13% ABC and EA in an apical position to norm – larger BW;
  - 2% ABC and EA in a coronal position to norm – smaller BW.

- **Apical position of EA** – pseudo-healing following episodes of periodontitis and/or mechanical or surgical trauma;
- **Passive** (apical location of BW) and altered passive eruption (coronal location of EA with short clinical crowns);
- **Restored teeth** have a larger BW;
- **Implants** – BW is located more apically compared to natural teeth.

Methods for determining BW dimension

To preserve the BW it is essential to determine its dimension and location. Since it is impossible to determine the BW by visual inspection, the methods available include:

- **Tactile** – most popular method by sounding bone (along long axis of tooth) and transgingival probing (perpendicular to tooth). Requires local anaesthetic; invasive, erratic reading in presence of inflammation or presence of a long EA;
- **Parallel profile radiography** – questionable unnecessary radiation exposure;
- **Ultrasound** – non-invasive, variable readings, which are averaged for a given tooth;
- **Soft tissue cone beam computed tomography (ST-CBCT)** – CBCT scan taken with photographic cheek retractors to displace lips and cheeks, and requesting patient to place tongue to floor or back of the mouth to allow visualisation of the gingival soft tissues (buccal and palatal/lingual). Non-invasive, precise measurements of both soft tissues and bone in both axial and perpendicular axes to tooth. Questionable unnecessary radiation exposure, unable to distinguish between EA and CTA or inflamed and healthy tissues.

**Key points**

- The dentogingival apparatus consists of epithelium, connective tissue and bone, and its health is paramount for successful prosthodontic treatment.
- It is essential to determine dimension and location of BW before starting restorative treatment.
- The most popular methods for determining BW are tactile and ST-CBCT.
Prosthodontic considerations

### Table: Tooth Shape, Gingival Scallop, and Distance from Interproximal Bone Crest to Mid-Facial Bone Crest

<table>
<thead>
<tr>
<th>Tooth Shape</th>
<th>Gingival Scallop</th>
<th>Distance from Interproximal Bone Crest to Mid-Facial Bone Crest (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square</td>
<td>Flat</td>
<td>2.1</td>
</tr>
<tr>
<td>Oval</td>
<td>Scalloped</td>
<td>2.8</td>
</tr>
<tr>
<td>Triangle</td>
<td>Pronounced Scallop</td>
<td>4.1</td>
</tr>
</tbody>
</table>

**PERIODONTAL HEALTH**

- **Contact points**
- **Operative trauma**
- **Scaling/disinfecting**
- **Trauma from occlusion**
- **Patient**
- **BW**
- **Surgery**
- **Chemotherapy**
- **Peri-implantitis** (preoperative)
- **Peri-implantitis** (postoperative)
- **Black triangles**
- **Incomplete papilla fill**
- **PPS (periodontal plastic surgery)** is used to expose teeth, e.g., crown lengthening or cover exposed tooth roots, e.g., soft tissue grafting
- **GBR (guided bone regeneration)** is used for correcting bony defects, or bone augmentation before implant placement

**REGENERATIVE MEASURES**

- **GBR** (guided bone regeneration) is used for correcting bony defects, or bone augmentation before implant placement

- **PPS** (periodontal plastic surgery) is used to expose teeth, e.g., crown lengthening or cover exposed tooth roots, e.g., soft tissue grafting

**BW violation:**
- Inflammation around right central incisor crown
- Recession around existing defective crowns

**PPS**

GBR (guided bone regeneration) is used for correcting bony defects, or bone augmentation before implant placement.
Achieving and maintaining periodontal health is influenced by numerous factors, including disruption of the biofilm by scaling/root planing, surgery, chemotherapy (local and systemic), patient factors (oral hygiene, constitutional, systemic illness, habits) and degree of operative trauma during clinical procedures. A paradigm shift is also emerging regarding the treatment of periodontal disease. Conventional scaling, root planing and surgery for eliminating pockets is being replaced by a more minimal, non-invasive approach of full-mouth ultrasonic debridement for disrupting the biofilm and thereby achieving disinfection of the root. Periodontal health is essential before starting prosthetic treatment, and is a constituent of the health, function, aesthetic (HFA) triad.

**Periodontal biotypes and bioforms**
The periodontal biotype plays a significant role when planning prosthodontic and implant therapies. Periodontal biotypes represent gingival texture and architecture around teeth and are classified as:
- **Thin-scalloped** – delicate, prone to gingival recession, dehiscences and fenestrations;
- **Thick-flat** – fibrotic, resilient, prone to periodontal pocket formation;
- **Medium** – intermediate between the above two extremes.

The periodontal bioform describes the degree of gingival scallop around teeth, which is primarily dictated by tooth shape, and can broadly be categorised as square, oval or triangular, corresponding to the flat, scalloped or pronounced scalloped bioforms, respectively.

**Contact points**
The relationship of the contact point (either of natural teeth or artificial prostheses) to the interproximal alveolar bone crest determines the amount of interproximal gingival papilla fill. If the distance is 5 mm or less, total papilla fill is evident in the gingival embrasures. If the distance is greater than 5 mm, incomplete papilla fill is observed, especially with thin biotypes, colloquially referred to as ‘black triangles’. However, to achieve complete papilla fill between two adjacent dental implants, the distance required is less than for natural teeth, i.e. <3 mm.

**Trauma from occlusion**
Trauma from occlusion is a major contributing factor in periodontal disease and can present as bone loss without periodontal pocket formation. Trauma from occlusion can be:
- **Primary trauma** – with an adequate (healthy) periodontium;
- **Secondary trauma** – inadequate (diseased) periodontium, resulting in teeth that are incapable of withstanding occlusal forces in an axial direction, leading to migration, fremitus and flaring. The treatment depends on the severity of trauma and includes orthodontic alignment (to correct osseous defects and improve crown-to-root ratios), occlusal equilibration, occlusal stabilising splints, periodontal splints, bone regenerative therapies, and implants (for replacing strategic teeth for occlusal stabilisation).

**Biologic width violation**
The previous chapter discussed the significance of the biologic width (BW). Many clinical procedures can potentially violate the BW, and therefore compromise a healthy periodontium and success of an artificial prosthesis. The consequences of BW violation depend on the host response and include:
- **Adaptation** – a new BW forms in a more apical position to restore health of the periodontium;
- **Persistent inflammation** – requires orthodontic extrusion, or bone resection by a surgical approach to restore the BW;
- **Gingival recession** – causing asymmetrical gingival zeniths, ‘black triangles’, especially with thin-scalloped biotypes;
- **Pocket formation** – common with thick-flat biotypes;
- **Perio-endodontic lesions** – abscesses or chronic periapical pathology.

**Peri-implantitis**
Periodontal diseases also plague dental implants. Inflammation around implants is classified as:
- **Mucositis** – reversible inflammation without bone loss;
- **Peri-implantitis** – inflammation combined with irreversible bone loss around implants due to infection, more prevalent with partially dentate ridges due to cross-infection from adjacent periodontally involved teeth, compared to edentulous arches. Peri-implantitis is time dependent, affecting a small number of patients following implant therapy. The risk factors associated with this condition are unclear, but links have been postulated with systemic illness (e.g. diabetes, osteoporosis, obesity), habits (e.g. smoking, drinking extremely hot fluids), local factors (e.g. bone quality and quantity, reduced blood supply) and implant design and surface coatings.

**Periodontal plastic surgery**
Periodontal plastic surgery (PPS) is indicated for correcting deformities caused by periodontal disease to restore function, aesthetics and longevity of restorative therapy. PPS is divided into two categories:
- **Exposing tooth** – crown lengthening for improving crown-to-root ratio, enhancing aesthetics (altering width-length ratio of tooth or reducing gingival display during smiling), rectifying altered passive eruption, pocket reduction, re-establishing BW, and restitution of erratic gingival contours;
- **Gingival grafting** – increasing the width of attached gingiva or root coverage according to Miller’s classification. Soft tissue grafts are usually harvested from the palate (membranes can also be used) and sutured in situ at the recipient site(s).

**Regenerative therapy**
Regenerative therapies involve augmenting bone volume lost as a result of periodontal disease for repairing bony defects, or establishing an adequate platform for eventual implant placement. The principles for guided bone regeneration (GBR) are to retard epithelial growth to allow time for bone formation. This is achieved by using a combination of membranes (resorbable and non-resorbable) and bone grafting materials, such as autogenous bone (from host, e.g. nasal spine, mandible or iliac crest), allografts (from animals, e.g. bovine-derived prion-free tissue) and xenografts (synthetic materials, e.g. particulate ceramics and hydroxyapatite).

**Key points**
- Factors influencing periodontal health include periodontal biotypes, contact points, trauma from occlusion and BW violation.
- Corrective measures include periodontal plastic surgery and regenerative therapies.
- Peri-implantitis, although affecting a minority of patients with implants, is a significant concern for implant survival rates.
The dental pulp

AETIOLOGY (BACTERIA)
- Caries
- Tooth wear
- Fractures
- Iatrogenic

PATHOGENESIS
- Pulpitis
- Necrosis
- Periradicular lesion

CLINICAL DIAGNOSIS
- Pain: Throbbing, lingering, spontaneous, sensitivity or painless
- Swelling
- Mobility/Extrusion
- Periradicular

TREATMENT
- Pulpotomy
- RCT
- Re-treatment
- Apicectomy

Microscope
- NiTi
- Lasers
- Materials
A healthy dental pulp ensures survival of a natural tooth and any artificial restorations. The sections below discuss recent thinking and developments for clinical management of pulpal diseases.

Aetiology
Pulpal diseases are bacterial in origin, from the resident oral microbiota, either directly or indirectly. Some causes include:

• Caries – direct bacterial assault of the pulp;
• Tooth wear – eventual pulpal pathosis due to attrition, abrasion, erosion and abrasion;
• Tooth fractures – pulp exposure due to extra-oral accidents or masticatory misadventures;
• Iatrogenic – pulp exposure during restorative procedures.

Examples of microbes found in root canals and periradicular lesions include Enterococcus faecalis, Candida albicans, Actinomyces israelii, Propionibacterium propionicum, cytomegalovirus and the Epstein–Barr virus.

Pathogenesis
Whatever the cause, microorganisms initiate an inflammatory response (pulpitis). Bacterial toxins precede bacterial invasion, causing a vascular response by releasing cytokines and mediators. If the bacterial insult is confined to the hard tissues, a reparative and protective secondary dentine barrier is formed. If the pulp is exposed, formation of a soft tissue barrier is impossible since the pulp is devoid of epithelial cells. Therefore, the bacterial invasion and proliferation is profuse, leading to colonisation of the root canal system and subsequently the periradicular areas. The infected periradicular areas react with a protective response by bone resorption to contain and eliminate the infection, which is visible as an osteolytic bone lesion (periapical lesion) on a radiograph.

Clinical manifestations and diagnosis
Precise and efficient diagnosis is essential for determining the appropriate treatment. Differential diagnosis includes pulpitis (reversible and irreversible) and necrosis (partial or complete) with or without periradicular involvement. A major clinical challenge is differentiating between reversible and irreversible pulpitis; at present, this decision is mainly based on guesswork. Some symptoms and tests for pulpal diseases include:

• Pain – throbbing, lingering, spontaneous, tender to touch or tooth sensitivity;
• Painless – e.g. complete pulpal necrosis in older patients;
• Swelling – intra- and extra-oral;
• Percussion sensitivity – TTP (tender to percussion);
• Tooth mobility;
• Extrusion – combination of periodontal/endodontic lesions;
• Pulp vitality tests – thermal, electrical, chemical, pulse oximetry (see Chapter 5);
• Periapical radiolucency – assessed by radiographic or CBCT evaluation;
• Systemic – fever, lethargy, malaise, anxiety.

Treatment modalities
Management of the damaged pulp is predominantly concerned with reducing or eliminating bacteria. Some options are summarised below.

• Pulpotomy with pulp capping – indicated for acute traumas of healthy pulps in young individuals (with an enhanced regenerative potential), for encouraging pulp regeneration or repair by formation of secondary dentine using a pulp-capping agent, e.g. calcium hydroxide.
• Pulpectomy with root canal therapy (RCT) – extirpation of infected pulps. RCT has the following objectives: debridement, shaping, disinfecting and obturating the root canal system.

Failure of endodontic treatment is attributed to lack of asepsis during treatment, failure to eliminate infection from the root canal and/or periapical areas, or subsequent leakage due to poor obturation or defective coronal restorations. In these circumstances, the treatment options are:

• Re-treatment with a new, correctly fitting coronal restoration;
• Surgical endodontics – apicectomy and retrograde filling;
• Extraction with subsequent implant(s). Implants may also be considered for failed apicectomies or complex re-treatment cases.

Technological adjuncts
The last two decades have witnessed a burgeoning of technological advances for improving endodontic therapy, including the operating microscope, ultrasonic devices, electronic apex locators, lasers, light-activated disinfection, NiTi (nickel-titanium) files and miniaturised instruments for working with magnifications up to x32. In addition, newer materials such as dentine bonding agents, Biodentine (Septodont) and mineral trioxide aggregate (MTA) have improved treatment outcomes.

Endodontic controversies
As with many disciplines, the schism between clinicians and researchers leads to contradictory views. Advancements in biologically based knowledge are slowly adopted into clinical practice. Furthermore, success or failure is in the eyes of the beholder. Many different criteria may be used to assess endodontic outcomes, e.g. absence of pain, survival of the tooth, survival of a restoration, apical bone regeneration, or elimination of infection.

Some current controversies include:

• Whether to leave or remove the smear layer;
• One- vs two-appointment RCT;
• Ideal measures for promoting regeneration (of pulp) or repair (secondary dentine), e.g. using bioactive substances;
• Importance of coronal vs apical seal (i.e. significance of location of microorganisms – apical or coronal part of root canal);
• Direct vs indirect pulp capping (step-wise excavation);
• Efficacy of disinfecting agents – e.g. sodium hypochlorite, chlorhexidine, calcium hydroxide, tetracycline isomer compound;
• Concept of sterile periradicular granulomas;
• Apical terminus location and healing with cementum-like tissue;
• Lateral condensation vs vertical compaction obturation.

Key points
• Understanding the biological processes ensures correct diagnosis, and selection of the most appropriate endodontic treatment.
• Technological advances have resulted in more predictable therapy, but further research is required to resolve current controversies.
Intraradicular support

Is a post necessary?
Is the remaining coronal dentine sufficient to support an extracoronal restoration?

**INDICATIONS**

**GUIDELINES**

- Tooth anatomy
- Adequate alveolar bone support
- Post length : crown length ratio
- Root length
- Post width
- Ferrule effect

**TYPES**

- Cast metal
- Steel
- Zirconia
- Canal prep
- Radiograph of GP filling and metal post
- Cast metal post and core

**PLACEMENT**

- Ribbon
- Carbon fibre
- Glass fibre
- Perforation
- Posts in premolars
- Posts in molars
Posts, or intraradicular supports, do not strengthen or reinforce teeth. In fact the opposite is true: removal of dentine from a root canal to accommodate a post weakens the structural integrity of the root. Heavily broken teeth due to trauma or caries, with or without a root filling, may present with insufficient tooth structure to retain an extra-coronal definitive restoration. Therefore, the purpose of a post and core is to gain intraradicular support for the definitive restoration.

Indication for posts
If there is sufficient remaining coronal dentine to support a restoration, a post is superfluous. This is especially true for molars with considerable amounts of dentine or large pulp chambers. At the other extreme, the incisors have smaller amounts of coronal dentine, which is reduced following trauma, caries or endodontic abscess cavities. In these circumstances, a post is essential for retention of a permanent restoration. Furthermore, root-filled teeth have reduced proprioceptive response, and are therefore more vulnerable to masticatory and occlusal forces.

Guidelines for post placement
Before placing a post, certain criteria must be fulfilled in order to ensure its survival and that of the overlying extracoronal restoration. Some factors to consider are:

- **Tooth anatomy:**
  - **Molars** – choose the largest and straightest canal for post placement, i.e. distal canals of mandibular molars and palatal canals of maxillary molars. Placing posts in curved root canals often results in perforations into the periodontal ligament or alveolar bone;
  - **Premolars** – smaller pulp chambers, with tapering roots exhibiting thin mesiodistal cross-section with proximal invaginations;
  - **Incisors and canines** – post is unnecessary if sufficient coronal dentine is present. Mandibular incisors have thin, tapering and narrow mesiodistal root morphology;
  - **Sufficient alveolar bone support** encompassing at least half of post length into the root;
  - **Minimum 1:1 post length/crown length ratio**;
  - **Root length** long enough to accommodate a 4–5 mm apical root filling seal and ½ to ¾ of the post length;
  - **Post width** not exceeding ½ of root width at narrowest point and 1 mm of remaining circumferential dentine;
  - **Ferrule effect** – at least 1.5 mm height and width of remaining coronal dentine.

Ideal properties of a post
The ideal properties of a post can be summarised as follows. Similar mechanical and physical properties as natural teeth, e.g. modulus of elasticity, compressive strength, coefficient of thermal expansion and optical characteristics. The post material should be biocompatible, non-corrosive and hypo-allergenic, should minimise microleakage, prevent root or restoration fractures (both cohesive and adhesive fractures) and exhibit favourable clinical handling and ease of use. The dental market is inundated with posts of different materials, shapes, configurations, surface finishes and colours. There is no single post that has all the properties for every clinical situation, and often a compromise is necessary.

Choice of post
Posts can broadly be categorised as custom-made or prefabricated. Custom posts are usually made of cast metal or alumina ceramics by an indirect technique. This is useful for making a unified post and core to replace extensive coronal dentine loss. However, the process involves two visits to the surgery with the possibility of contamination of the root canal due to provisional cement failure or defective temporary restorations.

Prefabricated posts are the most popular type, offering expediency, single-visit placement and immediate preparation of core build-ups, and are available in a large selection of materials and designs:

- **Metal**, e.g. stainless steel, brass, titanium. Disadvantages include poor aesthetics, root fracture, corrosion and nickel sensitivity;
- **Ceramics**, e.g. alumina, zirconia or porcelain fused to metal. High flexural strength and fracture toughness, favourable aesthetics. However, the drawbacks are difficult retrievability and propensity for root fracture;
- **Fibre** posts, e.g. pliable ribbon, glass, quartz or carbon fibre. Flexible, similar physical properties to dentine, e.g. modulus of elasticity of dentine = 15 GPa. Highly aesthetic (light-transmitting), easily retrievable, bonding to dentine with dentine bonding agents, and mitigate root fracture;
- **Design** – tapered types require less dentine removal, but offer poorer retention compared to parallel designs. The surface finish can be smooth or serrated and may incorporate cement vents for luting agents. The threaded or screw posts (active posts) offer enhanced retention, but at the expense of root fracture susceptibility due to dentine stresses.

Canal preparation and post cementation
Placing a post requires shaping the canal to accommodate the post geometry by removing a part of the root filling (usually gutta-percha). A thorough knowledge of root anatomy is essential before canal preparation. The two methods for gutta-percha removal are thermal and mechanical. The thermal approach is tedious but less traumatic. The mechanical approach involves using rotary instruments such as Gates-Glidden burs or P-type reamers, which may inadvertently disrupt the apical seal or result in lateral perforation.

The majority of posts are passive, requiring a luting agent for cementation into the root canal. Zinc phosphate cement has the longest clinical history but is prone to leakage. Glass-ionomers offer dentine adhesion, but their poor mechanical properties may cause cement failure leading to microleakage. Composite-based resins have high compressive strength and dentine adhesion with dentine bonding agents, but are technique sensitive.

Key points
- Careful consideration is required before placing a post, as the latter weakens the tooth.
- No ideal post system exists, and a pragmatic approach is necessary.
- Meticulous root canal preparation and choice of cement are essential for long-term post and definitive restoration survival.
Coronal support: core build-up

PREREQUISITE
- Retain maximum amount of tooth structure
- Preserve marginal ridges
- Incorporate ferrule effect

MATERIALS
- Amalgam
- Resin-based composite
- Glass ionomer
- Ceramics
- Cast gold

VITAL TEETH
- Amalgam
- Composite
- Cast gold
- Ceramic
- Fill-in with glass ionomer
- Fill-in with flowable composite

NON-VITAL TEETH
The purpose of a core build-up is to provide retention and resistance for definitive, usually extracoronal, restorations. The final restoration can be partial or full coverage depending on the amount of residual tooth substrate. Cores can be built up on either vital or non-vital teeth, which have previously received a post to gain additional intraradicular support from the endodontically treated root.

**Ideal properties of a core build-up material**

At present, a single restorative material does not offer all the ideal properties of a core build-up material, which are:
- Adequate physical properties (flexural and compressive strength) to resist intra-oral forces;
- Non-allergenic;
- Biocompatible;
- Preventing microleakage of oral fluids at core-tooth interface;
- Chemical bonding or bonding to tooth substrate, both enamel and dentine;
- Similar thermal properties to natural teeth (coefficient of thermal expansion and contraction);
- Minimum water absorption;
- Dimensionally stable;
- Cariostatic;
- Ease of manipulation.

**Materials for core build-up**

The essential factor for a successful and long-lasting core, irrespective of the material used, is ensuring that at least 1.5 mm of dentine is present for the ferrule effect. The most popular materials for core build-ups are amalgam, resin-based composite, glass ionomer, ceramics and cast alloys.

Amalgam has traditionally been used as a build-up material, offering excellent strength, low solubility and bonding by micro-mechanical retention to dentine using dentine bonding agents (DBA). The disadvantages are poor aesthetics, a protracted setting time requiring a second visit for preparation of the core, and patient concerns regarding its possible toxicity, a doubt refuted by scientific research.

Resin-based composites offer superior aesthetics and the ability to bond to dentine with DBA, and the flowable varieties allow ease of manipulation, especially for cementing posts in root canals. However, their drawbacks are polymerisation shrinkage, hydroscopic expansion, incompatibility with eugenol root-filling materials and technique-sensitive protocols.

Glass ionomers have the advantage of chemical adhesion with dentine, but their poor physical properties (low tensile and compressive strengths) are incapable of withstanding intra-oral forces. Therefore, their use is limited to filling in small defects, and they are not recommended for bulk build-ups.

Ceramics and cast alloys require an indirect technique and are reserved for cores with intraradicular posts, offering a unified post and core complex. Cast gold is resilient but has poor aesthetics beneath highly translucent all-ceramic crowns. Also, certain types of ceramics can be fused onto zirconia posts with excellent aesthetics. However, zirconia posts are stiff and difficult to retrieve if there are endodontic complications requiring re-root treatment.

**Core build-up for vital teeth**

Various methods are available for building a foundation for teeth that have lost enamel and dentine due to trauma, caries or previously failed fillings. The two crucial factors for cores on vital teeth are, first, to preserve the maximum amount of healthy tooth and, second, to prevent pulpal involvement. The importance of keeping the remaining tooth substrate is maintaining tooth stiffness, which depends on preservation of the marginal ridges. If the latter are lost, tooth stiffness is severely compromised, requiring either cuspal coverage (onlay), or a full coverage crown.

The techniques for retaining cores on vital teeth include:
- Pins – questionable due to dentine crazing, and the possibility of inadvertent perforation into the pulp and periodontium;
- Cavity modification – judicious and strategic creation of undercuts, slots and grooves to retain the build-up material;
- Dentine bonding agents – for enhancing adhesion of amalgam and resin-based composites to coronal dentine;
- Luting agents – bonding to dentine, e.g. amalgam with wet zinc phosphate or glass ionomers.

**Core build-up for non-vital teeth**

Materials for core build-up on non-vital teeth are similar to that for vital teeth. The ferrule effect is also applicable for non-vital teeth. However, since additional support is gained from intraradicular posts, the fundamental issue to address is minimising material interfaces. This means that materials of the post/core complex should have similar properties. When similar materials are used there is less stress concentration at the interfaces and reduced microleakage; such a post/core complex is structurally better placed to withstand intra-oral forces. This is the rationale for fabricating a unified post/core complex using an indirect technique with either cast alloys or ceramics.

With the direct technique, a post/core complex is made during a single visit, but the different material interfaces are a compromise, with poorer mechanical properties. Therefore, when using a direct approach, precise clinical procedures and appropriate material selection are essential for ensuring longevity of the post/core complex, and the subsequent permanent restoration.

**Key points**

- Core build-ups on vital and non-vital teeth are used to provide retention and resistance for permanent restorations.
- It is essential to preserve as much natural tooth substrate as possible, incorporating the ferrule to maintain structural integrity.
- There is no ideal material for a core build-up.
- Cores on vital teeth should avoid pulpal involvement.
- A unified post/core complex is preferred for non-vital teeth, because it avoids material interfaces.
Anterior dental aesthetics: basic principles

<table>
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<th>FACIAL</th>
<th>DENTOFACIAL</th>
<th>DENTAL</th>
<th>GINGIVAL</th>
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<td>Frontal facial view</td>
<td>Interpupillary line parallel to incisal plane</td>
<td>Width/length ratio</td>
<td>Gingival exposure</td>
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<tr>
<td>Sagittal facial view</td>
<td>Rickett’s E-plane</td>
<td>Axial inclination</td>
<td>Thick periodontal bioform</td>
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<td>Lip length</td>
<td>Age</td>
<td>Incisal embrasures</td>
<td>Black triangles</td>
</tr>
<tr>
<td>Race</td>
<td>Sex</td>
<td>Width progression</td>
<td>GAL class II</td>
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</tbody>
</table>
Anterior dental aesthetics is primarily concerned with the appearance of the maxillary anterior six teeth. The majority of research has been directed towards the size, shape and alignment of the maxillary incisors and canines, their relationship to each other and the antagonist dentition, and to the surrounding soft tissues including the gingivae, lips and facial features. Dental aesthetics is best analysed by considering the face and then **zooming closer to the dental elements**.

### Facial perspective

The facial perceptual can be divided into **frontal** and **sagittal** views. From the **frontal view**, the key features are:

- **Imaginary horizontal parallel lines** acting as **cohesive forces** for facial symmetry;
- **Facial midline**, perpendicular to horizontal lines, acting as **segregative force** to add interest to the facial composition;
- **The interpupillary line** is used as a reference for assessing the inclination of the incisal plane.

From the **sagittal (profile) view**, the analysis consists of:

- **Imaginary horizontal parallel lines**;
- **Frankfurt horizontal plane**;
- **Ricketts’ E-plane**;
- **Steiner and Burstone lines**;
- **Naso-labial angle**.

### Dentofacial perspective

Zooming closer, the **dentofacial composition** concentrates on the teeth and their relationship to the surrounding soft tissues in **static** and **dynamic muscular positions**.

The static position is a **habitual** (not relaxed) state, the lips are slightly parted with **minimal muscular activity** and the teeth are out of occlusion. The degree of tooth exposure is determined by the LARS factor:

- **Lip length** (maxillary) – varies from **10 to 36 mm**. Short lip = greater maxillary tooth exposure. Long lip = greater mandibular tooth exposure;
- **Age** – **youthfulness** equates to greater maxillary tooth display, while reduced muscular tonicity of the lip musculature in **advancing years** results in less maxillary and **greater mandibular tooth display**;
- **Race** – increasing maxillary tooth display from Caucasians, Asians to Blacks;
- **Sex** – females have **shorter maxillary lips** and display more of the maxillary teeth compared to men.

The dynamic positions are **relaxed** and **exaggerated smiles**. Some points to consider are:

- **Smile arc (line or curvature)** – imaginary line of the **incisal edges** of the maxillary teeth, which should be **parallel** to the concave curvature of the mandibular lip;
- **Bilateral negative space (buccal corridor)** – space separating the teeth from the corners of the lips;
- **Phonetics** – positions of the teeth relative to the soft tissues (lips and tongue) for proper pronunciation of sounds, for example:
  - ‘M’ – habitual muscular position of lips;
  - ‘F’ and ‘V’ – buccal surface of maxillary incisors contact mucosal (not cutaneous) part of lower lip;
  - ‘S’ – vertical dimension of speech or edge-to-edge position of the upper and lower incisors;
  - ‘TH’ – tongue touches palatal aspect of maxillary teeth.

### Dental perspective

The dental perspective is concerned with **tooth shape, dimensions** and **alignment** and **progressive width proportions** between the maxillary incisors and canines. Some aspects include:

- **Shape** – genetically determined;
- **Size** – the width/length of teeth is referred to as the **w/l ratio** or its value as a percentage. The w/l ratio for narrow teeth can be as small as **60%** and for wide teeth greater than **100%;**
- **Alignment** – intra-arch positioning and **axial inclination**;
- **Incisal embrasures** – angles between the incisal edges or tips of teeth, influenced by the degree of tooth wear. Incisal embrasure angles increase from the anterior to the posterior teeth;
- **Width progression** – traversing distally from the centrals to the canines in specified increments or percentage widths of the teeth;
- **Overjet (horizontal: ideal 2.7 mm) and overbite (vertical: ideal 4.0 mm).**

### Gingival perspective

The gingival architecture surrounding the teeth is determined by the undulations of the underlying bone and the morphology and size of the teeth. Gingival considerations include:

- **Gingival exposure** – refers to the amount of gingiva visible between the gingival zeniths of the maxillary teeth and the lower border of the maxillary lip during a relaxed smile. The amount of tolerable exposure is around **3 mm**;
- **Periodontal biotype** – the texture of the attached gingivae, classified as thick, normal or thin;
- **Periodontal bioform** – degree of gingival scallop, categorised as highly scalloped, normal or flat;
- **Gingival embrasures** – amount of proximal gingival papilla fill, linked to the **distance of the contact points to the interproximal osseous crest**. A distance of **less than 5 mm** ensures complete papilla fill without unsightly ‘black triangles’;
- **Gingival aesthetic line (GAL)** – gingival contour progression from central incisor to canine:
  - **Class I** – GAL angle is 45–90°, lateral incisor is touching or below (1–2 mm) GAL;
  - **Class II** – GAL angle is 45–90°, lateral incisor is above (1–2 mm) GAL, and its mesial aspect overlaps the distal aspect of the central incisor;
  - **Class III** – GAL angle is 90° and the canine, lateral and central incisors all lie below GAL;
  - **Class IV** – the gingival contour cannot be assigned to any of the above three classes.

### Key points

- Anterior dental aesthetics is primarily concerned with the maxillary anterior six teeth.
- Aesthetic analysis is expedited by sequentially analysing the facial, dentofacial, dental and gingival perspectives.
**Anterior dental aesthetics: theories**

### Geometric Theories

#### Golden Proportion
- The repeated width proportion of anterior six teeth is in the Golden Proportion viewed from the frontal aspect.
- Progressing distally, the distal tooth is 62% of the immediate mesial tooth.

#### Natural Proportion
- The repeated width proportion of each tooth is not identical.
- Progression from central to lateral incisor is 66%.
- Progression from lateral incisor to canine is 84%.

#### Golden Percentage
- The width of individual teeth is a percentage of the total width of the anterior six teeth.

#### RED Proportion
- Consistent repeated ratios are more important than a specific ratio.
- For average tooth dimension of 78% (w/l ratio of 0.78), the recommended RED is 10%.
- For short teeth, 80% RED, and tall teeth a 62% RED (or the Golden Proportion).

### Psychological Theories

- Full, voluptuous lips equating to large, round teeth.
- Thin, emaciated lips equating to slender, delicate teeth.

### Perception Theories

<table>
<thead>
<tr>
<th>Aesthetic anomaly</th>
<th>Ideal</th>
<th>Tolerance</th>
<th>Aesthetic anomaly</th>
<th>Ideal</th>
<th>Tolerance</th>
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<tbody>
<tr>
<td>Smile arc (convexity)</td>
<td>2.7 mm</td>
<td>1.2 mm(3s) to 2.7 mm(7s)</td>
<td>Central incisor gingival discrepancy</td>
<td>0 mm</td>
<td>2 mm</td>
</tr>
<tr>
<td>Overbite</td>
<td>2.7 mm</td>
<td>5.7 mm</td>
<td>Lateral incisor gingival height</td>
<td>-0.4 mm</td>
<td>+1.2 mm to ~2.9 mm</td>
</tr>
<tr>
<td>Maxillary central-to-incisal step</td>
<td>1.4 mm</td>
<td>2.9 mm</td>
<td>Width of lateral-to-central incisor</td>
<td>78%</td>
<td>45%</td>
</tr>
<tr>
<td>Bilateral negative space</td>
<td>16% of smile</td>
<td>8% to 22%</td>
<td>Discrepancy dental / facial midline</td>
<td>0 mm</td>
<td>2.9 mm</td>
</tr>
<tr>
<td>Positive canine or molar torque</td>
<td>None</td>
<td>Irrelevant</td>
<td>Discrepancy upper / lower midline</td>
<td>0 mm</td>
<td>2.9 mm</td>
</tr>
<tr>
<td>Maxillary gingival display</td>
<td>2.1 mm</td>
<td>+0.4 mm to ~3.6 mm</td>
<td>Occlusal plane cant</td>
<td>0 mm</td>
<td>3 mm (or 4°)</td>
</tr>
</tbody>
</table>

Degree of tolerance by laypersons for various aesthetic anomalies (after Ker et al., *JADA* 2008; 139: 1318–27)
The search for a magic formula to quantify beauty has preoccupied artists, scientists and philosophers for over 5000 years. Yet, to date, there is no formula, law or dictum available that can decisively define the essence of beauty. Many hypotheses, opinions and ideas abound, which can broadly be categorised as geometric, psychological and perceptual theories.

**Genesis of beauty**

One of the earliest attempts to analyse beauty was by the ancient Egyptians around 3000 BC. The mathematicians of the time realised the importance of proportion for creating aesthetically pleasing objects. The idea of the Egyptian triangle was extensively used in arts and crafts, and as an architectural template for building the famous sphinxes and pyramids of Egypt.

The first person to postulate a mathematical formula for analysing beauty was Pythagorus in 530 BC with the concept of the golden number, $\Phi = 1.618$, and its reciprocal (1/1.618 = 0.618), the golden proportion (GP). The significance of the GP is its prevalence in inanimate objects and animate beings. Items perceived as beautiful can be related to the GP; the beauty of the maxillary anterior six teeth, viewed from the frontal aspect, can be related to the GP.

- **Williams** (1914) – classified tooth shape as square, tapering or ovoid;
- **Lombardi** (1973) – first person to propose that the width progression of the maxillary anterior six teeth, viewed from the frontal aspect, can be related to the GP;
- **Preston** (1993) – disputed the GP and proposed the natural proportion for the width progression from the central to lateral to canine;
- **Gillen** (1994) – dispelled the myth of the GP for the maxillary anterior teeth;
- **Snow** (1999) – proposed that the anterior six maxillary teeth are in the golden percentage;
- **Ward** (2001) – emphasised that a specific ratio is irrelevant, and proposed a fixed recurring esthetic dimension (RED) for the anterior six teeth;

All the above theories have been invalidated by subsequent studies, and none is unequivocally prevalent in the maxillary anterior dentition, particularly the GP, which has been ubiquitously quoted in the dental literature. Nowhere is the saying ‘A lie told often enough becomes truth’ (Vladimir Lenin) more appropriate than with the GP. Many researchers have concluded that the GP is only present in 10% of the population, yet this pseudo-standard is the cornerstone (and excuse) for many so-called aesthetic dental ‘makeovers’. Furthermore, the difference in tooth widths using various theories can be as little as 0.5 mm, an amount barely perceptible at close distance, let alone at a social viewing distance.

**Geometric theories**

The concept of proportion and form has been the basis for many geometric theories in aesthetic dentistry. Below are some of the authors who have proposed mathematical guidelines for aesthetics of the maxillary anterior sextant:

- **Williams** (1914) – classified tooth shape as square, tapering or ovoid;
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Psychological theories

Linking psychology with tooth form, contour and colour has also been the subject of numerous studies:

- **White** (1874) – coined the ‘temperamental theory’, correlating tooth differences with an individual’s disposition;
- **Frush and Fisher** (1958) – dynestyhetic theory related the sex, age and personality (SAP) of a person with tooth form, contour and alignment of the anterior teeth;
- **Rufenacht** (1990) – morphopsychological concept relating facial and bodily features (morphology) with psychology as the determining factor for the shape and size of teeth;
- **Ahmad** (2001) – synaesthetic perception: emotional and subconscious decisions and choices take precedence over cognitive or mathematical rationality for aesthetic appraisal.

Most of the psychological theories are opinions, and cannot be confirmed or refuted by rigid scientific analysis. However, science cannot explain everything, and emotional and psychological factors are relevant because they account for patients’ intangible desires and wishes. For this reason, the patient’s input should be incorporated into every treatment plan involving aesthetic dental care.

Perception theories

Perception theories concentrate on what is perceived, both by the providers (dentists, ceramists) and end users (patients). The salient difference between psychological and perception theories is that the former concern ‘the way we see ourselves’, while the latter concern ‘the way others see us’. Perceptual theories are currently becoming popular increasingly for aesthetic analysis and assessing the outcome of aesthetic treatment. Recent publications include:

- **Kokich** (1999) – first study using image manipulation to assess smile attractiveness, concluding that laypersons are less discriminating than dentists and orthodontists regarding aesthetic aberrations;
- **Pinho** (2007) – concurred that perception between dentists and laypeople vary enormously;

Perception theories gauge response from patients (and the dental team) and are extremely valuable for treatment planning, especially for preventing overtreatment. Furthermore, since patients are oblivious to minor aesthetic aberrations, it is the duty of dental professionals not to unnecessarily sensitise their patients or ‘manufacture’ dental conditions requiring interventional aesthetic therapy. However, the sample population for many of these surveys is small, specific to countries and cultures. Therefore, the findings cannot be applied to all populations or to every individual.

**Key points**

- There are no magic formulas, no magic numbers, no Holy Grail and no Da Vinci Code for evaluating or creating beauty.
- Geometric theories are a framework, not a formula.
- Psychological theories are pragmatic, not dogmatic.
- Perception theories are subjective, not objective.
Anterior dental aesthetics: guidelines

Schematic and sequential guidelines for aesthetic treatment planning:

- TEMPLATE
- GEOMETRIC
- EXISTING
- NEW
- PSYCHOLOGICAL
- PATIENT INPUT
- PERCEPTION
- CLINICAL FEASIBILITY
- FINALISE AESTHETIC TREATMENT PLAN
There are numerous theories regarding dental aesthetics, broadly categorised into geometric, psychological and perceptual. No single theory adequately explains the aesthetics of the maxillary anterior six teeth, or can be utilised to prescribe a definitive treatment plan. In reality all theories can be synergistically used to analyse and finalise anterior dental aesthetics.

**General guidelines**

Before proposing schematic guidelines for dental aesthetics, it is important to establish principles for treatment planning of aesthetic cases:

- At present, there are no generally accepted objective standards for designing smiles;
- Dental aesthetics cannot be determined or analysed using a single parameter;
- Avoid sensitising patients to minor aesthetic anomalies, which they would normally accept or otherwise ignore;
- Discourage sensitising patients to minor aesthetic anomalies based on media or peer pressure and social trends;
- The culture of dissatisfaction marketing for sensitising patients should be discouraged;
- Adopt a minimally invasive approach for resolving unacceptable dental aesthetics;
- Creating diversity in the maxillary anterior sextant is the key to individuality.

**Template**

The starting point for a dental aesthetics prescription is establishing a template, which can either be existing or new.

An existing template is the existing dentition, and the proposed aesthetic changes are designed to integrate within this framework. This ensures a minimally invasive approach, and avoids unnecessary over-treatment. If the anterior sextant is edentulous, or requires extensive alterations, one or more of the geometric theories can be used as a starting point for creating a new template. For example, if there is extensive crowding, misalignment or diastemata, a new working template is designed by simulations, e.g. diagnostic wax-up or intra-oral mock-ups. The choice of which geometric theory to use is empirical; often the difference in tooth widths between these theories can be as little as 0.5 mm. However, the following aspects should be incorporated into a template:

- The overall symmetry and balance of the dento-facial complex is the salient factor for an aesthetically pleasing smile, rather than individual or localised items;
- The average w/l ratio of the maxillary teeth is 0.78 or 78%;
- The central incisors are dominant;
- The average maxillary tooth display during a relaxed smile is 75%;
- No specific ratio for repeated proportions is applicable to all individuals;
- Smile arc (line) is parallel to curvature of the mandibular lip during a relaxed smile;
- Acceptable maxillary gingival display during a relaxed smile is approximately 3 mm, thereby avoiding a ‘gummy’ smile.

**Patient input**

After defining a working template, either existing or new, the next stage is modification of the template by the patient’s input. The patient’s wishes are predominantly related to psychological and perceptual theories:

- The patient’s input is essential for a successful aesthetic treatment outcome;
- The patient’s persona is moulded by intellect, culture, social interaction and economic status;
- Women are usually more intuitive and emotional than men, and therefore make a more critical judgement about beauty and self-appearance.

The second aspect regarding the patient’s input is perception. If an aesthetic aberration is unnoticed or the patient is oblivious to its presence, is it justifiable to correct it? Furthermore, many patients accept gross aesthetic abnormalities, and have little desire to make any changes. In both circumstances, coercive sensitisation to these irregularities that do not compromise health or function is counterproductive, and at times unethical. In addition, aesthetic anomalies are more apparent to the trained eye of a dentist than that of a layperson, whose naiveté is often a blessing. Lastly, most perception theories are based on frontal view assessments and oblique (profile), and dynamic visualisations require further research.

**Clinical feasibility**

The last stage of aesthetic treatment planning is assessing whether the patient’s wishes are clinically feasible, and if they can be incorporated into the patient’s prevailing clinical scenario. For example, if tooth wear has resulted in minimal space for restorative materials due to alveolar compensation, it is futile to provide restorations before creating space by the use of orthodontic appliances.

Another example is conceding to patients’ wishes for irreversible procedures that may compromise dental health in the future, for example, providing elective cosmetic treatment entailing destruction of healthy teeth for the sake of vanity. Many so-called ‘cosmetic makeover’ procedures are questionable, ephemeral and possibly unethical.

Finally, science is dogmatic with little leeway, while art is nebulous, open to interpretation. Since aesthetics is an art, not a science, the scientific community is probably wasting its time trying to quantify rules and principles to decipher this entity. Hence, to date, all attempts over the last 5000 years to apply scientific rules and guidelines have failed to determine rigid principles for dental aesthetics. Aesthetic objectivity still remains an elusive goal, and perhaps one that may never be reached.

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**Key points**

- No objective rules exist for analysing or prescribing dental aesthetics.
- The best guidelines for aesthetic treatment planning are adopting a minimally invasive approach, combining the available theories, i.e. geometric, psychological and perceptual.
- Patient participation is essential for successful outcome of an aesthetic treatment plan.
Anterior dental aesthetics: bleaching

**MECHANISM**
- Vital: In office and at home
- Non-vital: Walking bleaching

**TECHNIQUES**
- Preoperative Tray with 10% or 35% carbamide peroxide
- Postoperative Intracoronal 35% carbamide peroxide

**SIDE EFFECTS**
- Sensitivity or altered enamel morphology
- Shade rebound
- Reduced enamel microhardness
- Reduced dentine bond strength
- Increased microleakage of existing restorations
- Root resorption or periradicular necrosis
- Reduced fracture strength

**PRECAUTIONS**
- Tooth protection
- Gingival protection

**Bleaching tray**

**Bleaching agents**

**Light-activated units**

**Before restorations (pre-bleach)**

**Before restorations (post-bleach)**
Dental bleaching is an effective, economical and minimally invasive approach to whitening discoloured teeth. Since its introduction two decades ago by Haywood and Haymann, the at-home technique has proved a successful treatment modality for improving unsightly stained teeth. Bleaching is also therapeutic for periodontal health and favours maintenance of oral hygiene. Furthermore, the transient irritation of soft and hard tissues is innocuous and reversible.

**Mechanism**

Whitening teeth is achieved by any one of three processes, i.e. erosive, abrasive and oxidation. The most popular method is oxidation since erosion and abrasion potentially damage hard tissues by irreversibly altering tooth morphology. Furthermore, excessive enamel loss is counterproductive for tooth whitening, since it allows visibility of the darker underlying dentine.

The oxidation process uses bleaching chemicals that penetrate the interprismatic enamel substrate and convert the pigmented carbon rings to lighter carbon chains. The higher the concentration of the bleaching agent the greater and more rapid the effect. This process alters enamel micromorphology, affecting both the organic and inorganic phase of the hard tissue. The negative effect of oxidation is that bleaching chemicals, with a low pH, demineralise enamel. However, the effect is usually transient, since calcium in the saliva and use of fluoride dentifrices reverse the effect by remineralisation of the enamel surface layer.

**Techniques**

The commonly used bleaching agents are carbamide peroxide (urea peroxide) in concentrations ranging from 1% to 45%, hydrogen peroxide (3% to 50%) and sodium perborate. These agents are available as gels, varnishes, mouthwashes and toothpastes. The concentration of the bleaching agent determines the duration of treatment. A high concentration results in rapid whitening in a shorter time, while lower concentrations require longer to take effect. There are two main methods for bleaching, either in office or at home (with professional supervision). The latter can be combined with an in-office ‘jump start’, followed by slower completion at home.

Vital bleaching can be prescribed alone for whitening teeth or can be part of a global aesthetic treatment plan, e.g. before veneers, crowns or tooth-coloured ‘white’ fillings. In isolation, bleaching can be used to alter colour for teeth displaying yellow, brown/grey or tetracycline intrinsic stains. The technique involves fabricating carefully adapted custom-made plastic trays using a heat/vacuum forming machine. The trays are filled with the chosen agent and placed over the teeth for specified durations, followed by brushing with a toothpaste containing a high concentration of sodium fluoride (2800 ppm). The duration of treatment depends on the extent of discolouration; the bleaching process can take 2–6 weeks at home if the trays are worn for 2–3 hours per day using 10% carbamide peroxide. The efficacy is 2–10 shades of colour modification on the Vita Classic shade guide arranged in value order. However, there is a 1–2 shade rebound after 2–4 weeks. Therefore, it is advisable to wait before proceeding with new aesthetic restorations so that the latter can be matched to the stabilised colour of the bleached teeth. For severe stains, e.g. intense tetracycline staining, whitening may take 6–12 months. During the bleaching process, it is essential to provide professional supervision throughout treatment, and monitor changes with photographs and reference shade tab guides.

Non-vital bleaching is a third option used to lighten endodontically treated teeth, often referred to as intracoronal or ‘walking bleaching’. Before starting, it is essential to ensure that the existing root filling has a satisfactory apical seal to prevent leaching of the bleaching agents into the periradicular areas, and causing root absorption. The technique involves placing bleaching agents into the pulp chamber and hermetically sealing the cavity with either glass ionomer or a resin-based composite filling to prevent microleakage and percolation of bacteria.

**Light-activated bleaching** involves using bleaching chemicals containing carotene to accelerate the breakdown of the active ingredients when exposed to high-intensity light or lasers. However, light alone has no effect on tooth whitening, but the heat generated by lights may accelerate the whitening effects of bleaching chemicals. Furthermore, heat can dehydrate teeth, leading to greater postoperative sensitivity.

**Precautions**

While effective and simple, certain conditions are required before considering bleaching:

- **Tooth protection** – pre-treatment sensitive areas, e.g. cervical or abrasion lesions, should be sealed with glass ionomer. Also, bleaching areas of gross tooth wear with exposed dentine may cause further dentine erosion. Finally, for pronounced fluorosis or developmental banding, micro-abrasion may be indicated to avoid uneven bleaching;
- **Gingival protection** – rubber dam or other gingival barriers are essential when using in-office high-concentration bleaching gels.

**Side-effects**

Some side-effects of bleaching include:

- **Sensitivity** (tooth and gingival), particularly with higher concentrations of bleaching agent, but is mitigated by remineralisation with fluoride, potassium nitrate or sodium citrate;
- **Reduced enamel microhardness** (outer 25μm surface) immediately after bleaching, usually reversed by saliva remineralisation in 3–4 weeks;
- **Reduced dentine bond strengths** (especially using sodium perborate), but there is little change in enamel bond strength 1 week post-bleaching;
- **Increased microleakage** at the interface between dentine and restorative material, but margins on enamel remain intact;
- **Effects of bleaching on restorative materials**, especially composites and glass ionomer fillings, which may cause existing fillings to become more conspicuous;
- **Excessive bleaching with high concentrations may result in chemical and morphological changes in enamel structure** leading to porosity, pitting, reduced fracture strength, erosion or lesions emulating initial caries.

**Key points**

- Bleaching is a simple and effective method for whitening teeth.
- Professional supervision and monitoring are essential to enhance treatment and mitigate side effects.
Choice of intracoronal restorations

**Non-cavitated carious lesions**
- Discolouration below intact enamel. Oral hygiene reinforcement, diet control, caries-susceptible individual.
- Minimally invasive to allow enamel remineralisation of hard tissues.
- **Monitor**
- CHX & F varnishes

**Cavitated carious lesions**
- Discolouration of enamel and dentine, breakdown of enamel and presence of infected soft dentine, endodontic complications.
- Partial or complete excavation of diseased tissues and restore with bioactive materials to encourage repair.
- **Glass ionomer**
- Replacement of amalgam restorations with composite resin fillings

**Replacement restoration**
- Secondary caries, tooth or restoration fracture, endodontic, periodontic, occlusal complications.
- Elucidate cause of failure before repairing or prescribing replacement restorations.
- **Repair restoration**
- Replacement of defective and stained composite restorations
Intracoronal restorations are defined as those surrounded by one or more natural tooth surface(s) and can broadly be categorised according to Black’s cavity classification: classes I, II, III, IV and V, and the newly added class VI.

Treatment for intracoronal lesions depends on a variety of factors, and for optimal clinical decision-making, it is necessary to accurately diagnose pathology, determine aetiology, identify risk factors and assess prognosis for various treatment options.

Non-cavitated carious lesions
Current research has highlighted the ability for enamel to remineralise following carious attack. Therefore, a non-cavitated carious lesion extending into dentine, with appropriate treatment, has the potential to be arrested by remineralisation of the demineralised enamel hard tissues. The factors to consider for non-cavitated lesions are:

- **Aetiology** – cariogenic bacteria;
- **Clinical presentation** – discolouration below surface of an unrestored tooth; caution is necessary when using sharp probes, in order to avoid piecing the delicate demineralised surface enamel;
- **Symptoms** – none or sporadic sensitivity;
- **Risk assessment** – patients with poor oral hygiene, inadequate diet control, or individuals with high caries susceptibility require restorative intervention;
- **Treatment options** – minimally invasive, monitor for low-risk patients, or restore for high-risk patients;
- **Type of restoration** – chlorhexidine (CHX) and fluoride (F) varnishes, fissure sealing, direct restorations;
- **Choice of restorative materials** – bioactive restorative materials (glass ionomers, resin-based composites), or amalgam;
- **Prognosis/outcome**:
  a) Halted carious lesion with or without remineralisation of enamel – monitor with periodic application of varnishes and/or fissure sealants;
  b) Reparative ‘healing’ with bioactive restorative materials – monitor;
  c) Progression to cavitated carious lesions – intervention with direct fillings.

Cavitated carious lesions
Once cavitation is evident, restorative intervention is necessary to prevent progression of the lesion. The factors to consider for cavitated lesions are:

- **Aetiology** – cariogenic bacteria;
- **Clinical presentation** – fractured and discoloured enamel with underlying carious, discoloured soft dentine, affecting any surface, or a combination of surfaces. The morphology and depth of the lesion depends on the extent of disease progression. Health, aesthetics and function may be compromised and endodontic complications may ensue;
- **Symptoms** – sensitivity, pain, abscesses;
- **Risk assessment** – assess oral hygiene, diet control, caries susceptibility, endodontic involvement and periodontal and occlusal factors;
- **Treatment options** – minimally invasive (partial or minimal caries excavation and restoration) or conventional (complete caries excavation and restoration);
- **Type of restoration** – direct restorations (using Black’s classification to define location of lesions). For larger coronal defects and destruction, indirect inlays or full coverage may be considered;
- **Choice of restorative material** – bioactive restorative materials (glass ionomers, resin-based composites), amalgam, ceramic, cast gold or metal fused to porcelain;
- **Prognosis/outcome**:
  a) Reparative ‘healing’ with bioactive restorative materials – monitor;
  b) Tooth or restorative material fractures – cuspal or full coverage;
  c) Endodontic involvement – root canal therapy.

Replacement restorations
Replacement of failed or defective restorations constitutes about 60% of operative dentistry. Before considering a new restoration, it is essential to elucidate the cause of failure, promote preventive measures and provide an appropriate restoration to prevent future eventualities. The factors to consider for replacement restorations are:

- **Aetiology** – hostile oral conditions such as cariogenic bacteria, occlusal loads, fatigue, temperature changes, aqueous environment, poor clinical technique or incorrect material selection (e.g. microleakage, restorative material failure);
- **Clinical presentation** – recurrent or secondary caries. It is worth remembering that a marginal discrepancy or gap is not necessarily a predictor of secondary caries or disease process, fractured tooth or restorative material, poor aesthetics, pulpitis, periapical lesions, periodontal or occlusal complications;
- **Symptoms** – pain, abscesses or soft tissue laceration due to sharp edges of fractured teeth/restorations;
- **Risk assessment** – assess oral hygiene, diet control, caries susceptibility, endodontic, periodontal and occlusal factors, poor clinical technique;
- **Treatment options** – repair vs replace benefits. For small restorations, a ‘like for like’ approach may be all that is required, provided that the cause of failure is deciphered and rectified. For larger failed restorations, it may be necessary to prescribe an alternative type of restorations, or alternative material, or both;
- **Type of restoration** – direct restorations (using Black’s classification to define location of lesions). For large restorations with loss of coronal tissue, the options are indirect inlays, onlays or full coverage crowns;
- **Choice of restorative material** – bioactive restorative materials (glass ionomers, resin-based composites), amalgam, ceramic, cast gold or metal fused to porcelain;
- **Prognosis/outcome**:
  a) Reparative ‘healing’ with bioactive restorative materials – monitor;
  b) Tooth or restorative material fractures – indirect inlay;
  c) Endodontic involvement – root canal therapy;
Extensive coronal tissue loss incapable of supporting an intracoronal restoration – extracoronal indirect full coverage.

**Key points**
- The choice of intracoronal restoration depends on accurate diagnosis.
- Both non-cavitated and cavitated lesions should be treated with a minimally invasive approach and periodically monitored.
- It is essential to elucidate the cause of failure before prescribing a replacement restoration.
Choice of materials for direct restorations

**COMPOSITES**
- 10-year-old filling
- Failed filling
- Deciduous teeth
- Cervical fillings

**ADVANTAGES**
- Highly aesthetic
- Large varieties of materials for varying clinical situations
- Minimally invasive cavities
- Bond to tooth structure with DBA
- Acceptable physical and mechanical properties
- Reinforce tooth/restoration complex
- Light and chemically cured
- Bioactive
- Suitable for direct restorations, e.g. pit & fissure sealing, class I, II, III, IV, V, VI, tunnel cavities, aesthetic masking of discoloured teeth, and indirect inlays and veneers

**DISADVANTAGES**
- Polymerisation shrinkage and stresses
- Technique sensitive and protracted procedures
- Microleakage
- Shorter survival rate in stress-bearing areas compared to amalgam
- Water adsorption
- Wear
- Discolouration
- Costly; increased material costs and longer clinical time

**AMALGAM**
- Replacement of defective composite fillings
- Replacement of defective amalgam fillings
- Staining
- Wear

**ADVANTAGES**
- Established clinical history
- Long-term survival rate
- Suitable for large Class I, II
- Forgiving technique
- Economical
- Micro-mechanical retention with DBA

**DISADVANTAGES**
- Poor aesthetics
- Corrosive byproducts
- Mercury exposure
- Invasive cavities

**GLASS IONOMERS**
- 10-year-old filling
- Failed filling
- Deciduous teeth
- Cervical fillings

**ADVANTAGES**
- Chemical adhesion to tooth
- Bioactive
- Combination materials with resin-composites to improve properties
- Suitable for pulp capping, luting agents, class V and fillings in deciduous teeth

**DISADVANTAGES**
- Poor mechanical properties
- Poor survival rate compared to amalgam
- Crack formation when exposed to oral environment
Material selection for intracoronal direct restorations is a daunting task. At present, there is no material on the market that is a true substitute for dentine and enamel, and a compromise is usually necessary depending on the prevailing clinical situation. Most intracoronal cavities are restored using a direct technique. However, inlays are also possible using an indirect technique. The performance and survival of any direct restoration is multi-factorial, depending on the location of the tooth, type of tooth, restoration design and size, number of surfaces involved, operator factors (experience, dexterity and technique), patient factors (age, attitude to dental care, oral hygiene) and the choice of material. The main reasons cited for failure are secondary caries, fractures, discolouration, marginal discrepancies, wear or endodontic involvement.

**Palliative dressings**
The most popular temporary palliative dressing is zinc oxide eugenol. Zinc oxide powder is mixed with eugenol liquid to form a condensable putty. Care is necessary if the definitive filling is resin-based since eugenol retards the setting reaction of most resin-based composites.

**Silver mercury amalgam**
The use of silver mercury amalgam dates back to the beginning of the last century when Black first described his classification of dental cavities. Dental amalgam is a mixture of silver alloy powder mixed with mercury, creating a condensable slurry that solidifies at intra-oral temperature. Amalgam, unlike composites, is a relatively forgiving material, not dependent on stringent clinical protocols. Its use is still ubiquitous, with longer survival rates (compared to composites) for large direct restorations in posterior, load-bearing teeth. However, recent concern about low-level mercury exposure is scientifically unfounded, but remains contentious for many patients. Some European countries have banned amalgam use altogether, while others have contraindicated its use in susceptible patients, e.g. females of child-bearing age. Other disadvantages include the need to remove excess tooth substrate when creating undercuts (but micro-mechanical adhesion is possible using dentine bonding agents – DBA), leaching into enamel/dentine with subsequent tooth discolouration, amalgam tattoos on the oral mucosa, and environmental waste concerns.

**Resin-based composites**
Resin-based composite fillings are rapidly becoming the first choice for direct intracoronal restorations. A composite filling material is a combination of organic resin (e.g. Bis-GMA, urethane dimethacrylate or TEGMA) and an inorganic filler (e.g. quartz, glass or silica). The size and percentage of filler loading determines the properties of the final material. Several varieties are available:

- **Conventional** composites (quartz, glass): filler particle size = 1–50 µm;
- **Microfilled** composites (silica): filler particle size = 0.01–0.1 µm;
- **Hybrid composites** (quartz, glass and silica): 1–50 µm (75%) and 0.04 µm (8%) i.e. total filler content of 83%, which can be increased to 90%;
- **Nano-composites** – similar properties to microfilled and hybrid composites but with smaller nano-particle fillers;
- **Flowable** – reduced filler content, reduced viscosity, reduced polymerisation stresses but increased shock-absorbing capabilities;
- **Bulk-fill composites** – can be cured to a depth of 5 mm, e.g. SonicFill (KerrHawe SA, Switzerland), SDR (Dentsply, Germany).

The major advantages of composites are the colour, similar to natural teeth, the ability to bond to tooth structure (with DBAs), minimally invasive cavity preparation, similar thermal diffusivity to dentine (acting as thermal insulators), acceptable mechanical properties, reinforcement of the restoration–tooth complex, command setting with curing lights, and bioactivity. A bioactive material is one that forms crystalline deposits at the tooth interface, thereby improving marginal adaptation. Composites are indicated for most direct restorations as well as indirect inlays. The major disadvantage of resin-based composites is polymerisation shrinkage (1.5–3%) and stresses during the setting phase which result in microleakage, secondary caries, marginal staining, postoperative sensitivity and cuspal fractures. Polymerisation shrinkage can be mitigated by altering the material properties (e.g. higher filler content, pre-polymerisation) and clinical techniques (e.g. bonding to enamel rather than dentine, cavity design with low C-factors, incremental placement and varying curing light modes). Finally, long-term water absorption leads to porosity and accelerated wear.

**Glass ionomers**
The distinguishing feature of glass ionomers is their ability to chemically bond to tooth surfaces by chelation of the calcium ions within the hydroxyapatite with the polyacid in the material. Another benefit is enhanced bioactivity, especially with the addition of fluoride. They are therefore indicated for pulp capping, linings, luting cements, class V cavities and fillings in deciduous teeth. The drawbacks of glass ionomers are poor mechanical properties, water adsorption and crack formation.

**Combination materials**
Several combination materials are available, exploiting the beneficial properties of composites and glass ionomers. For example, resin-modified glass ionomers most closely resemble conventional glass ionomers, offering improved adhesion to tooth, while compomers (polyacid-modified composite resins) have a closer relationship to composites, with improved mechanical properties. Another combination of resin and glass ionomers is the giomer, with enhanced fluoride-releasing properties by incorporation of a pre-reacted glass (PRG). A recent development is using Ormocer® technology for direct restorations. The latter exhibit excellent wear resistance, but poor polishability. The latest materials to emerge are the compobonds combining a resin-based composite with a DBA. The first of these materials is a self-adhesive flowable composite, Vertise Flow (KerrHawe SA, Switzerland) obviating the need to use a DBA before placing the composite filling.

**Key points**

- Irrespective of mercury exposure concerns, amalgam still has good survival rates for large cavities in posterior teeth.
- Although technique sensitive, resin-based composites are becoming the first choice for direct restorations.
- Glass ionomers offer chemical adhesion to tooth, and are useful for pulp capping, luting agents, and fillings in deciduous teeth.
- Numerous combination materials are available, exploiting the respective benefits of different materials.
**Choice of extracoronal restorations**

### Extracoronal restorations

- **EXTRACORONAL RESTORATIONS**
  - Onlays
  - Full-coverage crowns
  - PLV

### Survival rates

<table>
<thead>
<tr>
<th>Type of restoration</th>
<th>Survival rate (%)</th>
<th>Period (years)</th>
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<tbody>
<tr>
<td>Inlay and onlays</td>
<td>95</td>
<td>7–10</td>
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<tr>
<td>Porcelain fused to metal (PFM)</td>
<td>&gt; 95</td>
<td>10</td>
</tr>
<tr>
<td>Porcelain laminate veneer (PLV)</td>
<td>&gt; 94</td>
<td>12</td>
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<tr>
<td>Leucite-reinforced pressed glass – IPS Empress® (anterior)</td>
<td>&gt; 95</td>
<td>11</td>
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<tr>
<td>Lithium disilicate IPS Empress 2® (anterior and posterior)</td>
<td>&gt; 95</td>
<td>5</td>
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<tr>
<td>Glass infiltration – In-Ceram® (anterior and posterior)</td>
<td>&gt; 98</td>
<td>5</td>
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<tr>
<td>Polycrystalline alumina – Procera® (anterior)</td>
<td>&gt; 99</td>
<td>7</td>
</tr>
<tr>
<td>Polycrystalline alumina – Procera® (posterior)</td>
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<td>7</td>
</tr>
<tr>
<td>Zirconia (multiple unit fixed partial denture; FPD)</td>
<td>74</td>
<td>5</td>
</tr>
</tbody>
</table>

### Clinical examples

- **Cavity size**
  - When the width of an intracoronal cavity exceeds 1/2 the distance of the cusp tips, an onlay or crown is necessary.

- **Cracked tooth**
  - A symptomatic cracked tooth syndrome often required coverage of the offending cracked cusp(s).

- **Replacement crown**
  - Defective crowns are a common reason for providing a superior fitting crown to prevent decay and maintain periodontal health.

- **Discoloured cusps**
  - Amalgam or metal corrosive byproducts of old restorations can result in unsightly appearance, requiring removal and coverage with an extracoronal restoration.

- **Stained composites**
  - Large, defective, failing, stained composites on anterior teeth are candidates for ceramic PLVs.
The transition between an intracoronal and an extracoronal restoration is based on the amount of remaining tooth substrate following removal of decay and/or existing restorations. If sufficient dentine and enamel are present, an intracoronal restoration (direct or indirect) is the first choice of treatment. With greater tooth loss, reduced retention, coronal destruction and mutilated anatomy, an indirect extracoronal restoration is superior for restoring morphology, function, aesthetics and durability. Essentially, extracoronal restorations are classified as onlays, veneers and full-coverage crowns. The distinction between an onlay or veneer and a partial coverage crown is nebulous, and various configurations have been proposed, e.g. ½, ¾, ⅞, etc. depending on the remaining tooth substrate and the type of restorative material used.

Decision-making rationale
Decision-making with the informed consent of the patient depends on the following criteria:

- **Minimal intervention** – retaining maximum tooth structure and respecting periodontal, occlusal and pulpal health;
- **Tooth integrity** – strength of remaining tooth structure, and performance and durability of the chosen restorative material;
- **Clinical feasibility** – access for facilitating preparation, placement, impressions and cementation;
- **Prognosis and survival rates** – resistant to wear, occlusal forces, fractures and ease of oral hygiene procedures;
- **Aesthetics** – location of tooth in mouth;
- **Cost** – use of a dental laboratory increases fees compared to a direct approach.

Decision making-guidelines
Below are indications for indirect restorations:

- **Cavity size** – for posterior teeth with defective old restorations, the criteria for replacement depend on the size of the cavity once the restoration and decay are removed. If the occlusal width of the intracoronal preparation is greater than half the distance of the buccal and lingual cusp tips, an extracoronal restoration should be considered. In these circumstances, an onlay or full-coverage crown is necessary to protect the thin cross-section and fragile cusps, and to increase the tooth’s resistance to fracture;
- **Cracked tooth syndrome** – tooth fracture associated with pain on biting and sensitivity to sugary foods. Diagnosis is by trans-illumination from the buccal or lingual aspects to ascertain the location and depth of the fracture lines(s). Horizontal fracture lines usually result in breakage of the involved cusp. If pain persists, following tooth preparation and temporisation beyond the visible fracture line, endodontic therapy or extraction may be indicated;
- **Fractured cusps** – deep apical or subgingival fractures may necessitate endodontic treatment, e.g. crown lengthening before crowning;
- **Unsupported cusps** – if decay or existing restoration necessitates removal of all supporting dentine, the remaining unsupported enamel should be removed and incorporated into an onlay preparation;
- **Endodontically treated teeth** – more susceptible to fractures than vital teeth, since the former lack proprioceptive response. The treatment options depend on the size of the access cavity and existing restorations. If the access cavity and existing restoration are small, a direct composite is an ideal choice. However, for larger restorations, an onlay, reduced crown, conventional crown, or possibly an endocrown (gaining macromechanical retention from the pulp chamber of root-filled posterior teeth) should be considered;
- **Parafunctional habits or hard diet** – patients with bruxism or who eat hard food are candidates for cuspal coverage;
- **Discoloured cusps** – usually resulting from amalgam leakage byproducts, which are unsightly if visible during a smile may require removal and replacement with an onlay;
- **Hemisectioned teeth** – full coverage for splinting to adjacent teeth for stability;
- **Existing crown** requiring replacement due to fractured porcelain, colour mismatch, defective margins or gingival recession;
- **Short clinical crowns** – if the remaining tooth substrate is insufficient for an onlay, full coverage offers better retention;
- **Splinting teeth** – mobile teeth can be splinted using crowns, but this is a highly destructive and questionable modality. A less invasive option for symptomatic mobile teeth is splinting with orthodontic wire luted with a resin-based composite;
- **Fixed partial denture (FPD)** – either to close a space or to replace a failing FPD;
- **Implant-supported crowns** – both single and multiple splinted units;
- **Elective crowns** – if the patient declines orthodontic treatment to realign teeth, or to mask discoloration for improving aesthetics or to raise the occlusal vertical dimension (OVD). However, to provide crowns on vital teeth solely for aesthetic reasons is questionable practice.

Survival rates
Inlays and onlays can be fabricated from composite resin, ceramics and cast gold. The current trend is to use tooth-coloured restorations, which limits the restorative materials to composites or ceramics. Unilayered silica-based ceramics include feldspathic, leucite-reinforced pressed glass or lithium disilicate. Furthermore, the use of CAD/CAM technology has increased the popularity of these indirect restorations. Both inlays and onlays have a success rate of greater than 95% over 7–10 years, and bulk fracture of the restoration is cited as the predominant reason for failure.

Porcelain laminate veneers (PLVs) are usually prescribed for anterior teeth, which require superior aesthetic, but have low structural demands (see Chapter 36). The most popular materials for PLVs are high glass content silica ceramics that can be adhesively bonded to the underlying tooth structure (preferably enamel). PLVs have shown to be extremely successful, with some studies reporting survival rates after 12 years of greater than 94%.

Full coverage crowns can be fabricated using metal, porcelain fused to metal (PFM) or all-ceramic. The all-ceramic units are usually bilayered with a dense ceramic core for strength (e.g. glass-infiltrated and polycrystalline alumina or transformation-toughened polycrystalline zirconia) and a weaker veneering porcelain (e.g. silica ceramics) for aesthetics. All-ceramic units on anterior teeth have a higher success rate than on posterior teeth. The overall survival rate is comparable to that for PFM crowns; silica is better suited for anterior teeth, while alumina and zirconia are better for posterior teeth. Again, the main reason for failure is catastrophic fracture or chipping of the veneering porcelain.

Key points
- Extracoronal indirect restorations are indicated for compromised teeth with reduced tooth substrate.
- Choosing the type of extracoronal restoration depends on the clinical scenario and survival rates.
- The survival rate for indirect ceramic restorations is about 90% over 10 years and is comparable to that of PFM units.
Cast metal alloys, titanium and resin-based composites

**Advantages**
- Long-term successful clinical history
- Established clinical and laboratory protocols
- High strength and resistance to fracture
- Versatility for fabricating a large variety of indirect restorations
- Ability to fuse porcelain on metal substructure
- Choice of strengths for varying occlusal demands
- Ideal for long-span FPD on both natural and implant-supported abutments
- Ability to solder units, e.g. post-ceramic soldering
- Enhanced micromechanical adhesion using DBAs and self-adhesive resin cements
- Reduced opposing tooth wear

**Disadvantages**
- Poorer aesthetics compared to all-ceramic units
- Corrosion byproducts
- Allergic reactions to base metals
- Poor insulators, resulting in transient sensitivity to temperature
- Greater plaque accumulation compared to glazed porcelain margins of all-ceramic units

**Titanium**

**Advantages**
- Highly biocompatible
- Corrosion resistance
- High strength and rigidity
- Low density and weight
- Withstands large temperature fluctuations
- Lightweight prostheses
- Laser welding of multiple units
- Utilise CAD/CAM technology for milling frameworks

**Disadvantages**
- High casting shrinkage
- Technique-sensitive dental laboratory protocols
- Expensive equipment for processing

**Resin-based composites**

**Advantages**
- Aesthetic restorations
- Improved aesthetic and mechanical properties compared to directly placed composites
- Tight interproximal contacts
- Excellent anatomical form
- Precise marginal integrity
- Improved surface texture
- Reduced opposing tooth wear
- Similar thermal expansion as natural tooth
- Fibre reinforcement for increased strength
- Good insulators
- Reduced cost compared to cast metals and titanium

**Disadvantages**
- Increased cost due to use of a dental laboratory, compared to direct restorations
- Technique-sensitive, adhesive luting protocol
- Weaker materials compared to cast metals and titanium

**Comparison of MOE**

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Modulus of elasticity (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enamel</td>
<td>73</td>
</tr>
<tr>
<td>Dentine</td>
<td>19</td>
</tr>
<tr>
<td>Alveolar cortical bone</td>
<td>14</td>
</tr>
<tr>
<td>Alveolar trabecular bone</td>
<td>1.4</td>
</tr>
<tr>
<td>Resin-based luting agent</td>
<td>9</td>
</tr>
<tr>
<td>Resin-based composite filling material</td>
<td>20</td>
</tr>
<tr>
<td>Lithium disilicate ceramic core</td>
<td>102</td>
</tr>
<tr>
<td>Veneering fluorapatite porcelain</td>
<td>67</td>
</tr>
<tr>
<td>Zirconia core</td>
<td>210</td>
</tr>
<tr>
<td>Zirconia veneering porcelain</td>
<td>80</td>
</tr>
<tr>
<td>Cast gold alloys</td>
<td>80–100</td>
</tr>
</tbody>
</table>

Gold inlay  
Titanium framework  
Composite inlay
Several materials are available for indirect restorations including cast metal alloys, titanium, resin-based composites and ceramics. Traditionally, metal alloys were the ideal choice for indirect restorations, but recent material advances are rapidly changing this paradigm, making composites and ceramics formidable contenders for clinical suitability and longevity. This chapter discusses cast metal alloys, titanium and resin-based composites, while Chapter 31 elaborates on ceramics.

The success and longevity of any restorative materials depends on:
- Patient factors – oral hygiene, patient constitution and medical history;
- Material properties – strength, wear, biocompatibility, marginal integrity, physical and chromatic stability, resilience for resisting occlusal forces and retaining anatomical form, and prevention of secondary caries;
- Clinical technique – material manipulation, placement and maintenance.

**Strength of restorative materials**

Ideally, a restorative material should mimic the physical, mechanical and optical properties of the tissue it is replacing. The modulus of elasticity (MOE) plays a pivotal role in determining the success or failure of a material, and the surrounding or underlying natural tooth substrate. Restorative materials with similar MOE to dentine, such as resin-based composites, absorb stresses, allowing dissipation by dentine, the periodontal ligament and surrounding alveolar bone. Conversely, rigid material with an MOE similar to enamel, such as ceramics, are more stress-resistant and transfer forces to the weaker material, i.e. dentine, making the tooth more susceptible to root fracture.

**Cast metal alloys**

The most frequently used cast metals in dentistry are high noble content gold alloys, which can be classified as:
- Type I – low strength for small inlays and intraradicular posts;
- Type II – medium strength for large inlays and onlays;
- Type III – high strength, for full-coverage crowns and fixed partial dentures (FPD);
- Type IV – extra high strength, for full-coverage crowns, FPD and denture frameworks.

The nobility of dental casting alloys usually depends on the gold content, which ranges from 60% to 75%. For increasing strength, the amount of gold decreases and is replaced by other metals such as silver, copper, platinum, palladium and zinc. While hardness, MOE and tensile strength increase with decreasing gold content, resistance to corrosion also decreases. Recent concern about palladium allergy, especially among nickel allergy sufferers, has led to doubts about the use of palladium in dental prostheses.

Base metal alloys containing non-noble metals such as nickel, cobalt and chromium exhibit high strength (especially in thin cross-sections), are lighter in weight, and are indicated for crowns, bridges and partial denture frameworks. The disadvantages include allergy to nickel, greater rigidity compared to noble alloys, and therefore may result in fracture of the veneering porcelain in long-span bridges. Furthermore, adjustments to the metal substructure are more difficult.

**Titanium**

Titanium and titanium alloys are well established in the aerospace industry due to their favourable mechanical and physical properties. Titanium is mined as an oxide, but is refined to a metallic state using the Kroll process. Titanium is available in four grades of pure titanium or three grades of titanium alloys containing traces of aluminium, vanadium and iron. Its strength, rigidity and ductility are similar to that of other casting alloys used in dentistry.

Titanium is a highly reactive material that readily forms an oxide layer on its surface when exposed to oxygen. The oxide layer confers anticorrosive properties, and allows bonding of fused porcelain or polymers for aesthetic restorations. In addition, the surface can be sprayed with apatite coatings for implants to enhance osseointegration. The passivating oxide layer is also advantageous for soft tissue attachment around titanium abutments used to support the eventual dental prosthesis on subperiosteal implants. Developments in processing methods such as lost-wax casting, CAD/CAM milling and electric discharge machining have expanded its application in dentistry for crowns and partial denture frameworks for implant-supported prostheses. This is a promising development for the future, and titanium could challenge or replace conventional noble and base metal alloys for indirect restorations, especially in conjunction with CAD/CAM fabrication.

**Resin-based composites**

The drawbacks of direct composite restorations include poor wear resistance, chromatic instability, water adsorption and marginal discrepancies. Most of these problems are due to polymerisation shrinkage, stresses within the materials and techniques for placement and polishing. To overcome these deficiencies and improve clinical performance, indirect composite restorations have been developed. The main difference between direct and indirect composites is the method of polymerisation. With the former, photoactivation is used intra-orally to initiate the setting reaction. In the latter, special ovens are used to set the material by light, heat and pressure, which increases the degree of conversion to 98%, compared to 50–70% for direct composites. Indirect processing improves colour stability and mechanical properties of the composite such as hardness, tensile strength and flexural strength and reduces the stresses of polymerisation shrinkage. Furthermore, extra-oral shaping of the restoration allows better proximal contacts and occlusal morphology. Indications for indirect composite restorations include inlays, onlays, veneers, crowns and fibre-reinforced FPDs, especially for patients who refuse intra-oral metal or have parafunctional activity. However, due to the relative low strength of composites, careful occlusal assessment is essential.

**Key points**

- The success of indirect restorations depends on patient, material and operator factors.
- The choice of material depends on specific clinical needs and patient preferences.
- Popular materials include cast metal alloys, titanium and resin-based composites.
## Ceramic Materials

### Ceramic Types

<table>
<thead>
<tr>
<th>Ceramics</th>
<th>Uni- or bi-layered restorations</th>
<th>Uni or bi-layered</th>
<th>Bi-layered</th>
<th>Uni or bi-layered</th>
<th>Bi-layered</th>
<th>Uni or bi-layered</th>
<th>Bi-layered</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feldspathic</strong> (Silica-based ceramic)</td>
<td>Uni- or bi-layered restorations</td>
<td>Uni or bi-layered</td>
<td>Bi-layered</td>
<td>Uni or bi-layered</td>
<td>Bi-layered</td>
<td>Uni or bi-layered</td>
<td>Bi-layered</td>
</tr>
<tr>
<td><strong>PFM</strong> (Press ceramics, Silica-based ceramics)</td>
<td>Uni- or bi-layered restorations</td>
<td>Uni or bi-layered</td>
<td>Bi-layered</td>
<td>Uni or bi-layered</td>
<td>Bi-layered</td>
<td>Uni or bi-layered</td>
<td>Bi-layered</td>
</tr>
<tr>
<td><strong>Alumina-based ceramics</strong></td>
<td>Uni- or bi-layered restorations</td>
<td>Uni or bi-layered</td>
<td>Bi-layered</td>
<td>Uni or bi-layered</td>
<td>Bi-layered</td>
<td>Uni or bi-layered</td>
<td>Bi-layered</td>
</tr>
<tr>
<td><strong>Zirconia-based ceramics</strong></td>
<td>Uni- or bi-layered restorations</td>
<td>Uni or bi-layered</td>
<td>Bi-layered</td>
<td>Uni or bi-layered</td>
<td>Bi-layered</td>
<td>Uni or bi-layered</td>
<td>Bi-layered</td>
</tr>
</tbody>
</table>

### Advantages

- **Feldspathic** (Silica-based ceramic): Life-like appearance, ideal for veneering metal or high strength ceramic substructures, smaller particle size reduces opposing tooth wear, amenable to hydrofluoric acid etching and silane for hermetic seal with tooth substrate.
- **PFM** (Press ceramics, Silica-based ceramics): Long history of clinical success, forgiving clinical and laboratory procedures, non-adhesive cementation possible.
- **Alumina-based ceramics**: Highly aesthetic, improved masking ability compared to feldspathic porcelain, pressable onto metal or high strength ceramic substructures, reduced plaque accumulation & opposing tooth wear, amenable to hydrofluoric acid etching and silane for hermetic seal with tooth substrate.
- **Zirconia-based ceramics**: Extremely high strength, indicated for a variety of single and multiple units, good masking ability, available in different colour ingots, reduced bacterial retention compared to titanium.

### Disadvantages

- **Feldspathic** (Silica-based ceramic): Weak, prone to fractures, unable to use non-adhesive or glass-ionomer cements, poor making of underlying tooth discoloration.
- **PFM** (Press ceramics, Silica-based ceramics): Opposing tooth wear with older feldspathic formulations, veneering porcelain fracture, metal allergies, metal or opaque shine through, greater plaque accumulation on metal lingual collars.
- **Alumina-based ceramics**: Low strength, large connector dimensions for FPD.
- **Zirconia-based ceramics**: Chipping of veneering porcelain, inability to incorporate stress-relieving precision attachments, no long-term clinical data available for survival rates, high cost of CAD/CAM machines and fees/units, reduced light transmission (48%) compared to alumina (72%).

### Strengthening mechanism

- **Feldspathic** (Silica-based ceramic): None.
- **PFM** (Press ceramics, Silica-based ceramics): Metal substructure has high strength for supporting porcelain.
- **Alumina-based ceramics**: Leucite glass or lithium disilicate.
- **Zirconia-based ceramics**: Glass infiltration or densely (polycrystalline) transformation toughening.

### Method of fabrication

- **Feldspathic** (Silica-based ceramic): Platinum foil, refractory die, CAD/CAM ingots.
- **PFM** (Press ceramics, Silica-based ceramics): Lost wax for metal, Powder/liquid or pressed for veneering porcelain.
- **Alumina-based ceramics**: CAD/CAM, Powder/liquid or pressed for veneering porcelain.
- **Zirconia-based ceramics**: CAD/CAM, Powder/liquid or pressed for veneering porcelain.

### Clinical indications

- **Feldspathic** (Silica-based ceramic): Inlays, onlay veneers, porcelain jacket crowns.
- **PFM** (Press ceramics, Silica-based ceramics): Single and multiple anterior and posterior units.
- **Alumina-based ceramics**: Inlays, onlay, veneers, all-ceramic anterior crowns, anterior bridges.
- **Zirconia-based ceramics**: Anterior and posterior single units, anterior 3-unit FPD, implant abutments.

### Recommended luting agent

- **Feldspathic** (Silica-based ceramic): Conventional resins.
- **PFM** (Press ceramics, Silica-based ceramics): Zinc phosphate, polycarboxylate, glass ionomer and resin cements.
- **Alumina-based ceramics**: Conventional resins.
- **Zirconia-based ceramics**: Resin-modified glass-ionomer or adhesive resins.

### Proprietary products

- **Feldspathic** (Silica-based ceramic): Numerous.
- **PFM** (Press ceramics, Silica-based ceramics): Empress I®, e.max®, Cerinate®, Fortress(™).
- **Alumina-based ceramics**: In-Ceram® Alumina, Procera® Alumina.
- **Zirconia-based ceramics**: In-Ceram® Zirconia, Procera® Zirconia, Lava® Zirconia, Cerec®, e.max® Zircon, YZ Cares®, DC Zirkon®, Everest(™).

### Longevity

- **Feldspathic** (Silica-based ceramic): Brittle, location in mouth and type of restoration determines durability.
- **PFM** (Press ceramics, Silica-based ceramics): Excellent, > 95% over 10 years, > 70% for 15 years, and > 50% for 30 years.
- **Alumina-based ceramics**: > 90% over 10 years for anterior units, < 50% for posterior units and FPD.
- **Zirconia-based ceramics**: Anterior single units > 95% over 10 years.

### Comparison of mean flexural strength (MPa)

<table>
<thead>
<tr>
<th>Ceramic Type</th>
<th>Zirconia</th>
<th>PFM</th>
<th>Procera Alumina</th>
<th>In-Ceram Alumina</th>
<th>e.max</th>
<th>Empress I</th>
<th>Feldspathic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength</td>
<td></td>
<td></td>
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</tbody>
</table>

### Comparison of mean hardness (GPa)

<table>
<thead>
<tr>
<th>Ceramic Type</th>
<th>Zirconia</th>
<th>PFM</th>
<th>Procera Alumina</th>
<th>In-Ceram Alumina</th>
<th>e.max</th>
<th>Empress I</th>
<th>Feldspathic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness</td>
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</tbody>
</table>
Ceramics are a significant class of indirect restorative materials that are revolutionising contemporary dentistry. The main reason is their lifelike appearance compared to metal-ceramic or all metal restorations.

Overview
Ceramics are inherently brittle materials and susceptible to fracture. Microscopic imperfections within the material are termed Griffith flaws, which grow into cracks, and if unimpeded, lead to catastrophic fracture of the ceramic. The cracks are propagated by the hostile oral environment: dynamic (occlusal forces) and humid (stress corrosion). Furthermore, static fatigue is time-dependent, which eventually results in breakage. Many strengthening mechanisms are used for halting fracture propagation including reinforcement and infiltration with glasses as well as phase transformation toughening. Preventing fractures also depends on the clinical scenario, method of fabrication of the restoration, and the manufacturing technique and strengthening process of a specific ceramic.

For the reasons cited above, in order for ceramics to survive in the oral cavity, they must be supported, either by the natural tooth substrate or an artificial substructure. Two types of ceramic restorations are possible: first, a uni-layer restoration that is entirely composed of ceramic and gains support from the underlying tooth substrate, and second, a bi-layer restoration with a substructure to support the veneering porcelain. The substructure can be of either metal, or a dense high strength ceramic.

Classification
Many classifications have been proposed to categorise ceramics depending on material composition (type of matrix and filler), aesthetics properties (translucency), strengthening process, method of fabrication (manual or milling), and manufacturing process (powder/liquid or ingots), etc. The simplest classification of ceramics is based on the material from which they are made, i.e. silica, alumina or zirconia.

Silica
Silica-based ceramics have a high glass content, making them highly aesthetic. These dental ceramics have excellent optical properties due to the addition of filler particles for enhancing opalescence and fluorescence, and shades to mimic the colour of natural enamel and dentine. However, their drawback is lack of strength, and they are therefore often used for veneering stronger substructures. Examples include alumino-silicate glass, e.g. feldspathic, synthetic porcelain, and leucite reinforced. Silica-based ceramics can be strengthened by the addition of filler particles to the glass base, e.g. lithium disilicate, and are termed glass ceramics. They are used for fabricating all-ceramic restorations, either as the entire restoration form (uni-layered), or acting as substructures for subsequent veneering (or layering) with weaker feldspathic porcelain (bi-layered).

Metal-ceramic
Porcelain fused to metal (PFM) restorations have a metal substructure to support a weaker silica-based veneering porcelain. These restorations have 50 years history of clinical success, and show versatility in the type of restoration that can be fabricated including single and multiple units on both natural teeth and implant abutments.

In addition, they have established clinical and laboratory protocols, with survival rates greater than 95% over a 10-year period. They are often used as a benchmark for assessing newer types of all-ceramic restorations. The major disadvantage of PFM restorations is poor aesthetics, particularly greying at the cervical margins due to visibility of the metal substructure or ‘shine’ through thin periodontal biotypes.

Alumina
Alumina-based ceramics have a lower or no glass content but higher strength than silica-based ceramics, and are available as two varieties. The lower glass content is a 3-D interpenetrating phase whereby molten glass (alumina, magnesium or zirconia) is infiltrated into the matrix, e.g. In-Ceram® Alumina and In-Ceram Spinell®. The second type of alumina has no glass, and is a highly packed polycrystalline structure, e.g. Procera® Alumina. Due to the hardness and poorer aesthetics of alumina, uni-layered restorations are impossible. The alumina substructure is usually veneered with silica ceramics to create bi-layered restorations with improved aesthetics and reduced opposing tooth wear.

Zirconia
Zirconia-based ceramics may eventually become a universal all-ceramic material. Technological advances are rapidly developing zirconia into a ubiquitous ceramic for use in single and multiple units in both anterior and posterior regions of the mouth. The high strength of zirconia allows fabrication of FPDs with connectors that have similar dimensions to metal substructures. Zirconia is available in three phases, depending on the amount of fillers, e.g. calcium, magnesium, yttria and ceria. The cubic version is fully stable at room temperature, while the tetragonal phase is partially stable. The latter phase changes to the monoclinic phase under stress and impedes crack formation. An infiltrated variety is also available, similar to the In-Ceram® Alumina, called In-Ceram® Zirconia. Zirconia restorations are exclusively fabricated using CAD/CAM technology either in its chalky or fully sintered states for bi-layered prostheses.

CAD/CAM blocks (ingots)
Most ceramics and composite resins are available as blocks (ingots) for numerous CAD/CAM milling machines. The advantage of ingots is that they are manufactured in a controlled and repeatable process compared to manual powder/liquid build-up or the pressed processes. The stringent industrial process confers superior mechanical and physical properties, with ingots devoid of the porosity that is prevalent in manual build-ups, layering or pressed ceramics. For example, a feldspathic ceramic block (ingot) has a flexural strength of 130 MPa, twice that of conventional layered feldspathic porcelains.

Key points
• Dental ceramics create lifelike restorations, but have a propensity to fracture.
• Ceramics can be classified as silica, alumina and zirconia.
• CAD/CAM technology is likely to revolutionise fabrication of indirect restorations.
Micro-invasive and minimally invasive techniques

Caries infiltration concept

Bitewing
- Bitewing radiograph showing early, interproximal, non-cavitated carious lesions

HCl
- 10% HCl for etching surface enamel

Infiltrate
- Application of resin infiltrate to seal enamel porosities

White spot
- White spot lesion after removal of orthodontic brackets

HCl
- 10% HCl for etching surface enamel

Postoperative
- Application of resin infiltrate for immediate improvement of aesthetics

Microabrasion

Comparison of techniques

<table>
<thead>
<tr>
<th>Technique</th>
<th>Constituents</th>
<th>Mechanism</th>
<th>Indications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caries infiltration concept</td>
<td>10% HCl, ethanol and resin infiltrate</td>
<td>Chemical</td>
<td>Early, non-cavitated interproximal or facial carious lesions</td>
</tr>
<tr>
<td>Microabrasion</td>
<td>Various concentrations of HCl and abrasives</td>
<td>Chemo-mechanical</td>
<td>Superficial enamel staining, e.g. dental fluorosis</td>
</tr>
<tr>
<td>Air abrasion</td>
<td>Aluminium oxide, silica or bicarbonate soda particles</td>
<td>Mechanical</td>
<td>Cleansing fissures, removing early surface carious lesions, class VI carious and erosive cavities, removing small old composite restorations, removing superficial enamel stains, prophylaxis, and roughening composite cores before luting definitive indirect restorations</td>
</tr>
<tr>
<td>Carisolv</td>
<td>Gel combined with hand and rotary instruments</td>
<td>Chemo-mechanical</td>
<td>Caries excavation, especially in deciduous teeth</td>
</tr>
<tr>
<td>Lasers</td>
<td>Various types</td>
<td>Photo-mechanical</td>
<td>Caries excavation, especially in deciduous teeth</td>
</tr>
<tr>
<td>Oscillating tips</td>
<td>Fine grit diamond tips</td>
<td>Mechanical</td>
<td>Shaping cavities following caries or defective restoration removal</td>
</tr>
</tbody>
</table>

Preoperative

Isolation

Postoperative

Cleansing fissures, removing early surface carious lesions, class VI carious and erosive cavities, removing small old composite restorations, removing superficial enamel stains, prophylaxis, and roughening composite cores before luting definitive indirect restorations
This first section on tooth preparation discusses **micro-invasive and minimally invasive** techniques. These treatment modalities are minimally invasive, atraumatic, avoiding more traditional and invasive rotary techniques for tooth preparation.

### Micro-invasive techniques

Caries describes the **process** and **lesion** of dental decay. Caries is an **infectious disease**, and the protagonist bacteria is *Streptococcus mutans*, which attacks dental hard tissues. The **driving force** of caries is not the bacteria per se, but the **biofilm** that contains the bacteria and carbohydrates. If the biofilm is removed or disturbed, caries can be **reversed** or **arrested by remineralisation** with calcium and fluoride ions present in saliva.

The earliest carious lesion is termed a ‘**white spot’** that can be **active** or **inactive**. Micro-invasive techniques such as the **caries infiltration concept** (Icon, DMG, Germany) aim to arrest early caries before cavitation occurs. This is probably the least invasive method of tooth preparation, involving etching with hydrochloric acid (HCl) and applying an **infiltrate** (low-viscosity resin) that penetrates and seals the lesion by **capillary action**. This treatment is indicated for early **interproximal** lesions, and is also effective for immediate **improvement of aesthetics** after removal of fixed orthodontic brackets.

### Microabrasion

**Microabrasion** is recommended for removing unesthetic staining that is limited to the superficial layer of enamel due to **fluorosis**, **prosthodontic demineralisation**, **localised hypoplasia** or other idiopathic brown/white enamel **dysmineralisation**.

Enamel **fluorosis**, especially of the maxillary anterior teeth, is due to excessive intake of fluoride (**greater than 1 ppm**) during the second and third years of life. The **source of fluoride** is from foodstuffs such as milk, salt, vitamins, infant preprepared food, and the indigenous water supply or dental preventive measures such as toothpaste and rinses. Although fluoride is an **anti-caries** measure, excess amounts prevents maturation of the enamel, increasing its porosity and presenting as **white, yellow or brown striations and staining**.

The **microabrasion** process involves simultaneous **acidic erosion** and **mechanical abrasion**. The technique uses a slurry of HCl, usually mixed with pumice or other abrasive, that is applied to the surface enamel either with a hand applicator, or using rubber cups in a slow dental handpiece. A 6% HCl concentration reveals a **micromorphological** appearance that is similar to intact, untreated enamel without an etch pattern, and is less erosive than 37% phosphoric acid, confirming that this type of minimally invasive treatment **does not damage the structure of enamel prisms**. Also, fluorosed teeth are **hypermineralised**, with a higher concentration of fluoride in the outer **200 µm** layer of enamel that is more resistant to acid etching.

The technique involves isolating the teeth beforehand with conventional or light-cured **rubber dam** to prevent ulceration of the soft tissues. The slurry is applied and repeated until the stains are removed and an acceptable tooth colour is achieved. This is followed by application of **topical sodium fluoride** to encourage remineralisation of the enamel. A possible explanation for the **improvement in tooth colour** after microabrasion is that the acid penetration into enamel may **remove the retained amelogenin proteins** that are attributed to the lesion of enamel fluorosis. Furthermore, the polished tooth surface results in enhanced **specular reflection** that camouflages underlying enamel imperfections.

The **drawback** of microabrasion is the risk of **caustic burns** to the gingiva, and rubber dam is therefore mandatory. If the slurry is incessantly applied and the dentine exposed, **hypersensitivity** is possible. However, microabrasion should be considered the first line of treatment for removing intrinsic enamel stains before more aggressive restorative options are considered.

In **severe fluorosis**, a variation of the macroabrasion technique is to use fine **diamond burrs** (60µm grit) for initial removal of intense fluorotic stains and to adjust the macromorphology. The enamel surface is then **polished** with aluminium oxide discs and silicone tips before continuing with the HCl slurry. In addition, office or home **bleaching** is prescribed to lighten the teeth. This combination of chemical and mechanical abrasion is often referred to as the **chemo-mechanical approach**.

### Other methods

Other methods of minimally invasive tooth preparation include **air abrasion**, which is a mechanical method for roughening the tooth substrate to increase mechanical retention for resin-based fillings. Particles of silica, **aluminium oxide (50 µm)** or bicarbonate of soda are jetted onto the tooth from a dental handpiece using compressed air. The procedure is painless, rarely requiring anaesthesia. A wide range of clinical applications are possible, ranging from cleansing fissures, to removing small old composite restorations. **Precautions** include wearing protective glasses, isolation of the affected teeth with rubber dam to prevent inhalation, and avoiding contact with intact resin-based or glass ionomer fillings.

Treatment of small cavitated carious lesions, especially in deciduous teeth, or cleansing fissures of organic debris before sealing, can also be achieved with other minimally invasive protocols. **Carisolv®** is a chemo-mechanical technique using a gel to dissolve denatured collagen in cavitated carious lesions, followed by hand and rotary instrumentation for debridement of the cavity. **Lasers**, e.g YAG:Er CTL-1601 are also employed for painless carious excavation. Finally, **oscillating diamond tips**, which are less invasive than burs, are useful for shaping cavities following caries removal.

### Key points

- Micro-invasive and minimally invasive tooth preparation techniques are aimed at preserving as much natural tooth as possible.
- The caries infiltration concept is the least invasive method for treating early carious ‘white spot’ lesions.
- Microabrasion is atraumatic and highly effective for restoring aesthetics due to superficial enamel staining.
- Other minimally invasive preparation techniques include air abrasion, Carisolv®, lasers and oscillating diamond tips.
**General guidelines for rotary tooth preparation**

**Dental burs**
- Initial bur - 125 µm
- Final bur - 12 fluted TC
- Sinuous preparation
- EVA bur to remove unsupported enamel margins

**Soft tissue integrity**
- Flat plastic and Zekrya retractor
- Zekrya retractor
- Gingival retraction cord to protect gingiva
- Gingival retraction cord

**Hard tissue integrity**
- Pulp chamber size
- Copious irrigation
- Intermittent preparation
- Immediate dentine sealing
Conventional tooth preparation involves using rotary instruments in preparing teeth to receive either direct or indirect restorations, and is currently the most widely used method worldwide. Tooth preparation is potentially destructive to both the hard and soft tissues, and should be carried out efficaciously, expeditiously and with extreme care to avoid inadvertent or iatrogenic trauma. The guidelines presented below are applicable to all types of tooth preparation using rotary instruments.

Instrumentation
Rotary instruments refer to burs that prepare a tooth by either grinding or cutting. A dental bur has a stainless steel shank with blades of various geometries and shapes. Alternatively, the bur shank can be coated with diamond grits or tipped with tungsten carbide (TC) blades or flutes, for cutting or polishing, respectively. The most popular variety are diamond burs, which are classified according to their shape, size and the diamond grit particle size that varies from 10 µm to over 200 µm. The bur shank fits either a friction grip (FG) turbine handpiece, or a latch-type attachment of a micro-motor contra-angle (CA) handpiece. The specifications of handpieces vary according to the manufacturer, but are broadly divided into turbines rotating at speeds above 300,000 rotations per minute, while the slower micro-motors speeds vary from 1,000 to 40,000 rotations per minute, depending on torque and gear reduction/increasing ratios.

Soft tissue integrity
The soft tissues of the oral mucosa, tongue and lips should be sufficiently retracted to allow a clear field of view and to prevent lacerations by the rotary instruments. The circumferential friable gingival margin requires special attention, to minimise not only transient but also long-term effects of trauma. The initial trauma is bleeding, which hinders clinical procedures such as margin visualisation, impressions and cementing procedures, while long-term effects includes persistent gingival inflammation, periodontal pockets or unwanted gingival recession, compromising ‘pink aesthetics’ in the anterior regions of the mouth. Gingival recession is highly likely with pronounced scalloped gingival contours and/or thin biotypes. Protection of the gingiva is by transient retraction using hand instruments such as small flat plastics, Zekrya gingival retractor, and retraction cords. All these methods provide protection against inadvertent violation of the biologic width, and for promoting a haemorrhage-free protocol.

Hard tissue integrity
Besides soft tissue protection, it is also essential to protect the dental hard tissues: enamel, dentine and the alveolar housing of teeth, to avoid morbidity or mortality. The long-term eventualities are endodontic complications, bone resorption and periodontal pockets. Various studies have endeavoured to evaluate the number of teeth undergoing pulpal pathosis following tooth preparations. The number of teeth losing vitality following full coverage crowns has varied from as little as 2% to over 13% over a 10-year period. Therefore, any tooth scheduled for full coverage crowns should have a preoperative endodontic assessment including history of previous symptoms, clinical and radiographic examination, and vitality tests.

The two factors for maintaining hard tissue integrity of teeth are cutting efficiency (CE) and temperature elevation. Cutting efficiency is defined as the most expedient method for tooth preparation. The critical threshold for CE of diamond grit size is 150 µm. A larger diamond grit size does not increases CE, but leads to microscopic cracks in the enamel and dentine, which weakens the remaining tooth substrate. In addition, the roughened surface created with coarser burs leads to a greater surface roughness (Ra), which complicates laboratory procedures such as waxing and casting, and introduces porosity in the luting agent at the cementation stage. Furthermore, the coarser grit generates heat precariously close to the pulpal necrosis temperature of 41.5°C. Hence, it is prudent to choose burs with a grit size of <150 µm and progressively reduce the grit size as the preparation approaches dentine, to prevent overheating and to create a smoother surface finish.

Other factors to consider during tooth preparation are:
- Size of pulp chamber, which should be assessed radiographically and the amount of tooth reduction carried out precisely with silicone indices. In young teeth, the pulp is larger than in older teeth because the pulp chamber in the latter is reduced due to deposition of secondary dentine in response to carious, restorative, occlusal and extra-oral traumas;
- Preservation of natural tooth substrate is essential to ensure tooth rigidity and insulation from temperature fluctuations, and to prevent impregnation of the dentine tubules with oral pathogens;
- Non-vital teeth are structurally compromised with reduced proprioceptive response, predisposing them to fracture. Care is therefore necessary to design extracoronal restorations that enhance the fracture resistance of the remaining tooth. Teeth with intraradicular support are prone to coronal microleakage that may compromise the root filling as well as the final restoration;
- Cooling with copious irrigation at water temperatures below 32°C mitigates the frictional heat generated during preparation;
- Pressure applied during tooth preparation should be minimal and intermittent to reduce temperature elevation, and allow heat dissipation. Excess pressure is often necessary if burs are damaged, degraded or clogged with debris. Ideally, burs should be discarded after a single tooth preparation, or cleaned in an ultrasonic bath before sterilisation. Furthermore, the trauma to the dental pulp is cumulative. Heavily or repeatedly restored teeth are especially vulnerable to additional trauma of tooth preparation, which may result in pulpal necrosis;
- Time taken to prepare a tooth should be an absolute minimum. Relentless and protracted preparation is unproductive, often resulting in endodontic complications;
- Immediate dentine sealing of prepared teeth with a dentine bonding agent (DBA) removes the smear layer, seals patent dentine tubules, halts bacterial ingress, reduces postoperative sensitivity and results in superior bonding of the definitive restoration when using a resin-based cement.

Key points
- The use of rotary instruments or burs is the most popular method for preparing teeth for direct and indirect restorations.
- Tooth preparation is potentially destructive and caution is necessary to maintain both soft and hard tissue integrity.

General guidelines for rotary tooth preparation
Chapter 33
Preparation for resin-bonded fixed partial dentures

Anterior metal RBFPDs are useful as temporary measures awaiting a more permanent solution. The metal wing retainers can cause greying, especially with thin incisors.

FRC FPDS are reinforced with fibres instead of metal, and are more aesthetic, especially for the anterior regions of the mouth.

FRC can either be intracoronal ('inlay' retained), or full coverage (extracoronal retained). For posterior teeth, the pontic sites can be further strengthened by incorporating multidirectional fibres, or rods.

Advantages and disadvantages of RBFPD

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
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<tr>
<td>Minimal tooth preparation</td>
<td>Survival rate of 5 years</td>
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<tr>
<td>Excellent short-term prostheses for young patients, and while awaiting</td>
<td>Debonding likely, especially with parafunctional habits</td>
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<td>healing of bone and soft tissue grafts and implants, splint mobile teeth</td>
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<tr>
<td>Choice of metal, composite and ceramic frameworks</td>
<td>Short-span bridges, limited to 2 or 3 units</td>
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<tr>
<td>Economical compared to conventional FPD or implants</td>
<td>Exacting adhesive protocol for cementation</td>
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Resin-bonded fixed partial dentures (RBFPDs) were introduced by Rochette in 1973 for splinting periodontally compromised mandibular anterior teeth. The indirect prosthesis is made of perforated cast metal retainers or wings, with or without pontics, which are cemented to the lingual or palatal surfaces of abutment teeth with a resin-based luting agent. RBFPDs are minimally invasive, requiring less tooth preparation compared to conventional FPD. They are usually indicated for short spans of two or three units. Longer spans are possible if the occlusion is satisfactory without bruxist activity. However, increasing the number of abutments causes interabutment stresses leading to a greater chance of debonding. RBFPDs are indicated for anterior and posterior regions of the mouth, with the following uses:

- As minimally invasive fixed prostheses for unrestored, intact adjacent teeth, teeth in younger patients with large dental pulp chambers, or following acute trauma resulting in avulsion of a tooth;
- As temporary or stopgap prostheses to allow integration of hard and soft tissue augmentation, while awaiting implant placement or during the osseointegration phase of implant therapy;
- A short-span FPD as an alternative to conventional FPD or implant-supported prostheses;
- For splinting mobile, periodontally compromised teeth.

Several configurations of RBFPD are described. These include retentive wings either side of the pontic, or a cantilever design, using only one abutment tooth for the retainer, with a suspended pontic. For the latter, the pontic on the opposite side of the retainer can be supported by an intracoronal rest seat for correct location and stability. RBFPDs have approximately 90% survival rate over a 5-year period, with greater success reported in the maxilla than the mandible.

Rochette and Maryland appliances

Both the Rochette and Maryland FPD are fabricated from cast metals and their fitting surfaces etched in the dental laboratory. The difference between the two is the design of the metal retainers: the Rochette retainers are perforated to increase mechanical retention, while Maryland retainers are non-perforated. If a pontic is incorporated, its metal substructure can be veneered with a resin-composite or porcelain. The drawbacks of metal retainers are the metal shine-through or greying of thin abutment teeth, debonding and over-contoured retainers.

Fibre-reinforced composite

To improve aesthetics, gain additional retention and reduce opposing tooth wear, cast metal retainers can be substituted with a reinforced resin composite. Fibre-reinforced composite (FRC) FPDs are composed of two types of composite:

- Substructure – either pre-impregnated fibres in a resin matrix or non-impregnated polyethylene fibres;
- Superstructure – a hybrid or micro-filled veneering composite bonded to the substructure composite with heat and light polymerisation. To prevent delamination and create high bond strengths, it is essential to maintain an oxygen inhibition layer between composite increments, or to condition the substructure composite with a silane coupling agent.

FRC FPDs can either be full coverage (extracoronal) or partial coverage (intracoronal) ‘inlay’ retained, depending on the restorative status of the adjacent abutment teeth.

The framework design of FRC depends on whether full or partial coverage is planned. Nevertheless, the framework should offer sufficient rigidity to support the veneering composite and resist occlusal forces, which is achieved by incorporating multidirectional fibres, adequate bulk of fibres, and including bars at pontic sites.

Tooth preparation

The tooth preparation for an RBFPD depends on the existing restorations in the abutment teeth. Heavily restored teeth with extensive amalgams or composite filling require full coverage type of preparations, while for smaller class I, II and III restorations an intracoronal approach is appropriate. In addition, retentive features, preferably confined within the enamel, such as proximal/occlusal grooves and lingual steps are beneficial and avoid over-contoured prostheses and sufficient occlusal clearance. For intact, virgin teeth, no preparation is usually necessary, except creation of guiding planes, occlusal stops and finish lines for path of insertion and location, respectively.

Prosthesis design

Metal substructures or frameworks can be fabricated from both noble and base cast metals, such as nickel chrome alloy. The framework is designed for maximum extent onto the lingual/palatal surfaces to increase the surface area for bonding, without compromising aesthetic, occlusion or periodontal health. For molar abutments, the framework is wraparound to maximise retention and resistance form, and can be either C-shaped, confined to the lingual surface, or D-shaped, extending onto the occlusal aspect. In addition, the retainer thickness should be >0.8mm for sufficient strength. Other options include fabricating a high-strength CAD/CAM ceramic framework, with pressed or layering veneering porcelain for the pontic.

Cementation

Luting an RBFPD involves using an adhesive bonding technique, which is operator-sensitive and influences the longevity of the prosthesis. A conventional or adhesive resin-based luting agent is recommended. The intaglio surface of the retainers is pre-treated with air abrasion, electrolytic etching or silanation. The fitting surface of the abutment tooth can also be air-abraded and/or etched with 37% phosphoric acid to enhance bonding. Since dentine is rarely exposed, the bond to enamel is more predictable, assuming proper isolation to prevent contamination by saliva and blood.

Key points

- Resin-bonded fixed partial dentures are minimally invasive, indirect prostheses.
- They are indicated for a variety of clinical applications, and have a survival rate of approximately 90% over 5 years.
- The framework can either be cast metal or fibre-reinforced composite that is veneered with either resin-based composite or porcelain.
- An adhesive technique is necessary for luting RBFPDs using resin-based cements.
Preparation for inlays and onlays

Cavity configurations

Inlay

Guidelines for inlay preparation include taper, cavity depth, isthmus width, internal and external line angles, and occlusal and cervical margin location.

Onlay

Guidelines for onlay preparation incorporating cusp(s) include sufficient cusp reduction (minimum 2 mm) and occlusal clearance (minimum 1.5 mm).
Conventional teaching stipulates that tooth preparation be material-orientated, i.e. geometric, to accommodate the properties of the restorative material. Conversely, contemporary techniques dispel this destructive overpreparation in favour of disease- or defect-orientated preparations. Modern restorative materials are capable of restoring teeth that have smaller or minimally invasive preparations, and therefore allow a larger amount of natural dental tissues to be retained.

Indirect inlays and onlays are indicated for extensive cavities in premolars and molars, due to rampant caries, or to replace defective existing restorations. An inlay or onlay preparation conserves more of the natural tooth, removing less tooth substance (6–27%) compared to a full-coverage crown (68–76%).

Definitions
An inlay is an indirect intracoronal restoration that does not support or replace cusps of a tooth. Furthermore, all occlusal contacts in centric, protrusive and lateral excursions are guided by cusps of the natural tooth.

An onlay is an indirect restoration that incorporates, supports and replaces one or more tooth cusps. The functional occlusion is supported by the restorative material that covers the involved cusps. An onlay can incorporate an inlay preparation or be restricted to the occlusal surface to replace an eroded occlusal table, or to raise the occlusal vertical dimension (OVD).

Various cavity configurations of onlays and veneers are possible; for example, a veneerlay restoration that combines an onlay and veneer preparation.

Guidelines for inlay preparation
The conventional guidelines for inlay preparations are:

• Taper – the occlusal and cervical boxes should have 6° tapers for adequate path of insertion/withdrawal;
• Isthmus width – 3 mm at the mesial and/or distal aspects;
• Cavity depth – 3 mm to accommodate an adequate bulk of restorative material (cast gold, composite or ceramic);
• Internal line angles – smooth, devoid of undercuts;
• External line angles – occlusal and cervical box finish lines should have a 90° cavo-surface angle for ceramics and composites, and a 45° bevel for cast gold to allow burnishing;
• Occlusal margin location – avoiding centric contacts, or guiding/supporting cusps;
• Cervical margin location – finish line within enamel, and if possible, coronal to the cement-enamel junction.

However, the ongoing improvement in material properties and refined clinical techniques afford greater latitude, allowing a more defect- or disease-orientated preparation. In the past it was essential to remove minor undercuts (either due to caries or existing amalgam fillings retained by undercuts) by removing enamel at the occlusal surfaces to expand the cavity. But now the undercuts can be filled with relative ease using dentine bonding agents (DBAs) and flowable composites. Alternately, minor undercuts can be left in situ, since modern impression materials are flexible enough to allow removal of the impression without distortion or tearing, and the undercut can be subsequently blocked out on the plaster cast in the dental laboratory.

Guidelines for onlay preparation
Tooth preparation for onlays follows similar guidelines for inlay preparation, but offers greater leeway. An onlay preparation can incorporate an inlay preparation, or cover the entire occlusal table without an inlay preparation. In the former situation, an inlay preparation is carried out, and if deemed necessary, susceptible cusps are reduced by 2 mm to accommodate the restorative material. The cavo-surface finish line is 90° for ceramics and bevelled 45° for cast gold. An onlay is prescribed because of severe coronal destruction and ensuing loss of tooth substrate resulting from tooth wear, decay or endodontic complications, and for restoring or raising the OVD. In these circumstances, the preparation is minimal, limited to defining finish lines with correct cavo-surface angles. Finally, a minimum of 1.5–2 mm occlusal clearance or opening (if increasing the OVD) is necessary for the restorative material.

Recent research has verified that irrespective of the number of cusps (both functional and non-functional cusps) incorporated into an onlay preparation, the fracture resistance of the indirect restoration is unaffected, and can even restore the fracture strength to the equivalent of an unprepared, intact tooth. Furthermore, compared to inlays, onlays are more efficacious in protecting tooth structure because an onlay preparation design is more resistant to tooth fractures.

CAD/CAM inlays and onlays
The latest advances for fabricating indirect restorations in a few hours is by using CAD/CAM technology. The technique involves making an intra-oral optical impression of the preparation or extra-oral scanning of a plaster cast of the cavity. Using CAD/CAM computer software, a virtual restoration is designed, which is subsequently milled using machinable ceramic ingots (feldspathic, pressed leucite glass, lithium disilicate, alumina and zirconia). The milled restoration is polished, stained, glazed, etched and silanated, ready for adhesive luting.

The guidelines for tooth preparation for CAD/CAM restorations are identical to those for conventional fabrication methods. However, if an optical impression is utilised, clearly delineated margins and sinuous line angles, devoid of undercut are obligatory, with little room for error. In addition, the finish lines, when possible, should be located supragingivally to facilitate digital scanning of the preparation or a plaster cast of the preparation.

Key points

• Inlays and onlays are indirect restorations for large cavities in or on premolars and molars.
• Inlay and onlay preparations are more conservative than full coverage crowns, and the ensuing restoration can enhance fracture resistance of a tooth.
• CAD/CAM technology offers efficacious fabrication of various indirect restorations using a variety of ceramic and resin-based composite materials.
Preparation for porcelain laminate veneers

**INDICATIONS**

- Preoperative
- Preparation
- Cast
- Postoperative
- Preoperative
- Wax-up
- Postoperative

**PREPARATION DESIGNS**

- 0.4 mm cervical 1/3 and 0.7 mm incisal 2/3 preparation
- Incisal wrap for superior aesthetics
- Ideally, supragingival margins
- Break contact points

**PREPARATION GUIDELINES**

- Incisal cut
- Incisogingival cut for axial reduction guide
- Clear stent for mock-up & temps
- Protect soft tissues

**PLY PREPARATION FEATURES**

- Supragingival margin
- Healthy gingival tissues
- Preparation within enamel
- Clearly defined enamel margins

- Smooth, sinuous outline, devoid of undercuts
- Incisal wrap
- Incisal wrap for superior aesthetics

**Silicone index**

- Silicone index
- Silicone index

**Stent**

- Stent
- Gingival protector

- Buccal
- Incisal edge
- Cervical
- Interproximal

Healthy gingival tissues
Preparation within enamel
Clearly defined enamel margins
Porcelain laminate veneers (PLVs) have proved to be one of the most successful and long-lasting indirect aesthetic restorations. However, PLVs are also one of the most clinically and technically challenging restorations, and their success is attributed to careful and meticulous protocols. PLVs are the most frequently used and abused restorations in cosmetic dentistry, especially in the case of ‘extreme make-overs’. In addition, careful analysis of the patient’s psyche is essential before embarking on irreversible elective cosmetic procedures, particularly if expectations are beyond clinical feasibility.

Rationale
The ethos of PLV is based on the principles of preserving as much natural tooth substrate as possible, especially enamel, and utilising this natural hard tissue foundation to support thin veneers of porcelain. Generally, resin-bonded PLVs require ⅓ to ½ tooth reduction compared to complete coverage crowns. In addition, PLVs conserve natural tooth structure, tooth vitality, rigidity and structural integrity, prevent postoperative sensitivity and therefore ensure longevity of natural tooth structure, tooth vitality, rigidity and structural integrity, compared to complete coverage crowns. In addition, PLVs conserve.

To prevent mutilation of tooth structure for spurious short-term aesthetic gains, it is worth remembering the following dictum before prescribing PLV:

- The purpose of PLV is replacing lost enamel and dentine not
- As a substitute for enamel and dentine

Indications for porcelain laminate veneers
PLVs are primarily aesthetic restorations for improving tooth colour, morphology and alignment. They are usually placed on buccal surfaces of teeth in the maxillary anterior sextant, but are also indicated for:
- Space management, e.g. diastemata closure, or correcting imbrications;
- Restitution of occlusal vertical dimension (OVD) using the Dahl concept, following bite collapse due to tooth wear;
- Combination restorations, e.g. veneerlay (combination of a veneer and an inlay or onlay);
- Palatal veneers due to fracture, erosion or breakdown of defective restorations.

Preparation designs
Unlike crown preparations that have predefined geometric configurations to provide retention and resistance form, PLV preparations are non-retentive and entirely dictated by a diagnostic wax-up. Consequently, there is no ideal preparation design, and tooth reduction (if necessary) is influenced by aesthetics objectives, occlusal and functional needs, endodontic and periodontal considerations, amount of remaining tooth substrate, existing fillings, tooth morphology and alignment, choice of ceramic and the patient’s wishes.

There are four aspects to consider for PLV preparations:
- Buccal (facial) – retain ⅙ to ⅔ enamel for maintaining enamel rigidity, finish lines within enamel, cervical ⅓ reduction of 0.4 mm, and remaining ⅔ facial reduction of 0.7 mm;
- Incisal edge
  Window – conservative, poor aesthetics;
  Feather-edge – conservative, chipping at incisal edges, poor aesthetics;
- Incisal wrap (with palatal chamfer, bevel or butt joint) – invasive, superior aesthetics, requires 1 mm occlusal clearance, allows tooth lengthening (especially following tooth wear);
- Cervical – ideally margins within enamel, supragingival or subgingival to mask discolouration and conceal porcelain/tooth interface;
- Interproximal – retain or break contact points depending on clinical situation and treatment objectives.

The PLV preparation should feature clearly defined finish lines, smooth surface roughness, a sinuous outline devoid of undercuts, and sufficient space to accommodate adequate porcelain thickness for strength and to prevent an over-contoured restoration. If preparation is unnecessary, any aprismatic enamel should be roughened using microabrasion techniques to enhance bond strength before luting the veneers with dentine bonding agents (DBAs). Pre-existing composite fillings can reduce bond strength and may require replacement beforehand, or during the cementing process.

Preparation guidelines
A diagnostic wax-up is the starting point for PLV preparations. It allows 3-D visualisation of the proposed outcome, and is preferred to 2-D image manipulation software simulations. Also, a diagnostic wax-up acts as a template for a silicone index (for guided tooth preparation), a transparent vacuum-formed stent or thermoplastic matrix (for intra-oral mock-ups and temporary coverage), and a guide for fabricating the definitive porcelain veneers.

Many methods have been proposed for tooth preparation including freehand, silicone index guides and cutting through mock-up simulations. The most precise method is using silicone indices, cut in several planes, to guide and minimise inadvertent tooth reduction. Tooth reduction is accomplished by placing depth cuts using round diamond burs of varying diameters. The depth cuts are joined for the axial reduction using straight-sided 135° chamfer burs of decreasing particle size diamond grit, and smoothed with tungsten carbide finishing burs. The reduction should mimic the tooth curvature in all planes (mesiodistal, inciso-gingival) for ensuring an even, predefined thickness of porcelain. If required, interproximal contacts are broken with finely coated diamond discs. To prevent laceration of the gingival margins or interproximal papillae, the latter are protected by either flat plastic instruments or the Zekrya gingival protector. If dentine is exposed, immediate dentine sealing (IDS) using a DBA is advisable before impressions or fabricating provisional restorations.

Key points
- PLVs are highly aesthetic and predictable restorations, but require meticulous attention to detail for long-term success.
- There is no ideal tooth preparation (if required) for PLVs, which depends on the clinical scenario and treatment objectives, and is guided by a diagnostic wax-up.
- Preserving enamel is the key to success.
Preparation for full coverage crowns and fixed partial dentures

**Margin location**
- Supragingival
- Equigingival
- Subgingival

**Margin geometry**
- Knife-edge shoulder chamfer
- Supragingival margin
- Preparation height > 4 mm
- Smooth, sinuous outline, devoid of undercuts
- Convergence angle
- Healthy gingival tissues
- Facial reduction
- Axial reduction
- Occlusal/incisal reduction

**IDEAL PREPARATION FEATURES**

**Preparation design**
- Remove unsupported enamel with reciprocating EVA diamond tip

**FPDs**
- Large connector dimensions for ceramics
- Small connector dimensions for metal
Full coverage crowns or abutments for fixed partial dentures (FPD) on natural teeth are probably the penultimate indirect prostheses before considering extractions and implants. Furthermore, before embarking on these highly destructive preparations, alternative adhesive restorations such as onlays or endo-crowns should be considered. Full coverage crowns are also indicated for implant-supported single-unit crowns and FPDs, which minimizes the number of implants required for oral rehabilitation.

Crown preparation is usually for 360° coverage, but various configurations are possible such as ½, ¾, ¾, etc., depending on the remaining tooth substrate. Essentially, tooth preparation for crowns is material-oriented, i.e. the tooth is prepared to accommodate the properties of specific restorative materials such as gold, resin-based composites or ceramics.

**Margin location**

The preparation margins, or finish lines can be placed in three locations:

- **Supragingival** – indicated for low lip lines, posterior crowns, knife-edge finish lines or thin periodontal biotypes. This is an ideal position since it allows both oral hygiene access, and clinical visibility for monitoring. Furthermore, gingival inflammation is minimal, and biologic width integrity is preserved;
- **Equigingival** – ideal when the underlying tooth colour is acceptable and an all-ceramic restoration is utilised;
- **Subgingival** – indicated for high lip lines, profound tooth discolouration, masking or altering the unsightly tooth colour, or for all-ceramic crowns with a dense opaque core, e.g. zirconia, to hide the crown/tooth transition. However, subgingival margins should only be considered for thick periodontal biotypes, which have less propensity for postoperative gingival recession, and located within the gingival sulcus to prevent violation of the biologic width. For subgingival carious lesions, crown lengthening or orthodontic extrusion may be necessary to locate the finish lines in a more favourable position.

**Margin geometry**

Margin geometry describes the shape of the tooth preparation finish lines. Three basic shapes are possible: knife or feather-edge, shoulder (or butt joint) and chamfer. The knife-edge is minimally invasive and conservative, advocated for full metal crowns, especially in the posterior regions of the mouth. Because the preparation is minimal, the margin must be located supragingivally. The disadvantages include indistinct finish lines and larger margin opening compared to a butt joint, bulbous crowns due to under-preparation, and is therefore contraindicated for all-ceramic crowns. The shoulder preparation (90° to 120°) is more aggressive than a knife-edge margin. It is suitable for PFM and all-ceramic units. However, the internal line angles should be rounded, devoid of undercut. The chamfer preparation has a generally accepted geometry angle of 135° that allows a gradual shade tooth/crown transition, aids scanning for CAD/CAM fabrication, and is ubiquitously recommended for most all-ceramic units and electroformed crowns. Furthermore, because the smallest CAD/CAM millings tips are 1 mm, they cannot reproduce preparation detail below this threshold.

**Preparation design**

A crown preparation requires retention form to prevent dislodgement and resistance form to resist occlusal and masticatory forces. As a general guide, full metal crowns require less tooth reduction compared to PFM or bi-layer all-ceramic units. A preparation design should incorporate the following features:

- **Occlusal/incisal reduction** – 1 mm to 1.5 mm in all excursions for clearance, and for enhanced fracture resistance of the restorative material;
- **Axial taper** – ideal 4° mesial and distal taper (or 8° convergence angle), acceptable range is 6–15°, i.e. translating to a mesial and distal interproximal reduction of 0.75–1.5 mm;
- **Facial and lingual reduction** – 1–1.5 mm depending on the margin geometry, and the facial-lingual thickness of the tooth;
- **Incisal-lingival height** – a minimum of 4 mm is desirable for adequate resistance form. It may be necessary to build up or fill in deficiencies with resin-modified glass ionomer or resin-based composites or to incorporate retention grooves for added retention;
- **Sinuous outline, devoid of undercuts and smooth surface**, is essential for impression making, cementing, and facilitating fabrication of the restoration in the dental laboratory. Furthermore, sharp line angles may initiate fractures at the fitting or intaglio surface of all-ceramic restorations. Also, the tooth preparation should follow the contours and anatomy of the natural tooth, retaining as much enamel and dentine as possible. Finally, serrated, unsupported enamel margins following preparation should be trimmed with either hand chisels, or preferably with reciprocating EVA diamond tip for delineating a clearly visible finish line.

**FPD considerations**

Tooth preparation for fixed partial denture (FPD) abutments is identical to single units but with the following additional considerations:

- **Parallelism** – all abutment teeth should have the same path of insertion/withdrawal. Various methods are available for achieving parallelism, e.g. as intra-oral jigs;
- **Connector dimensions** – are the weakest link of FPD frameworks, and their dimensions depend on the type of restorative material. Cast metal or titanium frameworks require less surface area for connectors than ceramics, e.g. 12–20 mm² is necessary for glass ceramics, 9–16 mm² for alumina and zirconia and 6.25 mm² for porcelain fused to metal;
- **Pontic design and size** – e.g. ridge-lap, ovate, or modified ovate pontics depending on morphology of the alveolar ridge(s);
- **Precision attachments** – are incorporated to relieve stress in long-span FPDs. Precision attachments require additional space at the occlusal and interproximal areas, and can only be used with cast metal frameworks.

**Key points**

- Full coverage tooth preparation is highly destructive and requires careful consideration.
- Crown preparation involves considering margin location, margin geometry and preparation designs.
- Additional features for FPD abutments include parallelism, space for connectors, pontic designs and incorporation of precision attachments.

Preparation for full coverage crowns and fixed partial dentures  Chapter 37  83
### Properties of Materials for Provisional Restorations

<table>
<thead>
<tr>
<th>Material</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal</td>
<td>Pre-formed morphology, no matrix required, can be relined with self-cured resins</td>
<td>Require extensive adjustment to obtain good marginal fit, contact points and occlusion, poor wear resistance, poor aesthetics</td>
</tr>
<tr>
<td>Polycarbonate</td>
<td>Pre-formed morphology, no matrix required, can be relined with self-cured resins, good wear resistance, good aesthetics</td>
<td>Require extensive adjustment to obtain good marginal fit, contact points and occlusion</td>
</tr>
<tr>
<td>PMMA</td>
<td>Resilient, good wear resistance and aesthetics, heat and pressure polymerisation improves physical and mechanical properties of material, easy intra-oral relining, repaired with flowable composites, suitable for long-term use and long-span multiple units, can be reinforced with metal copings for increased strength for lengthy use, especially for the healing phase of implant-supported prostheses</td>
<td>High exotherm, unsuitable for intra-oral fabrication, high shrinkage, unpleasant colour, free monomer causes gingival irritation, requires matrix, higher cost for laboratory-fabricated provisionals</td>
</tr>
<tr>
<td>PEMA</td>
<td>Less exotherm than PMMA but higher than bis-acryl, suitable for intra-oral fabrication, selection of shades and stains, easily relined, and repaired with flowable composites, suitable for medium-term use, ideal for relining metal, polycarbonate and PMMA shell crowns</td>
<td>Poorer wear resistance than PMMA, prone to staining, considerable shrinkage, allergies to residual uncreated monomer, unsuitable for long-span multiple units for lengthy period of use, unpleasant colour</td>
</tr>
<tr>
<td>Bis-acryl</td>
<td>Most popular of all materials for provisionals due to ease of use and delivery via syringe mix, low exotherm, no objectionable odour, minimal shrinkage, stronger than PEMA, ideal for single and short-span multiple units, and suitable for long-term use</td>
<td>High cost and waste, matrix required, brittle, difficult to reline, unsuitable for long-span multiple units</td>
</tr>
<tr>
<td>UDMA</td>
<td>Light-cured, good mechanical properties, large selection of shades, good aesthetics, easier relining than bis-acryl</td>
<td>High cost and waste, matrix required, high exotherm due to light-curing polymerisation</td>
</tr>
<tr>
<td>Resin-based composite restoratives</td>
<td>Excellent aesthetics, ideal for temporary veneers, can be used with or without matrix but temporary cement is not necessary, also possible to make laboratory provisional to compensate for polymerisation shrinkage for improved mechanical and optical properties</td>
<td>Expensive, time consuming, difficult to distinguish natural tooth substrate and filling material and may require time-consuming removal and/or damage to tooth preparation</td>
</tr>
<tr>
<td>Modified composites</td>
<td>Low viscosity, ideal for intracoronal provisionals for inlays, matrix and temporary cement not necessary</td>
<td>Weak, prone to wear, poor interproximal and occlusal contacts, discolouration with food dyes, difficult to remove if undercut present</td>
</tr>
</tbody>
</table>

**Intra-oral technique for fabricating provisional**

1. Impression or vacuum matrix
2. Tooth preparation
3. Dispense bis-acryl
4. Locate matrix
5. Preoperative
6. Preparation
7. Acrylic provisional
8. Fabricating an indirect vacuum matrix
9. Provisional for inlays
10. Preoperative
11. Wax-up
12. Vacuum stent
13. Intra-oral vacuum stent
14. Cavity preparation
15. Temporary inlay
16. Postoperative
A provisional (or temporary restoration) is used as an interim before fitting the indirect definitive restoration or prosthesis. In essence, a provisional is disposable, but should remain for the intervening period while awaiting the permanent analogue.

**Function of provisionals**
Besides acting as a stopgap, provisionals have numerous useful functions for assuring the ultimate success of the permanent restoration, such as:

- **Health** – of exposed dentine and pulp vitality. In addition, periodontal health requires monitoring, especially if there is prevailing information due to previous defective restorative margins, crown lengthening or implant and surgical augmentation. Healing may be accompanied by gingival recession and may require relocation of the preparation margins, particularly for anterior restorations. In addition, a provisional is useful for tissue sculpturing, either at a pontic site or around implant abutments in order to achieve acceptable ‘pink aesthetics’;
- **Function** – for planned occlusal changes such as anterior guidance, lateral excursions and vertical dimension alterations. Also, the restorations should be comfortable and not an impediment to phonetics or embouchure;
- **Aesthetics** – when gross morphological changes are planned, e.g. restitution of worn dentition or for elective cosmetic procedures. Provisionals based on diagnostic wax-ups are minimally invasive, and are ideal for assessing aesthetics and function before carrying out irreversible tooth preparation;
- **Tooth preparation** – sufficient tooth removal in order to accommodate restorative materials using intra-oral guides for precise and calculated tooth reduction, e.g. for adhesively retained PLVs.

**Choice of materials**
The number of materials on the market for provisionals is both impressive and confusing, and the choice is dictated by the intended use and the clinical scenario. Materials for provisionals are broadly divided into metals and resins.

- **Metals** – pre-formed single crowns or short span FPDs without the need for a matrix, e.g. stainless steel, aluminium, nickel and chromium;
- **Resins** – polycarbonate (pre-formed single units), PMMA (polymethyl methacrylate), PEMA (polyethyl methacrylate), bis-acryl, UDMA (urethane dimethacrylate), resin-based composite restoratives (flowable and nonflowable) and modified composites (for inlays and onlays).

**Techniques for fabrication**
Nearly all provisionals require some type of matrix for fabrication. Freehand fabrication is possible but time-consuming, e.g. temporary composite veneers. The matrix can either be pre-formed or custom-made, which is the most popular method. There are two techniques for fabricating provisional: the direct (intra-oral) and indirect (extra-oral). The direct technique involves using a matrix, for example:
- Based on envisaged tooth morphology from the diagnostic wax-up using a vacuum-formed thermoplastic matrix;
- Pre-formed metal or plastic shell crowns.

The indirect technique (extra-oral) involves using a dental laboratory or in-office casting of models. This technique is ideal for long spans that are intended for lengthy periods of usage, especially for implant-supported prostheses while awaiting osseointegration. Two methods are available:

- **Simulating tooth preparations** on a preoperative or diagnostic wax-up cast, and fabricating PMMA shells in the laboratory that are subsequently relined in the mouth using cold-cured resins after tooth preparation;
- **Taking an impression of the prepared abutments**, and then fabricating PMMA provisionals that are cemented with an appropriate temporary luting agent.

**Provisionals for PLV** present a challenge because little retention is offered from minimal tooth preparation. In these circumstances, if the preparation is within enamel and the contact points are retained, no temporary restoration is necessary. However, if dentine is exposed or contact points broken, the options are as follows:

- **Freehand composite build-up** with spot etching, without a bonding agent;
- **Composite, bis-acryl or PEMA**, either alone or in combination with a vacuum-formed matrix or silicone impression matrix, and then cemented with spot etching and a flowable composite. Also, linking multiple provisional veneers improves retention and prevents dislodgement.

**Provisionals for intracoronal** restorations such as inlays can be fabricated from a variety of resins, but the most popular materials are light-cured modified composites that are directly dispensed into the cavity preparation and set with a light-curing unit.

**Temporary cements**
A temporary cement should be strong enough to retain the provisional, yet weak enough for the practitioner to remove the restoration when necessary. Furthermore, it should be palliating to the hard and soft tissues, maintain structural integrity and vitality of the tooth, and promote gingival health. The most popular temporary cements are zinc oxide/eugenol formulations, available as non-eugenol and transparent varieties. Other cements include zinc phosphate, polycarboxylate and flowable composites.

To minimise the marginal opening between the provisional and tooth preparation margins, the provisional should not be overfilled; the temporary cement should be judiciously applied to the cervical margins and axial walls, but not to the occlusal intaglio surface.

<table>
<thead>
<tr>
<th>Key points</th>
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<tbody>
<tr>
<td>• Provisionals are interim restorations used while awaiting the definitive restoration or prostheses.</td>
</tr>
<tr>
<td>• Properly constructed and accurately fitting provisionals are essential for the long-term success of the permanent restoration.</td>
</tr>
<tr>
<td>• A selection of materials is available for fabricating provisionals, using either direct or indirect techniques.</td>
</tr>
</tbody>
</table>
### Impression materials

#### CHOICE OF IMPRESSION MATERIALS

- **Removable prosthodontics**
  - Preliminary impressions: Alginate, dental compound
  - Partial dentures: Monophase PVS or polyether
  - Full dentures: ZnO/eugenol paste, light body PVS or polyether

- **Fixed prosthodontics**
  - Partial edentulous ridge: Mono PVS
  - Edentulous: Plaster cast

- **Teeth**
  - Wax addition: ZnO/eugenol

- **Implants**
  - Impressions with impression copings
  - Impression abutments
  - Teeth: Monophase PVS or polyether, digital impression
  - Implants: Monophase PVS or polyether, digital impression

#### Definitions

<table>
<thead>
<tr>
<th>Property</th>
<th>Description</th>
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<tbody>
<tr>
<td>Tear resistance</td>
<td>Ability of a material to resist tearing in small cross sections, e.g. deep subgingival margins</td>
</tr>
<tr>
<td>Elastic recovery</td>
<td>The degree of recoil of a material without permanent elastic deformation, e.g. from tooth preparation undercuts</td>
</tr>
<tr>
<td>Dimensional stability</td>
<td>Ability to withstand stress without permanent deformation, e.g. heavy body or putty formulations</td>
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Impressions are required for fabricating indirect restorations and indirect prostheses. The choice of impression material depends on the type of prosthesis. While some materials have multiple uses, predictable and precise impressions are achieved using specific materials for removable and fixed prosthodontics. Regrettably, substandard impressions are often accepted by clinicians in the expectation that the dental technician can ‘fake and make’ missing or inadequate details of intra-oral anatomy. Precise and accurate impressions are challenging and require knowledge of:

- Impression materials (this chapter);
- Impression techniques and armamentarium (Chapter 40);
- Soft tissue management (Chapter 41).

Many impression materials used in dentistry since the 1950s are now archaic or redundant, including plaster, polysulphides (rubber base), reversible hydrocolloids and condensation silicones. However, a minority of older-generation or esoteric clinicians still find use for these materials. The impression materials discussed below are the most popular in contemporary prosthodontics.

**Dental compound**

Dental compound is a thermodynamic material that softens with heat and sets to a rigid consistency in the oral cavity. Due to its thermodynamic behaviour, additions or corrections are relatively easy. However, its low strength and brittleness are drawbacks, often causing breakage, and uses include customising stock trays, preliminary impressions for full dentures, or supporting areas of deep sulci and edentulous ridges.

**Zinc oxide eugenol paste**

The use of zinc oxide/eugenol paste is exclusively for tissue-supported removable full dentures (RPD). The material’s enduring property is that it does not displace soft tissues of edentulous ridges, or buccal sulci, thus avoiding pressure spots on fitting surfaces, and overextended buccal flanges, respectively. Furthermore, voids can readily be corrected by adding wax without repeating the impression. However, the material is unsuitable where there are profound ridge undercuts; it is also contraindicated in patients who object to its pungent taste and odour or who suffer from eugenol allergy.

**Irreversible hydrocolloids**

Alginites are irreversible hydrocolloids, frequently used for preliminary impressions for custom tray fabrication, opposing arch impressions, diagnostics (study models) making extra-oral provisional restorations, and for orthodontic cast records. Alginites are inexpensive and relatively technique-insensitive but dimensionally unstable, requiring almost immediate pouring.

**Polyvinyl siloxane**

Elastomers, e.g. polyvinyl siloxanes (PVS), and polyethers, are the most popular impression materials for fixed prosthodontics, including implant-supported prostheses. PVS materials, also known as addition silicones or vinyl polysiloxane (VPS), were introduced in the 1970s, as addition reaction silicone elastomers. Their popularity is attributed to ease of use (automix and cartridge delivery systems), patient-friendliness (odourless, insipid), accuracy, dimensional stability, average tear resistance, good elastic recovery, long-term storage, multiple pouring, immersible in aqueous disinfectants, and availability in a range of viscosities and working/setting times for innumerable impression procedures. In addition, PVS materials are suitable for many impression techniques including quadrant, full arch and one- and two-stage protocols using either dual or monophase consistencies.

Some disadvantages of PVS materials are that the setting reaction is retarded by latex glove contamination, which can be mitigated by using an automix machine or washing the tooth preparation with 3% hydrogen peroxide. Also, silicones are hydrophobic (high contact angle) and therefore impressions of subgingival crown margins may be problematic. However, as discussed in Chapter 41, efficient soft tissue management negates this unfavourable property.

**Polyether**

Polyethers are the second most popular impression materials for fixed prosthodontics. They offer excellent accuracy, dimensional stability, superior tear resistance and elastic recovery. Another benefit is their hydrophilic (low contact angle) property, facilitating impressions of deep intracrevicular restorative margins. Earlier polyethers had disadvantages of high rigidity and pungent odour/taste, but newer versions offer lower viscosities and are tasteless. A major drawback is that multiple pours are not possible, which are essential for modern laboratory fabrication procedures, especially when using CAD/CAM methods. Finally, due to their hydrophilicity, a non-water-soluble disinfectant is necessary.

**Digital impressions**

A digital or virtual impression uses a scanner to digitise the tooth preparation and sounding tissues, including the gingivae and adjacent and antagonist dentition. This can either be performed intra-orally, or from an analogue impression or cast of the tooth preparation. Software converts the digitised data into an image, which can be manipulated, archived and disseminated (e.g. to the dental laboratory) via the Internet. Using CAD/CAM software, the dental technician designs the restoration, and the resultant computer file is relayed to a milling machine where the restoration is fabricated.

The digital impression is an emerging technology, undergoing rapid changes, and has several advantages over analogue impressions, eliminating the following problems or dilemmas:

- Material and tray selection;
- Material separation from tray, distortion due to inadvertent handling or storage, and damage to, or loss of the original impression if a replacement restoration is necessary;
- Expediency.

**Key points**

- Impressions are necessary for indirectly fabricated prostheses.
- Choosing the correct impression material for a specific prosthesis is essential for success.
- Contemporary materials for analogue impressions yield reliable and predictable impressions.
- Digital impressions are the method of the future, but require further sophistication of existing equipment and software.
**Impression techniques and armamentarium**

**SINGLE-STAGE IMPRESSION TECHNIQUE**
- Measure arch width
- Apply adhesive to plastic or metal tray
- Air dry and wait 5 min
- Load PVS heavy body in tray
- Light body onto abutments
- Trim excess material
- Trim loose cord
- Check for absence of voids and drag
- Ensure finish line is clearly discernible

**TWO-STAGE IMPRESSION TECHNIQUE**
- Apply adhesive
- Load heavy body... and bleed material
- Load PVS heavy body into tray
- Take initial impression
- Trim channels...
- Tissue management
- Light body on preparations and locate initial impression onto arch
- Inspect impression
- Untrimmed model
- Trimmed model
- Ensure area apical to finish line are recorded
- Ensure areas apical to finish line are recorded
Besides choosing the correct impression material for a specific restoration, the technique and armamentarium also influence the accuracy of an impression.

**Tray selection**

**Rigid vs non-rigid:** the rationale for using a rigid tray is to avoid distortion by controlling dimensional stability and minimising polymerisation shrinkage. Conversely, plastic or non-rigid trays cause distortion, even if using light-bodied materials. As a general rule, plastic trays are suitable for single units, but metal trays are preferable for multiple units.

**Stock vs custom:** stock trays offer convenience and disposability (plastic variety). Most fixed prosthodontic impressions are feasible on metal stock trays with modifications using dental compound material. However, well-adapted, uniformly spaced (4 mm) custom trays fabricated from autopolymerising or light-cured resins are an ideal choice for removable prostheses, complex cases involving a combination of teeth and implant-supported restorations, or if voids and drags are persistent in a stock tray impression. Also, care is necessary when using rigid materials, e.g. polyethers or putty-wash techniques, especially in the presence of undercuts, which may prevent removal of the custom tray after the material has set.

**Perforated vs closed:** the reasoning for using a perforated tray is that the holes act as vents for excess material. However, the drawback is that material seepage may elicit a gagging reflex.

**Inter-arch vs intra-arch:** Full or intra-arch trays are essential for removable, and preferred for fixed, prosthodontics. In some countries, there is a penchant for using inter-arch trays, which simultaneously act as a bite registration. While this may be useful for single units, the disadvantages include ensuring complete closure in centric occlusion, distortion of the delicate ‘triple tray’ (plastic variety), inability to assess jaw excursions, and technically challenging laboratory procedures.

**Tray adhesive**

The function of a tray adhesive is to prevent material lifting off the tray and causing mass discrepancies. The tray adhesive should be compatible with the given impression material, i.e. alginate, PVS or polyether. Furthermore, to ensure efficacy of the adhesive, it should be applied and allowed to dry before making an impression.

**Material manipulation**

Most contemporary materials are available in cartridges for automatic electronic mixing units or auto-mixing hand-held dispensers. Manual mixing is almost redundant due to infection control concerns, heterogeneous mix, inadequate mixture of base and catalyst, and the introduction of porosity. Temperature was often used with older generations of materials to manipulate the setting time and alter viscosity. However, these practices alter the chemical composition of the material, and result in erratic setting reactions. Furthermore, newer materials are available in a range of setting times and viscosities, obviating the need to use heat or cold to alter the physical properties. One of the drawbacks of PVS materials is that their setting reactions are affected by latex. Therefore, handing PVS should be limited to non-latex or polyethylene gloves. Also, complete setting of most elastomers is affected by residual acrylic monomer of some provisional restorative materials, but is unaffected by haemostatic agents used for gingival retraction.

**Undercuts**

Undercuts present a problem and may be present due to:
- Inadequate tooth preparation;
- Interproximal gingival embrasures (black triangles);
- Deep sulci;
- Atrophic alveolar ridges, e.g. pontic sites;
- Malaligned teeth.

Most softer varieties of elastomer are sufficiently flexible to overcome minor discrepancies, but blatant and profound undercuts should be blocked beforehand with wax to avoid locking of the impression tray on the teeth or tearing the material at crucial areas such as finish lines.

**Moisture control**

Moisture control involves controlling salivary flow, intracrevicular fluid and gingival haemorrhage. The former is by using salivary ejectors and high volume aspiration, while the latter is by soft tissue management (discussed in Chapter 41). An arid environment is essential for recording subgingival margins using hydrophobic impression materials, e.g. PVS. Some PVS impression material can be pre-treated with surfactants or topical agents to encourage hydrophilicity.

**Single and two stages**

The most commonly practised protocol is the putty-wash technique, either single-stage or two-stage:
- **Single-stage:** the tray is loaded with a heavy-body material while a light-body wash is simultaneously dispensed onto the prepared abutment(s). The advantage is expediency, but the downside is distortion of the tray and displacement of the soft tissues;
- **Two-stage:** the first stage involves taking a heavy-body or putty impression, either before or after tooth preparation, with or without an appropriate spacer, or using individual tooth copings. The second stage is dispensing a light-body wash onto the abutment(s) and relocating the tray with the set putty into the mouth. The rationale is that shrinkage is minimised, since the heavy- and light-body materials set separately, but accurate location of the tray may be challenging.

**Recoil**

All elastomeric impression materials suffer from recoil, which may result in a prosthesis fitting the plaster die, but not the intra-oral abutment. To minimise this effect, the impression material should be allowed to set passively, without excessive pressure while holding the tray, and removed rapidly once the material(s) have set.

**Key points**

- Technique and armamentarium determine the accuracy of an impression.
- Factors such as tray selection, tray adhesive, material manipulation, undercuts, moisture control, single-stage or two-stage and passive setting reaction all influence the accuracy of an impression.
Impressions: soft tissue management

**CHEMICAL RETRACTION**
- Tooth preparation
- Expasyl in situ
- Gingival retraction

**PERIODONTAL HEALTH**
- Violation of the biologic width
- Defective crown margins
- Healthy periodontium surrounding veneers and crown

**DOUBLE CORD RETRACTION TECHNIQUE**
- Tooth preparation and healthy gingiva
- Dry, thin 1st cord
- Place 2nd, thicker cord
- Preoperative

**GINGIVAL RETRACTION**
- Unacceptable impression
  - Indiscernible finish line, voids, drags
- Acceptable plaster model
  - Discernible finish line, and area apical to crown margin
- Inspect impression detail
- Proceed with impression
- Ensure abutments are dry
- Fabricate prostheses
- Moisten and remove 2nd cord
- Wait 5 mins
The last factor determining the accuracy of an impression is efficacious soft tissue management. This involves a transient displacement (retraction) of the circumferential gingivae surrounding the prepared tooth, or implant abutment in order to:

- Visualise the finish line;
- Maintain an arid environment, particularly for addition silicone (PVS) impression materials;
- Accommodate a sufficient bulk of intrasulcular impression material (at least 0.2mm thickness);
- Record an area apical to the finish line to create a correct emergence profile of the artificial prosthesis.

The definitive restoration is only as good as the impression. Adequate soft tissue management is essential for both analogue and digital impressions. Apart from the need to choose the appropriate impression material and to use a correct impression technique, most substandard impressions are attributed to ineffective soft tissue control. Soft tissue management can be categorised as, first, achieving and maintaining periodontal health, and second, manipulating the gingivae to facilitate impression making.

**Periodontal health**

The primary determinant for achieving a successful impression is achieving and maintaining periodontal health. A healthy periodontium is a prerequisite for facilitating not only impression making but also subsequent stages such as the try-in and cementation procedures. There are two aspects influencing periodontal health: patient and operator factors.

The patient factors are predominately beyond the patient’s and clinician’s control, including:

- Genetic predisposition or constitution;
- Age, race, gender, e.g. pregnancy and osteoporosis;
- Systemic illnesses, e.g. diabetes, compromised immune system, psychological stress, bisphosphonate or radiation therapy;
- Dental biotype and bioform;
- Oral pathogens;
- Local trauma or previously compromised vascularity, e.g. periapical lesions;
- Socio-economic status;
- Oral hygiene, local irritants, e.g. smoking, alcohol abuse.

Conversely, the operator factors are within the clinician’s control, and are remediable with proper techniques, including:

- Oral hygiene, smoking cessation counselling and meticulous prophylaxis;
- Maintaining biologic width integrity;
- Ensuring correct emergence profiles of all provisional and definitive restorations;
- Precision fitting of provisionals to encourage gingival health.

Gingival healing can be as rapid as a few days, or prolonged over several weeks, depending on the prevailing patient factors, or the degree of iatrogenic insult during restorative procedures. Therefore, impressions should be deferred until a stable and healthy gingival architecture is evident. This is extremely important for anterior ‘pink aesthetics’, where erratic gingival contours following gingival recession can be displeasing and may compromise aesthetic outcomes.

**Chemical retraction**

Chemical retraction is the least traumatic method for achieving gingival retraction using hygroscopic gels, usually incorporating haemostatic agents, e.g. Expasyl (KerrHawe SA, Switzerland). This method is ideal for equi- or shallow subgingival preparation margins, where minimal retraction is necessary, but may be challenging for deeper, subgingival finish lines.

**Physical retraction**

The most predictable and widely practised method for gingival retraction is using retraction cords, with or without haemostatic agents. This is the preferred method for subgingival margins using either the single or double retraction cord technique. The potential drawbacks are gingival injury and recession, especially with thin biotypes due to inadvertent trauma during cord placement and removal. If gingival bleeding is present, the cords can be presoaked in haemostatic agents such as buffered aluminium chloride, aluminium potassium sulfate or ferric sulfate. Adrenaline is contraindicated due to its undesirable effects of raising heart rate and blood pressure.

**Surgical retraction**

There are two circumstances when surgical intervention is necessary: first, gingival hyperplasia, and second, violation of the biological width. Gingival hyperplasia occurs in the presence of open, defective restoration margins, or if a previous restoration has been dislodged for a considerable time. If the preparation margins are approaching the alveolar crest, surgical crown lengthening is required for osseous resection to re-establish the biologic width. However, all forms of surgery are risky with thin biotypes, with possible ensuing gingival recession.

The surgical methods available are:

- Scalpel – conventional flap elevation and bone removal is the ideal procedure for crown lengthening, either for aesthetic gingival margin contouring or re-establishing the biologic width;
- Electrosurgery – using radio frequencies of greater than 1 MHz, electrosurgery is conducive for gingivectomy, widening of the gingival sulcus and coagulation;
- Lasers – e.g. argon, KTP, diode, Nd:YAG and microsecond-pulsed CO₂ lasers have similar functions to electrosurgery and are useful for soft tissue incisions and sulcular debridement;
- Rotary curettage – using diamond burs for gingival resection or sulcus widening. However, this is a highly destructive procedure, and the lack of tactile sensation can lead to widespread gingival trauma and prolonged haemorrhage.

**Key points**

- Proper soft tissue management is essential for facilitating and producing accurate impressions.
- The primary determinant for precise impressions is achieving and maintaining periodontal health.
- Soft tissue manipulation is achieved by a variety of gingival retraction methods including chemical, physical and surgical.
- The choice of retraction method depends on the prevailing clinical situation.
Computer-aided design and manufacture technology

**CAD/CAM protocol and fabrication methods**

- **CAPTURE**
- **CAD**
- **CAM**

**CAD/CAM protocol and fabrication methods**

- **Subtractive**
- **Additive**
- **Combination**

**Customised zirconia and titanium abutments**

- Acrylic single and multiple unit provisionals
- Resin-based composite inlays, onlays, veneers and crowns
- Feldspathic and leucite-glass inlays, onlays, veneers and crowns

**Implant abutments**

- Full contour
- Indirect restorations
- Partial contour

**APPLICATIONS**

- Wax-ups
- Implant abutments

**Models, splints and templates**

- Solid free-form or stereolithographic prototyping for producing resin full arch models, occlusal splints and surgical templates for guided implant placement

**Veneering dense ceramic cores**

- Fully automated production for multilayered strong and aesthetics restoration. High strength dense ceramic cores can be veneered with aesthetic high glass content silica-based ceramics using either direct-write assembly, direct shell production casting or laser sintering

**Applications**

- 3-D printing technology for creating wax-ups of individual copings or FPD frameworks that can be subsequently scanned for CAM

**CAPTURE**

- CAD of a single unit coping

**CAM**

- CAM of an FPD framework

**CAD/CAM**

- CAD/CAM implant abutment
CAD/CAM (computer-aided design and computer aided manufacture) technology is heralding a new age of digital dentistry. CAD/CAM involves three distinct processes: capture, design and fabrication.

**Capture**

Capture or digitisation is converting a 3-D structure into a dataset for creating a virtual representation of an object, e.g. by a triangulation process. This is achieved using 3-D scanners, which are either optical or mechanical. An optical scanner uses white light projections or laser beams, while a mechanical scanner uses a ruby ball which traverses the object and converts the information into a graphical computer image.

Capture can either be intra-oral, i.e. an optical impression of the prepared tooth/teeth and full-arch digital impressions, or anatomical dental duplicate, e.g. scanning an impression of the tooth preparations, poured plaster dies, or proposed wax-up of the prostheses.

**Design**

CAD is designing a restoration, which is subsequently stored as a computer file. At present there is no industry standard file format, and each system is manufacturer-specific and non-interchangeable. Several design processes are possible, including:

- **Extrapolation technique** – the morphology of the restoration is obtained from a software database;
- **Correlation technique** – involves taking two optical impressions, one of the prepared tooth and one of the envisaged occlusal morphology, which can either be a preoperative impression or a scan of a proposed wax-up;
- **Replication** – copying the occlusal anatomy of a similar type of contralateral tooth;
- **Functional technique** – two optical impressions, one of the preparation and the second of a functional generated pathway for designing the occlusal morphology.

**Fabrication**

CAM is fabricating or manufacturing a restoration by converting data from the computer file into a set of commands that are sent to the manufacturing unit, which can be chair-side (Cerec® System, Sirona, Germany), in a dental laboratory (Everest, Kavo, Germany), or a centralised production plant (Cara, Heraeus, Germany). To date, no single system can fabricate all types of restoration using the entire spectrum of restorative dental materials. The prostheses can either be full contour (finished by staining, characterisation and/or polishing or glazing), or partial contour (coping or framework), which is manually veneered to create full anatomical form. The methods for CAM include:

- **Subtractive method** – milling an ingot to the desired shape;
- **Additive methods**, for example:
  - Generative rapid prototyping (3-D printing) for fabricating wax patterns;
  - Solid free-form fabrication (stereolithography) for resin full-arch working models or surgical templates for guided implant placement;
  - Depositing material onto a die by selective laser sintering (e.g. for alumina and zirconia frameworks);
- **Direct-write assembly** is an evolving technology, based on a rapid prototyping approach to create dense ceramic cores and frameworks without the waste and damage associated with the milling process. It can also be used for veneering dense high-strength ceramic cores with high glass content ceramics, thereby totally automating fabrication of a highly aesthetic restoration;
- **Direct shell production casting** and **laser sintering** for placing veneering porcelain layers over a dense ceramic core;
- **Combination** of subtractive and additive methods (Procera, Goteburg, Sweden).

**Pros and cons**

The advantages of CAD/CAM fabricated restorations are:

- **Precision fit** – marginal opening of <10–50µm, eliminating dimensional inaccuracies of laboratory procedures of investing and casting, computer-aided parameters for ensuring accurate design of copings with adequate support for the overlying veneering porcelain, correct FPD connector and pontics dimensions, and bespoke implant abutments;
- **Expedience and predictability** – access to vast biogeneric database for creating occlusal anatomy and implant abutments (virtual wax-up), eliminating human error during onerous laboratory stages, shorter treatment times using chair-side systems, simultaneous implant fixture and abutment placement for immediate loading, and reduced manpower costs;
- **Aesthetic and durability** – full anatomical restorations that do not require veneering, e.g. inlays, onlays, veneers and crowns using polychromatic ingots with a variety of materials for specific aesthetic and functional needs;
- **Versatility** – besides indirect provisional and definitive restorations, CAD/CAM technology can also be utilised for surgical templates (stents), customised implant abutments and virtual occlusal relationships of dental arches, which may eventually replace conventional articulators. In addition, various materials including metals, resins and ceramics can be used depending on clinical needs.

The drawbacks include:

- **Unforgiving clinical protocols** (precise tooth preparation, excellent tissue management and accurate impressions);
- **Software and equipment training**;
- **Limitation of software and milling devices for complex designs**;
- **Poor aesthetics** with monochromatic ingots;
- **Software and equipment updates**, involving additional cost and time-consuming training.

**Key points**

- The CAD/CAM process can be divided into capture, design and fabrication.
- CAD is not limited to providing indirect restorations, but also has numerous applications such as for implant surgical stents.
- CAM can use a wide spectrum of dental restorative materials for fabricating precision fit, durable and aesthetic restorations.
- CAD/CAM is an evolving technology that promises a revolution in many existing clinical and laboratory procedures.
### Luting agents

#### Interfaces

- **Site of cohesive failure**
- **Site of adhesive failure**

#### TOOTH

- Natural substrates: enamel, dentine, cementum
- Artificial substrates: base liners (resin, dentine bonding agents, glass ionomers, calcium hydroxide, etc.), core build-up materials (composite, amalgam, glass ionomers), implant abutment (gold, titanium, ceramic)

#### RESTORATION

- Ceramics (silica, alumina, zirconia), gold, composite, titanium, e.g. crowns, bridges, inlays, veneers, Maryland/Rochette bridges, fibre reinforced bridges, orthodontic brackets

#### Natural Substrates

- Enamel
- Dentine
- Cementum

#### Artificial Substrates

- Base liners (resin, dentine bonding agents, glass ionomers, calcium hydroxide, etc.)
- Core build-up materials (composite, amalgam, glass ionomers)
- Implant abutment (gold, titanium, ceramic)

#### Site of Adhesive Failure

- **Cement-tooth interface**
- **Cement-restoration interface**

#### Site of Cohesive Failure

- **Cement-tooth**
- **Cement-restoration**

#### CONVENTIONAL CEMENTS

<table>
<thead>
<tr>
<th>Luting agent</th>
<th>Liquid</th>
<th>Powder</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Luting mechanism: cement-tooth interface</th>
<th>Luting mechanism: cement-restoration interface</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Zinc oxide/eugenol (ZOE)</strong></td>
<td>Eugenol, water, acetic acid, zinc acetate, calcium chloride, olive oil</td>
<td>Zinc stearate, zinc acetate, rosin</td>
<td>Palliative, ideal for provisional, reinforced, EBA (ethylenoxycetic acid) and super-EBA versions</td>
<td>Low strength, high solubility, brittleness, no antibacterial effect, retards setting of permanent resin-based cements</td>
<td>Mechanical interlocking</td>
<td>Mechanical interlocking</td>
</tr>
<tr>
<td><strong>Zinc phosphate (ZP)</strong></td>
<td>Phosphoric acid, aluminum phosphate, water</td>
<td>Zinc oxide, magnesium oxide, silica</td>
<td>Thin film thickness, modified ZP with silicate and fluoride offers improved aesthetics and fluoride release, respectively</td>
<td>High solubility, brittleness, no antibacterial effect, exothermic reaction, initial pH 2 may cause pupal irritation, pH neutralised after 48 h</td>
<td>Mechanical interlocking</td>
<td>Mechanical interlocking</td>
</tr>
<tr>
<td><strong>Polycarboxylate (PC)</strong></td>
<td>Polyacrylic acid, carboxylic acids (itaconic acid, maleic acid, tartaric acid), water</td>
<td>Zinc oxide, magnesium oxide, stannous fluoride</td>
<td>Bonds to metal, and tooth calcium ions via carboxy group, fluoride releasing, low film thickness</td>
<td>High solubility, brittleness, no antibacterial effect, technique sensitive mixing</td>
<td>Chemical adhesion with natural tooth substrate</td>
<td>Mechanical interlocking</td>
</tr>
<tr>
<td><strong>Glass ionomer (GI)</strong></td>
<td>Itaconic acid, tartaric acid, maleic acid, water</td>
<td>Zinc oxide, magnesium oxide, calcium aluminum fluorosilicate</td>
<td>Bonds to moist dentine, low film thickness, reduced pupal irritation, fluoride release, pre-capsulated and light-cured versions</td>
<td>Low strength, high opacity (poor aesthetics)</td>
<td>Chemical adhesion with dentine</td>
<td>Mechanical interlocking</td>
</tr>
</tbody>
</table>

#### Solubility

- ZOE > PC > ZP and GI > Resin

#### Pupal irritant

- Resin and ZP > GI > PC > ZOE

#### Shear bond strength; SBS (MPa)

- ZP
- GI
- RMGI
- Resin

#### Film thickness (mm)

- ZP
- GI
- RMGI
- Resin

#### Compressive strength (MPa)

- ZP
- PC
- GI
- RMGI
- Resin

---

Luting agents or cements are used for retaining indirect restorations on teeth or implant abutments. The functions of a luting agent are:

- **Retention** for preventing dislodgement of the restoration. However, retention alone is insufficient for success. A restoration may be in situ but, if microleakage is present, this may lead to pulpal and gingival irritation, requiring removal of the offending restoration;
- **Hermetic seal** between the tooth and restoration to minimise microleakage, prevent secondary caries and pulpal and gingival inflammation. In addition, an efficacious seal retards **dentine fluid movement**, mitigating hypersensitivity;
- **Resist oral functional and parafunctional forces**, which are particularly significant for tooth preparations with inadequate resistance form.

**Mechanism**
The cementation mechanism of cements is classified as:

- **Non-adhesive or mechanical interlocking** retention by engaging tooth surface and restoration intaglio surface irregularities, measuring 20–100 µm. This mechanism is applicable for all dental cements;
- **Micromechanical adhesion** is engaging finer surface irregularities of <2 µm created by etching, air abrasion, and usually in combination with a dentine bonding agent (DBA), to form a hybrid layer (0.5–10 µm) – discussed in Chapter 45;
- **Chemical (molecular) adhesion** by bipolar, Van der Waals forces and **chemical bonds**, which is the ideal adhesion, and contemporary cements strive to achieve this ideal.

**Interfaces**
The mechanism of retention by cements can broadly be termed **luting or bonding**. Luting provides non-adhesive retention, while bonding implies a closer approximation of the cement with the tooth and restoration, which includes **micromechanical and chemical adhesion**.

There are **two interfaces** between cements and the tooth/restoration complex. On the tooth side, the substrate is either dentine, enamel or cementum, and is called the **cement–tooth interface**. On the opposing side is the artificial restoration, termed the **cement–restoration interface**. Certain resin cements in conjunction with DBAs offer **chemical adhesion at both interfaces**. A large number of interfaces are created depending on the substrate on the tooth and restoration sides. These interfaces are the weakest link, accounting for **adhesive failure** of the restoration. Conversely, **cohesive failure** occurs due to cement breakdown or fracture within the tooth or the restoration.

A seal is essential to prevent microleakage between the **concealed interfaces** beneath the bulk of the restoration, as well as at the ‘open’ margins exposed to the oral cavity. Furthermore, the exposed margins are also vulnerable to **occlusal stresses transmitted from the coronal part** of the restoration to the cervical aspect, and the cement should be resilient enough to resist these forces and maintain a long-lasting hermetic seal.

**Properties**
Most properties of cements are assessed by laboratory tests that are useful for comparison, but not for clinical performance, e.g. zinc phosphate dissolves in experimental tests, but provides long-term retention in clinical practice, impeding toxins and preventing dentinal fluid flow. Also, the methodologies of various studies are rarely identical, making a judicious comparison very difficult. The favourable properties of a dental cement should include:

- **Physical** – similar elastic modulus, shade and optical properties to natural teeth, and provide thermal insulation;
- **Mechanical** – high compressive, fatigue, tensile and shear bond strengths (SBS), and promoting increased fracture resistance of restoration and the supporting abutment;
- **Chemical** – insoluble in oral fluids and resisting water sorption;
- **Biological** – biocompatible with dental and surrounding soft tissues, bacteriostatic and/or bactericidal, bio-regenerative (fluoride releasing);
- **Minimum film thickness** – 25 µm is often quoted as an ideal, but realistic in vivo values vary from 50 µm to 350 µm;
- **Radiopaque**;
- **Aesthetic**;
- **Handling properties** – ease of mixing or dispensing, sufficient working time, rapid setting time, adequate fluidity for thin film thickness.

**Classification**
Dental cements can broadly be classified into **conventional** (zinc oxide/eugenol, zinc phosphate, polycarboxylate, glass ionomer) and **contemporary** (resin and resin-modified glass ionomers – discussed in Chapter 44).

All dental cements consist of a **matrix** infiltrated by **filler particles** to confer favourable properties. The salient properties of some popular **conventional cements** are as follows:

- **Zinc oxide/eugenol** (discussed in Chapter 38) – palliative temporary cement used for provisionals, but caution is necessary when using a subsequent definitive resin cement since eugenol is a radical scavenger, possibly retarding polymerisation of resin-based luting agents;
- **Zinc phosphate (ZP)** – the first permanent cement, introduced in the 1920s, and was the gold standard for nearly half a century. ZP offers good mechanical properties, but poor marginal seal due to dissolution in oral fluids;
- **Polycarboxylate (PC)** – invented in the 1960s, based on ZP, but with the added benefit of being more biocompatible and the ability to bond to tooth substrate and metal. However, the technique-sensitive mixing procedure has made this cement almost redundant;
- **Glass ionomer (GI)** – introduced in the 1970s by Wilson, this polyacrylic acid composition offers chemical adhesion to dentine, fluoride release and a thin film thickness. The drawbacks are poor mechanical properties and unaesthetic opaque appearance, limiting its use to base liners. However, resin-modified glass ionomers (RMGI) have overcome many physical and mechanical limitations of GI (discussed in Chapter 44).

**Key points**
- Luting agents are used to adhere dental restoration to teeth or implants.
- An ideal cement should seal and retain a restoration, as well as resisting oral forces.
- Dental cements can be classified into conventional (ZOE, ZP, PC and GI) and contemporary (resins and RMGI).
### CONTEMPORARY CEMENTS

<table>
<thead>
<tr>
<th>Formulation</th>
<th>Variables</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Cementation mechanism: cement–tooth interface</th>
<th>Cementation mechanism: cement–restoration interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resin-modified glass ionomer (RMGI)</td>
<td>Pre-capsulated, chemical and light-cured</td>
<td>Adhesion to dentine, thin film thickness, antimicrobial fluoride releasing, low solubility, adheres to moist tooth substrate, reduced chemical trauma to pulp</td>
<td>Mechanically weaker than resins, significant post-cementation dimensional changes may fracture weak ceramics</td>
<td>Chemical adhesion to dentine</td>
<td>Mechanical interlocking</td>
</tr>
<tr>
<td>Conventional resins (CR)</td>
<td>Chemical, light and dual cured, low and high viscosities, shade tints to modify colour</td>
<td>High compressive strength, superior optical properties</td>
<td>Technique-sensitive, hydrolytic degradation, shade shift, over time, possible postoperative sensitivity with poor technique</td>
<td>Chemical adhesion</td>
<td></td>
</tr>
<tr>
<td>Adhesive resins (AR)</td>
<td>Dual cured, self-filling, self-adhesive, antibacterial, fluoride releasing</td>
<td>High compressive strength, superior optical properties, chemical bonding to cast metal, alumina and zirconia substructures</td>
<td>Technique-sensitive, hydrolytic degradation, shade shift over time, lower bond strength compared to CR, reduced postoperative sensitivity compared to CR</td>
<td>Micromechanical adhesion and/or chemical adhesion</td>
<td>Chemical adhesion</td>
</tr>
</tbody>
</table>

### CHOICE OF DEFINITIVE CEMENTS

<table>
<thead>
<tr>
<th>Type of restoration</th>
<th>Restorative material</th>
<th>Ideal cement</th>
<th>Possible cement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast metal crowns and inlays, intraradicular posts, porcelain fused to metal crowns and fixed partial dentures (bridges)</td>
<td>High gold and semi-precious alloys</td>
<td>AR, RMGi</td>
<td>ZP, PC, CR</td>
</tr>
<tr>
<td>Maryland/Rochette bridges and splints</td>
<td>Semi-precious alloys</td>
<td>AR</td>
<td>CRD</td>
</tr>
<tr>
<td>Fibre-reinforced composite bridges and splints</td>
<td>Composite, fibre</td>
<td>AR</td>
<td>CRD</td>
</tr>
<tr>
<td>Light-transmitting intraradicular posts</td>
<td>Fibre, zirconia</td>
<td>AR</td>
<td>CRD</td>
</tr>
<tr>
<td>Orthodontic fixed brackets</td>
<td>Metal alloy</td>
<td>AR</td>
<td>CRD</td>
</tr>
<tr>
<td>Inlays and onlays</td>
<td>Composite or silica-based ceramic</td>
<td>AR</td>
<td>CRD</td>
</tr>
<tr>
<td>Porcelain laminate veneers (feldspathic)</td>
<td>Silica-based ceramics</td>
<td>CRL</td>
<td>CRD, AR</td>
</tr>
<tr>
<td>All-ceramic crowns, e.g. feldspathic, leucite-reinforced pressed glass, lithium disilicate</td>
<td>Silica-based ceramics</td>
<td>CRL</td>
<td>CRD, AR</td>
</tr>
<tr>
<td>All-ceramic crowns and fixed partial dentures of glass-infiltrated alumina, densely sintered alumina, zirconia substructures</td>
<td>Alumina- and zirconia-based ceramics</td>
<td>AR, RMGi</td>
<td>-</td>
</tr>
<tr>
<td>Implant-supported crowns or fixed partial dentures</td>
<td>Porcelain fused to metal, or alumina- and zirconia-based ceramics</td>
<td>AR, RMGi</td>
<td>ZOE</td>
</tr>
</tbody>
</table>

**KEY**

AR, adhesive resins; CRL, conventional resin light-cured; CRD, conventional resin dual-cured; PC, polycarboxylate; RMGi, resin-modified glass ionomer; ZOE, zinc/oxide eugenol; ZP, zinc phosphate
Contemporary cements for definitive restorations can broadly be categorised as resin-modified glass ionomers (RMGI) and resins. The latter can be further subdivided into conventional resins (CR) and adhesive resins (AR).

Resin-modified glass ionomers
RMGIs exploit the benefits of both glass ionomers and resins. The glass ionomers bond to dentine, have a thin film thickness, release fluoride and are less prone to age degradation, while the resin part confers improved physical, mechanical and aesthetic properties. RMGIs are the most popular luting agents used in clinical practice due to ease of use, and are less technique-sensitive than resins. The indications include cast metal and high-strength ceramic core restorations such as alumina and zirconia for tooth abutments and implant-supported titanium and zirconia abutments.

Conventional resins
Resin cements have a similar chemistry to resin-based composite filling materials. An organic resin matrix (e.g. Bis-GMA) is infiltrated with inorganic filler (e.g. silica) particles, which are coated with silane to bind with the surrounding polymer (matrix). The type and amount of filler particles determine the physical, mechanical and optical properties of the cement. The major advantage of resins is superior mechanical and optical properties, and they are particularly indicated for bonding aesthetic ceramic restorations such as inlays, porcelain laminate veneers and all-ceramic crowns and fixed partial dentures (FPD).

The adhesion mechanism at the cement–tooth interface of resins is micromechanical in conjunction with a dentine bonding agent (DBA) by forming a hybrid layer. Some DBAs offer chemical adhesion by bonding with calcium ions from the hydroxyapatite of the tooth substrate. In order to resist the polymerisation stresses of the overlying resin cement, the bond strength of the DBA should be greater than 25 MPa. The DBA can either be separately applied beforehand, or incorporated within the cement. Caution is necessary with self-etching DBA since the acidic inhibition layer may be incompatible with the setting reaction of the resin cement. Cement contains self-etching primers to eliminate the etching and priming stages, while the self-adhesive varieties also contain a bonding agent to simplify clinical protocols. However, the self-etching/bonding cements are more efficacious bonding to dentine than enamel, but enamel bonding benefits from etching and adhesive application before cementation.

Conventional resins (CR) are recommended for silica-based ceramics where aesthetics is a paramount concern. Silica is a low-strength ceramic (flexural strength 100–300 MPa) with a high glass content, offering increased translucency and superior aesthetics, assuming the underlying tooth substrate is an acceptable colour. In addition, silica is amenable to etching with hydrofluoric acid (HF) to increase mechanical retention, and when treated with silane, creates silica–silane chemical bonds at the cement–restoration interface. A separate DBA, either a total-etch or self-etch system, is necessary to prepare the tooth substrate before cementation. CR cements are available in a large selection of tooth-coloured shades, enabling accurate colour matching. Furthermore, try-in pastes corresponding to the definitive cement shades allow colour assessment and alteration before final cementation.

Adhesive resins
Adhesive resins (AR) have similar chemistry to CR, but with the addition of an adhesive phosphate monomer, e.g. MDP (10-methacryloyloxydecyl dihydrogen phosphate) or 4-META (methacryloyloxyethyl trimellitic anhydride). This allows the cements to have broader applications for cementing cast metal as well as alumina and zirconia core restorations. The latter are classified as high-strength ceramics (flexural strength ranging from 400 MPa to >1000 MPa), not etchable with HF, and the lower glass content results in increased opacity with poorer optical properties, but greater masking capability for underlying tooth discolouration. The self-etching, self-adhesive AR are contraindicated for bonding PLVs since their higher pH of 2 is insufficient to adequately etch enamel compared to etching with 37% phosphoric acid that has a lower pH of 1.

Choice of cements
The choice of cement depends on the type of restoration, the restorative material and prevailing clinical scenario.

Non-retentive prostheses, such as Maryland/Rochette, fibre-reinforced fixed partial dentures (FPD), porcelain laminate veneers (PLV) and inlays/onlays, rely solely on the cement for retention. Furthermore, aesthetics is critical for PLV and ceramic inlays for proper shade matching. In both these circumstances, resin cements are ideal candidates, offering superior adhesion and enhanced aesthetics.

The basic rule when using porcelain in the oral cavity is that it must be supported. The major concern with porcelain is its inherent brittleness (high modulus of elasticity), making it vulnerable to fractures. Fractures in the hostile oral cavity are caused by the aqueous environment and physiological and pathological occlusal stresses. The weaker-strength materials such as silica-based ceramics must therefore be supported by the natural underlying tooth substrate. Alternately, instead of gaining support from tooth substrate, a weak silica ceramic can be supported by a dense core or substructure, which can either be metal (PFM) or ceramic, e.g. alumina or zirconia ceramics. Therefore, the later can be bonded with resin cements, or luted with other cements such as RMGI.

Lastly, the clinical scenario dictates the choice of cement. If the resistance and retention form of the tooth abutment is less than the ideal of 4° axial tapers (8° convergence angle), a resin cement is a prudent choice. Similarly, poor marginal integrity of the restoration may be sealed by resins, if a remake is impractical. Finally, for deep subgingival margins, an arid environment is challenging, and a RMGI that is less sensitive to moisture is a better choice.

Key points
- Contemporary definitive cements can be categorised as resin-modified glass ionomers (RMGI), conventional resins (CR) and adhesive resins (AR).
- The choice of cement depends on the type of restoration, restorative material and prevailing clinical scenario.
- The newer class of self-etching, self-adhesive resin cements simplifies the exacting clinical protocols associated with resin cements.
**BONDING MECHANISM**

**Step 1 Conditioning**

Enamel and dentine conditioning is usually carried out by 37% phosphoric acid for 20 seconds. On enamel, the prisms are etched, especially uncut, aprismatic enamel to increase the surface area for micro-mechanical interlocking. On dentine, the smear layer and the organic matrix are either removed or dissolved.

<table>
<thead>
<tr>
<th>Solvents</th>
<th>Water</th>
<th>Ethanol</th>
<th>Acetone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling point</td>
<td>100°C</td>
<td>78.5°C</td>
<td>56.5°C</td>
</tr>
<tr>
<td>Rehydrates collagen fibres</td>
<td>Yes</td>
<td>Partially</td>
<td>No</td>
</tr>
<tr>
<td>Facilitate resin penetration</td>
<td>No</td>
<td>Partially</td>
<td>Yes</td>
</tr>
<tr>
<td>Require moist dentine</td>
<td>No</td>
<td>Partially</td>
<td>Yes</td>
</tr>
<tr>
<td>Technique sensitive</td>
<td>Low</td>
<td>Intermediate</td>
<td>High</td>
</tr>
</tbody>
</table>

**Step 2 Priming**

Solvents carry monomers to create a transient hydrophobic environment for the subsequent step of adhesive application.

**Step 3 Bonding**

The adhesive is usually an unfilled resin that seals the exposed dentine tubules and forms a resin-collagen complex termed the hybrid layer. Also, above the hybrid layer is an adhesive layer, which ‘links’ to the resin-based restorative material.

**Comparison of total etching and self-etching agents**

<table>
<thead>
<tr>
<th>Etchant pH</th>
<th>Total etching</th>
<th>Self-etching</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Profound</td>
<td>Shallow (especially on enamel)</td>
</tr>
<tr>
<td>2</td>
<td>Removed</td>
<td>Dissolved and incorporated into the hybrid layer</td>
</tr>
<tr>
<td>Etching pattern</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hybrid layer thickness</td>
<td>Thicker</td>
<td>Thinner</td>
</tr>
<tr>
<td>Technique-sensitive</td>
<td>High</td>
<td>Expedient, but concerns about enamel etch pattern</td>
</tr>
<tr>
<td>SBS</td>
<td>Usually stronger than SE systems, comparable to enamel bond</td>
<td>Dentine bond is erratic, can be stronger than enamel bond. Aprismatic (uncut) enamel requires prior etching with phosphoric acid</td>
</tr>
</tbody>
</table>

**CLINICAL APPLICATIONS OF DBA**

- Smear layer
- Etched dentine
- Hybrid layer
- Desensitising
- IDS
- Resin filling
- Luting crowns
Resin-based composite fillings materials and cements require an intermediary adhesive to adhere to enamel and dentine. These adhesives are termed dentine bonding agents (DBA).

**Historical background**
In 1955, Buonocore introduced the acid etch technique for adhering acrylic restoratives to tooth substrate. While bonding to enamel has changed little since its inception more than a century ago, bonding to dentine has proved far more elusive, undergoing enormous changes. Scientific research has yielded a better understanding of bonding to dentine, resulting in many generations of DBAs over the last six decades. The breakthrough for dentine bonding came in the mid-1980s with the 4th and 5th generations of DBAs, with the state-of-the-art 7th generation introduced in the last ten years.

**Bonding to tooth substrate**
Bonding to enamel and dentine are fundamentally different processes. For achieving a bond to tooth, the prerequisites are an inorganic and hydrophobic environment. Enamel is nearly 90% inorganic with little water content and therefore conducive for a successful and predictable bond by micromechanical interlocking with exposed enamel prisms. On the other hand, dentine is 45% inorganic, 30% organic and 25% water. Consequently, bonding to dentine with a higher organic and hydrophilic environment is far more challenging.

**Dentine bonding mechanism**
Dentine bonding is primarily micromechanical adhesion, as opposed to true chemical adhesion. However, some newer DBAs claim true chemical adhesion with tooth substrate. There are three distinct processes for achieving a dentine bonding using DBAs:
- **Conditioning** the dentine with an etchant (usually 37% phosphoric acid) to remove or dissolve the smear layer and inorganic phase, exposing dentine tubules and collagen fibres;
- **Priming** with monomers (e.g. HEMA, PENTA or 4-META) to create a transient hydrophobic environment;
- **Impregnation** and penetration of an adhesive resin (e.g. bis-GMA, UDMA), to encapsulate and stabilise the collagen fibres and seal the dentine tubules by forming a resin–collagen complex termed the hybrid layer (also known as an inter-diffusion zone or resin–infiltrated dentine layer).

The thickness of the hybrid layer can vary from 0.5µm to 10µm. However, the thickness and morphology of the hybrid layer seems less important than its consistency and integrity (lack of gaps, porosity and voids), which are paramount for achieving efficacious and durable dentine sealing and bonding.

The solvents in the DBAs carry the monomers that are essential for an efficacious bond. After the inorganic phase is disrupted, the collagen fibres are unsupported and, if not sufficiently erected, collapse and leave little room for the subsequent adhesive resin. Therefore, the function of the solvents is to rehydrate collapsed collagen fibres as well as to create a transient hydrophobic environment by removing excess water for the subsequent penetration of the adhesive resin. Numerous agents such as water, acetone and ethanol have been used with varying success. Furthermore, many formulations of DBAs use a combination of these solvents to exploit the beneficial properties of each material.

**Contemporary DBAs**
Current DBAs can be categorised as total etching (TE) or self-etching (SE). With TE varieties, precursory etching of both dentine and enamel is followed by application of the primer and adhesive. The SE variety does not require etching, since all three stages of etching, priming and bonding are performed simultaneously. The salient difference between the two systems is that, with TE, the smear layer and inorganic phase of dentine are removed, while with SE the smear layer is incorporated into the hybrid layer. A major disadvantage of SE agents is that the bond to dentine may be superior than to enamel, since the pH of SE is higher than conventional phosphoric acid, and the enamel etching pattern is insufficient for an efficacious bond. At present, research is inconclusive as to which system is more efficacious or longer lasting. However, the advantages of the SE agents are:
- Less technique-sensitive;
- Degree of dentine moisture not a concern;
- Depth of etching and adhesive penetration into dentine are similar since both processes occur simultaneously, which may allay concerns about depth of resin penetration, and mitigate postoperative sensitivity.

**Efficacy**
The efficacy of a DBA is assessed by the shear bond strength (SBS) and marginal gap formation at the restoration–tooth interface. The SBS of the bonding agent should be sufficient to counteract the polymerisation stresses generated by the resin-based restorative material and, therefore, prevent breakdown of the bond. The gold standard for SBS comparison is the bond to enamel, ranging from 23MPa to 25MPa. Dentine SBS are erratic, ranging from as little as 3MPa to 25MPa. The reported marginal gap ranges from zero to 10µm, and minimising this gap is crucial for the success and longevity of the restoration.

Failure of the DBA is multi-factorial, depending on both the material properties and clinical techniques (adequate isolation, preparation design, mode of light curing, etc.). Marginal gap formation can result in:
- Secondary caries – depending on prevailing risk factors;
- Pulpal pathologies – in deeper cavities;
- Discolouration of tooth, filling and filling margins;
- Deterioration of the filling material.

**Clinical applications**
DBAs are used for nearly all resin-based esthetic dentistry (RED) and many prosthodontic & restorative protocols including:
- Desensitising, e.g. following tooth wear (erosion, abrasion, attrition and abrasion);
- Sealing and disinfecting following decay removal or tooth preparation;
- Bonding direct resin-based composite and amalgam fillings;
- Luting intraradicular supports (posts), and most indirect restorations (crowns, PLVs, inlays, FPDs, etc.).

**Key points**
- DBAs are unfilled adhesives used for bonding restorative materials to natural tooth substrate.
- Enamel bonding is more predictable and preferred compared to dentine bonding.
- Currently two DBAs are available: TE and SE agents.
## Luting techniques

### PRE-TREATMENT OF INTRA-ORAL ABUTMENT SURFACES

<table>
<thead>
<tr>
<th>Cement/abutment surface</th>
<th>RMGi</th>
<th>CR + 2–3 step DBA</th>
<th>CR + self-etching DBA</th>
<th>AR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enamel</td>
<td>None</td>
<td>Phosphoric acid</td>
<td>Phosphoric acid</td>
<td>Phosphoric acid</td>
</tr>
<tr>
<td>Dentine</td>
<td>None</td>
<td>Phosphoric acid</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

### PRE-TREATMENT OF INTAGLIO SURFACES

<table>
<thead>
<tr>
<th>Restorative material</th>
<th>High gold content alloy</th>
<th>Base or semi-precious alloy</th>
<th>Composite/amalgam</th>
<th>Silica ceramics</th>
<th>Alumina ceramics</th>
<th>Zirconia ceramics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-treatment of intaglio surface</td>
<td>Air abrasion + alloy primer (or tin plate or silica/silane coat) + 37% phosphoric acid</td>
<td>Air abrasion + 37% phosphoric acid</td>
<td>Air abrasion + 37% phosphoric acid + silane</td>
<td>4–10% hydrofluoric or 37% phosphoric acid (for cleansing)</td>
<td>4–10% hydrofluoric or 37% phosphoric acid (for cleansing)</td>
<td></td>
</tr>
</tbody>
</table>

**Clinical cementation procedure using conventional resin cement**

- Isolate abutments with cord and wedges
- Etch
- Rinse and dry
- Apply DBA
- Seat and mop cement
- Floss contact points
- Try-in paste to stop formation of the oxygen inhibition layer
- Remove cord and light cure
- Trim with #12 blade
- Polish, e.g. with EVA tips
- Check occlusion
- Irrigate with 0.2% chlorhexidine
The performance of any cement depends on clinical factors, pre-treatment of the indirect restoration intaglio surface, and the intra-oral abutment. The cementation technique is both time-consuming and exacting, and any omissions will compromise the durability and long-term survival of the restoration.

**Clinical factors**
Clinical performance of cements is influenced by:
- **Operator variables** – mixing, dispensing and loading cement, accounting for more than 50% of all risk factors;
- **Tooth preparation design** – ideal 8° convergence angle and adequate resistance form;
- **Material properties** – accounting for approximately 5% of risk factors;
- **Location of tooth** – anterior or posterior;
- **Patient factors** – oral hygiene.

**Pre-treatment of intra-oral abutment**
Pre-conditioning of the intra-oral abutment starts by removing the temporary cement, which is accomplished mechanically using hand instruments, rotatory plastic burs (OptiClean, KerrHawe SA, Switzerland) air abrasion, pumice paste or ultrasonic devices. Total removal is essential to avoid compromising the bond strength between the natural tooth substrate (or artificial abutment, e.g. intraradicular post/cores or implant abutments) and the definitive cement.

The next stage is isolation, either with rubber dam or intrasulcular gingival retraction cords. An air environment is essential for resin-based cements, but less critical for RMGI. **Rubber dam** is the ideal choice for cementing inlays in posterior teeth, but is unsuitable for anterior teeth since the retaining metal clamps can potentially traumatise the gingival margin, leading to recession, especially on anterior teeth with thin periodontal biotypes. **Gingival retraction cord**, dry or impregnated with an astringent, not only allows visualisation of the abutment margins, but also acts as a physical barrier to avoid excess cement entering the delicate gingival sulcus. However, retraction cord may be inappropriate around the implant abutments since the latter can damage the friable epithelial attachment.

**Tooth abutment pre-treatment** depends on the type of cement being used. If RMGI is employed, no further conditioning is necessary, irrespective of whether the abutment is dentine, enamel or artificial restorative material, e.g. a composite, amalgam, cast metal and ceramic core, or titanium, alumina and zirconia implant abutments. If a conventional resin (CR) is chosen and the abutment is natural tooth substrate, a total-etch technique (5th-generation DBA) is recommended to simultaneously etch both the dentine and enamel, followed by application of the primer and adhesive. If a selfetching (SE) DBA or adhesive resin (AR) is chosen, it is prudent to etch enamel (to create an adequate etching pattern, especially with uncut, aprismatic enamel), but not dentine. The reason not to etch dentine is that with SE DBA the penetration of the adhesive resin into etched dentine tubules is reduced, resulting in a weaker bond and possible postoperative sensitivity.

For artificial intra-oral abutments, the pre-treatment depends on the restorative material, e.g. for composite and amalgam core buildups, the pre-treatment is air abrasion followed by etching with phosphoric acid.

**Pre-treatment of intaglio surface**
The conditioning of the fitting, or intaglio surface, depends on the restorative material and the choice of cement (RMGI, CR or AR). The methods available are:
- **Mechanical** – rotary diamond burs, only indicated for cast metal surfaces;
- **Air abrasion**: aluminium oxide powder (30–50µm Al2O3 powder at 60–100psi pressure for 2–3 seconds per cm²). It has been suggested to use this method on high-strength ceramics such as alumina and zirconia, but recent research has revealed that air abrasion can **reduce strength by 30%** by forming microscopic cracks that propagate at the fitting surface during function;
- **Chemical**: hydrofluoric acid (HF; 4–10% for 3 minutes) for silica-based ceramics, followed by application of warm silane. HF and phosphoric acid cannot etch metal, alumina or zirconia, but are used for cleansing to ensure a contamination-free intaglio surface, especially following air abrasion. Other chemical agents include **alloy primers** or **tin plating** for some cast alloys;
- **Adhesive** – or unfilled resin, can be applied (but not light cured) onto the intaglio surface, irrespective of the type of restorative material if a resin-based definitive cement is used.

**Cementation procedure**
After pre-treatment of the abutment and intaglio surfaces, the next stage is dispensing the chosen cement. One of the major factors that reduces cement strength is introduction of air into the cement. For example, **10% porosity can reduce strength by 55%**. **Porosity** is primarily due to **method of mixing**, **polymerisation shrinkage** during the setting reaction and disintegration due to **fatigue and thermocycling**. For this reason, **auto-mixing dispensers** and **pre-capsulated cartridges** are ideal for a smooth, reduced porosity mix.

For inlays/onlays, Maryland/Rochette, fibre-reinforced bridges and orthodontic brackets, the **cement is placed on the recipient tooth or teeth.** For intraradicular posts, crowns, FPDs and PLV, the cement is **dispensed onto the intaglio surface of the restoration.** The restoration is correctly located and seated with pressure. **Excess cement is immediately mopped, and floss is used for the interproximal areas. If a retraction cord is placed beforehand, this is now removed together with excess cement, and the restoration firmly held in place during light curing from all aspects with an appropriate light intensity and duration (20 seconds for halogen lights and 10 seconds for LED lights of 800mW/cm²).** After setting, a #12 blade is used to trim set excess cement and the margins polished with silicone tips, interproximal diamond strips, and the sulcus irrigated with chlorhexidine to wash out remnants of cement and promote gingival health. Finally, the occlusion is checked and adjusted if necessary.

**Key points**
- **Successful cementation** depends on clinical factors, and appropriate pre-treatment of the intra-oral abutment and intaglio surface of the restoration.
- **Pre-treatment** of both the abutment and intaglio surface is determined by the restorative material and choice of cement.
- **The cementation procedure** should be executed meticulously for long-term survival of the restoration or prosthesis.
Removable prostheses

Removable Full Dentures
- Immediate aesthetic and function following extractions
- Ability to add teeth
- Economical
- Reduced treatment time
- Stomatitis
- Poor access for oral hygiene
- Caries
- Periodontal and endodontic lesions
- Tooth mobility
- Poor speech and mastication
- Bone resorption

Benefits
- Temporary prostheses during protracted treatment plan
- Periodontal splinting
- Training bases for assessing function and tolerance
- Surgical template for implants
- Definitive prostheses

Indications

Complications

Removable Partial Dentures
- Entirely tissue-borne
- Reinforced with metal

• Transitional acrylic denture
• Metal-reinforced framework
• CBCT-generated surgical guides
• Coloured ‘pink’ acrylic for soft tissue defects
Removable dentures are categorised as full (complete) or partial, and can either be immediate, delayed or replacement dentures.

There has been a significant decline in the provision of exclusively tissue-borne removable dentures in the last few decades, but an increase in implant-stabilised removable dentures. The reason is diminishing clinical knowledge and reduced expertise of technicians (and less experience), and a reluctance to provide removable prostheses when fixed prosthodontic solutions, such as implants, are available for oral rehabilitation. Furthermore, the success of removable dentures, especially of totally tissue-supported dentures, relies on acceptance by the patient and tolerance of the prosthesis, which is often difficult to assess and predict. However, this type of modality is valuable and indispensable in many clinical situations such as transitional phases of treatment, or as a definitive prosthesis when extensive grafting procedures for implants are contraindicated due to medical history or intra-oral or financial status.

**Indications**

The indications of removable prostheses include:

- **Transitional** full or partial dentures awaiting osseointegration for definitive fixed or removable implant-supported prostheses;
- **Periodontal splints**;
- **Training bases** for assessing altered OVD and anterior guidance;
- **Templates** (with radiographic markers) for preoperative CBCT scans for implant treatment planning;
- **Surgical stents** with drilling holes/sleeves for guided implant placement in fully or partially edentulous arches;
- **Definitive oral rehabilitation**.

**Edentulism**

The sequelae following tooth extraction are alveolar bone loss and remodelling, resulting in:

- **Pseudo class III** and cross-bites of dental ridges;
- **Differential** or **site-specific bone loss**, e.g. flabby anterior maxillary ridge, atrophic mandibular ridge;
- **Prominence of muscle attachments** hindering a denture prescription;
- **Reduced lower third facial height**;
- **Inadequate lip support**;
- **Premature ageing** by formation of facial grooves and fissures;
- **Social embarrassment**;
- **Psychological trauma**.

The above factors contribute to poor denture support, stability, retention, aesthetics and lip support. Further complications after fitting the denture(s) include denture stomatitis, inappropriate occlusal schemes (balanced occlusion or balanced articulation), altered taste sensation, painful TMJ (incorrect OVD), inadequate freeway space (2–3 mm advisable), correct position of maxillary central incisors relative to incisal papilla (9 mm anterior and 12 mm below), instability due to incorrect position of posterior teeth, and continual ridge resorption requiring relines or relabes.

**Removable full dentures (RFD)**

Edentulous ridges have varied presentation depending on the degree of resorption. For a well-preserved ridge, a denture is merely replacing teeth, while for an atrophic ridge, a denture replaces both the lost bone and teeth. However, full denture success is not only dependent on ridge morphology, but also on patient compliance. Retention of a maxillary full denture relies on suction from the palatal mucosa, peripheral flanges, tuberosities and a suitable post-dam. In contrast, retention of a mandibular denture is more challenging, depending on the patient’s neuromuscular adaptability, extension onto the retro-molar and buccal shelves, flanges, denture fixatives, or retention from strategically placed implants or retained roots.

Both upper and lower dentures can be reinforced with chrome-cobalt, or preferably lighter weight titanium for additional strength. This is especially useful for full dentures opposing a natural dentate arch, and for patients with a history of bruxism or fracturing acrylic dentures. In these circumstances, the ridges, flanges and peripheral extensions, including post-dam, are kept in acrylic for future relines. Another risky situation is a removable full denture against a full fixed arch prosthesis, which can potentially cause pressure necrosis of the opposing edentulous ridge.

**Removable partial dentures (RPD)**

Before replacing any missing teeth, it is important to consider the shortened arch concept, and if functional and aesthetic needs are met, replacing molar teeth is superfluous. If a fixed solution for replacing missing teeth is precluded, a removable prosthodontic alternative should be considered for oral rehabilitation. RPDs can be both tissue and tooth/teeth supported. Therefore, all supporting teeth require endodontic, periodontal and occlusal assessment. RPDs also offer the benefits of the potential to add future teeth, or overdentures with retained roots (or implants), being relatively inexpensive, and shorter treatment time compared to fixed options.

Many types of RPDs are possible depending on number and location of the missing teeth, and intended purpose of the removable prosthesis:

- **Total acrylic** bases and teeth are ideal as transitional, training, or templates for scans and fabricating surgical stents. In addition, clasps and rests can be incorporated to improve stability and retention;
- **Metal framework** with acrylic bases and teeth. This variety is suited for long-term usage, and semi-permanent periodontal splinting. CAD/CAM technology can be used to design and fabricate partial dentures frameworks in a choice of metals such as chrome-cobalt or titanium. In addition, the design can incorporate clasps, reciprocating bracing rests, milled guiding planes, anti-rotational features, precision attachments, and correct paths of insertion/removal to cater for numerous clinical situations.

**Key points**

- Removable prostheses are not an antiquated treatment modality, but have many uses in contemporary prosthodontics.
- The negative aspects of edentulism should be considered before extractions are planned.
- Partial dentures are classified as RFD and RPD, and supported by soft tissues, teeth or implants.
- Both RFD and RPD can be considered as definitive prostheses if implants are contraindicated.
### Osseointegration

<table>
<thead>
<tr>
<th>Process</th>
<th>Stimulus</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSTEINDUCTION</td>
<td>Bone fracture/trauma</td>
<td>Physiological healing process for bone remodelling</td>
</tr>
<tr>
<td>OSTECONDUCTION</td>
<td>Osteoconductive material</td>
<td>Bone apposition on surface of foreign material</td>
</tr>
<tr>
<td>OSSEOINTEGRATION</td>
<td>Biocompatible material</td>
<td>Structural &amp; functional integration with bone over time</td>
</tr>
</tbody>
</table>

**Osteoinduction**
Radiograph showing bone repair and remodelling following osseous trauma, e.g. after tooth extraction.

**Osteoconduction**
Radiography showing apposition of bone on the surface of a foreign body or material, e.g. bone grafting or implant.

**Osseointegration**
Photomicrograph showing intimate bone contact with threads of an implant.

**Clinical assessment of osseointegration**

**Visual**
This is probably the easiest method to check for absence of inflammation and suppuration.

**Radiographic**
Radiograph showing intimate bone contact with implant, without apparent pathology.
Apart from G.V. Black, P-I. Brånemark has made the most significant contribution to dentistry in the last century. His invention of dental implants has revolutionised the replacement of single teeth, partial edentulous segments and totally edentulous dental arches with both fixed and removable prostheses. Furthermore, implants are also used for providing anchorage for orthodontic, orthopaedic and orthognathic movements as part of oral rehabilitation.

**Definitions**

Three distinct processes describe bone healing and remodelling: osteoinduction, osteoconduction and osseointegration. These three mechanisms are interrelated but not interchangeable. However, terminology associated with bone growth, remodelling and repair is frequently misused and inaccurate. The definitions for the above are as follows:

- **Osteoinduction** – physiological process of bone healing and repair by osteogenesis following traumatic fractures;
- **Osteoconduction** – bone growth on the surface of osteoconductive foreign bodies, e.g. implants or synthetic bone grafting materials;
- **Osseointegration** – direct contact of living bone with an implant surface (without formation of fibrous tissue), which is maintained during **functional loading** over a long period.

**Processes**

The osteoinduction healing process is initiated following trauma to bone. Undifferentiated, mesenchymal cells are converted to preosteoblasts, which are eventually transformed to bone-forming osteoblasts and osteocytes by stimulation from inductive transformation growth factors such as bone BMP (bone morphogenic proteins). This is the normal mechanism that occurs during repair of a bone fracture and implant integration.

**Osteoconduction** is bone apposition on the surface of implants from pre-existing osteoblasts or immature mesenchymal cells that have been transformed by the osteoinduction process. The surface of the implant is said to be osteoconductive and promotes, in combination with the trauma of osteotomy, the stimulation of bone growth. Bone remodelling requires sufficient vascularisation and is signalled by bone growth factors such as insulin-like growth factor (IGF I, IGF II), fibroblast growth factor (FGF) and platelet-derived growth factor (PDGF). Bone conduction requires highly biocompatible materials such as commercially pure titanium or demineralised bone, and is not possible with incompatible materials such as copper or silver.

**Osseointegration** is a term coined by Brånemark to describe the **structural and functional integration** of implants with surrounding bone. The process of osseointegration is preceded by osteoinduction and osteoconduction, and implies that anchored implants are functionally maintained over time. Osteoconduction is short-lived, while osseointegration maintains bone anchorage of the implant over a long period. This was a monumental breakthrough in oral and craniofacial implantology, paving the way for replacing missing or lost teeth with dental implants.

Osseointegration is defined as structural and functional integration over time of an implant with the surrounding bone. The speed of osseointegration can be accelerated by **pre-treatment of the titanium implant surface** by roughening, coating with bio-affinity layers such as titanium oxides or hydroxyapatite. Furthermore, osseoperception is evident in patients that have implant-supported dental prostheses, i.e. there is sensory feedback from the loaded implant(s), similar to natural teeth.

**Clinical assessment**

Osseointegration per se is a histological principle that cannot be visualised clinically. However, it is essential to confirm osseointegration and stability of an implant before it can be prosthetically restored. Some methodologies proposed for assessing clinical osseointegration, and its subsequent monitoring, are as follows:

- **Visual** – healthy soft tissues around the fixture without inflammation, suppuration or pain;
- **Radiographic** – periapical or panoramic assessment of bone levels around implants, but because the images are 2-D, buccal dehiscences may be concealed. However, 3-D cone beam computed tomography (CBCT) or radio-stereo-photogrammetric analysis (RSA) techniques offer better evaluation;
- **Percussion** is probably the crudest method, involving tapping the implant with a hand instrument (similar to tapping a tooth suspected of endodontic lesions), and listening to the pitch of the tone. A high pitch indicates implant stability, while a low, dull pitch infers poorly integrated implant fixtures;
- **Periotest** – quantifies implant mobility in response to an electronically controlled translational hammer. However, readings are erratic and highly dependent on position and angulation of the testing instrument;
- **Dynamic modal testing** – using a rotational hammer that produces an electric voltage to plot a force vs time graph for assessing mobility. However, similar to the Periotest, the readings do not measure the implant in its free state and are highly apparatus-dependent;
- **Reverse torque** – a surgical handpiece attached to the implant head applies a reverse torque of 20 Ncm to ‘remove’ the fixture. This test is traumatic and may disrupt healing or lead to failure of an implant that is slow to integrate;
- **Resonance frequency analysis (RFA)** – measures the resonance frequency of implants to assess the healing process. A drawback with this method is that it fails to account for the initial bone quality and density, which greatly influences integration;
- **Impulse testing** – tests an implant in its free state without being encumbered with the testing apparatus. The implant is percussed with a floating calibrated hammer housed in a probe that records the acceleration time history (ATH). The latter is translated by a computer using the fast Fourier transform (FFT) algorithm. A comparison is made between an ideal graph and the testing graph to ascertain the ‘stiffness’ of the implant. This test is useful for both unloaded and loaded implants. However, assessing implants with multiple unit FPDs still requires further refinement.

**Key points**

- Dental implants have revolutionised the replacement of missing teeth.
- Osseointegration is defined as structural and functional integration over time of an implant with the surrounding bone.
- Various clinical tests are available for assessing osseointegration before restoring implant(s) with prosthetic unit(s).
### Implants: general considerations

#### BENEFITS
- Restore mastication, speech, aesthetics and support of facial soft tissues
- Prevent alveolar bone loss
- Prevent destruction of adjacent teeth for FPD
- Avoid inflammation of soft tissues and decay of natural teeth, associated with removable prostheses
- Predicable treatment modality with good long-term success rates
- Versatile treatment options, including single tooth replacement, rehabilitation of partially edentulous and fully edentulous ridges with either fixed or removable prostheses
- Choice of a large variety of prosthetic materials including cast alloys, titanium, ceramics and resin-based composites

#### PRECAUTIONS
- Specialist training and liaison with various dental specialists is mandatory
- Medical history may complicate surgical procedures
- Thorough preoperative dental assessment and treatment planning are key to success
- Protracted surgical phases may deter many patients
- Costly
- Unsuitable for very young and elderly patients
- Failure may cause local morbidity, and involve further surgical trauma to rectify problems

#### Single tooth
- Implant supported crown to replace missing tooth for restoring function without preparing adjacent teeth

#### Partially edentulous
- A FPD supported by 2 implants

#### Minimally invasive
- Pre- and postoperative radiographs showing excellent bone grafting healing and maintenance following implant therapy

#### Poor integration
- Experience and training is essential for success. Poor positioning and inadequate surgical techniques result in poor osseointegration

#### Suppuration
- Infection and suppuration places implants in precarious situations

#### Failing implants
- Two failing implants in the anterior maxilla due to insufficient bone and lack of preoperative assessment and planning
Dental implants are increasingly becoming the treatment of choice for missing dentition. Their indications include replacement of single teeth, partially edentulous ridges and fully edentulous arches. Implants are only the beginning of tissue engineering, and future research in genomics and proteomics will perhaps offer even greater benefits than titanium cylinders for the replacement of missing teeth.

**Rationale and indications**

Dental implants are no longer an esoteric treatment modality limited to a few specialised practices. The last two decades have witnessed a burgeoning demand for dental implants which is now pervading general dental practices. Furthermore, innumerable studies and controlled clinical trials report encouraging mean survival rates of endosseous implants greater than 90% over 10 years, irrespective of the number of teeth replaced or the type of definitive prosthesis. Due to this high level of predictable success, and unlike other dental treatment modalities (both direct and indirect restorations), implant fixtures are potentially placed for a lifetime. The rationale for implants to replace teeth, compared to tooth-borne fixed or tissue-borne removable prostheses are as follows:

- **Maintenance of alveolar bone** – bone requires stimulation to maintain its form and density. Tooth extraction leads to rapid absorption of the alveolar ridges, resulting in soft and hard tissue defects. For example, bone loss in the fully edentulous maxilla occurs in a medial and superior direction, while in the mandible the resorption is lateral and inferio. This results in a narrow maxilla, often tending to a class III skeletal relationship;
- **Soft tissue support** – edentulism also results in reduced support for facial soft tissues, causing premature ageing;
- **Improved mastication** – the bite force of implant-supported prostheses is similar to the natural dentition, unlike the reduced masticatory function experienced with removable dentures;
- **Improved phonetics** – because implant prostheses offer better stability compared to soft tissue-borne dentures;
- **Preservation of natural teeth** – in partially edentulous patients, adjacent healthy teeth are spared preparation;
- **Prevention of dental and soft tissue lesions** – both fixed and removable prostheses are potentially harmful to teeth (decay, endodontic and periodontal problems) and the soft tissues (inflammation and continual ridge atrophy). Preventing these unwanted pathologies improves oral comfort;
- **Improved aesthetics** – for both teeth and facial contours due to soft tissue support from implant-supported prostheses;
- **Replacing existing fixed or removable dentures** – a failing FPD with decayed, endodontic or periodontally compromised abutments is potentially ideal for implant therapy. Similarly, loose, uncomfortable dentures (especially mandibular) benefit by implant-supported overdentures, which offer improved mechanical stability, mastication, speech and prevention of further bone loss.

**Contraindications**

As mentioned above, there is no doubt that many patients can, and do, benefit from implants rather than traditional treatment modalities for oral reconstruction. However, implantology depends on many factors for a successful outcome. Some contraindications that may reduce the chances for optimal prognosis, or preclude patients from implant therapy, are:

- **Medical history** – the following conditions may complicate or delay healing following surgical procedures:
  - Endocrine disorders, e.g. diabetes mellitus, hypothyroidism and adrenal insufficiency;
  - Uncontrolled granulomatous diseases, e.g. tuberculosis and sarcoidosis;
  - Cardiovascular diseases, e.g. angina, aortitis, arteriosclerosis, aortic insufficiency or aneurysms;
  - Bone diseases, e.g. Paget’s disease, fibrous dysplasia, histiocytosis X or osteoporosis;
  - Carcinoma, e.g. oral, head or neck;
  - Radiotherapy of the jaws, head or neck;
  - Haematological disorders, e.g. anaemia, haemophilia (factor VIII deficiency), or factor IX, X, XII deficiencies, or reduced platelet count disorders, all predispose to poor haemorrhage control;
  - Autoimmune diseases, e.g. HIV;
  - Medication, e.g. bisphosphonates, immunosuppressant drugs following organ transplants;
  - Other factors, e.g. xerostomia, smoking, pregnancy, psychological stress, poor oral hygiene;
  - Very young and old patients – patients with primary or mixed dentitions are unsuitable candidates for implants, as well as the elderly or infirm, who may prefer non-surgical options;
  - **Surgical technique and experience** of the operator influence initial surgical trauma and subsequent successful osseointegration;
  - **Dental variables**, e.g. ridge anatomy, adjacent and opposing teeth, occlusal factors, soft tissue morphology;
  - **Previous dental history and present dental status**;
  - **Skilled multidisciplinary dental specialists** – liaison and successful co-operation with the prosthodontist, oral maxillofacial surgeon, orthodontist and dental ceramist;
  - **Duration of treatment** is usually protracted, especially if soft and hard tissue grafting is envisaged. Therefore, the patient should have a degree of patience and endurance to last the course. Furthermore, compliance with oral hygiene procedures and smoking cessation are essential for positive outcomes;
  - **Cost** is a major factor in the decision to embark on the implant option. While an implant-retained mandibular overdenture may be within the financial reach of many, a complex and comprehensive fixed oral rehabilitation may be limited to the few;
  - **Prognosis** depends on all the above variables, and if unfavourable factors are likely to compromise implant treatment, it may be prudent to seek alternative modalities, rather than commencing a plan that may be fraught with complications and yield unsatisfactory postoperative results.

**Key points**

- Dental implants are the state-of-the-art treatment modality for replacing missing teeth.
- Implants offer numerous advantages over conventional treatment options for restoring health, function and aesthetics.
- Although successful and predictable, numerous factors affect implant therapy, and contraindications should be thoroughly assessed beforehand.
Preoperative Planned extraction of left canine

PLANNING

Hard tissue augmentation? 
Soft tissue augmentation? 
Type of surgical protocol?

Number of implants? 
Type of implants? 
Fixed prosthetic units?

Type of provisionals? 
Osseointegration duration? 
Anticipated compromises?

Implants: treatment planning

FAVOURABLE OR RESOLVABLE

Prosthetically driven treatment planning (PDTP)

UNFAVOURABLE OR UNRESOLVABLE

Conventional FPD or removable prostheses
A patient considering dental implants should initially be assessed using MAP (medical, anatomy, prognosis) as described in Chapter 2. After this cursory evaluation, comprehensive diagnostic tests are essential (discussed in the Diagnostics section) before formulating a treatment plan. The current objective of implant therapy is restoring both function and aesthetics of missing teeth, and the key to achieving this goal is meticulous diagnosis and treatment planning.

Preoperative assessment
A detailed medical and dental history is followed by diagnostic tests, including radiographs, CBCT scans, photographs, diagnostic wax-ups and fabrication of surgical guides. If necessary, specialist advice is sought from the periodontist, endodontist, orthodontist, oral and maxillofacial surgeon, radiologist and the dental technician. The assessment should consider:

- Medical history;
- Existing dental status – periodontal, endodontic, and restorative status of existing teeth;
- Occlusion – parafunctional activity, occlusal stability (avoiding lateral forces on implant-supported prostheses), and sufficient occlusal clearance for prosthetic units;
- Arch shape – narrow, square, oval, crowding, spacing or posterior cross-bite may require preoperative orthodontic treatment;
- Proximity of vital structures – sinuses, neurovascular bundles (e.g. inferior dental nerve, mental and incisal foramen) or adjacent tooth roots;
- Reduced vascularity – due to previous periapical infections;
- Buccal plate thickness or its absence due to fistulas or fenestrations;
- Extent of bone defect – following tooth extraction, prevailing or previous periodontal disease, previous surgical trauma;
- Bone quality – classified as types I to IV; type I is highly dense cortical bone (e.g. in the mandible), and type IV is least dense cancellous bone (e.g. in the posterior maxilla). The ridge defect can either be vertical or horizontal, or a combination. For totally edentulous patients, ridge absorption often results in a transformation of class I to class III jaw relationship;
- Periodontal biotype and bioform – thin, highly scalloped biotypes predispose to gingival recession, while thick-flat biotypes result in pocket formation following surgical trauma or inflammation. Furthermore, thin-scalloped may also result in defects due to delayed bone remodelling, while thick-flat types result in gingival notches and scarring. Peri-implant biotypes around dental implants are also classified as thick and thin, similar to periodontal biotypes;
- Biologic width – a histological concept that is the sum of the linear measurements of the epithelial and connective tissues attachments around natural teeth, averaging 2.04 mm. However, clinically, the biologic width varies from as little as 0.59 mm to >3 mm depending on the type of tooth, and no minimum value has been identified as an absolute minimum for gingival health. The biologic width around implants is similar to that for natural teeth but the implant–epithelium junction is shorter and thinner, influenced by implant design, the presence of adjacent teeth, and platform switching that shifts the position of the microgap (either in a horizontal or vertical plane) to minimise circumferential bone loss. Differences between natural teeth and implants include that in the former the location of the biological width is supracrestal, while in the latter it is subcrestal. Also, the connective tissue fibres around natural teeth are perpendicular, but parallel around implants;
- Degree of keratinised gingiva – a minimum of 3 mm is usually quoted as essential;
- Interproximal papilla – for complete papilla fill between natural teeth, the distance of the contact point to the interproximal bone should be <5 mm. However, between two adjacent implants, this distance needs to be reduced to a minimum of 3.4 mm for complete papilla fill. In addition, sufficient interproximal spaces are required for adequate oral hygiene procedures;
- Aesthetics – degree of anterior maxillary tooth exposure at rest, relaxed and exaggerated smile. On average, a relaxed smile shows 75–100% of the maxillary central incisors plus the interproximal papilla. A low lip line shows <75% tooth exposure, while a high lip line shows >75% tooth exposure plus attached gingiva apical to the teeth (gummy smile). Sufficient lip support is also necessary to mitigate labial grooves;
- Patient’s dental literacy and attitude – counselling about dental preventive measures, tobacco and alcohol abuse, and oral hygiene. Elderly or infirm patients may not be able to tolerate protracted surgical procedures;
- Other – oral cavity access of a least 35 mm mouth opening at the site of implant placement for adequate surgical instrumentation;
- Risks vs benefits assessment and alternative treatment options, cost, anticipated treatment duration and written and verbal informed consent.

Prosthetically driven treatment planning
Previously, implant placement was dictated by the surgical approach, i.e. implants were placed according to the existing ridge anatomy. The contemporary approach is prosthetically driven treatment planning (PDTP), i.e. implant placement is dictated by the position of the final restoration(s), and a deficient ridge is augmented accordingly, ensuring that the implant(s) and subsequent restoration(s) are both functional and aesthetic.

The first stage of PDTP is a diagnostic wax-up for ascertaining ridge morphology, need for augmentation, number, position, angulation and type of implants (shape, size, surface treatment), the type of prosthetic rehabilitation (fixed, removable, screw- or cement-retained prosthesis). The wax-up also provides a template for any provisional restoration(s), a surgical guide (with or without CBCT scans) and a 3-D assessment of ridge anatomy.

- Mesial-distal – minimum 1.5–2 mm distance between implant and tooth and 3–4 mm between implant and implant;
- Bucco-lingual – minimum of 1–2 mm on both aspects;
- Incisal-cervical – head of implant should be 3 mm apical to the anticipated gingival margin or 3–5 mm apical to the cement-enamel junction of adjacent teeth, and its apex clear of vital structures. In addition, the platform should be aligned for correct emergence profile (<25°) without compromising the occlusion.

Key points
- Implant treatment planning involves meticulous assessment and diagnostic tests.
- Implant placement is prosthetically driven.
- Risk assessment is essential for realistic treatment outcomes and expectations.
Augmentation and site preparation

HARD TISSUE DEFECTS
Siebert’s alveolar ridge deficiencies

Class I: buccolingual loss with maintenance of apicocoronal height

Class II: apicocoronal loss with maintenance of buccolingual width

Class III: combination of buccolingual and apicocoronal loss

GRAFTING TECHNIQUES

Onlay block
Splint ridge
Socket preservation

Particulate ridge augmentation
Sinus lift
CTG
The surgical guide of the prosthetically driven treatment plan (PDTP) will elucidate whether pre-surgical augmentation is required for ideal implant positioning for existing bone and/or soft tissue deficiencies.

**Ridge defects**
Many criteria have been proposed for classifying ridge defects, for example, the Siebert for alveolar deficiencies, and systems based on tooth extraction, for example, the Meltzer classification. Ridge defects range from a pristine ridge with no resorption, requiring no augmentation, to extensive such as atrophic ridges presenting with labial concavities and knife-edge morphologies.

**Principles of GTR and GBR**
Guided tissue regeneration (GTR) is exclusion of connective and epithelial tissues in order to create space for cells of the periodontal ligament to colonise the root surface. Therefore, in GTR five components are involved: epithelium, connective tissue, periodontal ligament cells, cementum and bone. Guided bone regeneration (GBR) is similar to GTR, but only two components are involved: the connective tissue and bone. In GBR the competing, non-osteogenic connective tissue is excluded, and a space created to encourage bone formation.

**Bone grafting materials**
Bone grafting materials offer structural stability and space for the promotion of osteogenesis. Their mode of action can either be osteoconductive, acting as a scaffold for new bone regeneration, or osteoinductive, i.e. actively stimulating osteoblasts to form new bone. Graft materials can be used in combination to gain advantages of different materials. Examples of bone grafts include:

- **Autogenous grafts** – osteoinductive and non-immunogenic, harvested from the patient’s body, either intra-oral sites, e.g. ramus of the mandible, mandibular symphysis, nasal spine, maxillary tuberosity, zygoma, or extra-oral sites, e.g. iliac crest, hip marrow, ribs, cranium and tibial metaphyses. The graft can be blocks or bone scrapings, including those of the osteotomy for implant placement;
- **Allografts** – bone grafts from another individual, which are freeze-dried, demineralised and irradiated to prevent disease transmission. This avoids morbidity of a donor site, but the graft is less efficacious compared to an autogenous graft;
- **Xenografts** – cancellous bone from another species such as bovine or porcine that are deproteinised to eliminate the chances of disease transmission, and are available as particulate granules, blocks and collagen plugs. Xenografts are osteoconductive, and abundant quantities obviate surgical preparation of donor site(s);
- **Barrier membranes** – usually used in conjunction with particulate grafting materials for providing space and covering grafting materials for enhancing GBR. Membranes can be resorbable (e.g. collagen matrix, polyglycolic acid membrane or Vicryl) or non-resorbable (e.g. expanded poly tetrafluoroethylene or e-PTFE and titanium reinforced), requiring a second surgical stage for removal;
- **Platelet-rich plasma (PRP)** – accelerates the body’s natural postsurgical wound healing by two to three times. PRP is a platelet concentrate from the patient’s own blood, containing growth factors such as platelet-derived growth factor and transforming growth factor-beta;
- **Tissue engineering** – the latest and promising method for tissue regeneration by using self-polymerising scaffold structures in extraction or in surgically prepared sites.

**Bone grafting techniques**
The techniques available include:

- **Onlay block and veneer bone grafts** – utilise autogenous bone blocks that are stabilised with screw fixation onto the residual bone. Veneer grafts are indicated for knife-edge ridges and are more predictable than block grafts;
- **Particulate bone grafting** – the most popular procedure using a variety of grafting materials, which can be mixed together, and covered with membranes, or for extensive augmentation with customised titanium meshes. Indications include horizontal, small vertical defects, socket preservation, sinus lifts and simultaneous grafting with implant placement;
- **Socket preservation** – immediately following tooth extraction for maintaining space and preventing ridge collapse with the Bio-Col technique, using particulate bone and collagen plugs;
- **Sinus floor augmentation (sinus lift)** – indicated for the posterior maxilla for gaining bone volume by lifting the Schneiderian membrane and grafting the floor of the maxillary sinuses. Two techniques are advocated, depending on the amount of residual bone thickness. For ≤5mm vertical bone thickness the lateral wall approach is preferred, with or without simultaneous implant placement. If the bone thickness is 7–8mm, the osteome or closed technique is less aggressive, via a crestal incision, avoiding entry into the sinus;
- **Bone expansion** – by decorticalisation (split-ridge technique) with simultaneous implant placement in combination with various types of bone grafts.

**Other methods**
Other methods for preparing vertically deficient sites include periodontal growth, either by orthodontic extrusion of teeth destined for extraction for ‘gaining’ bone by moving the entire dentogingival complex in a coronal direction, or placing fixture devices that are periodically adjusted by the principle of distraction osteogenesis. Another method is lateral repositioning of neurovascular bundles and nerves, e.g. mental and inferior dental nerves, so that the latter do not impinge on the implant fixtures. However, these procedures can potentially cause paraesthesia and partial or complete anaesthesia.

**Soft tissue grafting**
Reconstructive periodontal plastic surgery is used to compensate or pre-empt gingival recession (especially with thin periodontal biotypes). The most popular method is submucosal and/or free gingival connective tissue grafts (CTG) from the palate, anterior to 1st molars or the tuberosities, in combination with coronally advanced flaps. Membranes and silk-gel scaffolds are a substitute for CTG, avoiding donor site surgery. Soft tissue grafting is more predictable when underlying bone support is present to support the gingival architecture.

**Key points**

- Augmentation is usually necessary for achieving functional and aesthetic implant therapy.
- Most grafting materials are osteoconductive, acting as scaffolds for new bone formation.
- Both hard and soft tissue grafting may be necessary for site development.
Two-stage procedure showing flap elevation, covering the implant and screw cover with soft tissue to allow osseointegration.

One-stage procedure showing flap elevation, and placing a transmucosal healing cap (abutment) to allow osseointegration.

Flapless procedure using a surgical stent for guided implant placement, and immediately loaded with a provisional prosthesis.
Surgical techniques have evolved considerably since the Bränemark protocol of distinct surgical and prosthetic phases for the delayed approach for implant rehabilitation. Currently, most surgical approaches are guided by a prefabricated surgical stent, with or without prior CBCT assessment. The surgical stage involves a flap or flapless preparation of an osteotomy. The implant is then screwed or tapped into the prepared site to ideally terminal at a supracrestal level, and the implant is either submerged by covering with soft tissue, non-submerged with a transmucosal healing abutment, or immediately restored with a provisional restoration.

Flap design
The basic requirement of a flap is that it should be conservative, while allowing adequate access to determine morphology, size and trajectory of the alveolar bone ridge. Several designs are advocated depending on clinical manifestations and include:

- **Full thickness** mucoperiosteal buccal, lingual or crestal incision flaps, with or without vertical releasing incisions, avoiding interproximal papillae if adjacent teeth are present. These flaps are ideal for gaining access, simultaneous bone grafting and osseous contouring;
- **Mini-flaps** are restricted to the area of implantation, e.g. a small buccal flap for single tooth replacement or a palatal peninsular flap for avoiding buccal incisions and the ensuing scarring in aesthetically sensitive maxillary anterior regions;
- **Tissue punch** – for exposing underlying bone for ‘flapless’ surgery. This method is ideal for broad flat ridges, with adequate attached gingiva, not requiring osseous contouring or hard or soft tissue augmentation at the time of implant insertion.

Flapless design
The flapless method is the least invasive surgical protocol, but is essentially a blind surgical procedure. The prerequisites for a flapless procedure are **adequate volume of bone** and **attached gingiva**. A surgical stent accurately guides the implant to the pre-designated position without needing to raise a flap. The fixture head is non-submerged and a transmucosal healing cap is placed to sculpt the soft tissue and allow maturation. The negative aspect of this protocol is lack of visualisation of the bone architecture, particularly if a prior CBCT scan has not been performed. Therefore, a flapless procedure is potentially fraught with the risk of inadvertent perforations, especially of thin buccal maxillary plates leading to fenestrations and implant thread exposure, while lingual perforation in the anterior mandible may cause haemorrhage at the floor of the mouth and impede respiration.

Two-stage – submerged
The two-stage or submerged delayed approach was originally proposed for stress-free integration of oral implants. It consists of submerging the implant to allow healing for 3–6 months (average 3 months for mandible, 6 months for maxilla). Afterwards, the implant is surgically exposed, the cover screw removed and the implant prosthetically restored. This method is preferable if primary stability is unattainable, or if extensive pre-surgical or concurrent bone grafting is required.

One-stage – non-submerged
For the one-stage or non-submerged approach the cover screw or transmucosal healing cap (abutment) on the implant is exposed to the oral cavity during osseointegration. After a suitable healing period, the cover or cap is removed and the implant restored without needing a second surgical procedure. Furthermore, the clinical success rate for the one-stage procedure is equally effective and predictable as the two-stage approach. Also, a single-stage procedure permits early loading, is patient friendly, reduces postoperative discomfort and is more economical. However, certain criteria must be met, e.g. no preliminary augmentations required, greater than 30 N/cm primary stability, an adequate circumferential zone of keratinised gingival tissue and adequate oral hygiene counselling to prevent and manage peri-implantitis and peri-implant mucositis, respectively. Peri-implantitis is defined as inflammation around an implant causing marginal bone loss, while peri-implant mucositis is a reversible inflammatory condition without accompanying bone loss.

Post-extraction placement
Another method for implant insertion is carried out immediately following tooth extraction, which can be immediate at time of extraction, delayed immediate (2–3 weeks later) or delayed conventional (3+ months later). Initial research findings regarding immediate placement and concurrent particulate bone grafting are promising, but long-term trials will need to establish the efficacy of this method.

Immediate loading
In the last few years, immediate (<1 week) or early (<2 months) loading of single and multiple tooth implants has been proposed to expedite the prosthetic rehabilitation phase. After placing the implant(s), a fixed provisional restoration(s) is/are immediately fitted. Immediate loading has also been proposed for immediate post-extraction implant placement in order to reduce treatment times and avoid uncomfortable removable prostheses during the integration stage. The technique is extremely sensitive, and preoperative assessment is essential for success. The present research confirms good short- and medium-term survival rates compared to delayed loading (>3 months), but long-term data is currently unavailable. Most of the literature reports case studies, rather than randomised clinical trials (RCT), carried out by experienced surgeons under stringent clinical situations on a limited number of patients. The few completed RCTs are inconclusive concerning peri-implant or marginal bone height loss. The prerequisites for immediate loading are:

- Absence of acute infection or active suppuration;
- Adequate vascularisation of the site, which precludes sites with previous surgical trauma (e.g. apicectomies) or longstanding chronic infection;
- Good bone quality, preferably type I or II, e.g. in the mandible;
- Primary stability >30 N/cm, without micro-motion (<50–150 μm) at time of placement;
- Occlusal loading is a contentious issue and some authorities distinguish between immediate provisionalisation and immediate loading. However, it is prudent to avoid undue occlusal stresses during healing, especially in lateral excursions, and in patients with a history of bruxism.

**Key points**
- Implant placement involves a surgical osteotomy with or without flap elevation.
- Surgical protocols include two-stage submerged, one-stage non-submerged and immediate post-extraction placement.
- Immediate loading is the latest method for expediting the implant prosthetic phase.
Types and configuration of implants

Dental implants can be:
1. Subperiosteal, placed onto bone
2. Transosseous, placed through bone
3. Endosseous, placed into bone, most popular type

The biomaterials from which implants are fabricated include titanium, and more recently, zirconia ceramics.

The surface modifications of an implant determine secondary stability, reduced healing times especially in low-density bone (Type III and IV).

Many thread profiles are available including, V- shaped, reverse buttress, square crest shaped, micro-threads (at implant neck), and macro-threads (on implant body), symmetrical and asymmetrical patterns.
Various criteria are used to categorise dental implants, including method of anchorage in bone, number of surgical procedures, materials for fabrication, configuration, type of connection (e.g. internal or external hexagon), dimensions, or the manufacturing company.

Types of dental implants

A dental implant provides support or anchorage for an intra-oral prosthesis. The basic types of dental implants are:
- **Subperiosteal – placed onto the bone**, custom-made for extensively resorbed alveolar ridges, usually involving CBCT scans to extrapolate the alveolar morphology, and using CAD/CAM software a bespoke titanium framework is constructed and surgically placed after flap elevation;
- **Transosseous – placed through bone**, usually in the mandible, but due to the extensive surgical protocol, their use today is almost redundant;
- **Endosseous (endosteal) – placed into bone**:
  - **Plate or blade form** – thin cross-section metal pieces, 65% narrower than root form implants, indicated for narrow ridges not amenable to bone grafting;
  - **Ramus frame** – long metal plates inserted into a resorbed mandible from the chin to ramus;
  - **Zygomatic** – for severely resorbed maxillae;
  - **Basal (lateral) implants placed via a palatal approach in the maxilla**;
  - **Root form** – mimicking the morphology of natural tooth roots, either screwed or pushed (press-fit) into the prepared osteotomy;
  - **Mini-implants or small diameter implants (SDIs)** – same as root form but with small diameters (<3mm). Uses include retaining overdentures, transitional implants for supporting provisional prostheses awaiting integration of larger diameter implants, and orthodontic anchorage.

Virtually all contemporary dental implants are endosseous root form, and the discussion below is therefore limited to these varieties.

Materials

The material from which a dental implant is manufactured be biocompatible, promote osseointegration and be biofunctional to resist oral forces (ranging from 200N to >2000N). The materials that meet these objectives are titanium and, more recently, zirconia ceramics.

Components

Implants are mechanical modular devices consisting of:
- **Fixture** – ‘root shape’ component that is inserted into the alveolar bone, providing foundation for the definitive restoration;
- **Abutment** – intra-oral superstructure that is screwed onto the fixture. The abutments can either be external fitting or internal fitting (see Chapter 54);
- **Definitive restoration** – prosthetic component that is placed onto the abutment, simulating a tooth or teeth;
- **One-piece implants** – the fixture and abutment components are incorporated into one piece, and subsequently restored with a definitive restoration after osseointegration.

The aim of any implant design is to maximise bone apposition at the implant–bone interface for osseointegration. The configuration of an implant is divided into its geometry, which determines primary stability, and surface modifications at the interface that determine secondary stability.

Geometry

Geometry refers to macromorphology or shape, i.e. 3-D profile, which is usually conical or tapered. Achieving primary stability is a prerequisite for osseointegration and discouraging fibrous tissue formation, and depends on bone quality, surgical technique and implant design (length and platform diameter), surface area, shape and thread profile. For dense bone, design is less important, but is paramount for stability in low-density bone, e.g. posterior maxilla. The often quoted minimum length is 10 mm, but newer, shorter designs have also proven successful. Tapered implants are better adapted for immediate placement post-extraction by compressing soft bone for primary stability.

The function of threads is to improve primary stability, increase surface area and translate tensile forces to compressive components to favour bone preservation. Many thread profiles have been proposed. The asymmetrical thread that varies along the length of the fixtures seems better, compared to a uniform symmetrical pattern. Also, rounded threads reduce peak stresses in bone during implant insertion. Many current implants have micro-threads at the neck and macro-threads, with altered pitch, along the body for self-tapping and bone compression. The neck of an implant requires special attention. Finite element analysis shows that this area has the highest bone stresses, causing marginal bone remodelling (MBR). An area above the crestal bone of an implant is necessary to form a biological width, similar to a natural tooth. Therefore, some designs have a polished collar at the neck to allow formation of a biologic width, while others have a rough neck to reduce disuse atrophy and retain a greater marginal bone, compared to polished collars.

Surface modifications

Micromorphology modifications of implant surface topography are for promoting and accelerating ‘secondary’ osseointegration, which predominantly determines secondary stability, especially in low-density bone. Some examples include:
- **Machined or polished surface** (Sa: <0.5 microm), originally proposed by Brånemark, but results in reduced bone implant contact compared to roughened surfaces;
- **Macro-irregularities** (Sa: >100 microm), e.g. pores or diffusion-bonded microspheres, and sintered porous surface for bone ingrowth;
- **Micro-irregularities** (Sa: <10 microm) to enhance interlocking of bone at a microscopic level, e.g. roughening by grit blasting, oxidation, acid etching or a combination of these processes;
- **Surface enhancement/coatings** – hydrophilic, hydroxyapatite coating, plasma spray, fluoride-modified surfaces by electrochemical etching to encourage calcium and phosphate deposition, nanotechnology surface modifications, osteoattraction for promoting healing by recombinant human growth factors, e.g. morphogenetic protein-2.

Key points

- Dental implants are modular devices placed into bone to support teeth.
- Most dental implants are endosseous root forms, made from titanium.
- The geometry of an implant determines its primary stability, while surface modifications determine secondary stability.
Implant abutments

Dental abutments are linked to the implants by:
1. Eternal connection, e.g. external hex
2. Internal connection, e.g. internal tri-lobe
3. Internal connection, e.g. Morse taper

Connections

Dental abutments can be:
1. One-component, combining abutment and fixture
2. Two-component, separate abutment and fixture

Types

Biocompatible, customisable, high strength, aesthetic, suitable for short-span FPDs, concerns about fracturing, encourage transmucosal epithelial attachment due to smooth surface

Biocompatible, customisable, excellent mechanical properties, ideal for long-span FPD multiple units, compromised aesthetics, encourage transmucosal epithelial attachment due to smooth surface

IMPLANT ABUTMENTS

Zirconia

Customised castable

UCLA-castable gold abutments ideal for misaligned implants, but gold and silica ceramics do not encourage epithelial attachment on abutment due to rough surface

Customised CAD/CAM

Most popular method for fabricating bespoke abutments fabricated from titanium or zirconia

Zirconia

Titanium

Stock abutments

Customised gold

Customised titanium

Customised zirconia

External

Internal lobe

Conical

All-in-one

Separate

Dental abutments are linked to the implants by:
1. Eternal connection, e.g. external hex
2. Internal connection, e.g. internal tri-lobe
3. Internal connection, e.g. Morse taper

Biocompatible, customisable, high strength, aesthetic, suitable for short-span FPDs, concerns about fracturing, encourage transmucosal epithelial attachment due to smooth surface

Biocompatible, customisable, excellent mechanical properties, ideal for long-span FPD multiple units, compromised aesthetics, encourage transmucosal epithelial attachment due to smooth surface

UCLA-castable gold abutments ideal for misaligned implants, but gold and silica ceramics do not encourage epithelial attachment on abutment due to rough surface

Most popular method for fabricating bespoke abutments fabricated from titanium or zirconia

Stock abutments

Customised gold

Customised titanium

Customised zirconia
An implant abutment provides support for the definitive intra-oral restoration(s), and the choice is dictated by the type of prosthesis (fixed or removable), location in the mouth, and the material for optimal anterior aesthetic and resisting both external (functional and parafunctional) and internal (preload) forces.

Implant abutments are available in two varieties:

- **One-component** – combining the abutment and fixture as an all-in-one implant;
- **Two-component** – separate abutment that is connected onto the fixture head with either a retaining screw (usually at a torque of 20 Ncm), or cemented into place. To prevent abutment screw loosening, some screws are gold-plated for improved retention by creating a bond equivalent to a ‘cold weld’. The two-component is the most popular and universal system, offering versatility for fixture angulation and numerous types of abutment to suit different definitive prostheses. The following discussion is therefore limited to this variety.

### Connections

The market is awash with more than twenty different types of implant–abutment connections. It is important that the connection offers optimal mechanical stability, strength, fatigue resistance, anti-rotation, prevent microleakage and screw loosening and provide a hermetic seal (minimum micro-gap, i.e. butt-joint gap between the abutment and the implant fixture of approximately 2–6µm). Currently, no connection (or interface) prevents bacterial penetration into the micro-gap. In addition, the clinically acceptable vertical and horizontal discrepancies (marginal fit) between the abutment and fixture should be similar to that of the marginal discrepancies between a natural tooth abutment and artificial restoration (approximately +/−50µm). Some popular implant/abutment interfaces include:

- **External connection**, e.g. external hexagon (hex), which was the original connection used by Brånemark for screwing a metal substructure for supporting a prosthesis. However, due to its small external height of 0.7 mm, this connection is incapable of withstanding intra-oral forces of individual crowns, and is better suited for connecting multiple implants restored with a fixed partial denture (FPD);
- **Internal connection** – available in a variety of seating depths into fixture (ranging from 1.2 mm to 4 mm), configurations and angles to provide excellent anti-rotational properties, examples include:
  - Hexagon (hex) – 6-point retention;
  - Internal tri-lobe – 3-point retention;
  - Conical interface, e.g. Morse taper and locking taper of <6° internal connection, relying on friction grip and/or screw retention with the strength of a ‘cold weld’.

Recent research has suggested that the type of connection, internal or external, has little influence on the stresses and strains transmitted to the bone.

### Materials

Implant abutments are fabricated from various materials including plastic, cast gold, titanium and ceramics. Plastic copings are inexpensive, and useful for provisional restorations, while awaiting osseointegration. Customised cast gold abutments were popular, but in recent years have been superseded by CAD/CAM customised copings. Alumina has the propensity to fracture during preparation and shaping due to relatively poor strength compared to zirconia. Recent research has highlighted that transmucosal epithelial attachment on abutments is only possible with titanium, aluminium or zirconia but not with silica ceramics or cast gold. However, epithelium will adhere to any clean and smooth surface, including cast gold and other restorative materials.

Today, the material of choice for abutments is either titanium or zirconia. Titanium is unsuitable for aesthetic-sensitive regions, and especially if definitive all-ceramic restorations are planned. Furthermore, titanium is a thermal conductor and, if exposed at the periphery, may cause marginal bone necrosis in patients who have a habit of ingesting hot drinks. Zirconia is the most promising material that may become ubiquitous for all abutments in the future.

### Prefabricated abutments

Prefabricated or stock abutments are available in different shapes, heights and predefined angles (10–25°) to accommodate varying interocclusal clearance and implant angulation. They can be further modified chair-side or in the laboratory, to compensate for implant misalignment. Platform switching has been proposed to minimise bone resorption at the neck of the implant fixture. The concept is to use smaller-diameter abutments than the implant fixture head to shift the micro-gap either in the coronal (vertical shift), or mesial (horizontal shift) directions to encourage a soft tissue biologic width, discourage bacterial penetration and thereby prevent marginal bone loss.

### Customised castable abutments

Castable UCLA abutments (developed in California) have revolutionised implant abutments, offering flexibility to compensate for misaligned implant fixtures by altering abutment angle, taper, finish line and width according to the position and emergence profile of the definitive crown. A plastic tube is trimmed and waxed to the desired shape and position and then cast in gold alloy, with or without a porcelain cervical shoulder margin, to avoid metal shine-through at the transition between the crown and soft tissues.

### Customised CAD/CAM abutments

The latest method for customising abutments is using CAD/CAM technology to machine titanium (with or without electroplated gold) or ceramics (with or without porcelain veneer masking layer) to the precise shape and position of an abutment. Zirconia is available in different shades to facilitate colour matching with the surrounding dentition. Furthermore, both titanium and zirconia can be used as a mono-block abutment crown, incorporating both the abutment and final restoration into a single entity to restore implants.

### Key points

- Implant abutments provide support for the definitive restoration(s).
- Abutments are linked to the underlying implant fixture by either an external or internal connection.
- Customised, CAD/CAM abutments fabricated from titanium or zirconia are the most popular for restoring implant(s).
Transferring data

Preoperative Wax-up Stent Healing caps Fixtures

Postoperative Framework Framework Impression Imp. copings

Fixed cement-retained Fixed screw-retained

Definitive cement retained crown Titanium abutment Location jig Screw holes Screw Definitive FPD

Mandibular IRO Maxillary IRO

Implants Ball abutments Overdenture Implants Bar-clip retainer Overdenture
The final stage of implant rehabilitation is transferring the intra-oral data to the dental laboratory for the fabrication of the definitive restoration or prosthesis. The definitive restoration can be fixed, supported either solely by implants, or in combination with natural teeth abutments. A removable prosthesis is supported by implants, with or without soft tissue support. The decision of the definitive restoration is made at the treatment planning stage, and determines the type, number and positioning of the fixtures and abutments for supporting the final restoration(s).

Transferring data
Following successful osseointegration, the intra-oral data needs to be transferred to the dental laboratory for prosthetic rehabilitation of the implant fixtures. The intra-oral data includes the number, location, size and angulation of implants together with surrounding soft tissues and the adjacent and opposing dentition. This is accomplished by taking an impression, face-bow and occlusal records. At present, the analogue method is the most popular, using PVS or polyether impression materials in a custom-made tray, but in future will be replaced by digital intra-oral impressions.

The analogue method involves using impressions copings (made of plastic, titanium or anodised aluminium), which can be for closed or open impression trays (the latter if the angle of the fixture(s) is anticipated to hinder withdrawal of the tray). In the dental laboratory, a stone model is poured using the corresponding implant analogues (made of stainless steel or brass), in preparation for abutment fabrication. The contemporary method for designing both implant abutment(s) and the definitive restoration(s) is by CAD/CAM technology. Alternately, abutment(s) and restoration(s) can be waxed and cast using conventional prosthetic protocols.

Fixed cement-retained
Cement-retained restorations can be used for either single crowns or multiple-unit FPDs. First, the abutment is screwed or tapped onto the implant fixture, and second, the final restoration is subsequently cemented onto the abutment. Cement-retained restorations are recommended for:

- Single anterior crowns for optimal aesthetics, especially all-ceramic units that can be adhesively bonded to an underlying ceramic (e.g. zirconia) abutment with self-adhesive resin cements;
- Severely misaligned implants to compensate for poor emergence profile;
- Facialy located screw access holes compromising aesthetics;
- Screw access and sealing fillings interfering with occlusal stability;
- Thin biotypes predisposed to gingival recession;
- Limited interocclusal clearance for accessing screw hole(s);
- Narrow-diameter crowns with inadequate width for placing screws.

A major problem with cement-retained restorations is gaining access to the abutment-retaining screw if screw loosening is suspected, which may require damaging the definitive restoration, particularly for cemented multiple-unit FPDs. Another concern is deep subgingival margins (>3 mm), making cement removal difficult.

Fixed screw-retained
Screw-retained restorations are also suitable for both individual crowns and FPDs. The abutment and crown (or FPD) is combined into a single prosthetic component, avoiding different material interfaces, giving increased strength and stability and eliminating cement remnants. The major benefit is retrievability, and the current trend is to use screw-retained restorations, especially for posterior single units and full-arch fixed reconstructions. Also, a small inter-arch space may reduce retention and resistance of a cemented restoration; if clearance allows, a screw-retained restoration provides superior long-term retention.

The drawbacks of screw-retained restorations are:

- Implant head requires vertical orientation, for anterior restorations the screw location should be in line with the incisal edge, and for posterior units towards the central fossa;
- Poor aesthetics if screw hole is incorrectly positioned, or requires masking with an opaquer;
- Micro-gap between the abutment and crown is apical to the gingival crest, predisposing to chronic gingival inflammation.

To conclude, the choice between a cemented or screw-retained restoration is empirical, depending on the clinician’s experience and preference and the prevailing clinical scenario. Research shows little difference between the two types of restorations with regard to peri-implant inflammation, marginal bone loss, or implant survival or success rates.

Implant-retained overdentures
Fixed implant-supported prostheses necessitating multiple implants may be contraindicated for several reasons including extensive bone grafting, anatomical obstacles, occlusal problems, elderly or infirm patients not able to tolerate protracted treatment sessions, and fiscal constraints. In these circumstances, removable implant-retained overdentures (IRO) provide improved retention, stability, aesthetics, phonetics, mastication and quality of life. IROs can either be entirely implant-supported, or a combination of mucosa-supported and implant-supported. A few strategically placed implants support an overdenture with either a ball abutment with O-rings, magnetic or tower abutments, bar-clip retainer with corresponding female matrices on the fitting surface of the prosthesis. Bar retainers are particularly useful for non-parallel implants.

For the edentulous mandible, usually 2 or 4 implants are placed in the interforaminal region, while for the maxilla 2 or 4 implants in the canine and second premolar regions support a retentive bar-clip attachment. Furthermore, if conventional-diameter implants greater than 3 mm are not feasible due to inadequate bone width, small-diameter implants (SDIs) or ‘mini-implants’ (1.8–2.9 mm) provide a conservative, minimally invasive alternative.

**Key points**

- Transferring intra-oral data requires taking an analogue or digital impression for fabricating the abutment and restoration.
- Fixed individual or multiple unit prostheses can be either cement- or screw-retained.
- Implant-retained overdentures provide an alternative to fixed units, especially using mini-implants.
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