Preface

Textbook of Endodontology is intended to serve the educational needs of dental students, as well as of dental practitioners seeking updates on endodontic theories and techniques. The primary aim has been to provide an understanding of the biological processes involved in pulpal and periapical pathologies and how that knowledge impinges on clinical management, and to present that information in an easily accessible form. Therefore, we have supplemented the core text with numerous figures and photographs, as well as with boxes highlighting key facts, important clinical procedures and key research. Case studies are given at the end of some chapters in order to further illustrate topics described in the text. In these various ways, the book provides information both at a foundation level, and at a more detailed level for the graduating student and practitioner.

The key information boxes are colour coded as an easy-to-use navigational aid for readers. Core concepts are coloured pink, while advanced concepts are purple. Clinical procedures are coded green and key literature boxes are blue.

This book is also intended to stimulate the reader to delve into the endodontic literature and the research methodology that forms our current knowledge base. To aid the reader, a selective reference list is provided and comments have been added to especially weighty or useful references. Important and interesting investigations are presented in the core and advanced concept boxes, and we hope that these features will encourage the reader to do his or her own research.

This book would not have been possible without the dedicated support of our co-authors – 18 highly respected clinicians and scientists, who, in addition to the editors, have contributed to this book. We thank them all sincerely for their time, effort and endurance during the editing process.

Gunnar Bergenholtz, Preben Hørsted-Bindslev and Claes Reit

Chapter 5

The multidisciplinary nature of pain

Ilana Eli

Introduction

Pain is a complex experience of a multidisciplinary nature that is always subjective and associated with emotional and cognitive factors. Today it is widely accepted that the mere activity in the nociceptor and nociceptive pathways of the nervous system elicited by a noxious stimulus does not represent pain. Pain is always a psychological state and can be reported also in the absence of tissue damage or any likely pathophysiological cause.

Pain is often the primary motivator for patients to seek health care in general and dental treatment in particular. Dental treatment is closely associated with pain. Most dental patients expect to experience some degree of pain during dental treatment and dentists often use pain as a diagnostic tool. Self-reports of pain serve the practitioner to locate possible pathology and to arrive at conclusions regarding diagnosis and treatment, e.g. the use of tooth pulp stimulation as a diagnostic test for pulp vitality (50). However, pain is an unreliable indicator of pathology (24). In fact, little correlation exists between the amount of tissue destruction and the reported presence or absence of pain, whether derived pulpally, periodontally or periapically (54).

It is impossible to view pain as only a unique sensory reaction, therefore pain is defined as 'an unpleasant and emotional experience associated with actual or potential tissue damage, or described in terms of such damage' (26). Thus, pain is always subjective and unpleasant and not necessarily related to a stimulus or direct tissue damage. It is an emotional and cognitive experience affected by stress, anxiety, expectation, focus of attention, gender and culture, in other words, a multidisciplinary experience (Core concept 5.1).

Unlike many other sensations that are evoked by external events (seeing, hearing), pain can be classified among the bodily sensations that are evoked by internal events (so-called 'need states' such as hunger and thirst). Like other need states, pain is affected by distraction, suggestion, culture and learning and is associated with a predictable behavior.

Core concept 5.1

Many people report pain in the absence of tissue damage or any likely pathophysiological cause. There is no way to distinguish this experience from that of tissue damage and it should therefore be accepted as pain. Activity induced in the nociceptor and nociceptive pathways by a noxious stimulus is not pain. Pain is always a psychological state.

In many acute pain situations, including pulpitis, anxiety may not only lower the pain threshold but may, in fact, lead to the perception that normally non-painful stimuli are painful. Although the explanation for such a phenomenon is not always fully understood, it is essential that the treating dentist accepts the fact that for the patient the experience is similar to that caused by drilling in a non-anesthetized tooth. In a similar manner, people differ in their pain perception and reaction according to their culture, social environment, gender and individual cognitive and emotional factors. Moreover, the same individual may react in a different manner to similar stimulations under different conditions (Core concept 5.2).

Pain may produce immediate behavioral manifestations, such as instantaneous withdrawal from the stimulus. It can also bring about long-term behavioral consequences, including the development of dental

Core concept 5.2

Pain research distinguishes between pain threshold and pain tolerance. Both are defined in terms of a subjective self-report:

- Pain threshold is the least recognizable pain experience.
- Pain tolerance is the greatest level of pain that one is prepared to endure.

anxiety and phobia, which in turn could lead to avoidance and severe neglect of dental care. Proper understanding of the pain phenomena enables the use of non-pharmacological modes for pain management and leads to better dental care and patient management in the immediate and long term. The various psychological factors that affect pain experience and their importance in dental treatment are addressed in this chapter.

Key literature 5.1

In an extensive review regarding pain and anxiety in dental procedures, Litt (36) found that in acute pain situations, anxiety and pain may be indistinguishable. Anxiety not only lowers the pain threshold, but may actually lead to the perception that normally non-painful stimuli are painful (e.g. vibration of the drill felt on an anesthetized tooth).

Psychological factors affecting pain experience

Affective factors

Impact of stress, fear and anxiety

It is widely believed that anxiety is associated with increased pain report (9). A tense and anxious patient is more inclined to report pain during treatment than a relaxed one, because anxiety creates the expectancy for future pain. Therefore, an anxious patient who arrives for treatment with former pain memory is likely to expect pain during the treatment. This causes the patient to filter selectively any information given prior to treatment and to focus on stimuli that can resemble or be associated with pain. The slightest pressure on the tooth, for example, can be interpreted as pain and initiate a pain reaction. Arousal caused by anxiety may also lead to increased sympathetic activity and muscle tension, which may cause additional pain.

Dental anxiety is a prevalent obstacle that affects human behavior in the dental setting (15). Among all dental situations, the one causing the highest levels of stress and anxiety are oral surgical procedures and endodontic therapies (5, 17, 52, 60). Thus, there is a high probability that patients who arrive for endodontic treatment are anxious and expect to experience some degree of pain during treatment. This may prompt patients to report pain during treatment even when there is no pathophysiological basis for such a report (e.g. drilling in a tooth with non-vital pulp). Sometimes the achievement of proper local anesthesia is extremely difficult and the patient continues to complain of pain in spite of several attempts at anesthesia. Such situations are closely associated with patients' fear of dental treatment (27, 58).

Because pain by definition is always subjective, there is no way to distinguish between pain due to psychological reasons and pain originating from actual tissue stimulation. In both cases it is regarded and reported by the patient as pain and should be accepted and referred to as such (Key literature 5.1).

Impact of mood

Mood, especially depression, influences pain perception and pain tolerance. There is a close relation between chronic pain states and depression (53). It has been hypothesized that chronic pain and depression are closely related, owing to similar neurochemical mechanisms in both disorders. Another reason for depressed mood is the way in which chronic pain interferes with important functioning in everyday life (e.g. decline in social activities and social rewards) (51).

Mood can affect pain perception also in short-term acute pain situations, such as dental treatment. For example, Weisenberg *et al.* (59) observed that acute pain perception was affected by a film-induced mood condition. In that study 200 subjects were exposed to three different types of films: humorous, a holocaust and a neutral. Before watching the film, immediately after and 30 min later, each subject was challenged with a trial of cold pressure pain. The results indicated that subjects who watched the humorous film tolerated the pain challenge better than any of the other subjects. This observation suggests that psychological approaches could have a significant effect on the sensory dimensions of pain and that pain tolerance in patients can be increased substantially with rather simple measures, including the showing of humorous films in the waiting room.

Cognitive factors

Pain is one of the most potent forms of stress. The experience of pain includes an actual confrontation with harm, which can be physical (e.g. injury), psychological (e.g. loss of control) or interpersonal (e.g. shame). As such, it is affected by both the potency of the stimulus and by the individual's ability to cope with the stressful event (49).

Attention versus distraction

Almost any situation that attracts a sufficient degree of intense, prolonged attention (e.g. sports, battle) can provide conditions for other stimulation to go unnoticed, including wounds that would cause considerable suffering under normal circumstances (39).

Broadly defined, distraction is directing one's attention from the sensations or emotional reactions produced by a noxious stimulus. Generally, distraction reduces pain compared with undistracted conditions (38).

Dentists can apply distraction techniques while treating their patients, e.g. by using background music or talking to the patient. Several advanced methods have been described as being effective in the dental clinic, such as mounting a television monitor near the ceiling and asking the patient to play a video game 'against the house' (8). Distraction techniques that require attentional capacity are effective in reducing pain-related distress, and even the simplest distraction technique is beneficial in reducing a patient's stress and pain perception.

Control

Research has shown that stress, coping mechanisms and reaction to pain are affected by the degree of control that patients feel they have over the stimuli that can induce pain (3, 35). For example, patients who were provided with information on N_2O analgesia showed higher pain tolerance thresholds to tooth pulp stimulation than patients who were not informed (13). Because the fear of uncontrolled, sudden, acute pain is a primary concern for most patients (33), continuous information regarding forthcoming procedures and the description of the likely sensations are important in order to provide patients with some sense of control or involvement. Thereby, anxiety and pain levels associated with dental procedures can be reduced (56).

Pain beliefs and expectations

Reaction to a stimulus, whether acute or chronic, is always affected by the meaning that the individual attaches to it. For example, the patient can interpret an episode of an unexpected and unexplained pain sensation during treatment as a sign of insufficient professional skill on the part of the dentist. This in turn can develop mistrust and make the patient assume that any further minor stimulus is a threat and evokes a pain reaction. Conversely, when mutual trust exists and when the patient has complete faith in the necessity of the treatment, such incidences are bearable and less traumatic.

In a classic experiment (1), subjects were requested to touch a vibrating surface for 1 s. Some were led to believe that the surface would cause pain, others that it would produce pleasure and the remainder were given no hint on what the vibrations would entail. As predicted, the 'pain subjects' usually reported the vibrations to be painful, the 'pleasure subjects' as pleasurable and the 'control subjects' as neutral sensations. This experiment shows that if a patient expects pain to occur during dental treatment, this increases the likelihood for pain to be perceived (Core concept 5.3).

> **Core concept 5.3**
>
> An ambiguous sensation can be perceived as either pleasurable or painful, based on individual cognitions and expectations. Therefore, patients' expectations influence the feeling of pain or no pain.

> **Key literature 5.2**
>
> In a study by Dworkin and Chen (12), subjects served as their own control when tooth pulp shocks were delivered either in a laboratory or in a clinical setting. A substantial decrease in the subjects' thresholds for sensation and pain, and in pain tolerance, was found when patients were challenged in the clinical setting. From this study it can be concluded that, in the dental office, patient's anticipation of threat and the associated anxiety are potent cognitive mediators of pain behavior. In other words, responses to pain stimuli change according to the situational context in which pain is experienced.

In stressful situations, behavior, thoughts and emotional reactions are influenced not only by the stimulus as such but also by the individual's perception of 'self-efficacy', i.e. one's belief in having the relevant and necessary coping skills (2). If a patient believes that he or she can successfully cope with the anticipated pain, then this perception increases the pain tolerance, and vice versa. Generally, those who avoid dental care because of fear and anxiety perceive themselves as being reliably less able to tolerate pain. Such patients often claim to have an 'exceptionally low pain threshold' or report themselves as 'completely unable to endure pain'. Such a low self-efficacy further lowers their pain tolerance level during treatment and increases the probability that pain will be experienced (29, 30, Key literature 5.2).

Pain prediction and memory

Usually, memory for the general intensity of pain is good. However, the level of pain remembered by patients regarding previous dental treatments is more closely associated with their expectations of pain rather than to their real pain experience (28). Furthermore, mood and affective states influence the memory of pain (19).

When dental patients experience recurrent pain during treatment, their recall of the experience has an increased magnitude. This may lead to increased anxiety and increased pain perception. As time elapses, the painful experiences tend to gain negative impact, probably due to reconstruction of memories to make them consistent with the existing level of anxiety. The vicious circle is enhanced by feelings of shame due to the inability to cope with the situation. Other defensive adjustment mechanisms, such as suppression ('I don't even want to think of that'), denial ('There is nothing wrong with my teeth') or projection ('I simply hate dentists'), further contribute to the patient's inability to cope with the situation and increases the probability of pain during treatment (15).

Memory of past pain experience also depends on the intensity of the present pain. When the pain intensity is high, patients remember the levels of their prior pain as being more severe than originally recorded (14). This situation is occasionally seen among patients who experience postoperative pain after their first session of endodontic therapy. Postoperative pain causes patients to remember former treatment as more painful than in fact was originally experienced. This, in turn, leads to higher stress, higher expectation of pain and lower tolerance of pain in the next encounter with the dentist.

Environmental factors

Direct and indirect learning

Part of our behavior results from life experiences. The concepts and coping strategies of various life events (including pain) are continually affected by learning processes. For a learned behavior to develop, exposure to the stimulus in question must occur, resulting in a response pattern (conditioning). Further reinforcement of the response pattern (positive or negative) leads to the acquisition of new behaviors.

Unfortunately, the dental situation provides numerous opportunities for negative conditioning and the acquirement of maladaptive behaviors. The most common stimulus in this respect is pain. Although acute pain during dental treatment can be avoided in most cases, there are still many adults who have experienced it during treatment in the past. A dental practitioner who acts without perseverance toward an apprehensive patient serves to reinforce the negative behavior, thereby decreasing the patient's tolerance to pain. Reactions of impatience toward the 'difficult to handle' patient, associated with unconscious punishment (treatment applied in an impatient and harsh manner), reinforce the negative behavior of the patient and lowers his or her pain tolerance.

Numerous learned behaviors associated with pain are based on negative reinforcement – something uncomfortable or fearful that should be avoided. This type of learning includes escape and avoidance (to avoid or prevent the unpleasant situation before it occurs). One example is that of patients who react with symptoms of pallor, nausea, sweating, dizziness or even fainting during administration of local anesthesia. In many instances, symptoms originate in the patient's fear of pain rather than being due to pathophysiological causes. The situation can result in significant stress to the dentist, who occasionally chooses to postpone treatment to the next appointment. Once the symptoms have served the patient as an adequate means to avoid the stressful situation, it may serve as a reinforcement to increase the probability of recurrence during subsequent confrontations. Patients develop a 'fainting prone' behavior that 'protects' them from the need to face treatment. The negative pattern is further reinforced by the dentist's reluctance to treat patients with such a medical history.

In some cases this maladaptive pattern is further reinforced by secondary gains, such as sympathy and attention from the environment, avoidance of unpleasant work or duties, etc. Reinforcement of pain behavior can also occur with pain medication. For some, the effects of pain medication reinforce pain behavior due to the development of physiological and psychological addiction. These individuals continue the pain behavior necessary and sufficient to lead to delivery of medication, even after the original nociceptive stimulus has resolved.

For learning to take place, patients do not have to have a direct experience. It can also be a result of observation (vicarious learning). This means that one sees what happens to another individual and assumes that one's own fate would be similar in nature. For example, a child who accompanies his or her parent to the dentist and watches a pain-related behavior may later, in a similar situation, imitate that behavior. Indeed, observing others respond to painful stimulation could either provoke or reduce the pain response of the observer (47).

Vicarious learning can also originate through identification (e.g. a parent who constantly complains about pain from a tooth or dental treatment) or through indirect suggestions. For a parent who brings his or her child to the dentist and reassures in a trembling voice that '. . . there is no reason to worry . . . it will not hurt at all . . .', the non-verbal suggestion may often be the reverse and cause increased pain sensitivity.

In conclusion, as with any other 'stressor', pain is also influenced by individually learned responses. Respondent and operant conditioning, indirect learning through modeling and suggestions, as well as social learning have a significant impact on the pain experience (6).

Social and cultural factors

The influence of social environmental factors and the level of approval given by different societies for the public expression of pain have a significant impact on pain behavior. A variety of studies in the 1950s and 1960s in the US found differences including denial of problems, social withdrawal and fewer complaints in cultural groups that tend to be more reserved, and more dramatic responses to pain, greater expressiveness and a need for social support in those cultural groups where expression of emotion is more accepted (61, 62, 63).

The cultural significance attributed to pain, symbols of pain and situations associated with pain make them acceptable or avoidable regardless of the actual intensity of the sensation. For example, acceptance of pain inflicted during the administration of local anesthesia as serving a positive purpose, rejection of pain caused by a needle puncture in the finger as symbolizing injury. The acceptance of pain does not mean that the feeling quality of the sensation has changed. The sensation is always unpleasant, but the unpleasantness is tolerated when cultural traditions call for its acceptance.

While ethnic groups differ with regard to factors that influence responses to pain, similarities exist in their report of the response. For example, a more recent study by Lipton (34) found that responses, attitudes and descriptions were relatively similar in facial pain patients from a wide variety of cultural backgrounds. Most of the items for which interethnic differences were found concerned emotions (stoicism vs expressiveness) in response to pain, and interference in daily functioning attributed to pain.

Further evidence exists that some dimensions of pain (time, intensity, location, quality, cause and curability) are universal, while others are culture-specific (40,41).

Gender and pain

Gender differences in response to pain stimuli are controversial. Some claim that women exhibit greater sensitivity to noxious stimuli than men (20), whereas others show only slight gender differences in ratings of chronic and experimental pain, pain-related illness behavior and personality (7).

In an extensive review concerning gender variation in clinical pain experience, Unruh (55) reports that women are more likely than men to experience a variety of recurrent pains. In most studies women report more severe levels of pain, more frequent pain and pain of longer duration than men. Women may be at greater risk of pain-related disability than men, but women also respond more aggressively to pain through health-related activities. Regarding psychosocial factors, the review shows that men may be more embarrassed by pain than women and that the meaning of pain may be affected by sociocultural factors and the perceived position of men and women in society. Embarrassment may cause men to minimize pain unless it increases in severity and interferes with work. Minimizing pain may be consistent with social and cultural norms that consider insensitivity to pain and pain endurance as attributes of virility.

There are considerable differences between types of clinical pain (22). Experimental pain, produced under controlled conditions by brief, noxious stimuli, differs from procedural and postsurgical pain. These kinds of pain have different meanings and make the study of pain more complex (Key literature 5.3).

Apparently, women and men make different assessments of procedural pain and may thus be affected differently by the experience. In a study regarding clinical pain in the dental office (18), it was shown that men expect to experience more pain preoperatively than women but remember less pain postoperatively. It was concluded that cognitive pain perception in clinical situations differs between genders, a fact that may originate in psychosocial factors such as expected gender roles.

Key literature 5.3

Eli *et al.* (16) investigated the relationships of gender, anxiety and pain in the dental setting. In the study, 32 women and 32 men underwent diagnostic tooth pulp stimulation by an electric pulp tester. Although there was no direct impact of gender on the various pain measures (sensitivity threshold, pain threshold, pain tolerance), there were significant differences in the relationship between pain tolerance and the subjective evaluation of the painful experience by both genders. In women, the relationship was negative (the higher the one, the lower the other), whereas in men it was positive (the higher the one, the higher the other). It was concluded that women were affected more by the objective characteristics of the stimulus, whereas men were also affected by its psychological significance.

Proper understanding of the variables that affect individual pain assessment in men and women is important, because it may produce emotional responses that can influence compliance.

Psychological approaches to pain management

Treatment strategies

Systematic attempts to treat pain have been closely aligned with how pain is conceptualized and evaluated (21). Traditionally, the focus in medicine (and dentistry) has been on the cause of the pain reported, with the assumption that there is a somatic basis for the pain and once it is identified the source can be blocked by medical or operative intervention. In the absence of physical basis, the situation was labeled as 'psychogenic pain'.

Today, it is widely accepted that such a dichotomous view is incomplete and inadequate. There is no question that physical factors contribute to pain symptoms, or that psychological factors play a part in pain reports. Therefore, an increasing range of psychologically based interventions is continuously incorporated in pain management.

Treatment of acute pain includes strategies based on information, distraction, relaxation and hypnosis. Generally, preparing the patient with coping skills such as information, distraction and relaxation helps to reduce the discomfort of potentially painful dental procedures. Patients who are properly prepared show less anxiety and present reports of low pain. Such non-pharmacological strategies facilitate acute pain management and are relatively easy to learn and perform. They should be part of the professional training of every dentist in general, as well as of specialties, especially in endodontics.

Effective treatment strategies for the management of prolonged chronic pain conditions (e.g. temporomandibular disease) include operant conditioning, cognitive–behavioral therapy, psychodynamic therapy, group therapy, biofeedback, relaxation and hypnosis.

Role of hypnosis as a mode for pain management in dental care

In spite of its ancient roots, hypnosis has been accepted only recently as a scientific and medical tool. Hypnosis has been surrounded by myths and mystery for so long that even today various popular misconceptions exist. There is no doubt that it is a powerful therapeutic tool (Core concept 5.4). From 1982 to 1985 alone, over 1000 articles were published on hypnosis (46), indicating an enduring willingness on the part of the scientific community to accept it as a legitimate topic for clinical and research investigation.

The use of hypnosis for anesthetic purposes dates back to the 19th century and is attributed to Recamier in 1821. In dentistry, Oudet used hypnosis as an anesthetic agent to extract a tooth in 1837 (48). Today, hypnosis has been described in the dental literature as having a dramatic effect when used as a sole anesthetic. Hilgard and Hilgard (23) summarized numerous case reports where procedures such as extractions, pulpotomies and pulpectomies were performed under hypnosis without other anesthetic agents.

Hypnosis is used in endodontic treatment (42–44) and in other dental procedures (32, 57) to allow treatment without stress or pain. For example, it can reduce both the strength and unpleasantness of electrical tooth pulp stimulation (25). The use of hypnosis to induce local anesthesia is especially effective for medically compromised patients (37), for patients with specific fears (i.e. dental syringe, needle or injections) (4) and in treating patients with true (or suspected) hypersensitivity to local anesthetic agents (45).

Core concept 5.4

Potential applications of hypnosis in dentistry include:

- Patients who suffer from dental fear, anxiety or phobia.
- Patients with excessive gagging reflex.
- Acute and chronic pain conditions.
- Enhancement of patient compliance with dental hygiene.
- Enhancement of patient adaptation to dentures.
- To induce local anesthesia in patients with specific fears and in treating patients with true (or suspected) hypersensitivity to local anesthetic agents.

Managing adverse reaction to local anesthesia

Occasionally, patients may present with a history of hypersensitivity to local anesthetic agents. The symptoms usually include immediate reactions to the injection procedure (dizziness, shortness of breath, tachycardia, etc.). Although the true incidence of local anesthetic allergy is low, such a history often involves both the patient's and the dentist's anxiety regarding the use of the drug in question. Hypnosis can play a major role in controlling pain and the associated distress. In many cases, adverse reactions to local anesthetic are psychogenic in nature. Fear of injection, or of dental treatment in general, could lead to some of the most frightening 'allergic' reactions – tachycardia and vasodepressor syncope. Even patients with a former diagnosis of allergy may not be allergic at all (10). Patients frightened by the use of local or general anesthesia, or those diagnosed as allergic, may suffer from severe adverse consequences. Patients correctly or incorrectly labeled as 'allergic' tend to postpone routine treatment until pain is intolerable, which causes deterioration of their dental condition (11). Again, hypnosis may be used as an efficient tool to induce analgesia/anesthesia and to enable routine dental care. Generally, the hypnotic response is easily achieved because of the patient's high motivation and because the method is solely used to achieve analgesia. Consequently, patients do not expect any 'psychological' intervention and therefore have less need to mobilize psychological defenses (31).

Case study

Generally, anxiety increases the perception of noxious events as painful. Fear and anxiety are often encountered in the dental situation. Therefore, it could have a major effect on the patient's report of pain and concomitantly on the diagnosis (and treatment) of various dental pathologies, including endodontic lesions.

A 16-year-old girl suffering from dental phobia arrived at a dental clinic for a routine examination. Owing to high dental anxiety, the patient had previously received treatment under general anesthesia. On entering the clinic, she manifested a high degree of apprehension but agreed (with apparent stress) to undergo 'initial' examination.

Examination revealed a radiolucent lesion between the roots of teeth 12 and 13. Sensibility tests performed on the teeth adjacent to the lesion evoked a clear pain response, suggesting a non-endodontic etiology. To avoid possible misdiagnosis, the tests were repeated several times by two independent dentists with identical result. Contralateral teeth reacted in a similar manner. The patient was referred for further consultation to an Oral Surgery Clinic. Outcome of sensibility tests was consistent with previous results. Each time a cold or electrical stimulus was applied to the teeth in question, the patient reacted with pain coupled with apprehension.

It was decided to perform an excision biopsy of the lesion under general anesthesia. Owing to the proximity of the lesion to the apex of tooth 12, it was assumed that following the biopsy a possible devitalization of the tooth would occur. To avoid this complication and further trauma, preventive endodontic treatment was suggested prior to biopsy.

When the pulp of tooth 12 was opened, a non-vital, necrotic tissue was revealed. The canal was cleaned and sealed without further intervention. Six months later the lesion had resolved and no further treatment was necessary.

Comment

Pain is often a poor indicator of the cause of a condition. In this particular case, patient anxiety, stress and anticipation of pain may have led to subjective interpretation of the applied stimuli as painful and to a clinical reaction that suggested the presence of a vital pulp. In the diagnosis of endodontic pathology, pain often serves as an important parameter of evaluation. The high incidence of fear and anxiety among dental patients, and the influence of anxiety on the pain experience, call for a reserved frame of mind to individuals' report of pain.

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Chapter 12

The root filled tooth in prosthodontic reconstruction

Eckehard Kostka and Jean-François Roulet

Introduction

After endodontic therapy a tooth must be restored to functional and esthetic demands. Teeth serving as abutments in prosthodontic reconstructions must be judged carefully regarding their ability to carry a load higher than the physiological one on a single tooth (Core concept 12.1; Fig. 12.1). In most cases the remaining tooth structure will be less than in vital teeth because the most frequently occurring reason for endodontic treatment needs is deep caries. Additionally, a further loss of tooth structure takes place during the preparation of the access cavity and the canal. The amount of coronal tooth structure is the most important factor in the decision for the kind of reconstruction. It is responsible for the retention of the restoration and the fracture susceptibility. When the remaining tooth structure does not provide enough retention for a core build-up, the root canal can support the retention by use of a post. Thus, in a single-rooted tooth with substantial loss of coronal tooth structure, post and cores are often needed.

There is evidence for changes in receptor properties in teeth with non-vital pulp leading to higher bite forces than in vital teeth (33). This must be considered by estimating the fracture susceptibility of a root filled tooth, especially within a prosthodontic reconstruction substituting some more teeth (Key literature 12.1).

Problems associated with root filled teeth as abutments

In order to achieve long-term clinical success in the prosthodontic restoration of root filled teeth it is essential to know the reasons for clinical failures. Some of these reasons, such as recurrent caries or periodontal breakdown, are the same as in vital teeth. One major difference to a vital tooth is the absence of a vital pulp with its potential of inflammatory reaction causing symptoms that act as a first indicator for the patient. To avoid caries and periodontal disease a proper recall regimen should be established to ensure adequate prophylaxis.

The loss of retention of a crown is possible in non-vital as well as in vital abutments, but in the latter early symptoms are warning the patient, rather than in a root filled-tooth. The following paragraphs discuss the problems associated with the prosthodontic reconstruction of root filled teeth.

Loss of retention

Retention loss is a failure of the connection between two parts of the restoration or the tooth respectively. A fracture within one of the materials may result clinically in a loss of retention as well, but its cause must be distinguished.

When the retention is lost at one abutment, either the complete prosthodontic reconstruction will feel loose, causing only slight symptoms in a tooth with non-vital pulp, or it will still be functioning satisfactorily and the partially lost retention remains undetected by the patient. In these cases the diagnosis of the retention loss is difficult but important. A gap between crown and tooth gives access to bacteria, possibly causing caries or periapical inflammation, depending on the location of the gap and the seal of the remaining barrier between the gap and the apex. Furthermore, the forces acting on the remaining reconstruction are higher, with an increasing risk of fracture or subsequent loss of retention of the other abutments. Therefore, it is of the utmost importance not to omit the minute check of the fit of every single abutment in a prosthodontic reconstruction at every recall examination.

The marginal fit is checked with a suitable explorer by trying to penetrate between the tooth and the restoration margin from an apical direction. If a gap cannot be felt, the movement of the restoration can be checked by applying a rocking and a push–pull motion with the fingers. In the case of a loose restoration, a movement of saliva along the cavo surface margin may be observed during this action. Movement at the margin should be

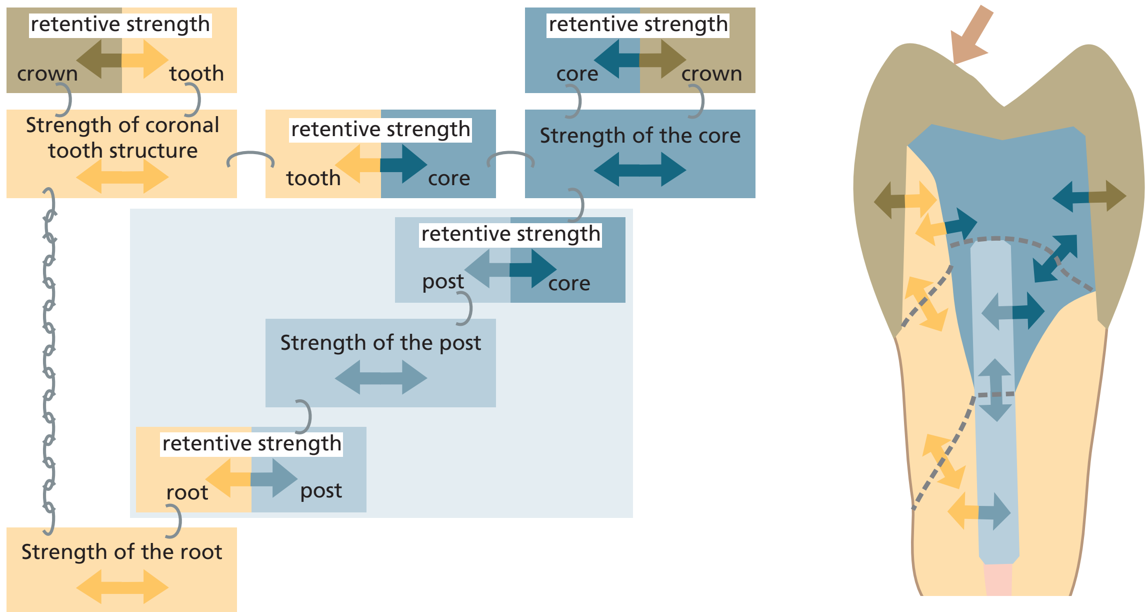


Fig. 12.1 Parts of a restored abutment tooth, with the weak points that have to withstand the acting forces compared with a system of chains.

Core concept 12.1

From a mechanical point of view in a prosthodontic reconstruction all parts of the restored abutment tooth and their junctions must resist the forces that act upon them. The strength of the complete reconstruction can be compared with a chain in which every link is one of the separate parts of the reconstruction, of the biological structures or their connections. Each chain is only as strong as its weakest link. In the case of two parallel chains, the overall strength is as high as the sum of the strengths of both chains, so when one is strong enough there is no need for the other one.

The term 'strength' means both the internal (tensile) strength of part of the reconstruction as well as the retentive (bond) strength between two parts.

In the case of an abutment tooth restored with a post and core, the links of the chains are as shown in Fig. 12.1.

Key literature 12.1

In 1986 Randow and Glantz (33) carried out a clinical experiment of exceptional design: in teeth of test persons they cemented crowns with extension bars to the buccal temporarily on matched pairs of neighboring or contralateral teeth, one being vital and one root-filled, supported with an individual cast post and core. Weights were applied at different lever arm positions until the test persons experienced pain. The pain loading level of the root filled teeth was more than twice as high as in the vital teeth. The experiment was repeated under local anesthesia but terminated at a loading level exceeding 125% of the root filled tooth without anesthesia. Under these conditions no difference in the reaction levels within the pair of teeth was observed, but in one root filled tooth a coronal dentine fracture occurred and the cemented post lost its retention.

These results show that root-treated teeth behave differently to vital teeth with regard to their tactile reactivity.

viewed using a magnifying glass. In the case of a subgingival margin, this examination is done with a suitable explorer.

Factors influencing retention

Retention of a crown

Factors influencing the retention of a crown on a prepared tooth are:

- Length of the prepared tooth
- Convergence angle
- Roughness of the preparation
- Roughness of the inner surface of the restoration
- Cementing agent.

Retention of a core build-up

The more the retention of the crown takes place on the build-up, the more important is its retention at the tooth. The build-up is attached to the tooth mechanically and/or chemically, depending on the material used. A plastic filling material can be condensed or syringed into undercuts, retention grooves or into the cervical part of the root canal. Additionally, it can be fixed by means of intradentinal pins or a post.

Retention of a post

The retention of a post depends on:

- Its design (tapered, parallel, individual)
- Insertion depth
- Macroretentions (thread, serrations)
- Microretentions (surface roughness)
- Cementing agent in combination with pretreatment of the dentine surface.

Fractures

Cohesive failure within a material occurs as a fracture.

Fractures of the superstructure

A fracture within the superstructure of a prosthesis does not depend on the endodontic treatment and can happen in a vital abutment as well, with the only difference that the reflective control of bite forces is reduced (33) due to the loss of receptors in the pulp or a change in the mechanoreceptor function in the periodontal membrane.

Core/post fractures

Core: The fracture susceptibility of a core build-up depends mostly on its dimensions, the material's strength and the forces acting upon it. Regarding these forces, there are major differences between anterior and posterior teeth in the amount and direction of force, the ratio between length and diameter and the area of the bonded surface. When a post is used, its coronal end can weaken the core build-up and exert stress, depending on its size and shape.

Post: A post often is the most retentive link in the chain of retention so will be more likely to cause fracture in the case of overload. Either it breaks itself or it fractures the root, depending on the strength of both. The fracture susceptibility of a post depends on the diameter, the material and the manufacturing process. It makes a great difference to the strength of the metal structure whether it is cast or wrought.

Tooth fractures

Factors influencing fracture risk

(1) *Mechanical properties of non-vital dentine*. For a long time endodontically treated teeth were thought to be more brittle due to a loss of moisture content. Several studies have investigated the mechanical properties of dentine in vital versus non-vital teeth (Key literature 12.2). Although the moisture content did vary significantly, the compression strength and tensile strength did not show any significant difference (14). Other factors may be more responsible for the increased fracture susceptibility of endodontically treated teeth.

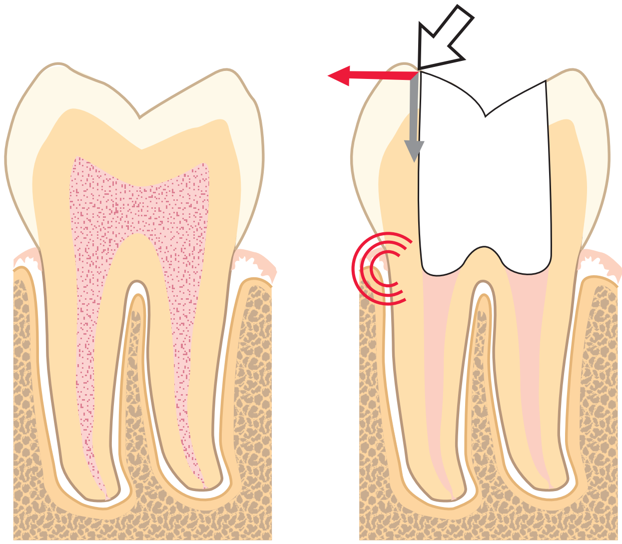
(2) *Amount of remaining tooth structure*. The loss of internal tooth structure in an endodontically treated tooth will be more responsible for its higher susceptibility to fracture than changes in its mechanical properties. Teeth with intact marginal ridges with only a small access preparation are most resistant against fracture and are not significantly weaker than intact teeth without any preparation (2, 10, 30, 34, 44). From a prosthodontic point of view, a maximum of internal tooth structure should be preserved to minimize the fracture risk. Thus, desirably the access would be minimal, i.e. just large enough to gain access to the canal. From this point of view the preparation of the canal, especially in the cervical area, should be as small as possible. This prosthodontic desire stands in contrast to modern endodontic concepts, where the direct straight access to the canal with a wide access opening for good overview is a general demand and good cervical flaring is recommended to ensure an optimal apical preparation, especially in curved canals. In more demanding root canal treatment it might be necessary to sacrifice sound tooth structure. In nearly straight canals the preservation of tooth structure can be the primary goal. The

Key literature 12.2

Sedgley and Messer (38) investigated the dentine in vital versus root-filled teeth: 23 matched pairs of contralateral teeth freshly extracted for prosthodontic reasons were subjected to different mechanical tests. One of the corresponding teeth was vital and the other was endodontically treated 1–25 years ago (mean 10.1 years). Into two slices of dentine 0.3 mm thick cut from the necks of the teeth, holes of 1 mm diameter were punched in a universal testing machine and the shear strength and toughness were calculated from the stress–strain curve. Additionally, in one of the slices the Vickers hardness was determined midway between the root canal and the periphery. The coronal root canal openings of the remaining roots were prepared as a seat for a cone-shaped steel rod, followed by loading the teeth until fracture in an axial direction.

Neither the punch shear strength or toughness nor the load to fracture differed significantly between vital and root-filled teeth. The hardness of the cervical dentine was 3.5% lower in endodontically treated teeth.

These findings indicate that teeth do not become more brittle following endodontic treatment.



(a) (b)

Fig. 12.2 (a) Intact tooth. (b) Forces acting on a root-filled tooth and resulting stress peak.

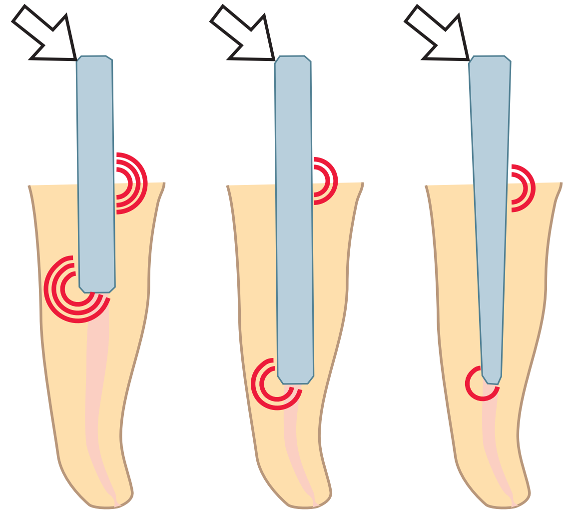


Fig. 12.3 Stress peaks at teeth with different posts.

prosthodontic reconstruction determines the forces acting on the tooth. The amount of tooth structure left after preparation determines its ability to carry loads. Which type of reconstruction is best suited for the remaining tooth structure needs to be judged at the very beginning of treatment.

When one or both of the proximal walls are lost, the tooth is substantially weakened as the support of the circumferential marginal ridges (and the roof of the pulp chamber) is lost and a horizontal force on a cusp acts over a long lever-arm on the weakest part in the cervical area, normally just above the alveolar crest. When a force acts on the oblique inner slopes of the cusps it will be divided into a vertical and a horizontal component, the latter exerting high stresses in the weak cervical portion (Fig. 12.2). Therefore an effective bonding or cuspal coverage is necessary whenever a proximal wall is lost and the cusps are not flat due to abrasion or anatomical form.

The (tensile) bond strength of any material to dentine is always weaker than the (tensile) strength of dentine. Therefore, the preservation of a maximum amount of dentine bulk should be the aim in endodontic therapy of an abutment tooth.

(3) *Type of post*. The type of post determines the amount of stress. Tapered posts, in contrast to parallel posts, lead to radial forces when loaded that are comparable to those of a wedge, and sharp edges (at the end of a post or at a tap) will induce stress, increasing the risk of root fracture (29, 42, 45).

(4) *Length of post*. The longer a post, the better the distribution of stresses, resulting in reduced stress at the apical end of the post because of leverage (Fig. 12.3) (15, 43). Extending the length to two-thirds of the root length results in a superior fracture resistance compared with short posts (16).

There is a lack of clinical data regarding the length of posts in relation to the level of alveolar bone, but it seems more favorable to extend the post below the alveolar crest when a post cannot be avoided.

(5) *Post diameter*. The thicker a post, the thinner and weaker will be the remaining tooth structure, leading to increased risk of fracture. On the other hand, a post must be thick and stiff enough to transmit lateral forces to the root uniformly. Normally, depending on the diameter of the root, the post diameter should not exceed 1.5 mm and in fragile roots this is less.

Perforations

Invaginations of the external root surface – stripping perforations

Roots are seldom round and often show curves, invaginations, flutes or other varieties in shape. The distal root of a mandibular molar is kidney-shaped in its cross-section, so care must be taken not to place the post preparation in the middle of the canal but in the bulkiest part of the root, i.e. the buccal or lingual edge (Fig. 12.4).

The mesial root of a lower molar and the mesiobuccal root of an upper molar are mostly curved in the distal direction. The most cervical parts of the canals go mostly

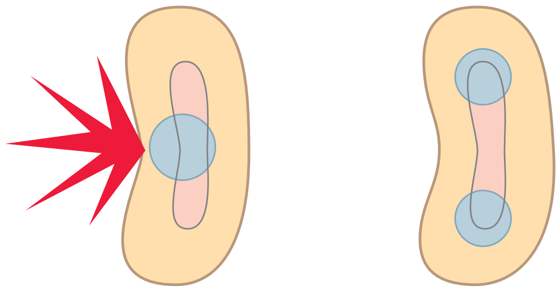


Fig. 12.4 Wrong and right placement of post in distal root of lower molar.

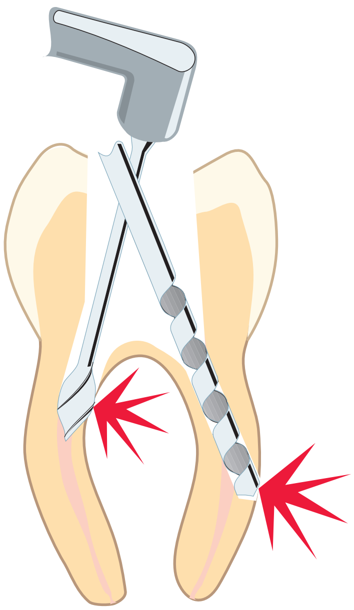


Fig. 12.5 Danger of perforation in curved canals.

in the mesial direction, so when this initial curve is not removed during the access preparation there is great danger of stripping perforation into the inter-radicular space or in the mesial direction (Fig. 12.5). Proper flaring and, especially, anticurvature filing are important not only to gain a straight access for the apical preparation of the canal but also for safe preparation of the post space (7).

Curvatures not perceptible in the X-ray

Even if the cervical part of the canal is straight, a more apical curvature may limit the length of a post. The most dangerous curvatures are in the plane not perceptible on the X-ray picture. Only knowledge of the anatomy of the root prevents perforation during preparation of a post space, e.g. the palatal roots of upper bicuspids and molars.

Deviation of the prepared canal

Gates–Glidden drills as well as Peeso reamers and some specific drills for post systems have a non-cutting self-centering tip, which ensures that the preparation of the post space will not deviate from a guiding canal being enlarged concentrically. In the case of a root filled tooth, the center of the root filling is the guiding structure. When the root filling deviates from the original canal, the center of the root filling is no longer the center of the root. Enlarging a deviated canal preparation concentrically can cause a lateral perforation, depending on the amounts of deviation, enlargement and dentine bulk in that direction.

Use of end-cutting drills

Special care must be taken when using the end-cutting drills provided with many post systems. Even when driven by hand, they can easily deviate from the canal. Therefore, removal of the root filling and preparation of the canal space should be done using drills with a non-cutting tip prior to use of the drills for these post systems (8, 31).

Excessive length/diameter

When a post is longer than the straight portion of the canal, a perforation is likely to occur. With increasing diameter of the post, not only the fracture risk but also the risk of perforation increases significantly, therefore a post should always be as thin as possible, i.e. just thick enough to gain some guidance and retention within the canal.

Reinfection/bacterial leakage

For leakage in general, see Chapter 13.

Microleakage of cemented posts

A major aim of the root filling is to seal the canal tightly to prevent bacterial leakage from the oral environment to the periapical tissues. Preparing the canal for receiving a post removes a substantial amount of the root filling and may disturb the seal of the remaining filling.

The subsequent cementation of posts may again seal the canal and reduce the risk of infection (9, 49). Adhesive luting of posts leads to a further decrease of leakage (3). However, leakage may occur during post space preparation. Immediate post space preparation is less likely to cause leakage than after complete setting of the sealer (32) and a root filling without tight seal of the access cavity allows leakage of bacteria within a few weeks (5, 48), so the post space preparation and the subsequent luting of the post should be established immediately. Aseptic conditions are imperative during post space preparation and ideally a rubber dam should be used. If impossible, it must be substituted by adequate moisture control and the post space should be irrigated with antiseptic solutions such as sodium hypochlorite, chlorhexidine or alcohol.

Length of root fillings under posts: There is clinical evidence that leaving at least 3 mm of apical root filling under posts decreases the probability of occurrence of periapical lesions (23). *In vitro* studies have shown that a remaining apical root filling of 5 or 7 mm prevents leakage better than one of 3 mm (28, 32), therefore a residual root filling of 3 mm should be the absolute minimum.

Kinds of core build-ups

Core build-up without a post

If enough coronal tooth structure remains to yield retention to a core build-up, a post will not be necessary. The build-up will fill the access cavity, any substance loss caused by caries or other reasons and may increase the height of the abutment. It must be taken into account that in most cases the outward walls of the remaining tooth structure will be reduced in thickness or removed completely during abutment preparation and so will not contribute to the final build-up retention. The retention of the build-up must be achieved at the tooth structure that remains after the final preparation!

Modern dentine adhesives are able to retain composite fillings in cavities without any retentive form but they may be overrated in successfully bonding build-up and prosthodontic reconstruction alone. For build-ups, a mechanical retention in addition to dentine bonding should always be used to gain a maximum overall retention.

The possibilities to achieve mechanical retention are different between single- and multi-rooted teeth. The size of the pulp chamber (in width and depth) in multi-rooted teeth is of considerable advantage for achieving mechanical retention. Undercuts are a natural property of multi-rooted teeth, with divergent canals thus providing excellent mechanical retention.

Because forces acting on all teeth are different and depend on the degree of destruction, further mechanical retention may be necessary via grooves, parapulpal pins or posts. In anterior teeth the forces act in a more horizontal direction and their cross-sectional area is smaller than in posterior teeth, resulting in unfavorable lever-arm relations.

Whenever the remaining tooth structure and the pulpal space support sufficient retention for the build-up, a post will be dispensable and should be avoided because the risks with the use of posts do not exceed the advantages in most cases.

Post and core systems

When a post is unavoidable there are different ways to establish it.

Prefabricated post/plastic core build-up
In contrast to a direct plastic build-up, an indirect one makes it necessary to remove undercuts, so that tooth structure valuable for strength and retention are removed. With a direct build-up the access cavity can be closed immediately after root filling. If this is done with a composite in combination with a suitable adhesive, the risk of bacterial leakage compared with a provisional closure is minimized. An adhesive build-up contributes more to the reinforcement of the tooth and minimizes the risk of fracture compared with a temporary material necessary during the period of manufacturing the laboratory-made post and core. These temporary materials do not bond to the tooth structure, they do not have the strength and it is necessary to remove them. Whenever a build-up with plastic material is possible it should be preferred (Core concept 12.2).

Cast post and core (direct/indirect technique)
To fabricate a cast post and core there are two different ways:

(1) The direct technique – an acrylic resin is used to form a core build-up directly in the mouth.

Core concept 12.2

The use of a prefabricated post in combination with a build-up in plastic material offers many advantages compared wtih a laboratory-made post:

(1) Saving of tooth structure:
  — undercuts can remain and serve for more retention.
(2) Immediate closure of the prepared canal.
(3) No need for a provisional restoration:
  — less danger of bacterial leakage
  — avoids higher fracture risk during provisional restoration
  — saves chairside time
  — saves cost.

In the case of a composite build-up, additional advantages are:

- Advanced esthetics
- Adhesive technique simply achievable
- Higher bond strength
- Decreased leakage.

(2) The indirect technique – making an impression and fabricating the post and core in the laboratory.

The resin used in the direct technique must be able to be burnt out completely during warming up in the casting procedure. It can be an autopolymerizing resin best used with a brush-on technique, applying alternately liquid and powder with a brush. A more convenient method is the use of a light-curing resin, owing to the individually determined working time and the absence of monomer vapors. Both resins can be prepared with the usual rotating instruments *in situ*. They can be used in combination either with a wrought precious alloy post, onto which the core part is cast, or with a burn-out acrylic post being lost in the cast procedure.

In the indirect technique there are also the two options of using a wrought precious alloy post to cast on or to cast the complete post and core from one metal. The mechanical properties of a wrought metal are superior to a cast one owing to the absence of voids and the more homogeneous structure being independent of the varying parameters of the casting procedure.

Indications for different kinds of core build-ups

The kind of build-up that is best suited for the individual situation depends on:

- The remaining tooth structure.
- The burden of the superstructure.

The ratio of these two factors influences not only the choice of build-up but also the prognosis of the long-term success.

In general, in all cases where sufficient retention can be gained without a post it should be avoided (Fig. 12.6). Whether a post and core should be of plastic material or a cast one is controversial. The plastic materials, especially composites, are usually preferred because their mechanical and adhesive properties have been improved.

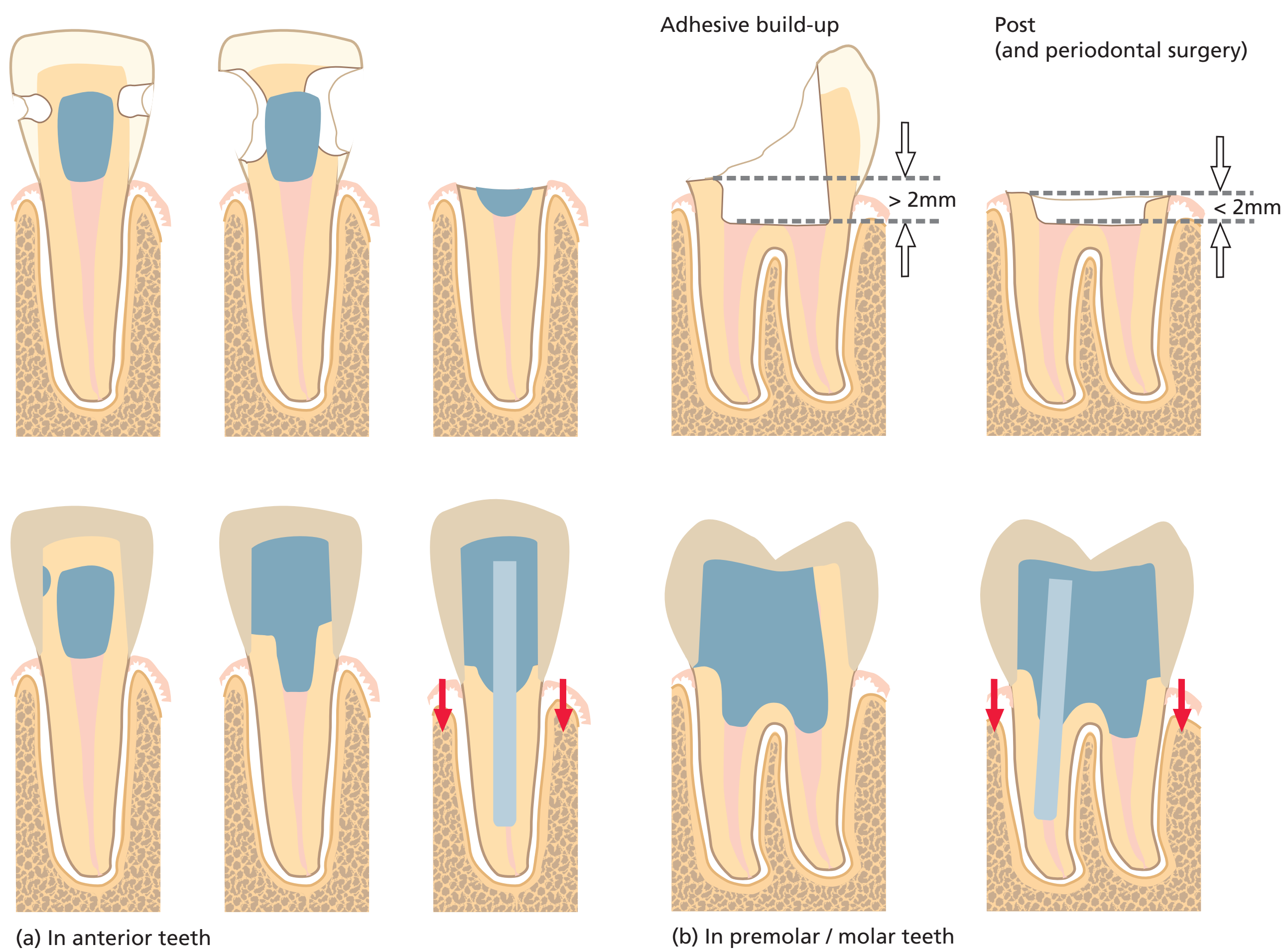


Fig. 12.6 Indications for different kinds of build-ups in anterior teeth (a) and premolar / molar teeth (b).

Bonding techniques for strengthening tooth structure

When a tooth with an open apex needs endodontic therapy, both the endodontic treatment procedures and the final restoration are a challenge. Because the walls of the root are thin, it is much more susceptible to fracture (47) and therefore an effective reinforcement is a major concern for long-term success. An effective reinforcement can be achieved by filling the post-carrying part of the root with light-curing composite using a transparent light-conducting post. After removal of that post, a prefabricated metal post can be cemented (Fig. 12.7), gaining a higher overall fracture resistance than a custom-made cast post and core, which is adapted to a weakened canal wall (37). By using light-transmitting posts, a curing depth up to 11 mm can be achieved, depending on the diameter of the post (26).

The risk of fracture increases from the beginning of endodontic therapy, so effective protection is necessary between appointments during a longer lasting endodontic treatment aiming at apexification of thin-walled roots. The above-described technique can be used also before finishing the endodontic treatment, allowing access to the apical part of the canal. A strengthening effect of an internal composite reinforcement up to 3 mm apical to the cemento-enamel junction has been verified (19).

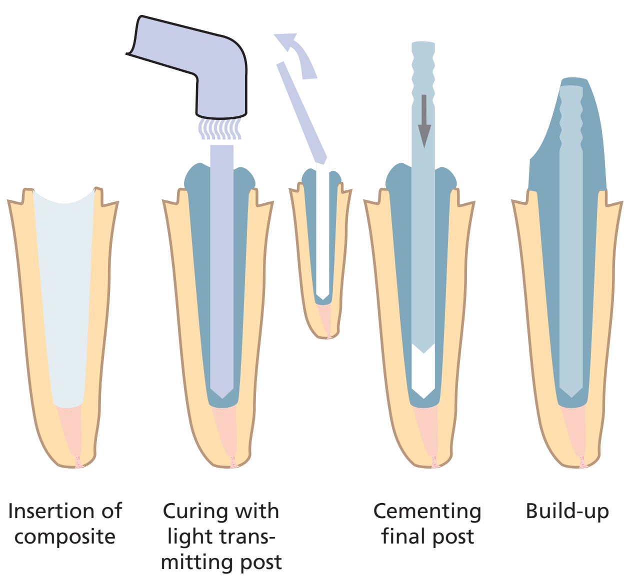


Fig. 12.7 Clinical procedure for strengthening thin-walled root: insertion of composite; curing with light-transmitting post; cementing final post; build-up.

Core build-up materials

Amalgam

Amalgam has been widely used for a long time as a plastic core material. It offers good mechanical and handling properties and has shown its suitability for core build-ups used with posts, pins or other retentive features (17, 25, 30, 46). However, in the discussion about mercury toxicity, this material has gained a bad reputation in latter years and its use for that purpose has been restricted in some countries.

Composites

Composite is the material of choice for a plastic core build-up. In combination with dentine adhesives it offers the possibility of superior bond strength to the tooth structure over the entire surface, leading to higher retentive strength. Its mechanical properties make it suitable even for substitution of more than half of the coronal tooth structure. Depending on the kind and amount of fillers, its hardness can be determined similar to that of dentine, facilitating the final abutment preparation. Its modulus of elasticity should be equal to or higher than that of dentine, resulting in enhanced reinforcement. In anterior teeth it also has aesthetic advantages when used in combination with all-ceramic reconstructions.

Ceramics

Recently, high-performance ceramics were introduced as core build-up materials, especially in anterior teeth. They have not only esthetic advantages but also superior strength. Using a surface pretreatment that depends on the kind of ceramic, they are cemented adhesively to the tooth, gaining a stabilizing effect. The fabrication of a ceramic post–core build-up is comparable to that of a cast metal post and core, not only because it is also done in the laboratory but also because there is the option to use a ceramic pressed around a preformed ceramic post or to fabricate the post–core build-up in one material as glass-infiltrated alumina (20). As a third option, post and core can be separate parts bonded together during the insertion (22).

Cements

Even cements with the highest compressive strength – the metal-reinforced glass ionomer cements – are not suitable as a core build-up material. Compared with composite resins or amalgam in studies regarding frac-

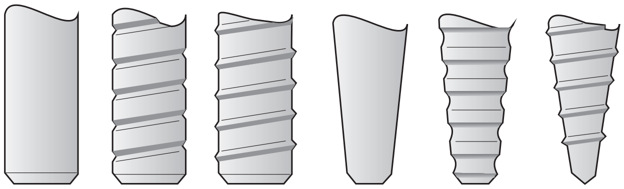


Fig. 12.8 Different types and shapes of posts.

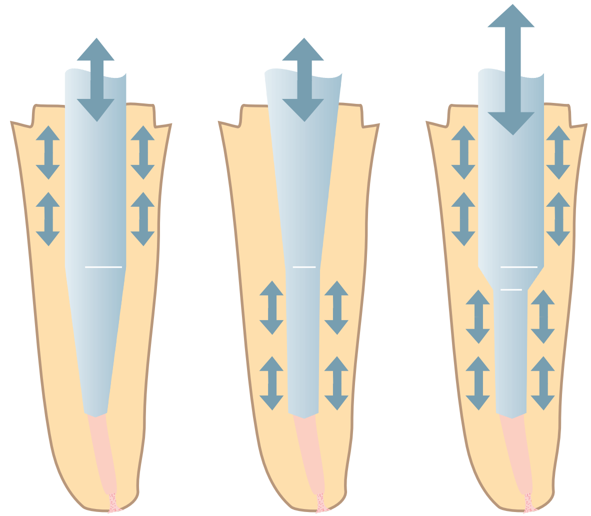


Fig. 12.9 Retention of different shapes of posts.

ture resistance, composite resins and amalgam always performed much better.

Resin-modified glass ionomer cements and compomeres, respectively, achieve a fracture strength similar to that of composite, but they undergo a slow expansion under water sorption leading to cracks in overlaying ceramic crowns (40). Thus, they are likely also to exert stress to other restorations and tooth structure.

Post systems and materials

Post systems: cylindrical, tapered, screws

In general, prefabricated posts may be either cylindrical or conical in shape, or a combination of both. Their surface may be smooth, rough or equipped with retentive devices such as grooves or a tap (Fig. 12.8). The two basic shapes have advantages and disadvantages and the principle of gaining retention is different for both geometrical forms.

A smooth cylinder that fits exactly into its matching cylindrical hole has no retention by itself because there is no force perpendicular to the fitting surfaces pressing the cylinder's surface against the hole's wall. By cementing a cylindrical rod into the corresponding hole, a tensile force onto the rod is changed into a shear load onto the cementing agent. The retention depends on the shear bond strength between the luting agent and the two surfaces and the shear strength of that material. This method of force conduction is favorable with respect to the properties of the luting agents commonly used in dentistry.

Any cone-shaped rod fits exactly into its matching hole. Because of the oblique shape of this rod, vertical forces are transformed into radial forces acting on the hole's wall. The amount of this force pressing the rod's surface against the walls depends on the convergence angle. This force increases the friction because friction is a function of the force perpendicular to the interface. On the other hand, this force produces stress over the entire length in a radial direction where the root is most susceptible to longitudinal fracture. When the retention is lost in a conical post it is lost suddenly and completely, in contrast to a parallel post where, after a first dislocation, there is still residual retention due to the parallel sites of the post.

A parallel post does not stress the root dentine at the walls of the post space but does not match the anatomical form of most of the roots. Thus, a parallel post of adequate diameter in the cervical area and of the same diameter in the apical area produces a potential point of fracture at the end of the post where the diameter of the root decreases, leaving a weak area in the remaining dentine wall. When the end of the post is not rounded or tapered, the sharp edge leads additionally to a peak in the stress of this area and the risk of perforations is high.

The shape of the post also has an influence on the insertion when a luting agent has to flow out of the prepared post hole. Although the space between a tapered post and its preparation diminishes continuously during insertion, a precisely fitting parallel post has a very small space for cement to escape from the very beginning of insertion. Thus, a parallel post must always have a venting groove for escape of the luting agent.

Each shape has distinct disadvantages of its own but by using suitable combinations (Fig. 12.9) these can be decreased. The most retentive one of these is a parallel post with a diameter decreasing in steps (right illustration in Fig. 12.9).

Surface structure, i.e. roughness, is of importance for both the post and the post's space. Different means are used to achieve sufficient surface roughness. Posts may be sandblasted, whereas the post's space may be roughened by mechanical means or chemically pretreated to gain micromechanical retention. Serrations of the post add significantly to retention.

Post materials

Metals

The most important mechanical property of a post material is Young's modulus for stiffness and tensile strength, resulting in fracture strength against bending forces. From that point of view stainless steel is superior to precious alloys and pure titanium. Under unfavorable conditions, which might be the case in the clinical situation, stainless steel is not resistant against corrosion. Corrosion may lead to loss of retention, structural weakening with subsequent post fracture or, most deleterious, to root fracture due to the expansion of the corrosion products. Stainless steel is therefore no longer licensed in Europe. Precious alloys showing no corrosion are somewhat weaker but still strong enough when used as a wrought post. They are the materials of choice for a cast post and core. Cobalt–chromium-based alloys are an economical alternative but they require troublesome work in the laboratory procedures.

The problems associated with the casting technology of titanium are due to the low specific weight and the high melting point, therefore it is necessary to check every cast object against porosities by X-rays but it cannot be excluded that microporosities still remain undetected to weaken a cast post and core. The mechanical properties of machined titanium alloy posts are superior compared with cast pure titanium individual post and cores (18).

Fiber-reinforced resins

Recently, epoxy-based carbon-fiber posts were marketed, followed by quartz and glass-fiber posts. They are luted adhesively and used in combination with a composite core material. *In vitro* studies have shown that the fracture resistance is lower compared with that of metal posts. But the mode of failure is fracture of the post or cervical root fracture, which is more favorable than the often much deeper root fractures of the metal posts. Furthermore, the fiber posts are easy to remove in the case of retreatment (27, 39).

Ceramics

In latter years new ceramics with high strength have come into clinical use as promising materials for full ceramic reconstructions: namely yttrium oxide partially stabilized zirconia and glass-infiltrated aluminium oxide ceramics (22). They offer high strength, the former produced as prefabricated posts and the latter used for custom-made post and core construction. Fabrication by cutting the shape out of a prefabricated block is also possible with these materials. Although a zirconia post is as strong as a titanium post and has a higher stiffness (1), its use should be judged carefully. There are still no long-term clinical results and the removal of such a post if retreatment should become necessary might be impossible, or at least conducted with a very time consuming procedure, leading to excessive dentine loss and a high risk of lateral root perforations.

Preparation techniques for posts

Moment of post preparation

After finishing the endodontic treatment it is essential to take precautions so that the risk for bacterial leakage along the remaining root filling is avoided. The final restoration therefore should be established as soon as possible (5, 48). Another reason for an immediate preparation of the post space is so that the dentist is still familiar with the individual canal anatomy.

Heat

The safest method of removing the root filling material without leaving the canal is by hot instruments and they should be used always as a first step in achieving the post space preparation. A hot plugger is introduced into the canal, repeatedly softening and removing the gutta-percha until most of the length is cleared. The use of solvent agents to soften the gutta-percha is obsolete because their action cannot be limited and there is evidence of more leakage after their use (28).

Rotating instruments

The next step in preparing the post space is the use of rotating instruments. It is essential to begin with instruments equipped with a non-cutting tip. In contrast to Gates–Glidden drills, Peeso reamers ensure a straight preparation. The drills are used in ascending diameters with low speed to avoid excessive heat (36). Orifice openers can also be used. The size of the last file gives an orientation about the appropriate diameter for the post. As soon as the rotating instrument cuts into dentine over almost all of the circumference, the corresponding drill of the post system is used. These drills often have end-cutting tips so they must be used very carefully and only for the final preparation to avoid perforations. After completing the preparation, an X-ray should be performed with the post in place to ensure its proper positioning.

Length of posts

This is limited by the curvature of the root and the necessary root filling needed to prevent leakage. An absolute minimum of 3 mm of apical root filling should remain (23). The length of a cylindrical post may be limited owing to excessive weakening of the root at the apical end of the post.

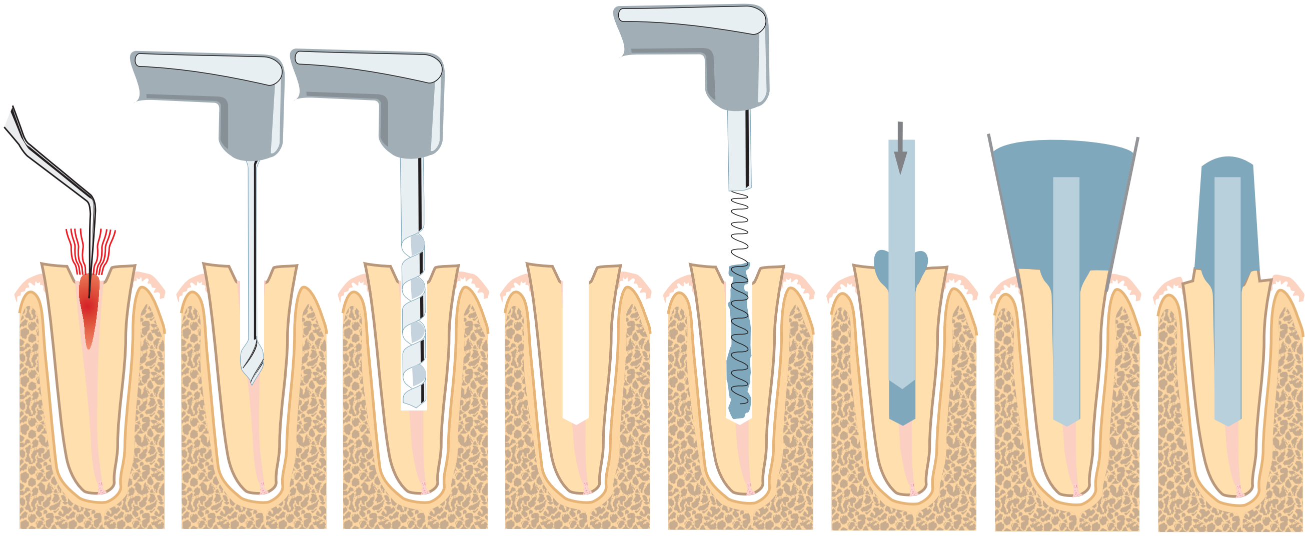


Fig. 12.10 Clinical procedure for preparing and inserting a post.

Cementing posts

The retention of a post depends more on factors such as shape, length and surface roughness than on the cementing agent. The cementing agent has to fill the gap between post and dentine wall and to transduce the forces between both. The classical cementing agent for fixed restorations is zinc phosphate cement. It is still the material of choice for metal posts in a standard situation because it is uncritical in handling and regarding dentine pretreatment. It is removable by ultrasonic instruments when retreatment is necessary. Resin cements are required for adhesive luting of ceramic or carbon-fiber posts. They require an adequate dentine pretreatment for removing or modifying the smear layer that is always present on mechanically treated dentine surfaces. On using dentine adhesives the manufacturer's instructions must be followed carefully. Of all resin cements, the most widely used and best proven contains active phosphate monomers. It has superior bond strength, especially towards metal. The curing has a distinct oxygen-prohibiting effect so that spreading on the mixing pad can prolong the working time.

In the cementing procedure it is essential to ensure dry conditions. The post space is rinsed with water and dried with paper points. Also, in the case of the use of zinc phosphate cement, removing the smear layer with ethylenediaminetetraaceticacid (EDTA) is recommended to clean the canal and enhance retention. The cement is mixed to a creamy consistency and applied with a lentulo spiral into the post preparation. The post is than seated carefully until it reaches the bottom of the preparation and left to harden undisturbed.

When using fast-setting resins the use of a lentulo spiral may be fateful because premature setting may hinder complete positioning of the post. When using these materials only the post is coated with the cement (21).

Prosthodontic reconstruction

Single tooth

The simplest case of prosthodontic reconstruction is the restoration of a single tooth. Often a prosthodontic reconstruction can be substituted by a composite filling (Fig. 12.11). When the composite is bonded to etched enamel and dentine by use of a suitable adhesive, the fracture resistance is increased considerably (11). As a temporary solution, an amalgam filling is also possible (Fig. 12.12). In the case of lost proximal ridges, a cuspal coverage should be established to reduce the risk of fracture (12, 13). Such an amalgam filling can last for some years and allow a proper observation period. Later on, the filling can remain as a core build-up and be prepared to receive the final cast restoration. This is also a cost benefit for the patient.

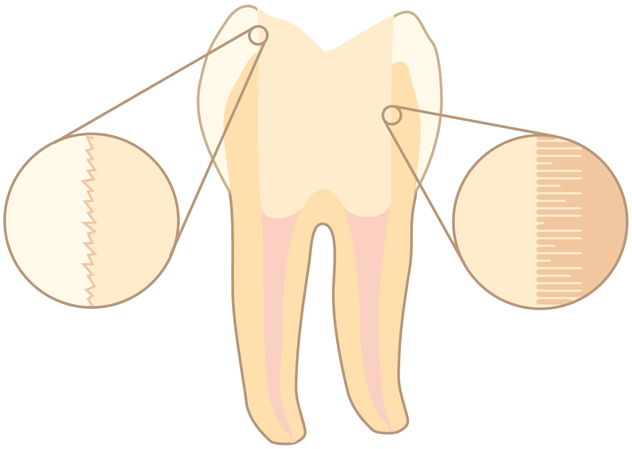


Fig. 12.11 Composite restoration.

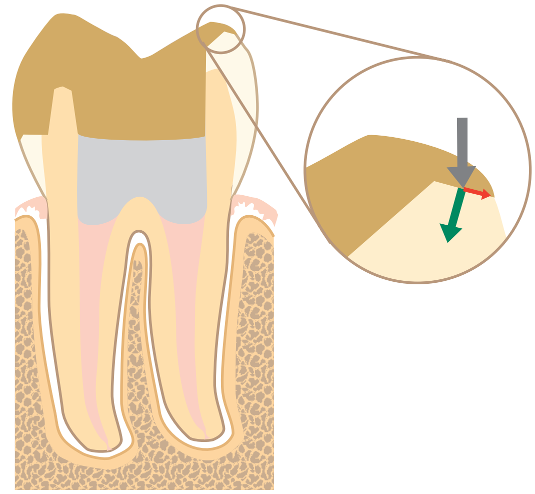


Fig. 12.14 Onlay.

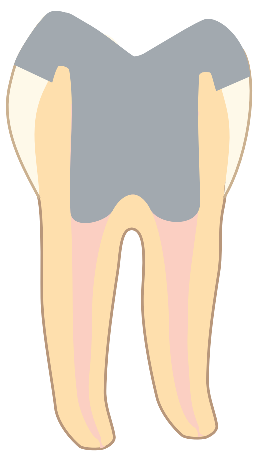


Fig. 12.12 Amalgam restoration.

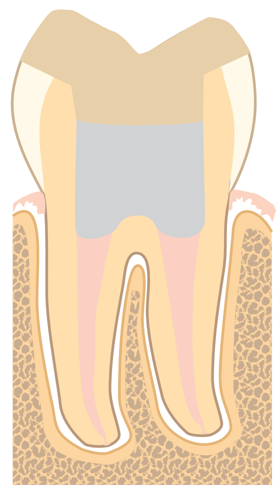


Fig. 12.15 Ceramic onlay.

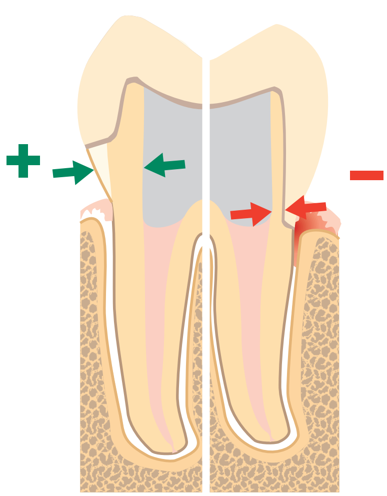


Fig. 12.13 Crown with different levels of preparation.

When the crown preparation is carried out the margin of the preparation should end as high as possible to the occlusal in order not to weaken the cervical area, which is weakened from the inside during endodontic therapy (Fig. 12.13). For this reason a partial crown or an onlay (Fig. 12.14) with a maximum preservation of sound tooth structure is most desirable. In an onlay, even minimal embracing of a cusp ensures that occlusal forces cannot act in a horizontal direction (see detail in Fig. 12.14).

In the case of thin remaining walls of coronal tooth structure and esthetic demands, a full ceramic restoration (Fig. 12.15) offers the advantage of adhesive bonding throughout the entire surface (35) and can be made as a core build-up and crown restoration in one piece (Fig. 12.16), which is desirable in the case of substantial loss of tooth structure (6).

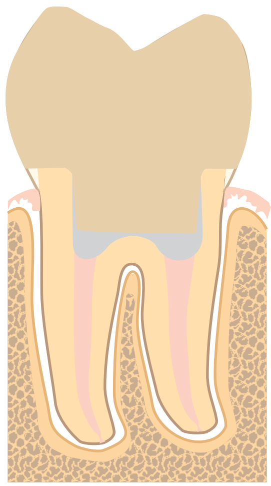


Fig. 12.16 Full ceramic 'endo-crown'.

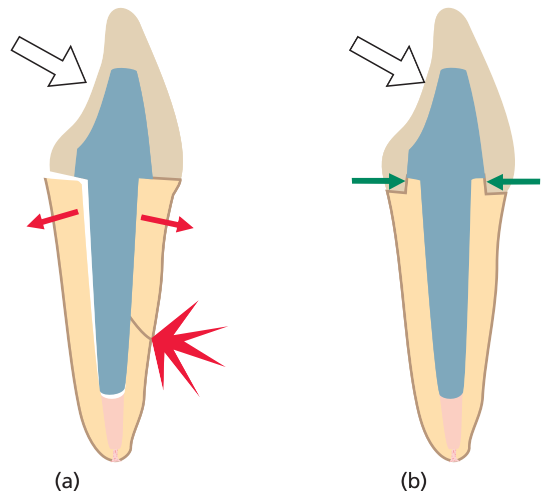


Fig. 12.17 (a) Risk of fracture without ferrule. (b) Effect of ferrule.

Preparation principles

Internal loss of tooth structure

The reduction of internal tooth structure takes place in several steps during the endodontic and restorative treatment:

- Access cavity
- Coronal flaring
- Preparing the root canal
- Preparing the post space (if needed)
- Removing undercuts, if a custom cast post and core will be established.

Although sufficient access and proper flaring are necessary for the success of endodontic treatment, every loss of dentine weakens the tooth (12). Thus, when a tooth serving or going to be used as an abutment needs endodontic treatment, the preservation of tooth structure must be considered during the endodontic procedure as well. When a tooth is already provided with a crown, it is highly recommended to remove the reconstruction before gaining access to the pulp chamber. This is done to achieve better orientation concerning two aspects: because the tooth has lost its natural shape, cervical or interradicular perforations are more likely to occur; and the amount of coronal dentine left is clearly visible. After endodontic treatment the decision for the kind of build-up is facilitated. Leaving the reconstruction in place makes the determination of the amount of coronal dentine impossible and allows only a blind estimation unless the reconstruction enables radiographic examination, as in the case of full ceramic crowns.

Ferrule design

Special care must be taken in the restoration of a tooth with a minimal amount of remaining coronal tooth structure, i.e. when the complete clinical crown is decayed and only the root remains. In this case a post will be necessary for sufficient retention. Generally, with decreasing root length the crown length will increase, resulting in an unfavorable ratio of leverage of crown versus root. Horizontal loads are supported and transferred by the post to the root, resulting in extreme tensile stress and thus increasing the risk of root fracture dramatically. A marginal preparation that embraces the root effectively participates in the transfer of horizontal forces onto the root and decreases the forces transferred by the post cervically on the opposite side (Fig. 12.17). Such an embracing collar is usually called a ferrule (Key literature 12.3). A prerequisite is the establishment of a ferrule of 1.5–2 mm (4, 14, 24, 41). If this is not possible, primarily a surgical crown lengthening procedure should be considered.

Key literature 12.3

In 1995 Libman and Nicholls (24) divided 25 extracted human central incisors into five groups and prepared them for complete cast crowns. Test teeth had cast dowel cores fabricated, with the ferrule height varying from 0.5 to 2.0 mm in 0.5-mm increments. The five control teeth did not have cast dowel cores. A 4.0-kg load was applied cyclically to each of the restored teeth at an angle of 135° to the long axis of each tooth at a rate of 72 cycles per minute. The load application point was predetermined by a waxing jig that was used to wax all crowns. An electrical resistance strain gauge was used to provide evidence of preliminary failure. Preliminary failure was defined here as the loss of the sealing cement layer between crown and tooth. The results of this study showed that the 0.5-mm and 1.0-mm ferrule lengths failed at a significantly lower number of cycles than the 1.5-mm and 2.0-mm ferrule lengths and control teeth.

For prosthodontic reconstructions substituting lost teeth a higher burden onto the remaining abutment teeth must be considered.

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