Cemental Tear: Literature Review, Proposed Classification and Recommendations for Treatment

Abstract

Cemental tears are an important condition of relevance to endodontics but are often overlooked. A cemental tear is the partial or complete detachment of the cementum from the cemento-dentinal junction or along the incremental line within the body of cementum. The limited attention received is most likely due to the low awareness amongst the dental professionals and challenges in accurately diagnosing them, resulting in misdiagnosis and erroneous treatment. The aim of this review is to describe the: (i) epidemiology and predisposing factors; (ii) clinical, radiographic and histological features; and (iii) the clinical management and treatment outcomes of cemental tear. This review included 37 articles published in English literature that comprised 8 observational studies and 29 case reports. The prevalence of cemental tears was reported to be lower than 2%; while the incidence remains unknown. *Internal factors* due to the inherent structural weakness of cementum and its interface with the dentine, and *external factors* that are associated with *stress* have been proposed as the two mechanisms responsible in the development and propagation of cemental tears. Predisposing factors that have been implicated were *tooth type*, *gender*, *age*, *previous root canal treatment*, *history of dental trauma*, *occlusal trauma and excessive occlusal force*; however, evidence is limited. Common clinical and radiographic manifestations of cemental tears resemble the presentations of primary endodontic diseases, primary periodontal diseases and combined endodontic-periodontal lesion. Clinical management usually focused on complete removal of the torn fragments and periodontal treatment, often combined with regenerative treatment. In this article, a new classification for cemental tears is developed that consists of *Class 0* to *6* and *Stage A*, *B*, *C* and *D* based on the: (i) location and accessibility of the torn cemental fragment; (ii) the pattern and extension of the associated bony defect in relation to the root length; and (iii) the number of root surface/s affected by the cemental tear/s and the associated bony defect. Recommendations for treatment strategies are also provided and linked to the classification to aid in streamlining the process of treatment decision making.

Keywords: Cemental tear, cementum, review, classification, treatment, regenerative treatment, infrabony defects.

Cemental Tear: Literature Review, Proposed Classification and Recommendations for Treatment

Introduction

A cemental tear can be either the incomplete or complete detachment of the cementum from the cemento-dentinal junction (CDJ) or its partial detachment along the incremental line within the body of cementum of the tooth root (Watanabe *et al.* 2012). Its incidence, prevalence, aetiology and mechanism of development remain a subject of debate and ongoing research (Lin *et al.* 2011, Lin *et al.* 2012, Lin *et al.* 2014, Jeng *et al.* 2018). In practice, it is common for cemental tear to be misdiagnosed as a vertical root fracture, an endodontic-periodontal lesion or as a failed periodontal or endodontic treatment (Tai *et al.* 2007, Jeng *et al.* 2018). Therefore, signs such as rapidly progressing periodontal attachment loss, isolated deep periodontal pocket, persistent abscess or sinus tract, despite adequate periodontal and/or endodontic treatment should alert clinicians to include a cemental tear within the differential diagnosis (Haney *et al.* 1992, Marquam 2003).

The diagnosis of cemental tear is often challenging, even for the experienced clinician (Ong *et al.* 2019). Lin and co-workers emphasized that careful evaluation of intraoral radiographs is essential to minimise the risk of misdiagnosis and unnecessary treatment (Lin *et al.* 2011). However, two-dimensional radiographic images, amongst its other well-known limitations, only allows the detection of cemental tear on the proximal aspects of the root (Lyons *et al.* 2005). Although direct inspection of a torn cemental fragment during exploratory surgery or extraction is indeed possible, histopathological findings from biopsied specimens remain the gold standard to confirm its diagnosis (Xie *et al.* 2017).

Currently, no clinical guideline or protocol is available on the management of cemental tears. Differences among clinicians in the management of cemental tears are reflected in the published case reports with variable treatment outcomes (see Table 1). These differences may be attributed to the individual's clinical experience, skill, background of specialty training, perceived worthiness to save the tooth, working environment and preference of the patient. The aim of this paper is to comprehensively review:

(i) epidemiology and predisposing factors;

(ii) clinical, radiological and histological presentations;

(iii) clinical management; and

(iv) outcome of cemental tear.

Electronic databases, including PubMed, Medline, Embase, Web of Science and Google Scholar, were searched using the terms 'cemental tear', 'cemento-dentinal tear', 'cementum fracture' and 'cementum crack'. Publication cut-off date was set to May 2021. In addition to the electronic databases, the 'accepted articles', 'early view' and 'pre-published online publication" of major international dental journals were also hand searched. Two independent reviewers (AL and PN) were involved in reviewing the full text of all the articles identified to ensure the articles fulfilled the overall scientific evidence for cemental tears. The reviewers also cross-checked the reference lists in all the reviewed articles, to ensure the articles listed had been identified via previous electronic and hand searches. In this literature review, 37 articles published in English language were reviewed, including 8 observational studies and 29 case reports (Table 1).

In this article, a new classification system for cemental tears from a three-dimensional perspective is proposed. Furthermore, treatment strategies are recommended for the management of cemental tears based on the:

(i) pulpal and periradicular status of the affected tooth;

(ii) presence or absence of signs and symptoms, occlusal trauma and tooth mobility;

(iii) location, extension and accessibility of the torn cemental fragment to mechanical removal; and

(iv) degree and pattern of alveolar bone loss.

Treatment strategies are also linked to the proposed new classification to aid in streamlining the process of treatment decision making.

Epidemiology and predisposing factors of cemental tears

Currently, the incidence of cemental tears remains unknown, perhaps due to their rare occurrence and low awareness of their existence among dental professionals. To date, only 2 articles have studied the prevalence of cemental tears. In a Turkish dental school, Keskin and Güler (2017) conducted a retrospective observational clinical study on a sample population of 1451 adult patients and 4629 permanent teeth using periapical radiographs taken using the bisecting angle technique, and reported the prevalence of cemental tears as 0.89%. Özkan and Özkan (2020) conducted a similar study based on the assessment of 813 cone-beam computed tomography images and reported a similarly low frequency of 1.9%. Both studies are limited in that they verified cemental tears from radiographs alone, without clinical examination.

Cemental tears usually present with either incomplete or complete separation of cementum along the root surface at the CDJ (Leknes *et al.* 1996, Watanabe *et al.* 2012), but it can also occur within the body of cementum along the incremental line or involve part of the root dentine adjacent to the cementum (Chou *et al.* 2004, Tai *et al.* 2007). Lin *et al.* (2012) studied 49 histological specimens collected from the teeth with cemental tears and found that the majority of the separation occurred at the CDJ (77.6%), while the rest occurred within the cementum (22.4%). Similar findings were also observed by Moskow (1969) (Table 1).

Once formed, cemental tears can induce local mechanical irritation to the surrounding periodontal tissues and alveolar bone, caused by the intermittent movement of the cemental fragment under functional occlusal loading (Qari *et al.* 2019). This movement has been claimed to sustain low-grade inflammation within the surrounding tissues (Qari *et al.* 2019). It has been postulated that the extension of inflammation in the coronal direction and the subsequent breakdown of the periodontal apparatus may eventually lead to communication of cemental tears to the oral environment through the formation of a periodontal pocket, opening a pathway for plaque accumulation and retention. Invasion of microbial pathogens via the exposed dentinal tubules, accessory or lateral canals may also create reservoirs of infection that serves to perpetuate and aggravate the periodontal and pulpal inflammation (Seltzer *et al.* 1963, Adriaens *et al.* 1988, Giuliana *et al.* 1997). It has also been theorized that periapical inflammation caused by the mechanical irritation of apically located cemental tears that have no communication to the oral environment should remain as sterile inflammation, except when the root canal system becomes infected.

Two mechanisms have been proposed in the formation and propagation of cemental tears, namely *internal* and *external factors* (Watanabe *et al.* 2012) (Table 2). *Internal factors* are largely congenital in origin and related to an inherent structural weakness in cementum. It has been attributed to the weak interconnecting fibrillar structures and adhesion between the cementum to dentine at the CDJ, or due to the structural weakening of the secondary or tertiary cellular cementum (Yamamoto *et al.* 1999, Watanabe *et al.* 2012). The interconnecting connective tissue between cementum and dentine at the CDJ comprises mainly glycoprotein, predominantly bone sialoprotein and osteopontin (Yamamoto *et al.* 2004). Hypothetically, this creates a connection that is weaker at the CDJ than the interface connecting the cementum to the periodontal ligament as the continuity of fibres in the connective tissue may be disrupted by glycoprotein (Haney *et al.* 1992).

Cementum can be categorized into two types, namely *acellular cementum* (i.e. cementum that contains extrinsic (Sharpey's) collagen fibres with no cell inclusions embedded within the collagenous matrix), and *cellular cementum* (i.e. cementum that contains mainly of intrinsic collagen fibres with the inclusion of cementocytes in the lacunae within the collagenous matrix) (Gonçalves *et al.* 2005, Yamamoto *et al.* 2016). Extrinsic (Sharpey's) fibres are secreted by fibroblasts and cementoblasts, whereas intrinsic fibres are secreted solely by the cementoblasts (Yamamoto *et al.* 2016). Functional impairment of the cementoblasts, as seen in specific systemic conditions such as malnourishment or aplastic anaemia, has been speculated to be associated with the weakening of the thickened *cellular cementum* (Watanabe *et al.* 2012). This predisposes the thickened secondary cementum to the development of cracks along the lamellar structure, typically seen in cases where multiple teeth are affected (Watanabe *et al.* 2012). Such cemental cracks can develop even when teeth are subjected to normal occlusal forces and continue to propagate into cemental tears with time (Watanabe *et al.* 2012). It remains unknown if aging of the cementum is a causative factor for cemental tears, although deterioration of the interface at the CDJ as a consequence of the aging process may potentially increase its susceptibility to cracks (Grant *et al.* 1972, Haney *et al.* 1992), and patients more than 60 years of age have been reported to be more predisposed to this condition (Lin *et al.* 2011).

By contrast, *external factors* are stress-induced and inflicted by intermittent or sudden episodes of stress in an excessive and abnormal fashion (Noma *et al.* 2007), causing a fracture line to develop along the CDJ or within the cementum itself (Watanabe *et al.* 2012). In fact, several case reports of cemental tears have been linked to a *history of dental trauma* (Camargo *et al.* 2003, Stewart *et al.* 2006, Kang *et al.* 2016, Borkar *et al.* 2019, Chawla *et al.* 2019, Nathani *et al.* 2021) or *occlusal trauma* (Harrel *et al.* 2000, Chou *et al.* 2004, Park *et al.* 2018, Borkar *et al.* 2019) (Table 1). Cemental tears have been postulated to occur on the pressure side of the tooth inflicted by occlusal trauma (Fan & Caton 2018). According to Noma *et al*. (2007), initiation of a cemental crack usually occurs in the more coronal region of the root. The crack propagates in an apical direction under repeated functional loading in a temporal manner.

Effects of *internal* and *external factors* may be aggravated by the loss of periodontal support that increases the susceptibility of a periodontally involved tooth to injury. This is due to the effect of secondary *occlusal trauma* (Watanabe *et al.* 2012), and structural weakening of the cementum as the result of mechanical instrumentation from periodontal therapy and bacterial infection (Moskow 1969, Leknes *et al.* 1996, Nathani *et al.* 2021) (Table 1). Reduction in the strength of dentine as the result of fatigue stress, age-related tissue changes, previous endodontic treatments and brittleness associated with the thickened secondary or tertiary cementum are also believed to contribute to the development of cemental tears (Dastmalchi *et al.* 1990, Yamamoto *et al.* 1999, Marquam 2003, Lyons *et al.* 2005, Tulkki *et al.* 2006).

From the literature review, several potential predisposing factors were identified, which include tooth type, gender, age, previous root canal treatment, history of dental trauma, and occlusal trauma or excessive occlusal force. However, any correlation established could only be regarded as 'suggestive' in nature at best due to an obvious lack of clinical studies with strong level of evidence in this area. Each of these factors will be discussed with reference to currently available evidence.

Tooth type

Tooth type was not reported to be a significant risk factor in two recent observational studies (Keskin & Güler 2017, Özkan & Özkan 2020). However, this was in disagreement with earlier studies that reported the association of anterior teeth with increased cemental tears (Leknes *et al.* 1996, Lin *et al.* 2011). Moreover, maxillary central incisors have been shown to be more frequently affected among the anterior teeth (Keskin & Güler 2017, Qari *et al.* 2019), even though others did not report any significant difference between the maxillary and mandibular central incisors (Lin *et al.* 2011). A summary of the case reports reviewed of 41 patients and 58 teeth revealed that cemental tears occurred in 34 (59%) anterior teeth, 17 (29%) premolars and 7 (12%) molars (Table 1). It can be argued that both the clinicians and patients might have been more willing to invest time, effort and money towards diagnosis and treatment of the anterior teeth due to their aesthetic value, in spite of facing non-healing after initial treatment; hence the greater chance of cemental tears being correctly diagnosed, treated and reported in anterior teeth.

Gender

The review of 41 patients in the case reports revealed that 26 (63%) were males and 15 (37%) were females (Table 1). Lin *et al.* (2011) conducted a retrospective clinical study on 71 teeth with cemental tears and documented that males and females contributed 77.5% and 22.5% to the total specimens studied, respectively. Other clinical studies failed to reveal any significant difference between genders (Keskin & Güler 2017, Özkan & Özkan 2020), but this might be due to the detection of cemental tears in only very small number of samples in relation to the total sample size.

Age

The average *age* of the 41 patients reviewed from the case reports were approximately 60 years old, ranging from 22 to 83 years (Table 1). Lin *et al*. (2011) also reported that cemental tears were found more frequently in persons older than 60 years of age compared to their younger counterparts. However, others did not find *age* as a significant risk factor (Keskin & Güler 2017, Özkan & Özkan 2020) (Table 1).

Previous root canal treatment

Thirteen (22%) of the 58 teeth reviewed had been previously root canal treated (Table 1). Similarly, Lin *et al*. (2011) reported that 24% of the teeth examined had been root canal treated and no significant correlation between the history of root canal treatment and the occurrence of cemental tears had been identified. It is noteworthy to mention that *previous root canal treatment* might be confounded by earlier misdiagnosis and subsequent treatment that is actually unnecessary in spite of the presence of cemental tears, which might make it difficult to investigate the cause and effect relationship. Keskin and Güler (2017) reported the detection of significantly more cemental tears in teeth that had not received *previous root canal treatment* compared to those that had received treatment (Table 1).

History of dental trauma

This literature review showed that 10% (i.e. 6 out of the 58 teeth) of the cases presented with a *history of dental trauma* (Table 1). Although Lin and co-workers also reported that 9.5% of the teeth examined had experienced traumatic injury, they did not find past dental trauma as a significant risk factor (Lin *et al.* 2011). Another possible means of dental trauma is the traumatic injury inflicted from extraction of a neighbouring tooth (Tulkki *et al.* 2006), supposedly due to injudicious use of the tooth as an anchorage or fulcrum, and direct damage to the periodontal apparatus during extraction. A rare finding of cemental tear on an autotransplanted molar has been reported (Nagata *et al.* 2016a), which might be associated with the trauma inflicted from the surgical manoeuvres during autotransplantation procedures.

Occlusal trauma or excessive occlusal force

A number of case reports suggested the impact of traumatic occlusion, severe occlusal tooth wear and the abutment tooth of a prosthesis as potential contributing factors (Haney *et al.* 1992, Harrel *et al.* 2000, Chou *et al.* 2004, Tai *et al.* 2007, Lin *et al.* 2010, Damasceno *et al.* 2012, Schmidlin 2012, Blum *et al.* 2013, Xie *et al.* 2017, Park *et al.* 2018, Borkar *et al.* 2019, Chawla *et al.* 2019, Nathani *et al.* 2021). However, strikingly, some of these findings were not supported by Lin and co-workers, as they did not find abutment teeth of prostheses and dentitions with reduced posterior support as significant risk factors (Lin *et al.* 2011). The same authors also reported that the placement of posts and cores did not correlate with cemental tears, whereas favouritism for eating hard food was found to be slightly correlated (Lin *et al.* 2011). The latter might be explained as the secondary impact of *occlusal trauma* induced from heavy masticatory loading, albeit the authors emphasized the need for performing further investigations to study the definitive contribution of various predisposing factors in the development of cemental tears (Lin *et al.* 2011). In fact, it will be difficult to establish the correlation between *occlusal trauma* and cemental tears, as *occlusal trauma* is commonly associated with periodontitis either acting as a primary aggravating factor to the progression of periodontitis or as the secondary effect of reduced periodontal support, tooth displacement and increased mobility (Pihlstrom *et al.* 1986, Jin *et al.* 1992, Fan & Caton 2018). It seems almost impossible to eliminate periodontal disease as a confounding factor when studying the relationship between *occlusal trauma* and cemental tears.

Clinical presentation of cemental tears

Cemental tears have been reported to affect single root surfaces in about 75% of cases (Lin *et al.* 2012). When this is the case, cemental tears can appear clinically as hard tissue fragments that are sheet-/piece-like (Camargo *et al.* 2003, Lin *et al.* 2012), thin (Watanabe *et al.* 2012), prickle-like (Ong *et al.* 2019), or tear-like (Schmidlin 2012) (Fig. 1). They have also been described as resembling a ledge-like projection on the root surface (Marquam 2003) and a foreign body (Damasceno *et al.* 2012). Those tears affecting multiple root surfaces usually present as detached U-shaped fragments that frequently involves the apical regions of roots (Stewart *et al.* 2006, Tai *et al.* 2007, Lin *et al.* 2012, Xie *et al.* 2017). The dimension of cemental fragments has been reported to range between 1 and 6 mm wide, 2 and 10 mm long (Haney *et al.* 1992, Ishikawa *et al.* 1996, Harrel *et al.* 2000, Chou *et al.* 2004, Tulkki *et al.* 2006, Tai *et al.* 2007) and $\leq$ 2 mm thick (Haney *et al.* 1992, Leknes *et al.* 1996, Stewart *et al.* 2006, Tulkki *et al.* 2006, Tai *et al.* 2007, Lin *et al.* 2012). Cemental tears can be located at the cervical (Ishikawa *et al.* 1996, Camargo *et al.* 2003), middle or apical part of the root (Kasaj *et al.* 2009, Lin *et al.* 2012). Although it has been reported that cemental tears were on the proximal root surfaces in nearly

80% of the cases (Lin *et al.* 2012), it might well be attributed to the fact that other surfaces, especially the lingual/palatal, are relatively more difficult to detect the presence of cemental tear radiographically when compared to proximal surfaces.

Lin and co-workers studied 71 teeth with a confirmed diagnosis of cemental tear and found that the majority of these teeth presented with an abscess and swelling (66%), deep isolated periodontal pockets > 6 mm (73%) and positive signs of pulp vitality (65%) (Lin *et al.* 2011). Vitality of the pulp usually remains unaffected by the presence of a cemental tear (Haney *et al.* 1992, Leknes *et al.* 1996, Harrel *et al.* 2000, Tulkki *et al.* 2006, Lin *et al.* 2010, Xie *et al.* 2017, Pilloni *et al.* 2019), unless the tooth had been previously misdiagnosed, leading to an unnecessary root canal treatment (Lin *et al.* 2011). Therefore, a vital pulp with concomitant periapical bone loss might indicate the possibility of a cemental tear (Tulkki *et al.* 2006, Lin *et al.* 2011), as periapical diseases of endodontic origin is usually associated with non-vital pulps with infected pulpal space (Bergenholtz 1974). This is more so in single rooted than multi-rooted teeth, as the chance of the latter giving false positive responses to pulp sensitivity tests increase because of the common occurrence of partial necrosis (Petersson *et al.* 1999). Some other conditions that are listed under the differential diagnosis in Table 3 can also produce vital pulp responses (Whaites *et al.* 2013a, b). It is strongly advised to repeat the pulp sensitivity tests on suspected teeth to avoid unnecessary treatment that is bound to be ineffective, disappointing and frustrating for both the patient and clinician (Lin *et al.* 2011).

Diagnosis is extremely challenging during the early stages of the development of cemental tears, since any pain is often difficult to localize (Haney *et al.* 1992). Semi-detached cemental fragment may remain within the periodontal tissues for a long period of time, causing either mild discomfort or no pain at all (Qari *et al.* 2019). Symptoms tend to become more pronounced as the fragment becomes fully detached (i.e. complete separation from the root), which is often associated with rapid isolated breakdown of the periodontal tissues (Haney *et al.* 1992, Ishikawa *et al.* 1996, Leknes *et al.* 1996, Müller 1999, Brunsvold *et al.* 2000, Camargo *et al.* 2003, Marquam 2003, Chou *et al.* 2004, Lyons *et al.* 2005, Tulkki *et al.* 2006, Watanabe *et al.* 2012, Xie *et al.* 2017, Chawla *et al.* 2019, Ong *et al.* 2019), with some cases developing into localized periodontal abscess (Lin *et al.* 2010, Park *et al.* 2018, Nathani *et al.* 2021).

Typical clinical features associated with cemental tears are gingival bleeding on probing (Müller 1999, Lyons *et al.* 2005, Damasceno *et al.* 2012), swollen gingiva or alveolar mucosa (Haney *et al.* 1992, Tai *et al.* 2007, Lin *et al.* 2010, Watanabe *et al.* 2012, Blum *et al.* 2013, Xie *et al.* 2017, Park *et al.* 2018, Ong *et al.* 2019, Pilloni *et al.* 2019), purulent discharge through the periodontal sulcus or sinus tract (Leknes *et al.* 1996, Harrel *et al.* 2000, Camargo *et al.* 2003, Stewart *et al.* 2006, Tai *et al.* 2007, Schmidlin 2012, Watanabe *et al.* 2012, Blum *et al.* 2013, Xie *et al.* 2017, Park *et al.* 2018, Ong *et al.* 2019), increased tooth mobility (Müller 1999, Brunsvold *et al.* 2000, Harrel *et al.* 2000, Stewart *et al.* 2006, Watanabe *et al.* 2012, Xie *et al.* 2017, Chawla *et al.* 2019, Ong *et al.* 2019, Nathani *et al.* 2021) and a root filled tooth with post-treatment disease (Leknes *et al.* 1996, Camargo *et al.* 2003, Stewart *et al.* 2006, Tai *et al.* 2007, Lin *et al.* 2011, Damasceno *et al.* 2012, Lin *et al.* 2012, Schmidlin 2012, Watanabe *et al.* 2012, Blum *et al.* 2013, Xie *et al.* 2017, Jeng *et al.* 2018, Chawla *et al.* 2019) (Figs. 1-3). However, it is important to note that none of these features are pathognomonic of cemental tears as they are also shared amongst other pathological conditions such as vertical root fractures, diseases of primary endodontic and periodontal origin, or combined endodontic-periodontal diseases (Tulkki *et al.* 2006, Ong *et al.* 2019). Direct intra-surgical inspection, either through exploratory surgery or tooth extraction, can often provide a definitive diagnosis of cemental tear (Nagata *et al.* 2016b) (Figs. 1 & 3).

Radiographical presentation of cemental tears

Radiographic assessment constitutes an important diagnostic procedure adopted by many clinicians and researchers in diagnosing, treatment planning and predicting the prognosis of cemental tears (Jeng *et al.* 2018). Detection of a "prickle-like" (i.e. a fine, sharp and vertical fragment) radiopaque mass adjacent to the affected root surface is a characteristic radiographic appearance of cemental tear (Haney *et al.* 1992, Ishikawa *et al.* 1996, Qari *et al.* 2019) (Figs. 1 & 2), although other descriptions have also been used to describe the radiopaque appearance, including flake-like structure (Xie *et al.* 2017), chip-like particle or fragment (Müller 1999), hard tissue-like material (Ong *et al.* 2019), calculus-like spicule (Chawla *et al.* 2019), raindrop-shaped (Ishikawa *et al.* 1996) and oblong (Pedercini *et al.* 2021) (Table 2). On occasions, detachment of the fragment can also be categorised using periapical radiographs as either semi-detached (Ishikawa *et al.* 1996, Harrel *et al.* 2000), or complete (Haney *et al.* 1992, Ishikawa *et al.* 1996, Müller 1999).

The fragment of cementum is often associated with a radiolucent osseous lesion denoting concomitant alveolar bone loss (Chou *et al.* 2004) (Figs. 1 & 2). Various patterns of radiolucent lesions associated with cemental tears have been reported, amongst which periapical and periodontal radiolucent lesions have been reported in approximately 65% and 86% of the cases, respectively (Lin *et al.* 2011). The latter was further sub-grouped on the basis of its shape (i.e. D- or J-shaped), thickness (i.e. thin or thick), and regularity in linearity (Qari *et al.* 2019). The lamina dura typically appeared destroyed (Blum *et al.* 2013). However, as with clinical findings, none of the radiographic patterns are pathognomonic of cemental tears (Qari *et al.* 2019). For example, lateral radiolucent lesion can also be a sign of periradicular involvement of an infected lateral canal, root perforation, root fracture, inflammatory root resorption and lateral periodontal cyst (Andreasen *et al.* 1989, Fuss *et al.* 1996, Heithersay 1999, Ne *et al.* 1999, Kerezoudis *et al.* 2000, Lin *et al.* 2011) (Fig. 1).

Radiographic differential diagnosis are listed in Table 2, including primary endodontic diseases, primary periodontal diseases, combined endodontic-periodontal diseases with or without vertical root fracture, lateral periodontal cyst, dentigerous cyst, solitary bone cyst, central giant cell granuloma, globulomaxillary cyst, nasopalatine cyst, ameloblastoma, odontogenic keratocyst, hypercementosis, cemento-osseous lesion, fibrous dysplasia, cementoblastoma, cemento-ossifying fibroma, odontoma, calcifying epithelial odontogenic cyst, calcifying epithelial odontogenic tumour, adenomatoid odontogenic tumour, ameloblastic fibro-odontoma, odontogenic fibroma or myxoma and osteosarcoma, etc. (Whaites *et al.* 2013a,b, Pedercini *et al.* 2021) (Table 2). Hence, should diagnosis remains doubtful in spite of the clinical, radiographic and cone-beam computed tomography (CBCT) evaluation, direct intra-surgical inspection, exploratory surgery or biopsy should be considered to rule out possible differential causes (Chou *et al.* 2004, Nagata *et al.* 2016b).

The diagnostic value of conventional radiographs for cemental tears remains debatable and questionable (Haney *et al.* 1992, Lin *et al.* 2011, Qari *et al.* 2019). Conventional radiographs are unable to detect cemental tears on the buccal or palatal surfaces of teeth due to the inherent limitation of the two planar imaging technique of a three-dimensional object (Brunsvold *et al.* 2000). Hence, parallax techniques have been proposed as an adjunct to the routine radiographic method (Lin *et al.* 2011). Small field of view CBCT has also been advocated as the imaging modality of choice when cemental tear is suspected (Watanabe *et al.* 2012), as it may improve the detection, diagnosis and understanding of the cemental detachment in a 3-dimensional view (Jeng *et al.* 2018, Ong *et al.* 2019). Irregularities and variation in thickness of the root outline, as well as the extent of fragment detachment from the cemento-dentinal junction might be more readily detected on CBCT images (Nathani *et al.* 2021, Ong *et al.* 2019, Pedercini *et al.* 2021, Pilloni *et al.* 2019) (Figs. 1 & 2).

Histopathological presentation of cemental tears

Histologically, cemental tears consist of *cellular* and/or *acellular cementum*, which appear as cemental lamellae with or without the presence of cementocytes within the lacunae (Haney *et al.* 1992, Harrel *et al.* 2000, Stewart *et al.* 2006, Tulkki *et al.* 2006, Tai *et al.* 2007, Damasceno *et al.* 2012, Watanabe *et al.* 2012, Ong *et al.* 2019) (Fig. 1), occasionally with some peripheral root dentine attached to the cemental fragment (Tai *et al.* 2007, Xie *et al.* 2017, Ong *et al.* 2019). The fragment is either embedded within or attached to the periodontal or connective tissue fibres, or adhered to the granulation tissue, inflamed fibrous tissue or fibrous scar tissue (Haney *et al.* 1992, Stewart *et al.* 2006, Tulkki *et al.* 2006, Tai *et al.* 2007, Watanabe *et al.* 2012) (Fig. 1). Lymphocytic infiltration is predominantly found with focal destruction of cortical bone (i.e. lamina dura) and the surrounding cancellous bone (Qari *et al.* 2019), although neutrophils and plasma cells may also be seen (Watanabe *et al.* 2012). This usually leads to a histological diagnosis of either *chronic fibrosing osteomyelitis* or *primary chronic osteomyelitis* (Qari *et al.* 2019).

Histopathological examination has been regarded as the gold standard for definitive diagnosis of cemental tears (Tulkki *et al.* 2006, Watanabe *et al.* 2012, Xie *et al.* 2017). As with any other surgical interventions, exploratory surgery carries the possibility of post-operative complications such as pain, swelling, bleeding, and infection. Precaution must always be exercised against encroachment and damaging of the vital anatomic structures such as the neurovascular bundle, especially when access is challenging. The clinicians should weigh the advantages and disadvantages of performing exploratory surgery as part of the diagnostic procedures. For example, a tooth that carries a hopeless prognosis will probably benefit from simple extraction to reduce the effect of surgical trauma. Biopsy may not always be necessary if direct intra-surgical inspection of the root surface allows detection of cemental tear (Nagata *et al.* 2016b) (Fig. 3); thereby saving the patient cost and time, as well as avoiding undesirable psychological stress.

Clinical management of cemental tears

Treatment of cemental tears should aim to completely remove the torn fragment whenever possible (Brunsvold *et al.* 2000, Chou *et al.* 2004, Lin *et al.* 2011, Jeng *et al.* 2018), because remnants of the fragment carry the inherent risk of further detachment that potentially hinders uneventful periodontal healing and results in complications associated with non-healing (Brunsvold *et al.* 2000, Ong *et al.* 2019). Successful management of cemental tears requires a multi-faceted approach (Tulkki *et al.* 2006, Tai *et al.* 2007). In order to achieve complete mechanical removal of the cemental fragment, one or more of the following treatment modalities have been suggested:

a. Scaling and root planing via non-surgical (Ishikawa *et al.* 1996, Damasceno *et al.* 2012, Xie *et al.* 2017, Borkar *et al.* 2019) and/or surgical periodontal treatment (Haney *et al.* 1992, Ishikawa *et al.* 1996, Müller 1999, Harrel *et al.* 2000, Camargo *et al.* 2003, Marquam 2003, Chou *et al.* 2004, Lyons *et al.* 2005, Tulkki *et al.* 2006, Tai *et al.* 2007, Lin *et al.* 2010, Schmidlin 2012, Watanabe *et al.* 2012, Blum *et al.* 2013, Park *et al.* 2018, Pilloni *et al.* 2019, Nathani *et al.* 2021);

b. Apical surgery (Camargo *et al.* 2003, Tai *et al.* 2007, Kasaj *et al.* 2009, Blum *et al.* 2013, Kang *et al.* 2016, Chawla *et al.* 2019, Ong *et al.* 2019);

c. Intentional replantation (Nagata *et al.* 2016b); or,

d. Extraction, for teeth with unfavourable or hopeless prognosis (Brunsvold *et al.* 2000, Stewart *et al.* 2006, Damasceno *et al.* 2012, Watanabe *et al.* 2012, Nagata *et al.* 2016a, Xie *et al.* 2017, Ong *et al.* 2019).

It is unnecessary to perform any active intervention if the cemental tear is merely a radiographical finding without any associated clinical signs and symptoms (Chou *et al.* 2004); however, it is always necessary to inform the patient. If intervention is indicated, the actual choice of treatment approach will not only depend on the preference of the patient, but also depend on the location of the cemental tear in relation to the root and the severity of periodontal involvement (Jeng *et al.* 2018). Treatment of the periodontal defect can range from non-surgical approach to combined surgical and regenerative procedures (Chou *et al.* 2004). A fragment that is located at the coronal-third of the root may be removed via non-surgical scaling and root planing (Jeng *et al.* 2018). For those fragments located deeper apically along the root and/or when non-surgical periodontal treatment has been ineffective, surgical periodontal approach is recommended (Jeng *et al.* 2018). Apical surgery is often indicated if the fragment is located at the apical-third of the root with signs of apical pathosis, in which case the need for prior root canal re/treatment must be considered (Jeng *et al.* 2018). Most importantly, the torn fragment must be removed in entirety, even though removal of the cemental tear *per se* does not always guarantee a successful outcome, particularly with the inherent structural weakness that can lead to a recurrence (Tai *et al.* 2007). Traumatic occlusion is a factor that may also affect success. Hence, its management, such as occlusal adjustment and splinting, is also crucial in preventing recurrence (Tai *et al.* 2007, Kang *et al.* 2016).

The main consideration in deciding which treatment modality (or combination) to adopt depends primarily on the location of the cemental tear in relation to the root. In this regard, the deepest apical extent of the cemental tear can be challenging to detect, and a solution to overcome this problem is needed to prevent its recurrence (Watanabe *et al.* 2012). In practice, non-surgical periodontal treatment approaches alone through the periodontal pocket may risk leaving behind the remnant of the cemental fragment and any associated infection, resulting in delayed or non-healing. Thus, a surgical approach through open flap debridement is regarded as a more predictable approach to ensure complete eradication of the periodontal infection (Brunsvold *et al.* 2000).

Guided tissue regeneration (GTR), with or without bone replacement grafting, has also been advocated to enhance the reattachment of the periodontal apparatus along the affected root surface and to promote osseous tissue ingrowth of the bony defect (Camargo *et al.* 2003, Dietrich *et al.* 2003, Marquam 2003, Tulkki *et al.* 2006, Kasaj *et al.* 2009, Lin *et al.* 2010, Damasceno *et al.* 2012, Blum *et al.* 2013, Lin *et al.* 2014). Collagen membranes serve as a barrier to prevent downgrowth of junctional epithelium and obstruct the ingrowth of connective tissue into the bony defect (Nyman *et al.* 1982). GTR and bone grafting procedures have been described in numerous case reports for the treatment of cemental tears and the associated osseous lesions (Haney *et al.* 1992, Müller 1999, Harrel *et al.* 2000, Camargo *et al.* 2003, Marquam 2003, Lyons *et al.* 2005, Tulkki *et al.* 2006, Watanabe *et al.* 2012, Xie *et al.* 2017, Park *et al.* 2018, Pilloni *et al.* 2019). Other regenerative approaches have also been proposed, including the application of biologic regenerative factors such as enamel matrix derivatives (EMD) either alone (Kasaj *et al.* 2009, Schmidlin 2012, Miron *et al.* 2016, Nagata *et al.* 2016b), or in combination with bone grafts and membrane barrier; recombinant human platelet-derived growth factor (rhPDGF-BB) with ß-tricalcium phosphate matrix (Nevins *et al.* 2005, Jayakumar *et al.* 2011); and hyaluronic acid (Pilloni *et al.* 2019). These materials can also be applied after scaling and root planing or just before the GTR procedures (Esposito *et al.* 2009, Matarasso *et al.* 2015). Similarly, topical application of antibiotics such as tetracycline, and a dentine conditioner such as EDTA onto the affected root surfaces had also been described (Harrel *et al.* 2000, Camargo *et al.* 2003, Lyons *et al.* 2005, Kang *et al.* 2016, Chawla *et al.* 2019).

Outcome of treating cemental tears

Treatment of cemental tears located at the middle- and coronal-third of the root were associated with comparable outcome, as the cases classified as healed were reported as 67% and 60% for tears at the middle- and coronal-third of the root, respectively; whereas only 11% were reported as healed for tears located in the apical-third of the root (Lin *et al.* 2014). It was speculated that cemental tears and infection located at the middle- and coronal-third of the root were relatively easier to access and eradicate, compared to the apical section of the root (Lin *et al.* 2014). Meanwhile, surgical intervention has demonstrated an approximately 30% greater chance of healing than non-surgical intervention alone (Lin *et al.* 2014). In short, factors affecting periradicular healing are highly dependent on site and treatment modalities. As far as tooth survival is concerned, treatment of a cemental tear should be regarded as a feasible option because 94% of the teeth treated have been reported to remain in functional retention (Lin *et al.* 2014). Prognosis of cemental tears is deemed to be more favourable than vertical root fracture, as the latter usually requires extraction of the tooth (Lin *et al.* 2011).

In general, the outcome of GTR procedures is better when combined with bone grafting and collagen membrane barriers, compared to the use of bone grafting alone (Camelo *et al.* 1998). The superiority of the former approach is demonstrated by the improved re-establishment of the periodontal attachment apparatus in both clinical and histological studies (Camelo *et al.* 1998). However, the effect of GTR in the treatment of cemental tears remains an area that warrants further research.

Conclusion of the literature review of cemental tears

Cemental tears, although rare, are important conditions since misdiagnosis results in incorrect and unsuccessful treatments. In this literature review, 37 published articles in English – 29 case reports and 8 observational studies, were included. From the literature, prevalence of the cemental tears was suggested to be lower than 2%; while the incidence remains unknown. *Internal factors* due to the inherent structural weakness of the cementum and the interface with the dentine, and *external factors* that are stress-induced had been proposed as the two mechanisms responsible in the development and propagation of cemental tears. Potential predisposing factors that have been suggested were tooth type, gender, age, previous root canal treatment, history of dental trauma and occlusal trauma or excessive occlusal force. The scarcity of evidence from the available literature revealed the need for further research to elucidate the exact aetiology, predisposing factors and pathogenesis of cemental tears.

Clinically, cemental tears resemble other common endodontic and periodontal conditions. Radiographical and CBCT presentations can also mimic bony lesions resulting from primary endodontic diseases, primary periodontal diseases, combined endodontic-periodontal diseases, vertical root fracture, and other conditions. Hence, definitive diagnosis requires direct intra-surgical inspection or histopathologic examination of the biopsied specimen to rule out other pathological conditions.

Clinical management reported in the literature consisted mainly of non-surgical and/or surgical periodontal treatment, apical surgery, intentional replantation and extraction; sometimes combined with regenerative approaches. Complete removal of the torn fragment has been claimed to be essential in treating cemental tears. However, there was an apparent lack of consistency between and within the operators in diagnosis and treatment planning, and marked procedural variations in how the same treatment approach was performed. In view of these issues, the authors identified the need to devise a classification for cemental tears to aid clinicians in the assessment of important clinical and imaging parameters in order to streamline the process of diagnosis and clinical decision making.

Proposed classification of cemental tears

The proposed classification is developed in view of:

i. facilitating future research by reducing heterogeneity in recording of findings;
ii. enabling comparison of findings over time;
iii. establishing a common language for communication amongst the profession; and
iv. streamlining clinical/radiographical/CBCT assessment, diagnosis, treatment planning and determination of prognosis.

The classification was developed from a detailed analysis and the integration of relevant findings from the observational studies along with common clinical, radiographical and CBCT characteristics of 58 teeth with cemental tears described in the case reports (Table 1). These cases were categorised manually into ‘*Classes*’ and ‘*Stages*’ taking into consideration the three-dimensional perspective of cemental tears and their associated bony lesions, based on the following parameters:

i. location and accessibility of the torn cemental fragment;
ii. pattern and extension of the associated bony defect in relation to the root length; and,
iii. number of root surface/s affected by cemental tear and the associated bony defect.

The schematic illustration of the classification based on *‘Classes’* is shown in Figure 4a and summarised in Table 3.

Class 0: Cemental tear with the entire fragment covered by intact alveolar crestal bone with no associated bony defect. Clinically, no part of the fragment can be detected visually or probed. Periapical radiographs and/or CBCT show the presence of normal alveolar bone without any radiolucent lesion; and the entire fragment lies within the periodontal ligament space that may or may not be associated with slight widening.

Class 1: Cemental tear with the entire fragment and the associated bony defect being covered by intact alveolar crestal bone. Clinically, no part of the fragment can be detected visually or probed. Periapical radiographs and/or CBCT show the presence of radiolucent lesions with the alveolar crestal bone intact; and neither the apical part of the fragment nor the radiolucent lesion involves the apex of the root (Fig. 1).

Class 2: Cemental tear with the entire fragment and the associated bony defect being covered by intact alveolar crestal bone. Clinically, no part of the fragment can be detected visually or probed. Periapical radiographs and/or CBCT show the presence of radiolucent lesions with the alveolar crestal bone intact; and either the apical part of the fragment or the radiolucent lesion, or both, involves the apex of the root (Fig. 2).

Class 3: Cemental tear with loss of alveolar crestal bone and infra-bony defect and/or dehiscence. Clinically, no part of the fragment can be detected visually or probed. Periapical radiographs and/or CBCT show the presence of radiolucent lesions that are associated with vertical or angular bone loss; and neither the apical part of the fragment nor the radiolucent lesion involves the apex of the root (Figs. 3 & 5).

Class 4: Cemental tear with loss of alveolar crestal bone and infra-bony defect and/or dehiscence. Clinically, no part of the fragment can be detected visually or probed. Periapical radiographs and/or CBCT show the presence of radiolucent lesions that are associated with vertical or angular bone loss; and either the apical part of the fragment or the radiolucent lesion, or both, involves the apex of the root (Figs. 6 & 7).

Class 5: Cemental tear with the coronal part of the fragment extending into the periodontal sulcus or pocket with infra-bony defect and/or dehiscence without an apico-coronal communication with the oral cavity. Clinically, the detached fragment can either be detected visually or probed. Periapical radiographs and/or CBCT show the presence of radiolucent lesions that are associated with vertical or angular bone loss; and neither the apical part of the fragment nor the radiolucent lesion involves the apex of the root (Fig. 8).

Class 6: Cemental tear with the coronal part of the fragment extending into the periodontal sulcus or pocket with infra-bony defect and/or dehiscence that may have an established apico-coronal communication with the oral cavity. Clinically, the detached fragment can either be detected visually or probed. Periapical radiographs and/or CBCT show the presence of radiolucent lesions that are associated with vertical or angular bone loss; and either the apical part of the fragment or the radiolucent lesion, or both, involves the apex of the root (Figs. 9 & 10).

Cemental tears can be further sub-classified into *'Stages'*. The schematic illustration of the classification based on *'Stages'* is shown in Figure 4b and summarised in Table 3.

Stage A: Cemental tear and the associated bony defect involves 1 surface of the root (Fig. 3).

Stage B: Cemental tear and the associated bony defect involves 2 surfaces of the root (Fig. 6).

Stage C: Cemental tear and the associated bony defect involves 3 surfaces of the root (Figs. 1, 5, 9 & 10).

Stage D: Cemental tear and the associated bony defect involves 4 or all surfaces of the root (Figs. 2 & 7).

If only two-dimensional (2D) radiographic images (i.e. periapical radiographs) are available for assessment, a case can solely be classified into '*Class*' alone to provide a *2D classification* (Fig. 8); whereas if three-dimensional (3D) radiographic images are available, a case can be classified into both '*Class*' and '*Stage*' to provide a *3D classification*. Three-dimensional radiographic assessment is based on the "worst case combinations" of parameters, including (i) the most apical extent of the cemental tear observed in any one plane; (ii) the maximum number of root surface/s affected by the cemental tear in any one plane; (iii) the greatest medio-distal, bucco/labial-palatal/lingual, and apico-coronal dimensions of the bony defect in relation to the root surface observed in any one plane; and (iv) the least favourable infrabony defects detected in any one plane (note: 1-walled intrabony defect as least favourable, while 3-walled intrabony defect as most favourable). Generally speaking, the use of *2D classification* based on 2D radiographic images may underestimate the severity and dimension measured of the various parameters, which will affect the process of clinical decision making and judgment, as well as determining the prognosis. Hence, the use of *3D classification* based on 3D radiographic images such as CBCT is strongly recommended. Although there is no clinical research data available to support or refute the importance of the proposed classification for cemental tears, the authors hypothesized that different *classes* and *stages* will have implications of varying levels toward technical challenges and procedural complexities of the clinical treatment, potential impacts toward treatment outcome and the incidence of post-treatment complications, such as external root resorption and recurrence of cemental tears.

For cases of cemental tears presenting with the pulpal diagnosis of '*non-vital pulp*', '*previously initiated therapy*' or '*previously treated*' are likely to be misdiagnosed as solely 'primary endodontic diseases' for *Class 0, 1* and *2* (Figs. 1 & 2); and 'primary endodontic diseases with secondary periodontal involvement', 'primary periodontal diseases with secondary endodontic involvement' or 'true combined diseases' for *Class 4* and *6* (Rotstein 2017) (Figs. 6, 7, 9 & 10). On the other hand, for those presenting with the pulpal diagnosis of '*vital pulp*' are likely to be misdiagnosed solely as 'occlusal trauma' or 'irreversible pulpitis' for *Class 0*; 'lateral periodontal cyst' for *Class 1* (Fig. 1); any of the differential diagnosis listed in Table 2 for *Class 2*; 'primary periodontal diseases' for *Class 3* and *5* (Figs. 3, 5 & 8); and 'primary periodontal disease with secondary involvement' for *Class 4* and *6* (Rotstein 2017) (Figs. 6, 7, 9 & 10).

Diagnosis and treatment planning of cemental tears are challenging, even for experienced clinicians. Therefore, clinicians should be inquisitive about acquiring knowledge and skills to elevate their competence and confidence in assessing, diagnosing and managing cemental tears and the associated pathosis. However, there are currently no guidelines or consensus on the management of cemental tears. In view of this, treatment strategies will be introduced in the following section with the intention to facilitate the process of treatment decision making in a logical step-by-step manner (Fig. 11).

Treatment strategies for cemental tears

Treatment of cemental tears aims at resolving three key issues: the torn cemental fragment, the associated periodontal and/or endodontic diseases, and the concomitant alveolar bone loss. Treatment strategies are based on the:

- pulpal and periradicular status of the affected tooth;
- presence or absence of signs and symptoms, as well as occlusal trauma and tooth mobility;
- location, extension and accessibility of the torn cemental fragment to mechanical removal; and
- degree and pattern of alveolar bone loss.

The step-by-step clinical approach to the treatment of cemental tears is shown on a flowchart in Figure 11. The first step is to determine the *pulpal status* of the affected tooth so that infection from the endodontic diseases can be addressed as a priority. *Non-surgical root canal re/treatment* (Fig. 11-a) serves to prevent the root canal infection or their by-products from causing additional periapical irritation (Nair 2004, Gomes *et al.* 2012, Neelakantan *et al.* 2019a, Neelakantan *et al.* 2019b), which can potentially contributes toward the pathogenesis and non-healing response in a tooth with cemental tear if left untreated (Cortellini *et al.* 2001a). Ideally, teeth with *previously initiated therapy*, *previously treated* teeth (Fig. 11-i) presenting with *technically adequate* root fillings in the *presence of signs and symptoms* (Fig. 11-i) and root canal treated teeth with *technical inadequacy* (Fig. 11-ii) should also be revised by *non-surgical root canal re/treatment* (Figs. 6 & 11-a) to optimize the overall treatment outcome (Peciuliene *et al.* 2006, Ng *et al.* 2008). At least *3 months* of waiting time is advised before proceeding to the subsequent steps of periodontal and regenerative treatment to facilitate uneventful periodontal tissue reattachment and to re-evaluate the periodontal condition after initial healing has taken place (Cortellini *et al.* 2011, Rotstein 2017) (Fig. 11).

In general, pulp vitality is thought to be unaffected by the presence of a cemental tear *per se* (Lin *et al.* 2011). This can be correlated to the literature on endodontic-periodontal diseases illustrating that periodontal diseases do not usually lead to pulpal necrosis unless the disease has extended apically along the roots to involve the apical foramen (Langeland *et al.* 1974, Czarnecki *et al.* 1979) or lateral canals (Seltzer *et al.* 1963). Therefore, root canal treatment is not indicated unless the pulp tissues have undergone necrosis or whenever treatment procedures may lead to undermining of the apical neurovascular supply to the pulp (Sommer *et al.* 1991). Therefore, teeth with vital pulps do not require root canal treatment prior to surgical intervention and regenerative therapy (Cortellini *et al.* 2001a), unless enucleation of the inflamed tissue, scaling and root debridement or removal of the cemental fragment will encroach the root apex (Cortellini *et al.* 2001a, 2015), as in *Class 2, 4* and *6* of the proposed classification (Fig. 11-iii).

Occlusal adjustment (Fig. 11-b) is recommended on the affected tooth demonstrating signs of occlusal trauma and tooth mobility (Reinhardt *et al.* 2015) (Fig. 11-v); as these factors potentially act to compromise occlusal stability and comfort during function (Reinhardt *et al.* 2015), aggravate the progression of periodontitis and affect the healing response after periodontal treatment (Glickman *et al.* 1969, Gher 1998, Nakatsu *et al.* 2014, Fan & Caton 2018). On the other hand, *occlusal adjustment* has been shown to improve the amount of clinical periodontal attachment gain after periodontal treatment, although evidence from randomized controlled clinical trials is lacking (Burgett *et al.* 1992, Weston *et al.* 2008, Foz *et al.* 2012). Hypermobile teeth should be considered for stabilization by *splinting* using composite resin bonded to the adjacent teeth or placement of temporary fixed bridges before any surgical intervention and regenerative periodontal treatment take place (Figs. 8 & 11-b); as increased tooth mobility has been demonstrated to negatively affect the treatment outcome (Cortellini *et al.* 2001b, Cortellini *et al.* 2011, Reynolds *et al.* 2015).

Presence of bony lesions associated with the cemental tears (Fig. 11-iv) should always be treated because they represent pathologic changes in the periodontium (Qari *et al.* 2019), often complicated by the involvement of secondary periodontal and/or endodontic diseases (Leknes *et al.* 1996, Lin *et al.* 2011). A cementum fragment that is inaccessible to mechanical removal, as in *Classes 1, 2, 3* and *4* and some cases of *Classes 5* and *6* of the proposed classification should be managed by *surgical approach* (Figs. 1, 6, 10 & 11-vi). However, fragments that can be accessed by mechanical instruments either supra- or sub-gingivally in the periodontal pocket, as in selective cases of *Classes 5* and *6* of the proposed classification (Fig. 11-vi), should be treated with *non-surgical periodontal treatment* as an initial approach (Jeng *et al.* 2018) (Fig. 11-c), followed by re-evaluation of the periodontal condition after an adequate time interval, preferably between *1 to 2 months*, for periodontal healing to occur (Segelnick *et al.* 2006).

Surgical intervention should be considered if the healing response is deemed unsatisfactory, or if access for removal of the entire length of the torn cemental fragment is impossible or uncertain via a non-surgical approach alone (Figs. 6, 10 & 11-d) (Lin *et al.* 2014, Jeng *et al.* 2018). *Intentional replantation* is also a feasible treatment option in suitable cases (Torabinejad *et al.* 2015, Cho *et al.* 2017, Mainkar 2017) (Fig. 11-g), particularly when access is challenging and/or where periradicular surgery carries a significant risk in causing damage to the vital structures in close proximity. Teeth with poor or hopeless periodontal prognosis should be considered for *extraction* (Kwok & Caton 2007, Jeng *et al.* 2018) (Figs. 8 & 11-g). In multi-rooted teeth, hemisection or root resection might also be feasible options in suitable cases (Mokbel *et al.* 2019, Setzer *et al.* 2019) (Fig. 11-g).

Regenerative treatment may be achieved via various approaches. Application of the biologic factor, EMD, has proven beneficial for the regeneration of the infrabony defects by stimulating the growth of hard and soft tissue, especially when cemental denudation of the affected root surface area is extensive (Heijl *et al.* 1997, Francetti *et al.* 2004, Esposito *et al.* 2005, Miron *et al.* 2016, Pilloni *et al.* 2021) (Fig. 10-h). Regenerative periodontal therapy with the application of EMD alone may be sufficient in treating narrow ($\leq 25^{o}$ radiographic angle) (Tsitoura *et al.* 2004) and *supportive anatomy defect* (i.e. *3-walled intrabony defect* and *crater*) of > 3mm depth (Tonetti *et al.* 2002) (Fig. 11-vii & 11-e).

Combined regenerative approaches using two or more combinations of the biologic regenerative factors (such as EMD and rhPDGF-BB with b-tricalcium phosphate matrix), bone replacement grafts and/or collagen membrane barrier are supported by clinical evidence to result in improved clinical efficacy (Matarasso *et al.* 2015, Reynolds *et al.* 2015) (Figs. 1, 6, 10 & 11-f), especially for cases presenting with *non-supporting anatomy defects*, i.e. *1-*, *2-walled intrabony defects* in cases classified as *Classes 3, 4, 5* or *6* with the sub-classification *Stages 2, 3 or 4* of the proposed classification (Figs. 10 & 11-viii), *dehiscence* and *osseous defects* $\geq$ *10 mm* (Dietrich *et al.* 2003, Tsesis *et al.* 2011, De Leonardis *et al.* 2013, Lin *et al.* 2014, Cortellini *et al.* 2015, Kao *et al.* 2015, Cortellini *et al.* 2020) or *buccal cortical bone height* $\leq$ *2mm* (Song *et al.* 2013), as in *Classes 1* and *2* of the proposed classification (Figs. 1 & 11-viii). Studies have suggested mutually enhancing effects when EMD is used in conjunction with bone grafts (Trombelli *et al.* 2008). Most favourable regeneration treatment outcome in terms of reduction in periodontal probing depths, gain in clinical attachment level and bone fill into the bony defects can be expected in most of the *3-walled intrabony defects*, followed by *2-walled intrabony defects* (Cosyn *et al.* 2012); whereas cases presenting with thin gingival biotype and *non-supportive anatomy defects* carry a greater risk of midfacial advanced gingival recession compared to the *supportive anatomy defects* (i.e. *3-walled intrabony defects* and *craters*) and thick gingival biotype (Cosyn *et al.* 2012, Kao *et al.* 2015).

As '*Stages*' denotes the number of surfaces affected by the cemental tear/s and the associated bony defect, it is anticipated that the severity of the pathosis and the complexity of the technical procedures involved increase from *Stage A to D*, in ascending order. Therefore, the demand for higher level of clinical skills and experience also increases concomitantly, along with the need for better visualisation. A dental operating microscope is therefore indispensable to improve access and to facilitate completeness of the removal of cemental tears, root planing and granulation tissue curettage during the operation.

In the context of treatment planning, the patient's personal preference and the clinical competence of the clinician should always be taken into consideration. Clinicians should not hesitate to consider referral to an appropriate specialist/s, including an Endodontist or a Periodontist, if the case is deemed to fall beyond the scope of ability for one to diagnose or manage, whenever appropriate.

Summary of new classification and treatment strategies proposed for cemental tears

A new classification for cemental tears is proposed. *Class 0* denotes *clinically inaccessible* cemental tear with the entire fragment covered by intact alveolar crestal bone with no associated bony defect. *Classes 1* and *2* denote the cemental tear with the entire fragment and the associated bony defect covered by intact alveolar crestal bone without (*Class 1*) and with (*Class 2*) apical involvement. *Classes 3* and *4* denote *clinically inaccessible c*emental tear associated with infra-bony defect and/or dehiscence without (*Class 3*) and with (*Class 4*) apical involvement. *Classes 5* and *6* denote *clinically accessible* cemental fragment associated with infra-bony defect and/or dehiscence without (*Class 5*) and with (*Class 6*) apical involvement. Cemental tears may be further sub-classified into *Stage A, B, C* and *D* representing tears that involve 1, 2, 3 and 4 or all surfaces or palatal/lingual surface of the root surface, respectively. Classification is subsequently linked to the treatment strategies in a step-by-step clinical approach, as appropriate.

Treatment of cemental tears should first address the infection from the endodontic diseases by *non-surgical root canal re/treatment*; and elective treatment should be considered if the apical neurovascular bundles are likely to be encroached and damaged during the subsequent steps of treatment. Asymptomatic cases without any associated pathology only require close *observation*. *Occlusal trauma* and increased tooth mobility should be stabilized by *occlusal adjustment and/or splinting*, as appropriate. *Surgical periodontal or endodontic treatment* is indicated if the fragment is *inaccessible* or in case of non-healing response after the initial *non-surgical periodontal treatment*. Infrabony defects, dehiscence, osseous defect $\geq$ 10mm and *buccal cortical bone height* $\leq$ *2mm* may benefit from *regenerative treatment* with *biologic regenerative factors, bone grafts,* and *membrane barrier*; either alone or in combination. Teeth with poor or hopeless periodontal prognosis should be considered for *extraction*; while multi-rooted teeth may receive *hemisection* or *root resection* in suitable cases. Referral to an appropriate specialist/s may be considered whenever appropriate.

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Figures and Tables

Figure 1 (a) Pre-operative periapical radiograph of previously treated tooth 21 presenting with cemental tear associated with radiolucency on the disto-lateral aspect at the mid-root level; (b) Sinus tract was traced with a gutta-percha cone that pointed to the radiolucent area; (c) Post-operative periapical radiograph taken after non-surgical root canal retreatment, surgical intervention and GTR procedures with the placement of Bio-Oss® (Geistlich Pharma AG, Switzerland) into the bony defect and Bio-Gide® (Geistlich Pharma AG, Switzerland) over the Bio-Oss® filled defect; (d) Periapical radiograph taken during the 7-month review, demonstrating markedly reduced radiolucent area surrounded by a band of sclerotic bone. Reconstructed CBCT images of 21 in (e) coronal, (f) sagittal and (g) axial views; (h) Pre-operative clinical view of 21 and the associated soft tissue swelling (2.5 mm × 2.5 mm) on the labial attached gingiva (arrowed); (i) Intra-surgical view that showed the presence of cemental tear on the root surface of 21 (arrowed); (j) Clinical view at the 7-month review, showing the continued absence of swelling and sinus tract after the surgery; (k) A piece of torn cemental fragment removed from 21; and (l) Histological specimen of the collected torn cemental fragment stained with haematoxylin & eosin. This case is an example of the classification of cemental tears - ***Class 1, Stage C***. Courtesy of Dr Eissa Bunashi.

Class 1, Stage C

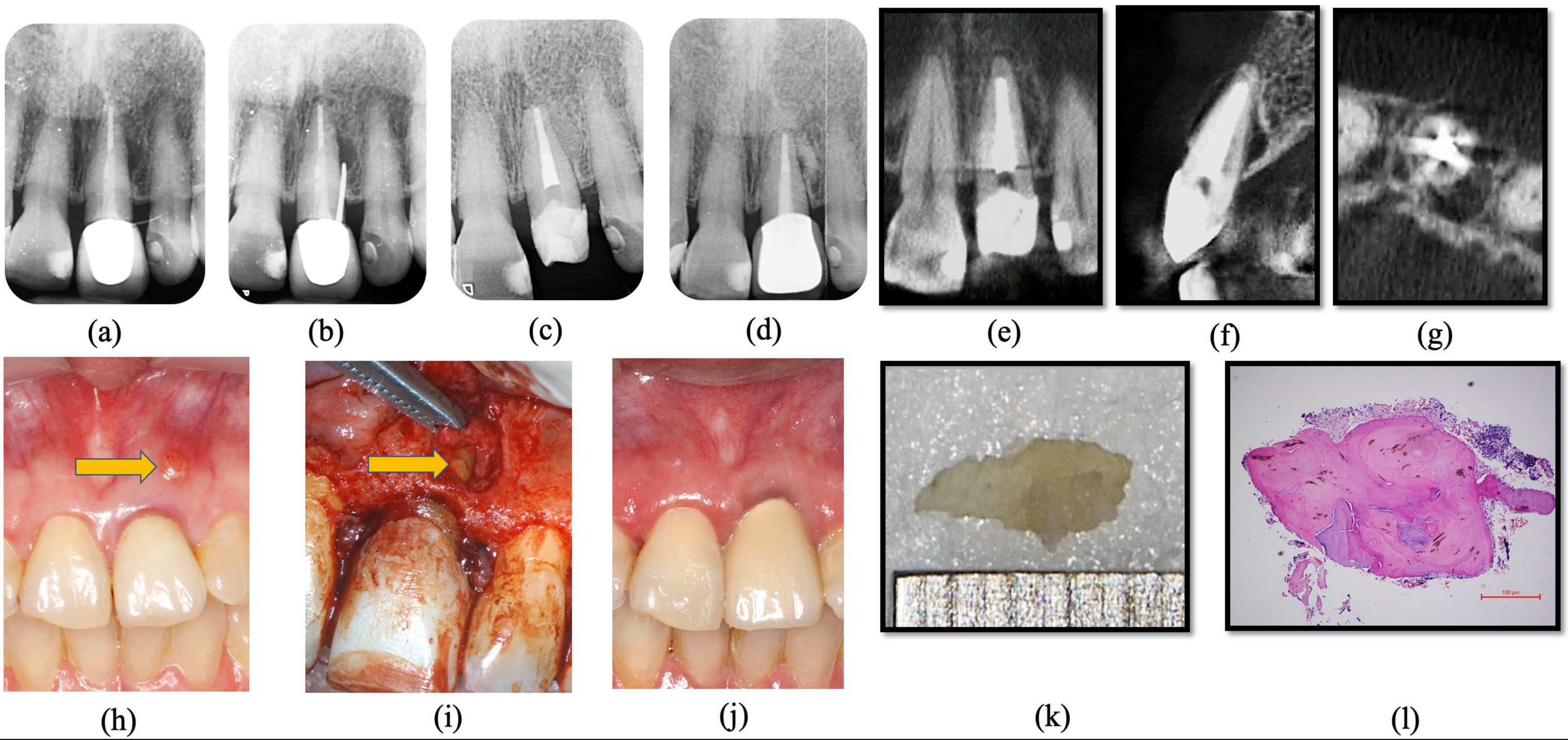


Figure 2 (a) Periapical radiograph of 21 presented with periapical radiolucency associated with cemental tear, demonstrated by the presence of “prickle-like" radiopaque mass at the disto-lateral aspect at the apical third level of the root, with a gutta-percha cone that pointed to the same level through the sinus tract; and reconstructed CBCT images of 21 in (b) coronal, (c) sagittal and (d) axial views; and (e) clinical view of 21 presented with suppurating sinus tract on the labial alveolar mucosa. This case is an example of the classification of cemental tears - ***Class 2, Stage D***.

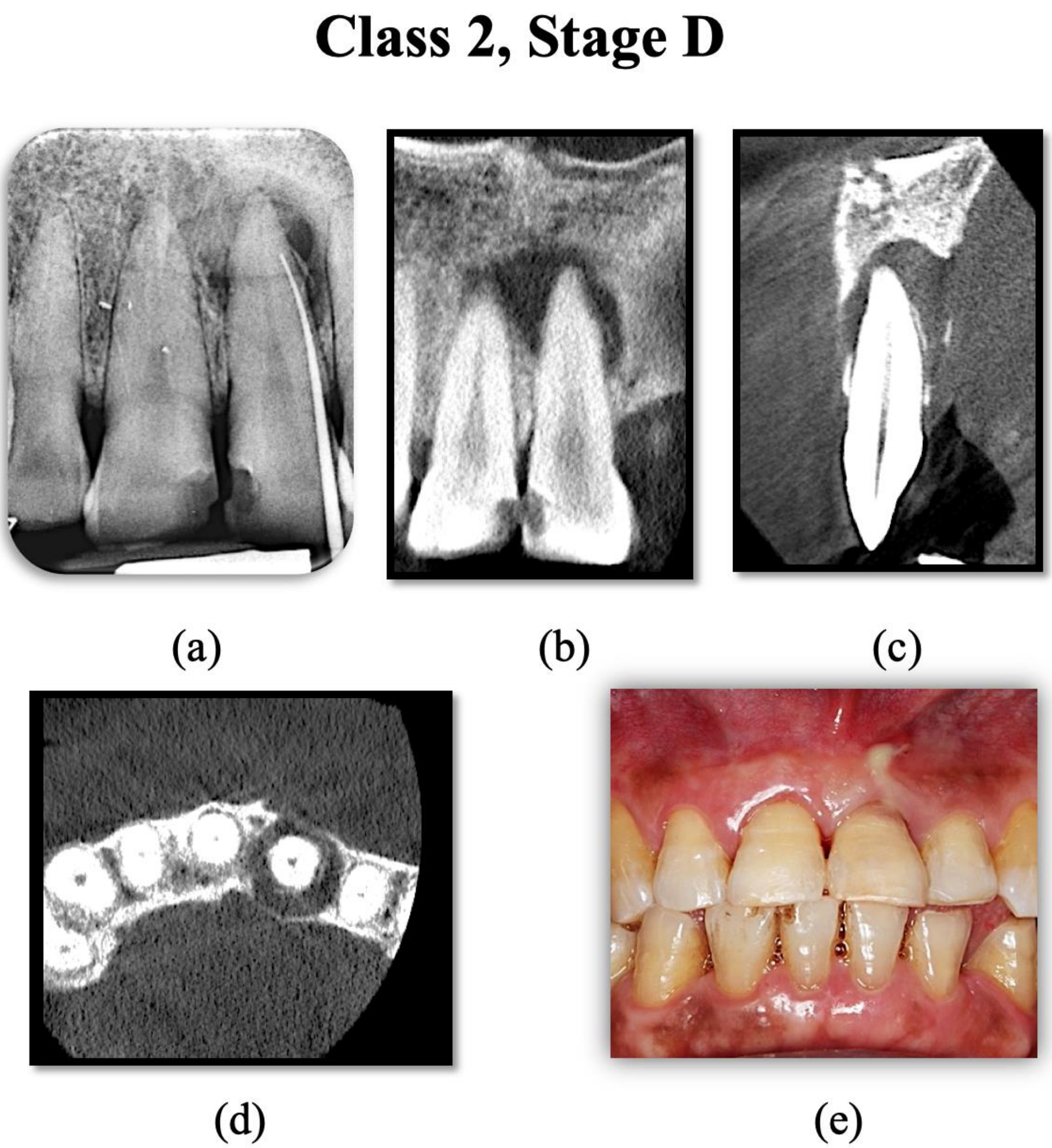


Figure 3 (a) Periapical radiograph of previously treated tooth 31 associated with widening of the periodontal ligament space; (b) Sinus tract was traced with a gutta-percha cone that pointed to the disto-lateral aspect at the apical root level. Reconstructed CBCT images of 31 in (c) coronal, (d) sagittal and (e) axial views; (f) clinical view of 31 and the associated soft tissue swelling (5 mm × 5 mm) on the labial mucogingival junction (arrowed); and (g) Intra-surgical inspection of 31 confirmed the presence of cemental tear (arrowed). This case is an example of the classification of cemental tears - ***Class 3, Stage A***. Courtesy of Dr Henry Li.

Class 3, Stage A

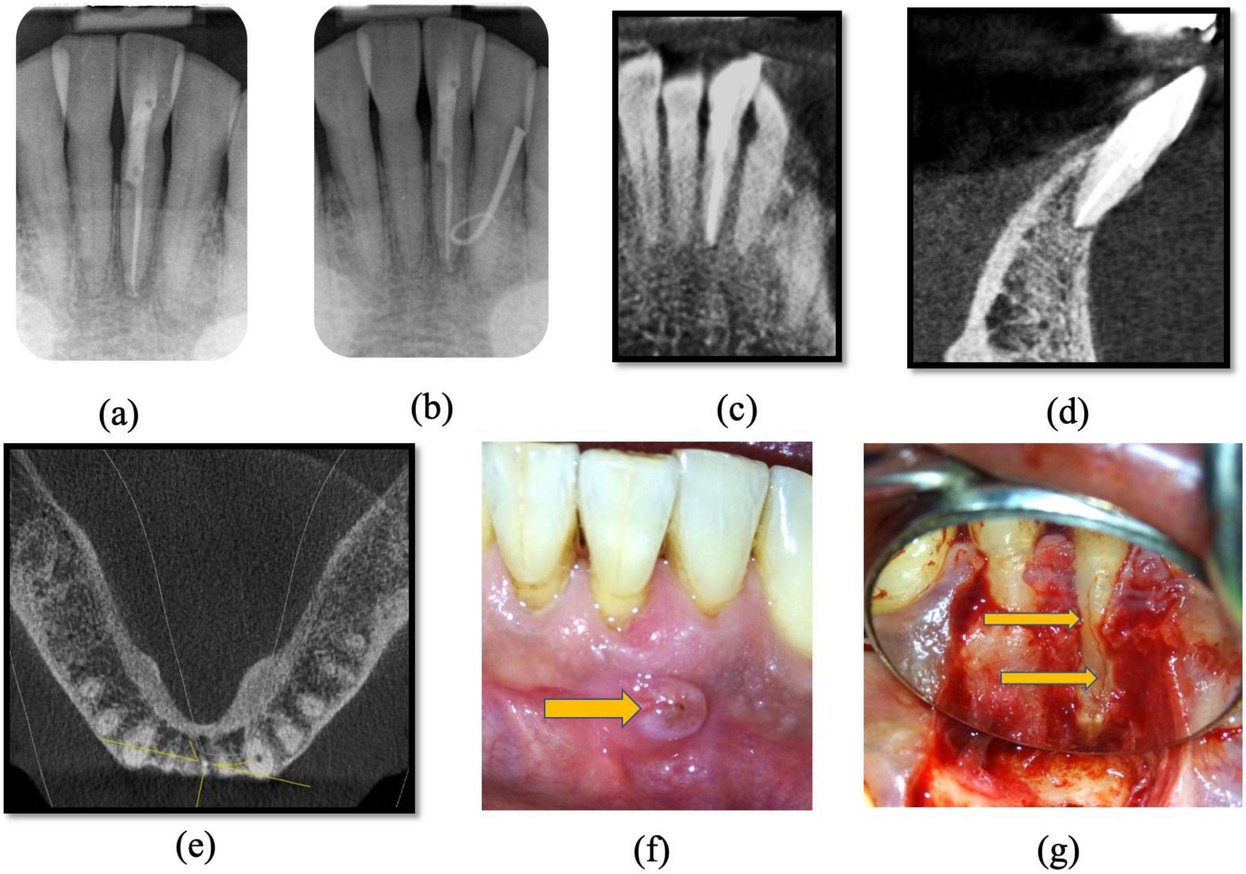
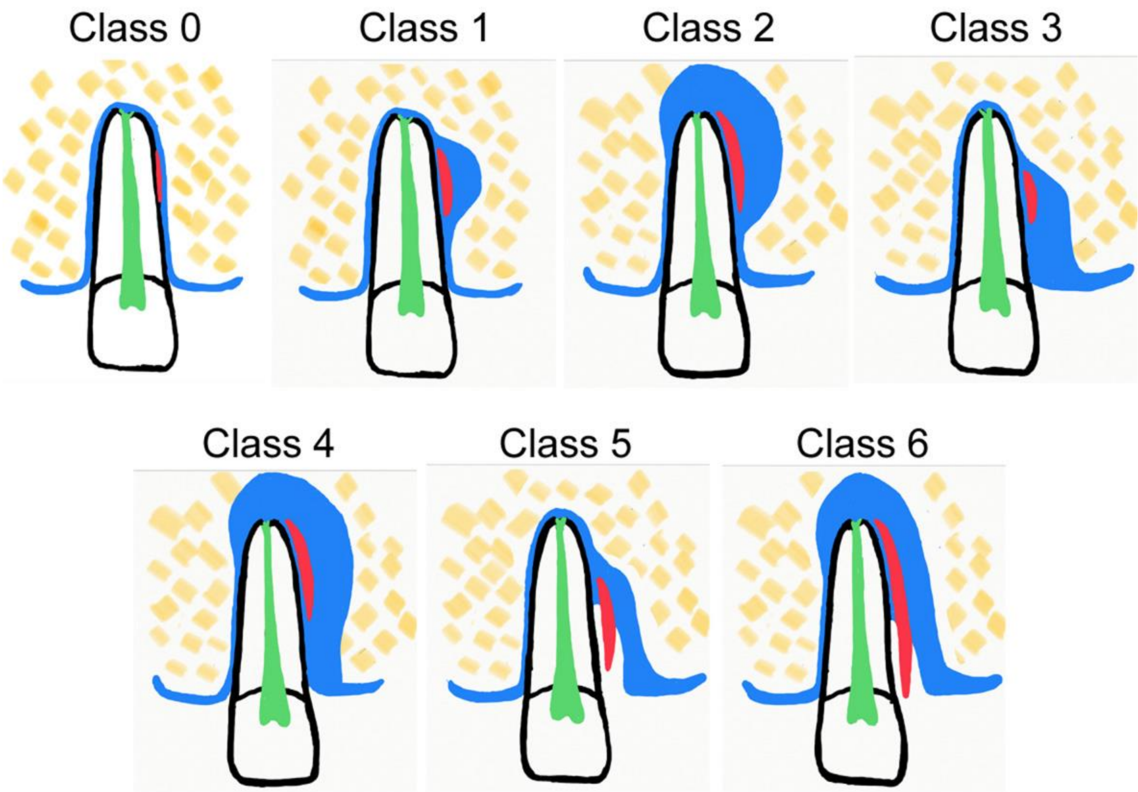


Figure 4 Schematic representation of the "Classification of Cemental Tears" based on (a) '*Classes*'; and (b) '*Stages*'. (Note: red = fragment of cemental tear, blue = radiolucent area, yellow = alveolar bone, black = outline of a tooth, green = root canal system)

4a


Class 0
Class 1
Class 2
Class 3
Class 4
Class 5
Class 6

4b

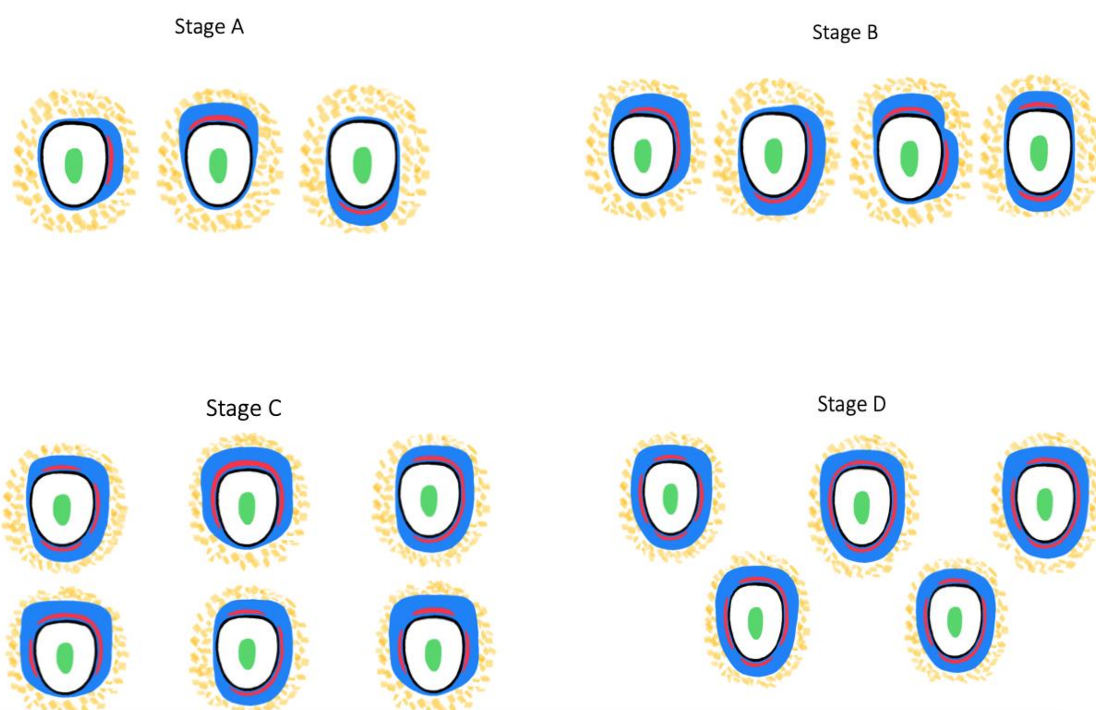

Stage A
Stage B
Stage C
Stage D

Figure 5 Example of the classification of cemental tears - ***Class 3, Stage C***. (a) Periapical radiograph of tooth 21 showed a canal that appeared obliterated and vertical crestal bone loss at the mesial and distal aspects, in association with cemental tears; and reconstructed CBCT images of 11 in (b) coronal, (c) sagittal and (d) axial views. Courtesy of Dr Alaa Jarkhi and Dr Elaine Hu.

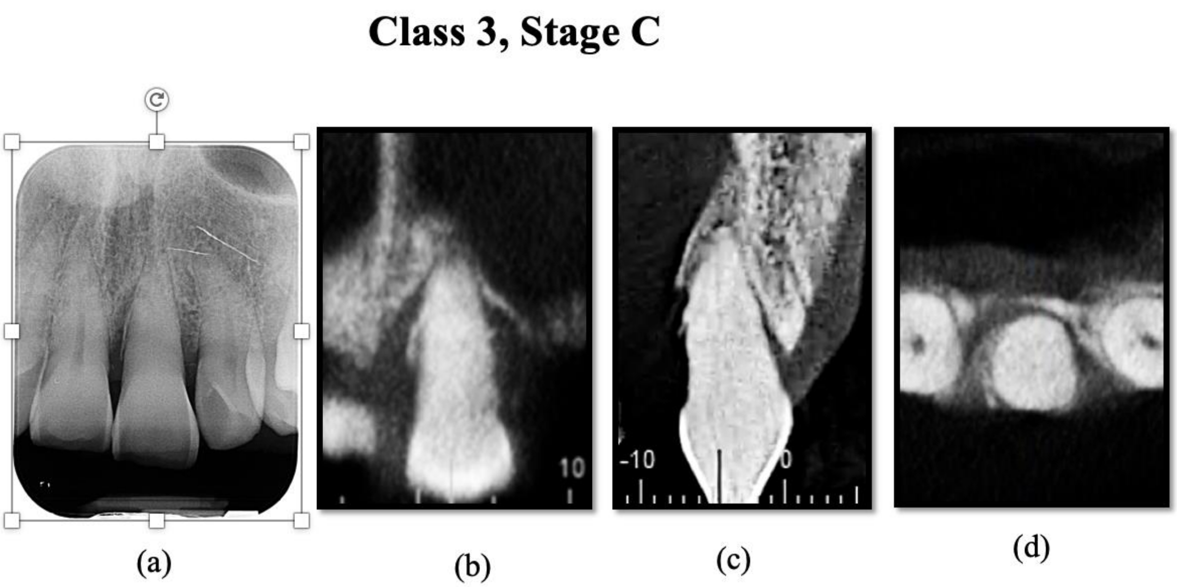
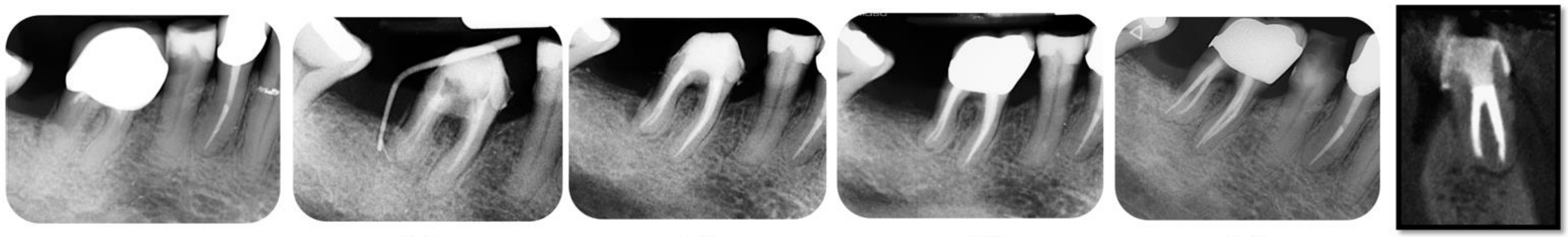
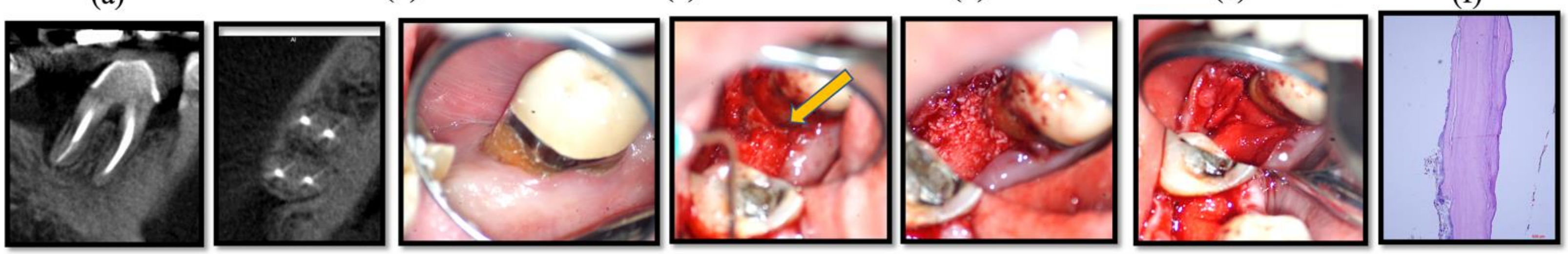


Figure 6 Example of the classification of cemental tears - ***Class 4, Stage B***. (a) Pre-operative periapical radiograph of previously treated tooth 46 presented with vertical crestal bone loss at the distal aspect of the distal root associated with cemental tear involving the apex; (b) Sinus tract persisted despite initiation of non-surgical root canal retreatment; (c) Post-obturation periapical radiograph; (d) Immediate post-operative periapical radiograph taken after surgical intervention and GTR procedures; (e) Periapical radiograph taken during the 6-month review showed the absence of periradicular radiolucency and reportedly free of clinical signs and symptoms; reconstructed CBCT images of 46 in (f) coronal, (g) sagittal and (h) axial views; (i) Clinical view of the distal aspect of 46 before surgery (mirror image); (j) intra-surgical view that showed the cemental tear on the distal root surface of 46 (arrowed, mirror image); (k) Placement of Bio-Oss® (Geistlich Pharma AG, Switzerland) and (l) Bio-Gide® (Geistlich Pharma AG, Switzerland); and (m) Histological specimen of the collected torn cemental fragment stained with haematoxylin & eosin. Courtesy of Dr Kelvin Ng.

Class 4, Stage B



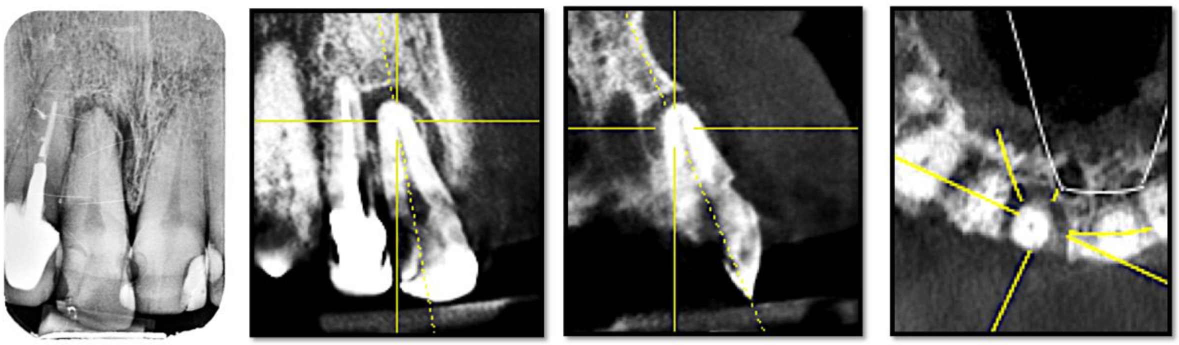
(a) (b) (c) (d) (e) (f)



(g) (h) (i) (j) (k) (l) (m)

Figure 7 Example of the classification of cemental tears - ***Class 4, Stage D***. (a) Periapical radiograph of tooth 11 presented with periapical radiolucency associated with cemental tear; and reconstructed CBCT images of 11 in (b) coronal, (c) sagittal and (d) axial views.

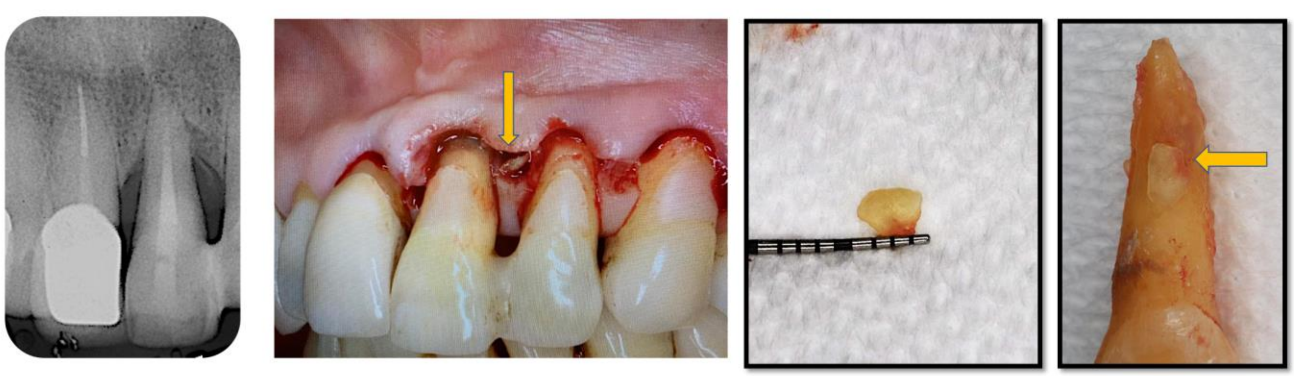
Class 4, Stage D



(a) (b) (c) (d)

Figure 8 Example of the classification of cemental tears - ***Class 5***. (a) Periapical radiograph of tooth 21 splinted to the adjacent tooth presented with vertical crestal bone loss at the mesial and distal aspects, in association with cemental tear and persistent deep periodontal pockets in spite of non-surgical periodontal therapy; (b) intra-surgical inspection of 21 confirmed the presence of cemental tear (arrowed); (c) a torn cemental fragment removed; and (d) direct inspection of the root surface with cemental tear of extracted 21. Courtesy of Dr Ian Lai.

Class 5



(a) (b) (c) (d)

Figure 9 Example of the classification of cemental tears - ***Class 6, Stage C***. (a) Periapical radiograph of tooth 36 presented with vertical crestal bone loss involving the apex at the distal aspect of the distal root, in association with cemental tear; and reconstructed CBCT images of 36 in (b) sagittal and (c) axial views. Courtesy of Dr Ian Lai.

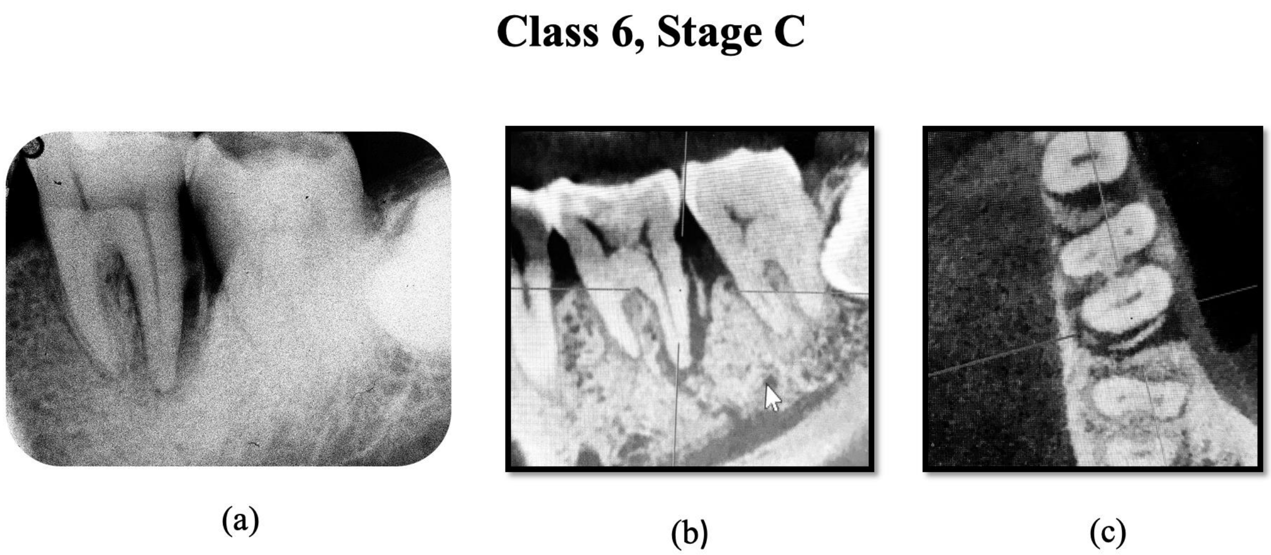


Figure 10 Example of the classification of cemental tears - ***Class 6, Stage C***. (a) Pre-operative periapical radiograph of tooth 21 presented with periradicular radiolucency with apico-coronal extension at the mesial aspect, in association with cemental tear and 9 mm periodontal probing depth with purulent discharge; apical half of the cemental fragment was not clinically accessible; (b-d) reconstructed CBCT images of 21 in (b) coronal, (c) sagittal and (d) axial views; (e) post-operative radiograph of 21 after surgical intervention and GTR procedures; (f) periapical radiograph taken during the 3-month review, demonstrating signs of *uncertain healing*; deepest probing depth had reduced to 6 mm and no other clinical abnormalities were detected. Intra-surgical clinical view of 21: (g) with the presence of a large piece of cemental tear on the mesial aspect of root surface (arrowed); (h) after the enucleation of granulation tissue, apicectomy, removal of cemental tears and root planing; (i) during application of EMD - Straumann® Emdogain® (Institut Straumann, Basel, Switzerland) on the denuded root surface; (j) placement of Bio-Oss® (Geistlich Pharma AG, Switzerland) into the bony defect; (k) placement of Bio-Gide® (Geistlich Pharma AG, Switzerland) over the Bio-Oss® filled defect; and (l) four pieces of torn cemental fragments removed from 21. Courtesy of Dr Amelia Cheung for (a) to (d).

Class 6, Stage C

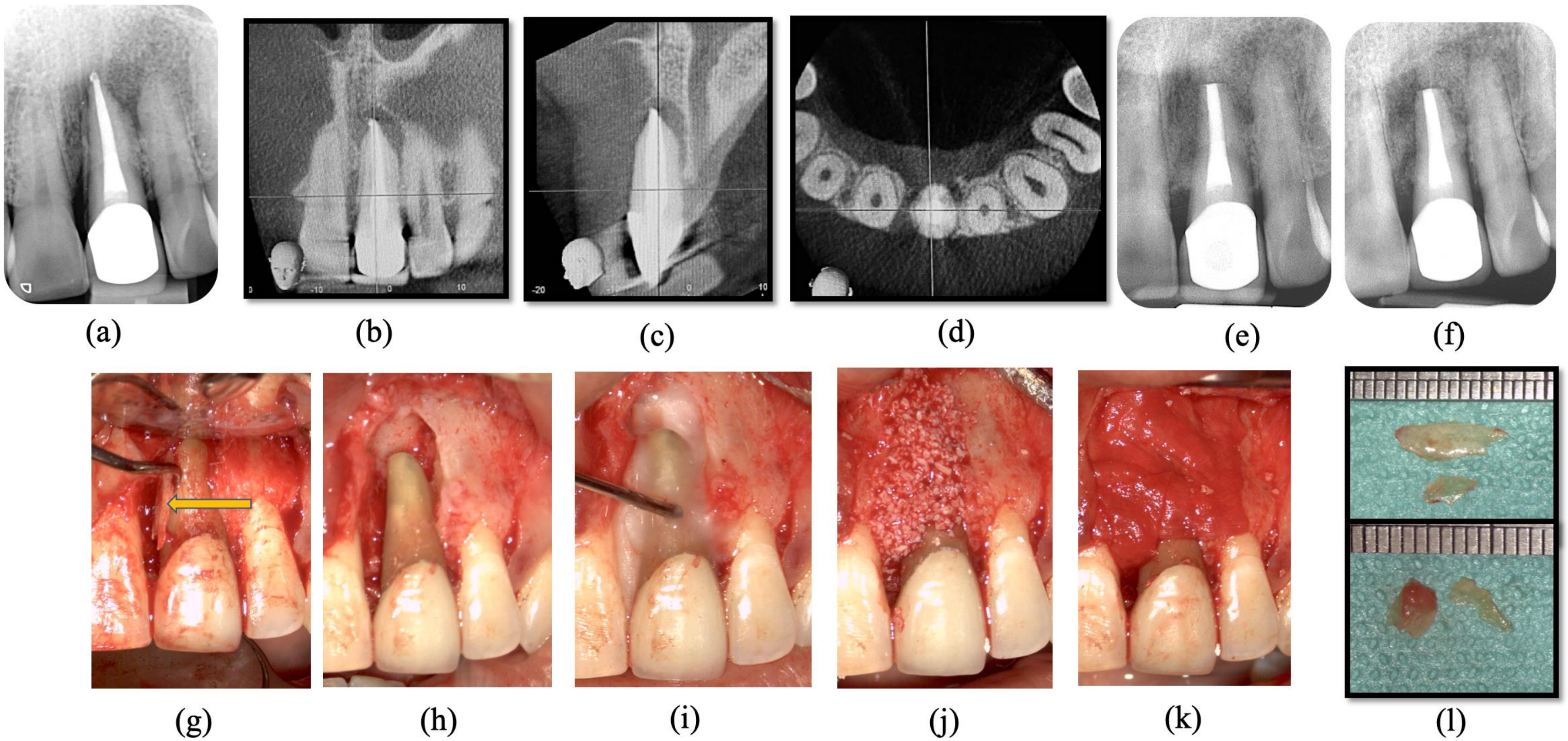


Figure 11 Flowchart illustrating the treatment strategies for cemental tears. (CeT = cemental tear, PARL = periapical radiolucency)

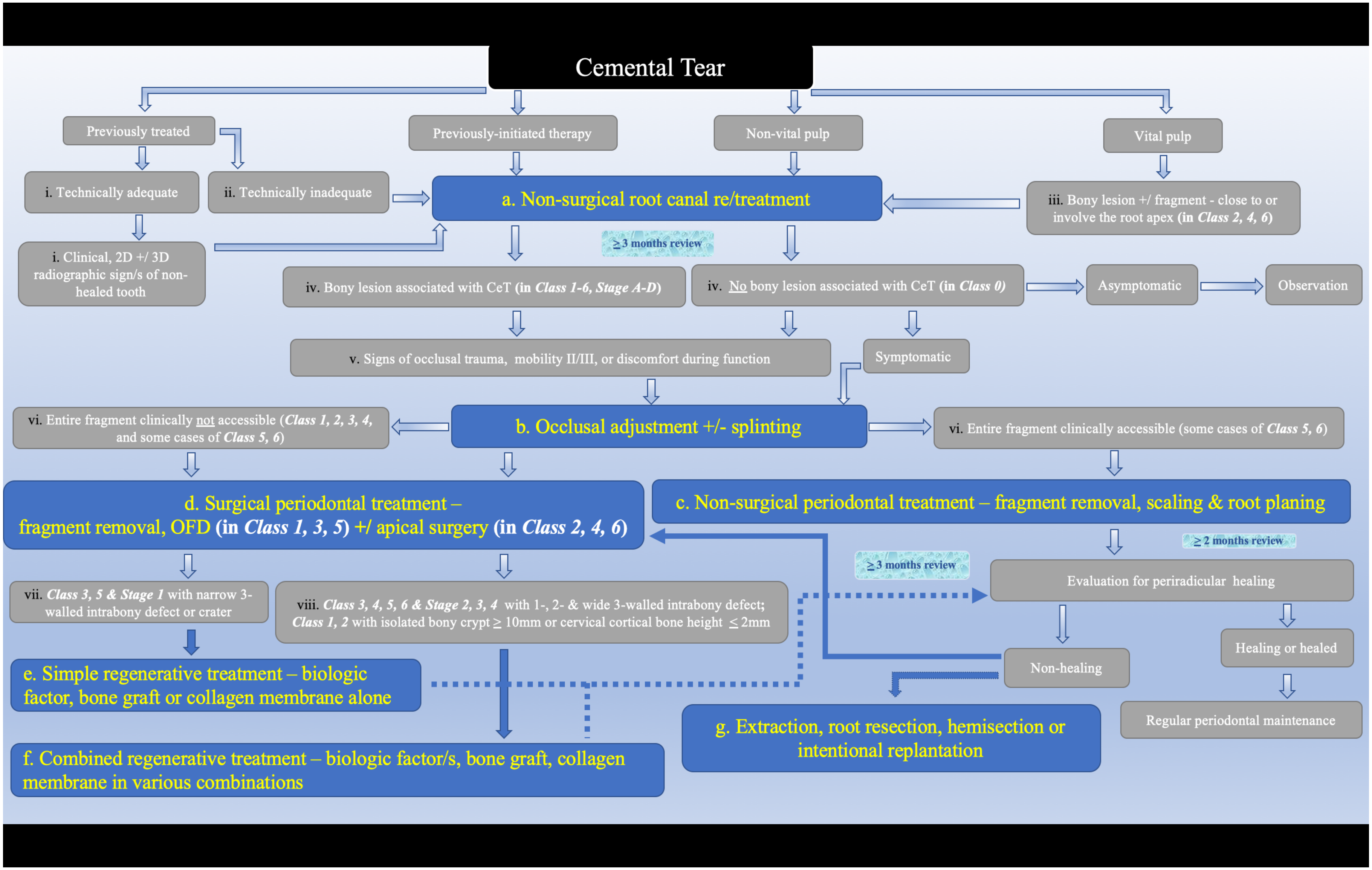


Table 1 Case reports and observational studies published in English language literature.

Table 1 Case Reports and Observational Studies Published in English Language Literature from 1969 to 2021.

A. Case reports

Author	Age (Gender)	Tooth type	Radiographic finding PAR	Radiographic finding CBCT	Biopsy	Finding and suspected factors	Treatment
Ishikawa *et al.* (1996)	72 (M)	11	Yes	No	No	Adult periodontitis, purulent discharge, PD≤8mm, excessive intrabony defect.	Not specified.
	55 (M)	11	Yes	No	No	Adult periodontitis, PD≤5mm.	Not specified.
	69 (M)	11, 21	Yes	No	No	Swelling, moderate mobility, PD≤8mm, extensive intrabony defect.	Not specified.
	68 (F)	25	Yes	No	Yes	Diabetes. PD≤6mm.	Not specified.
	67 (M)	35	Yes	No	Yes	Sinus tract, PD≤6mm, severe intrabony defect.	Surgical removal of CeT.
	54 (M)	36	Yes	No	No	Previous RCT & crown.	Not specified.
Müller (1999)	50 (F)	43	Yes	No	No	History of periodontitis. PD≤8mm, BOP, deep intrabony lesion, MII.	Surgical periodontal treatment. Bone graft/tetracycline, GTR.
Brunsvold & Lasho (2000)	60 (M)	41	Yes	No	No	Previous periodontal surgery. PD≤10mm, MIII. Large periapical lesion.	Extraction.
Harrel & Wright (2000)	63 (F)	35	Yes	No	Yes	History of periodontal treatment. Vital pulp, sinus tract, PD≤7mm, MII. Heavy occlusal loading & fremitus.	Occlusal adjustment. Surgical periodontal treatment. GTR.

Camargo *et al.* (2003)	61 (M)	21	Yes	No	No	History of trauma, previous RCT. Sinus tract, PD≤10mm, MI.	Non-surgical reRCT. Surgical periodontal treatment & apical surgery. Tetracycline on root. Bone graft & GTR. Splinting.
Marquam (2003)	71 (M)	21	Yes	No	No	Coronary bypass surgery, hypercholesterolemia.	Surgical periodontal treatment. GTR.
Chou *et al.* (2004)	52 (M)	15	Yes	No	Yes	History of occlusal adjustment due to fremitus. Crown. PD≤7mm.	Surgical periodontal treatment.
Lyons *et al.* (2005)	31 (M)	12	Yes	No	No	Previous RCT. PD≤8mm, BOP, MI.	Surgical periodontal treatment. Tetracycline, bone graft.
Tulkki *et al.* (2006)	79 (M)	45	Yes	No	Yes	Extraction of adjacent teeth & placement of implant. Vital pulp, PD≤10mm, REC≤4mm.	Surgical periodontal treatment.
Stewart & McClanahan (2006)	22 (M)	11	Yes	No	Yes	History of trauma, previous RCT & reRCT. Multiple sinus tracts, PD≤4mm, MII.	Extraction.
Tai et al. (2007)	79 (F)	21	Yes	No	Yes	History of trauma suspected, prosthetic abutment, previous RCT & reRCT. Swelling & sinus tract.	Surgical periodontal treatment & apical surgery – failed.
Kasaj *et al.* (2009)	50 (F)	14	Yes	No	No	Isolated deep pocket.	Surgical periodontal treatment. EMD for intrabony defect.
Lin *et al.* (2010)	72 (M)	46, 47	Yes (47) No (46)	No	Yes (2)	Likes to chew hard food, severe attrition, occlusal trauma suspected. Vital pulp, PD 47≤9mm, 46≤6mm, 47 gingival swelling & abscess, MII, angular defect.	Surgical periodontal treatment. Bone graft, GTR.
Damasceno *et al.* (2012)	50 (M)	35	Yes	No	Yes	Previous RCT & reRCT. post & core, prosthetic abutment. PD≤4mm, BOP.	Exfoliation of CeT. Non-surgical root canal treatment.

Haney *et al.* 2012	79 (F)	35	Yes	No	Yes	Prosthetic abutment. Vital pulp, oedema & suppuration, PD≤10mm, increased intrabony defect.	Surgical periodontal treatment. Bone graft.
Schmidlin (2012)	64 (M)	45	Yes	No	No	Prosthetic abutment with recurrent caries, previously initiated therapy. PD≤4mm, MIII.	Non-surgical RCT. Surgical periodontal treatment. EMD.
Watanabe *et al.* (2012)	49 (M)	13, 14, 15, 16, 23, 24, 25, 26, 31, 33, 34, 37, 41, 45	Yes	No	Yes (partial)	Aplastic anaemia. Swelling, sinus tract +/- purulent discharge, PD≤8mm, severe mobility.	13, 14, 15, 23, 25, 26, 45, 47 extraction. 33 surgical periodontal treatment.
Blum *et al.* (2013)	74 (M)	11	Yes	No	Yes	Myasthenia gravis & hyperlipidemia. Previous RCT & reRCT failed. Bruxism & malocclusion. Swelling, tenderness & facial oedema. PD≤9mm & purulent discharge through sinus tract. J-shaped radiolucency.	Surgical periodontal treatment & apical surgery. Bone graft, barrier membrane.
Kang *et al.* (2016)	60 (M)	11	Yes	Yes		History of trauma. TTP, discoloration, sinus tract, MII.	Non-surgical root canal treatment & apical surgery. Tetracycline, bone graft, barrier membrane. Splinting (after review).
Nagata *et al.* (2016a)	40 (F)	38	Yes	No	Yes	Previous RCT & autotransplantation. Vertical bone defect.	Extraction.
Nagata *et al.* (2016b)	83 (M)	11	Yes	No	Yes	Non-vital pulp, PD>10mm, MII.	Intentional replantation. EMD, ß-TCP, bone graft.
Xie *et al.* (2017)	35 (F)	25	Yes	No	Yes	Previous RCT. Non-vital pulp, swelling, sinus tract, pain, PD≤11mm, MIII, severe vertical bone loss.	Extraction.
	60 (M)	15				Prosthetic abutment. Non-vital pulp, PD≤7mm. MIII. Wear facets on opposing dentition, bruxism suspected.	Extraction.

	62 (F)	11, 21	Yes	No	Yes	Vital pulp, purulent swelling. PD 11≤10mm, 21≤9mm, MII, crowding & malocclusion.	Non-surgical periodontal treatment.
	53 (F)	11	Yes	No	Yes	Previous RCT, post/core & crown. Swelling, purulent sinus tract, PD≤9mm, MI. Root perforation.	Surgical repair of root perforation.
Park *et al.* (2018)	52 (F), 63 (F), 50 (M)	11, 11, 11	Yes	No	No	1. Rapid periodontal break down, gingival swelling. Occlusal trauma. 2. Swelling, sinus tract. Occlusal trauma. 3. Controlled hypertension, diabetes & hyperlipidemia.	1. Occlusion adjustment. OFD. 2. Occlusion adjustment. OFD. GTR. 3. Non-surgical periodontal treatment. OFD. Bone graft, GTR.
Borkar *et al.* (2019)	73 (M)	11	Yes	No	No	History of trauma. Pain & swelling. Occlusal trauma.	Non-surgical periodontal treatment.
Chawla *et al.* (2019)	34 (M)	12	Yes	No	No	History of trauma, previous RCT. Tender to percussion, PD≤10mm, MII. Attrition.	Non-surgical reRCT, surgical periodontal treatment & apical surgery. Tetracycline, bone graft .
Ong *et al.* (2019)	67 (F)	11, 21	Yes	Yes	Yes	Swelling, multiple sinus tracts with purulent drainage. 11 non-vital pulp, crown, PD≤6mm, MI. 21 previous RCT, crown, PD≤10mm, MII.	Extractions.
Pilloni *et al.* (2019)	61 (M)	11	Yes	Yes	No	Non-vital pulp, swelling, PD≤4mm, BOP.	Surgical periodontal treatment. Regenerative approach with hyaluronic acid & resorbable membrane.
Nathani *et al.* (2021)	53 (M)	21	Yes	Yes	No	Previous periodontal treatment. Non-vital pulp, CeT on mid-root, periodontitis stage III grade B, PD≤7mm, CAL≤11mm, REC=4mm, recurrent periodontal abscess, secondary	Non-surgical RCT, surgical periodontal treatment, modified papilla preservation flap.

						occlusal trauma, excessive occlusal overloading. ECR on 11.	
Pedercini *et al.* (2021)	67-80 (2F, 1M)	41, 22, 11	Yes	Yes	Yes (3)	41 previous RCT. sinus tract & swelling, PD≤7mm. 11 PD≤7mm. 22 PD≤5mm.	41 extracted. 11 bone graft, GTR. 22 apical surgery, bone graft, GTR.

B. Observational studies

Studies	Total samples size	No. of samples with CeT	Type of study	Radiographic finding		Histopathologic finding (n)	Finding and conclusion	Treatment
				PAR	CBCT			
Moskow (1969)	135 selected tooth sections of autopsied or surgical specimens	Not specified	Observational study	No	No	Yes	Plaque and calculus occupied space between CeT and root. Gouging of root surface by instrumentation. Thickened cementum. CeT at CDJ > within cemental layer.	Not applicable
Leknes *et al.* (1996)	22 extracted teeth Incisors 15/22, canines 3/22, premolars 4/22	17 extracted teeth	Observational study	Yes (partly)	No	Yes (1)	8/17 with vital pulp, 9/17 with previous RCT. Rapid attachment loss noted. CAL average 5-15.2mm, mean 9.7mm.	Not applicable
Lin *et al.* (2011)	114 teeth	71 teeth	Retrospective clinical observational study	Yes	No	Yes (61)	Incisors 54/71 (76.1%), men 55/71 (77.5%), >60 years of age 52/71 (73.2%), abscess 47/71 (66.2%), PD>6mm 52/71(73.2%), positive vitality	Non-surgical endodontic/periodontal treatment; apical/periodontal

							test 32/49 (65.3%), healthy opposing teeth 59/70 (84.3%), moderate to severe attrition 53/68 (77.9%), periodontal bone loss 61/71 (85.9%), periapical bone loss 46/71 (64.8%).	surgery; extraction.
Lin *et al.* (2012)		71 teeth 54/71 included	Retrospective clinical observational study	Not applicable	Not applicable	Yes	Proximal surfaces 79.6%, middle third 45.3%, apical third 41.4%. Piece-shaped 77.4%, U-shaped 22.6%. Length 3.8mm, width 2.2mm, thickness 0.9mm. Separation at CDJ 38/49 (77.6%), in cementum 11/49 (22.4%).	Not applicable
Lin *et al.* (2014)		71 teeth Only 33/71 (47%) were included for outcome assessment.	Retrospective clinical observational study	Yes	No	Not applicable	Healed 17/33 (51.5%), questionable 14/33 (42.4%), failed 2/33 (6.1%). Healed cases: apical 11.1%, middle 66.7%, coronal 60%. Healed by: non-surgical treatment 28.6%, surgical treatment 57.7%.	Non-surgical treatment 7/71 (9.9%), surgical debridement 13/71 (18.3%), surgical debridement, GTR & bone graft 13/71 (18.3%), extraction 38/71 (53.5%)
Keskin & Güler (2017)	1451 patients / 4629 teeth	13 teeth	Retrospective clinical observational study	Yes	No	No	Prevalence 0.89% (13/1451), F=8/943 (61.6%), M=5/508 (38.4%). Age, gender & tooth type showed no correlation. More CeT in maxillary teeth , teeth that had no previous RCT (10/13) and with apical lesions (11/13) noted.	None

Qari *et al.* (2019)		21 teeth	Retrospective clinical observational study	Yes	No	Yes	Maxillary central incisors 10/18 (47.6%), previous RCT 8/21 . Radiolucent patterns: D-shaped 38.1%, thin-vertical-line 23.8%, thick-vertical-line 14.3%, J-shaped 19.0%, PARL 4.8%.	Extraction 17/21. Surgical curettage 4/21.
Özkan & Özkan (2020)	813 patients (15886 teeth) M=417/813 F=396 /813	15 patients	Retrospective clinical observational study	No	Yes	No	Frequency 1.85%. F=7/396 (48.7%), M=8/417 (51.3%). Age, gender, tooth region, tooth type & previous RCT showed no correlation; teeth with periapical or periodontal lesions showed correlation.	None

Note: Abbreviation – BOP = bleeding on probing, ß-TCP = ß-tricalcium phosphate, CeT = cemental tear, CAL = clinical attachment loss, EMD = Emdogain®, GTR = guided tissue regeneration, OFD = open flap debridement, PAR = periapical radiograph, PARL = periapical radiolucency, PD = probing depth, RCT = root canal treatment, REC = gingival recession. Gender: F = female, M = male. Tooth mobility: Miller classification - Grade 1 = MI, Grade 2 = MII, Grade 3 = MIII;

Table 2 Summary of (a) etiologic factors; (b) clinical characteristics; (c) radiographic characteristics; (d) histopathologic characteristics; and (e) differential diagnoses of cemental tears.

Table 2 Summary of: (a) etiologic factors; (b) clinical characteristics; (c) radiographical characteristics; (d) histopathological characteristics; and (e) differential diagnosis of cemental tears.

Etiological factors	**Internal factors** - Structural weakness - Secondary and tertiary cementum deposition - Certain systemic conditions, e.g. malnourishment, aplastic anaemia - Age-related changes? **External factors** - Dental trauma - Occlusal trauma - Excessive occlusal loading (e.g. prosthetic abutment, parafunctional habit) - Previous periodontal therapy - Periodontal infection - Previous endodontic therapy - Tooth extraction.
Clinical characteristics	Mostly single-rooted tooth. Hard tissue cemental fragment that appears as: - Sheet- or piece-like, thin, prickle-like or tear-like - Ledge-like projection on the root surface - Foreign body Tears affecting multiple root surfaces: - Detached U-shaped fragments - Apical regions of roots more frequently involved Average dimension: - Width = 1 - 6 mm - Length = 2 - 10 mm - Thickness $\leq$ 2 mm Location: - Cervical, mid-root and/or apical root region - Proximal root surfaces Common presentations: - Abscess and swelling - Deep isolated periodontal pockets > 6 mm - Positive signs of pulp vitality - Rapid isolated breakdown of the periodontal tissues - Localized suppurative periodontal disease - Gingival bleeding on probing - Swollen gingiva or alveolar mucosa - Purulent discharge through the periodontal sulcus or sinus tract - Increased tooth mobility +/- fremitus - Root filled tooth with post-treatment disease
Radiographical characteristics	Radiopaque mass adjacent to the affected root surface that may appear: - Prickle-like - Flake-like structure - Chip-like particle or fragment - Hard tissue-like material - Calculus-like spicule - Raindrop-shaped - Oblong Patterns of radiolucent osseous lesion associated or surrounding the radiopaque cemental fragment can be divided into different: - Shape (i.e. D- or J-shaped) - Thickness (i.e. thin or thick) and regularity in linearity Lamina dura appear disrupted

Histopathological characteristics	- Torn fragment of cellular +/- acellular cementum - Cemental lamellae and incremental lines +/- cementocytes within the lacunae - Maybe some peripheral root dentine attached to the cemental fragment. - Fragment surrounded by or attached to periodontal or connective tissue fibres, granulation tissue, inflamed fibrous tissue or fibrous scar tissue. - Lymphocytic infiltration +/- neutrophils and plasma cells - Focal destruction of cortical bone (i.e. lamina dura) and the surrounding cancellous bone - Diagnosis: chronic fibrosing osteomyelitis or primary chronic osteomyelitis
Differential diagnosis	Primary endodontic diseases: - Irreversible pulpitis - Apical periodontitis or abscess - Radicular cyst - Focal sclerosing osteomyelitis Primary periodontal diseases: - Periodontitis or periodontal abscess Combined diseases: - Primary periodontal disease with secondary endodontic involvement - Primary endodontic disease with secondary periodontal involvement - True combined diseases +/- vertical root fracture Lateral periodontal cyst Solitary bone cyst Dentigerous cyst* Central giant cell granuloma Globulomaxillary cyst Nasopalatine cyst Ameloblastoma Odontogenic keratocyst Adenomatoid odontogenic tumour* Hypercementosis Cemento-osseous lesion Fibrous dysplasia Cementoblastoma Cemento-ossifying fibroma Odontoma Calcifying epithelial odontogenic cyst* Calcifying epithelial odontogenic tumour* Ameloblastic fibro-odontoma Odontogenic fibroma or myxoma Osteosarcoma *Note: * often/always associated with unerupted or impacted toot in proximity.*

Table 3 Classification of cemental tears in three-dimensional perspective.

Table 3. Summary of the Classification of Cemental Tear in Three-Dimensional Perspective.

Class	Stage
0: Clinically inaccessible, no bony defect. **1:** Clinically inaccessible, bony defect with crestal bone intact, no apical involvement. **2:** Clinically inaccessible, bony defect with crestal bone intact, apical involvement. **3:** Clinically inaccessible, infrabony lesion+/dehiscence, no apical involvement. **4:** Clinically inaccessible, infrabony lesion+/dehiscence, apical involvement. **5:** Clinically accessible, infrabony lesion+/dehiscence, no apical involvement. **6:** Clinically accessible, infrabony lesion+/dehiscence, apical involvement.	**A:** 1 root surface involved. **B:** 2 root surfaces involved, **C:** 3 root surfaces involved. **D:** 4 or all root surfaces involved.