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ROOT RESORPTION

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بسم الله الرحمن الرحيم

تحت إشراف الأستاذ الدكتور الأستاذ

Certification of the Supervisor

I certify that this project entitled "Root Resorption " was prepared by the fifth-year student Fatima Furat under my supervision at the College of Dentistry/University of Baghdad in partial fulfillment of the graduation requirements for the Bachelor Degree in Dentistry.

Dr.Abeer Ghalib

2022A.D.

Dedication

To GOD who save me and enlighten me to do this..

To my lovely family especially "my mother" who made me feel good with her warm words of praise...

And to my father who supported me and making me fell extra special.

To my "faithful friend" which never let me passed through alone and standed by my side...

To my supervisor for being patient with me, encourage me to do my best..

I want to send them all my love and thanks for reaching this moment..

GOD bless all..

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LIST OF ABBREVIATION

Abbreviation	Meaning	Page No.
IRR	Internal root resorption	3
ERR	external root resorption	3
RGD	Arginine glycine aspartic acid	3
PDL	Periodontal ligament	3
ECR	External cervical resorption	7
FOV	Field of view	8
CBCT	Cone beam computed tomography	8
REP	Regenerative endodontic procedures	10
ESR	External surface resorption	11
RCT	Root canal treatment	18
TCA	Trichloroacetic acid	18
EIR	External inflammatory resorption	20
ERR	External replacement resorption	25
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1.Introduction

Root resorption is the loss of dental hard tissue because of odontoclastic action. In permanent teeth, it is undesirable and pathological in nature. Root resorption may occur on the inner aspect of the root canal (internal root resorption) or on the outer aspect of the root (external root resorption). On radiographic evaluation, resorption may appear as either an apical root blunting, lateral root resorption or in rare cases excessive root loss. External resorption leads to the loss of cementum, dentin and bone. It may take place in vital as well as in non-vital teeth and is identified during routine radiographic or clinical examination, as majority of the cases are asymptomatic **(Adaki RV., *et al*. 2014).** In the primary/mixed dentition this is a normal physiological process resulting in exfoliation of deciduous teeth but in the adult dentetion is largely pathological .Resorption can occur both internally and externaiiy and is known to be initiated and maintained by many factors but pulpal necrosis, trauma, periodontal treatment, orthodontic treatment and tooth whitening agents are the most commonly described stimulants.**(Fuss Z, Tsesis I ,*et al*. 2003)** Thus, root resorption in the permanent dentition is a pathologic event; if left untreated, it may result in premature loss of the affected teeth. Root resorption occurs In three stages; initiation, resorption and repair ***(Mavridou A M, Hauben E, at el .2016)*** **.** The process of resorption may be self-limiting and go undetected clinically. Regardless of its location, root resorption is irreversible, and may result in discomfort for the patient, requires management and , in some cases, results in the premature loss of the affected tooth. Root resorption is often challenging to accurately diagnose and manage.

1.1.Aim of the study

The aim of this narrative review is to present the relevant literature on the aetiology, pathogenesis, diagnosis and management, as well as discuss the future directions of diagnosis and management of root resorption.

1.2Definition of root resorption

Root resorption is the loss of dental hard tissue due to odontoclastic activity **(Patel et al., 2018)**. In primary teeth, root resorption is usually physiological and desirable as it allows the underlying permanent successor to erupt. In permanent teeth, root resorption may occur within the root canal [internal root resorption (IRR)] or on the outer aspect of the root[external root resorption(ERR)]. In advanced cases, the resorptive defect may progress into the crown of the tooth. Regardless of its origins, it is irreversible and typically pathological in nature and may result in discomfort for the patient require treatment and in some cases, the premature loss of the affected tooth **.** The non-collagenous organic outer aspect of the root canal wall (odontoblast layer and predentine) and root surface (precementum and periodontal ligament) protect the underlying dentine from internal and external root resorption, respectively **(Wedenberg, 1987; Wedenberg & Lindskog, 1987).** Once the non-collagenous layer is damaged or irritated, odontoclasts are recruited to the site of injury or irritation by the release of proinflammatory cytokines. Odontoclasts may bind to extracellular proteins containing the arginine–glycine– aspartic acid (RGD) sequence of amino acids present on the surface of mineralized tissues by means of integrins **(Schaffner & Dard, 2003).** Studies have reported that periodontal ligament (PDL), cementum and dental pulp are able to express(RANK)/RANK ligand (RANKL) RANKL, which is essential for the differentiation of odontoclasts during root resorption **(Diercke et al., 2012; Kikuta et al., 2015; Uchiyama et al., 2009; Yamaguchi et al., 2006).** Odontoclasts are smaller, have fewer nuclei and sealing zones than osteoclasts and create resorption depressions, *Howship lacunae*, on the surface of the mineralized tissues **(Pierce, 1989)**. Root resorption may occur in three phases: **initiation, resorption and repair (Mavridou et al., 2016).**

2.Classification of root resorption

A classification based on the resorptive lesion's location on the root and its radiographic nature is suggested. Root resorption can be classified to**(Figure1)**:-

- **Internal root resorption**
  - Inflammatory root resorption
  - Replacement root resorption
- **External root resorption**
  - Surface root resorption
  - Inflammatory root resorption
  - Replacement root resorption
  - Transient apical breakdown

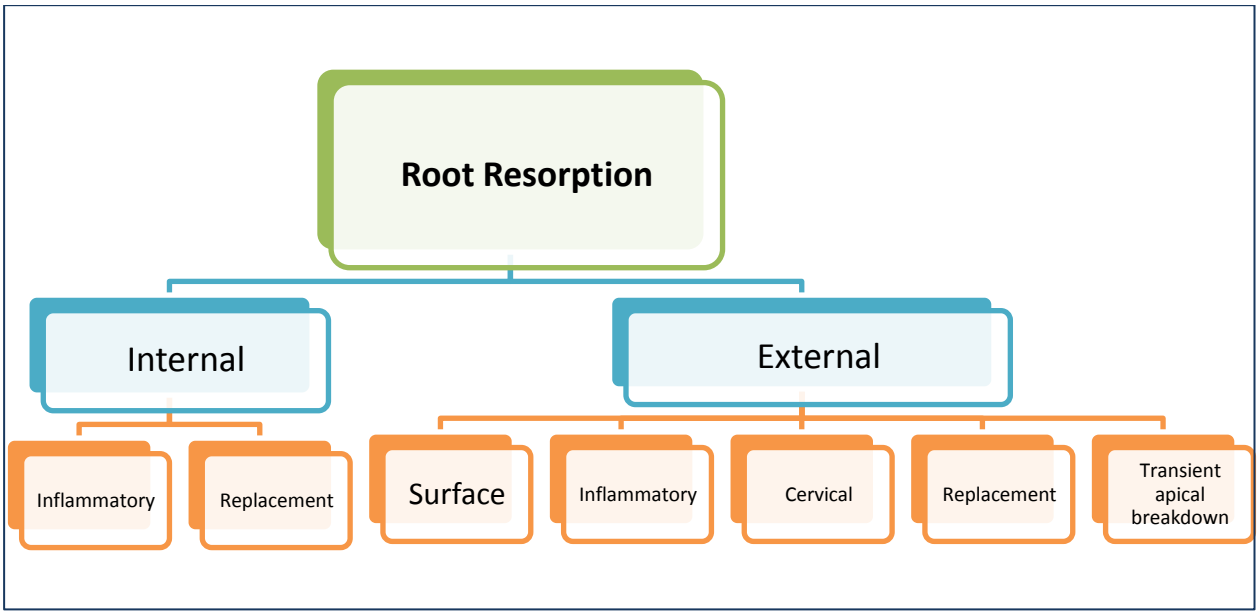

FIGURE 1 The classification of root resorptions based on their location in the root and the subsequent subclassification based on the pathogenesis.

3. Internal root resorption

Internal root resorption is initiated along the root canal wall and may result in the progressive destruction of the adjacent radicular dentine **(Tronstad, 1988)**. IRR may consist of granulation tissue only (*inflammatory internal root resorption*) or a combination of granulation and bone-like tissue (*replacement internal root resorption*; **(Patel et al., 2010)**).

3.1. Aetiology and prevalence of internal root resorption

The cause of IRR is not fully understood. It is widely accepted that IRR initiation is dependent on damage to the odontoblasts and (unmineralized) predentine layer exposing the underlying mineralized tissue to odontoclasts **(Wedenberg & Zetterqvist, 1987)**.

Several factors have been implicated in the injury and destruction of the predentine such as:-

1- Trauma **(Andreasen, 1970)**and Periodontal infections **(Rabinowitch, 1972).**

2- Caries-related pulpitis **(Rabinowitch,1972).**

3- Excessive heat during restorative procedures in teeth with vital pulps **(Rabinowitch, 1972).**

4- Orthodontic treatment **(Silveira et al., 2009)**

5- Cracked teeth **(Walton & Leonard, 1986)** .

6- Idiopathic dystrophic changes in healthy pulps **(Ashrafi & Sadeghi, 1980).**

The prevalence of IRR has rarely been reported in the literature. Thoma (1935) observed only one case of internal resorption out of 1000 teeth studied .**Ahlberg et al. (1983)** identified 51.5% (17 out of 33 teeth) of IRR in auto transplanted maxillary canines. The diagnosis of IRR in these studies was based solely on 2-dimensional radiographic findings, which could have underestimated the true prevalence of IRR **(Patel et al., 2010).**

3.2 Histopathology

It is well established that clastic cells are not capable of adhering to unmineralized collagen **matrices (Wedenberg, 1987; Wedenberg & Lindskog, 1987)**. Initiation of IRR is dependent on the removal and/or damage of the odontoblastic layer and unmineralized predentine **(Wedenberg & Zetterqvist, 1987)** and subsequent exposure of the underlying mineralised dentine **(Trope, 1998; Wedenberg & Lindskog, 1985).** Localized inflammation leads to an increase in clastic activity. Two phases of IRR (transient and progressive) have been reported **(Wedenberg & Lindskog, 1985).**

- Transient phase : is self-limiting as there is no inflammatory irritation and/or infection on the damaged root canal surface to stimulate and sustain the resorptive process.
- Progressive phase : In the progressive phase, the IRR continues due to bacterial stimulation of the clastic cells and a viable blood supply within the root canal. The source of noxious stimuli is the necrotic pulp coronal to the resorptive lacunae with the clastic cells being sustained by nutrients from the vital pulp tissue apical to the resorption site **(Tronstad, 1988).**

The histochemical profile was similar in both groups:-

- the resorptive process progressed more rapidly in primary teeth.
- The affected pulpal tissue was less vascular and infiltrated by inflammatory cells. **(Wedenberg & Lindskog, 1987).**
- intraradicular dentine is usually followed by deposition of metaplastic bone-like or cementum-like hard tissue instead of dentine in the resorption cavities **(Figure 2)**, and this has been described as 'frustrated repair' **(Patel et al., 2010).** It has been hypothesized that postnatal dental pulp stem cells from the vital (apical) pulp tissue are responsible for the metaplastic hard tissue of internal replacement root resorption **(Gronthos et al., 2002; Huang et al., 2009)**. A second hypothesis suggests that clastic cells originate from the periodontium **(Yang et al., 2009).**

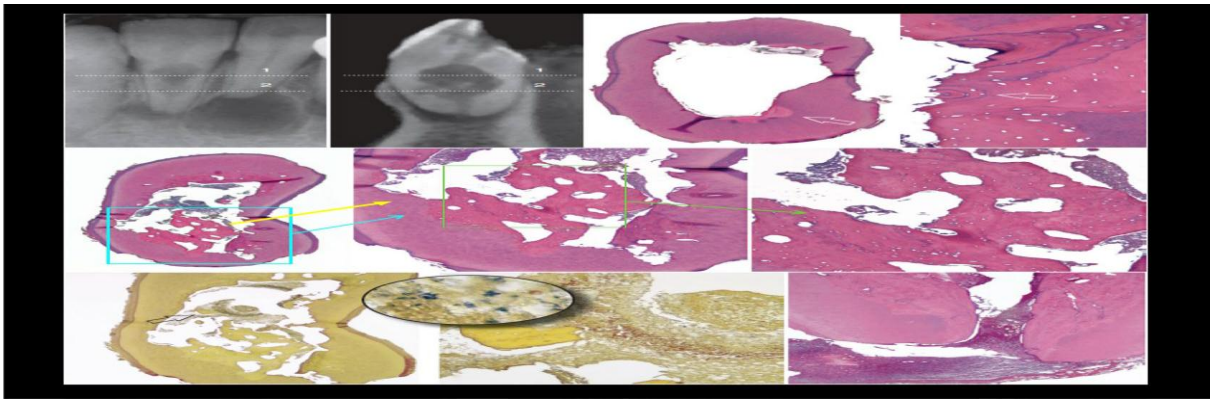

FIGURE 2: Internal replacement resorption.

3.3 Clinical features

Internal inflammatory and internal replacement types of IRR share similar clinical features. Teeth with IRR are often:-

- Asymptomatic and detected as an incidental radiographic finding **(Haapasalo & Endal, 2006; Patel et al., 2010).**
- The symptoms and signs of acute or chronic pulpitis.
- In established IRR cases, the pulpal tissue may become necrotic and chronically infected resulting in symptoms with or without signs of acute or chronic apical periodontitis **(Patel et al., 2010).**
- Patients may have an abscess or sinus, tenderness to percussion .
- IRR in the coronal third of the root canal may present with a pink discoloration in the crown of the tooth due to resorption and replacement of the hard tissue by fibrovascular granulomatous tissue **(Lyroudia et al., 2002).** This pink discolouration of the crown may also be misdiagnosed as external cervical resorption (ECR) **(Patel et al., 2009).**

3.4 Radiographic features

IRR may occur anywhere within the root canal system.

Internal inflammatory root resorption (Figure 3a) typically presents as a symmetrical oval or circular shaped extension of the root canal (ballooning) radiolucency **(Gartner et al., 1976).**

Internal replacement root resorption (Figure 3b) usually presents as an irregularly shaped radiolucency with a mottled or clouded appearance due to bone-like tissue deposits around the borders and within the resorptive defect **(Patel et al., 2010).**

It is well established that ECR and IRR share similar radiographic features on (2-dimensional) radiographs and can be indistinguishable from each other resulting in misdiagnosis **(Gulabivala & Searson, 1995; Tronstad, 1988)**.

In multirooted teeth, the IRR lesion in one root canal may be superimposed onto another unaffected root canal, thus causing confusion or even misdiagnosed as an ECR lesion **(Gartner et al., 1976; Patel et al., 2010).**

A high-resolution, small field of view (FOV), cone beam-computed tomography (CBCT) is recommended to investigate the exact nature of the IRR lesions, which appear to be potentially treatable **(American Association of Endodontists/American Academy of Oral & Maxillofacial Radiology, 2015; European Society of Endodontology, 2019**).

CBCT will accurately distinguish IRR from ECR, as well as confirm the nature (i.e. extent and presence of any perforation of the root canal wall, **Bhuva et al., 2011; Kamburoğlu et al., 2011; Lima et al., 2016)**. Several studies have confirmed that CBCT improves the diagnosis and treatment planning of root resorption when compared to radiographs **(Chogle et al., 2020; Ee et al., 2014; Madani et al., 2016; Patel, Dawood, et al., 2009; Rodrguez et al., 2017).**

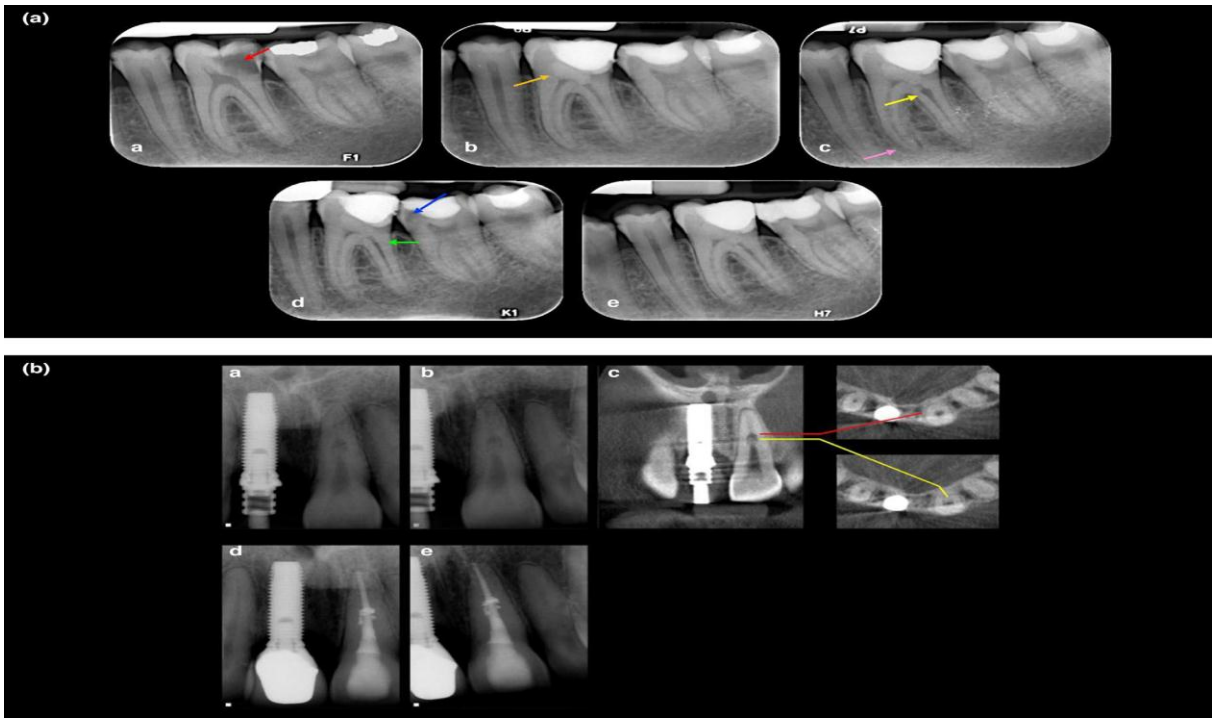

FIGURE 3: (a) **Internal inflammatory resorption** following pulpotomy. b) **Internal replacement resorption**.

3.5Management of internal root resorption

The management of inflammatory and replacement IRR are similar, it is essential to assess the extent of hard tissue destruction by taking a CBCT scan **(European Society of Endodontology, 2019)**.

If a perforation is detected, then irrigation must be limited to the coronal extent of the IRR to prevent an inadvertent hypochlorite accident **(Bhuva et al., 2011).**

1. **Endodontic treatment**:

- Endontic treatment should be considered only if the tooth appears to be restorable. The main objective of the treatment is to remove the bacteria and disinfect the root canal system, at the same time eliminating any remaining apical vital tissue, which is sustaining the resorption. Profuse bleeding may occur due to the granulomatous nature being disturbed and will stop once the inflamed pulpal tissue and granulation tissue have been completely removed.
- The canal should still be negotiable in cases of moderate Internal replacement root resorption; however, in more advanced cases, fine ultrasonic tips may be necessaryto fragment the metaplastic bone-like deposits to allow patency of the root canal to be established.
- Sodium hypochlorite is the irrigant of choice, due to the irregular nature of the resorptive defect, the irrigant should be energized after which an intracanal calcium hydroxide medicament may be used to enhance the disinfection and dissolve pulp tissue remnants in the inaccessible parts of the root canal space **(Burleson et al., 2007; Türkün & Cengiz, 1997)**.
- Warm vertical compaction has been shown to be a more effective root canal filling technique compared to lateral condensation and carrier-based techniques **(Tulsa Dental Products, Tulsa, OK, USA; Gencoglu et al., 2008; Goldberg et al., 2000).**

- A hybrid root filling technique is indicated when the canal apical to the perforating resorptive defect is filled with gutta–percha (GP), and a bioactive silicate cement is used to seal the resorptive defect **(Hsien et al., 2003; Jacobovitz & de Lima, 2008).**
- In cases where the perforating IRR defects are not amenable for internal repair, a surgical approach is indicated. The root canal system should first be accessed prior to the surgical repair and occluded with well-fitting GP points to maintain the patency of root canals from unintentional blockage in the subsequent surgical repair. Surgical exposure and debridement of the perforation followed by repair using bioactive hydraulic silicate cements are recommended **(Main et al., 2004).**

2. **Regenerative endodontic procedures (REP)** have been used recently to treat perforating IRR **(Arnold, 2021; Kaval et al., 2018; Saoud et al., 2016)**. **Saoud et al. (2016)** instrumented the entire root canal length and placed calcium hydroxide and triple antibiotic paste (metronidazole, ciprofloxacin and minocycline) in the root canal for 2 weeks each before sealing the root canal system with MTA. **Kaval et al. (2018)** debrided the entire root canal, followed by medicating the root canal with calcium hydroxide for 3 months before placing MTA over the blood clot. This treatment approach shows promising results with hard tissue formation in the perforated area and increased thickness of the root canal wall review after 2–3 years **(Arnold, 2021; Kaval et al., 2018).**

3.Extraction is indicated in cases where IRR is too extensive to be managed effectively.

4.EXTERNAL ROOT RESORPTION

External root resorption defines (ERR) as irreversible processes lyses in cement or cement-dentinal started to root surface of the teeth. This process appears in both teeth, with and without vitality, and the diagnosis is incidentally statutes on radiographs and clinical examination, although mostly are asymptomatic resorption**(Bergmans L., *et al*. .2002)**.

4.1External surface resorption

External surface resorption (ESR) is pressure induced resorption and occurs on the external surface of the root, it is non-infective and self-limiting, cemental repair ensues and it has also been described as pressure resorption **(Andreasen, 1981; Tronstad, 1988).**

4.1.1Aetiology and prevalence

- Pressure exerted by impacted teeth, orthodontic treatment, cysts or tumours are common causes of ESR**Killiany, 1999; Weltman et al., 2010)**. Teeth undergoing orthodontic treatment with a previous history of dental trauma are more prone to surface resorption **(Levander & Malmgren, 1988; Malmgren et al., 1982**).
- Increased orthodontic forces, as well as increased treatment times, may result in an increased incidence of ESR **(Roscoe et al., 2015; Weltman et al., 2010)**. It has been reported that orthodontic forces of 50–100 cN are optimal for orthodontic tooth movement and low risk of surface resorption **(Theodorou et al., 2019).**
- history of previous trauma **(Linge & Linge, 1983; Malmgren et al., 1982)**
- Class III malocclusion **(Kaley & Phillips, 1991)**
- Patient-related factors such as age and gender were found to be equivocal when it comes to higher risk of ESR **(Baumrind et al., 1996; Kjaer, 1995; Linge & Linge, 1983; Sameshima & Sinclair, 2001). Sameshima and Sinclair (2001)** reported a lower

incidence rate of ESR in Asian compared to white or Hispanic patients.

- **Systemic conditions** such as asthma have been reported to be associated with a greater incidence of ESR **(McNab et al., 1999)** whilst increased thyroxine hormone level has been reported to be associated with lower ESR incidence **(Shirazi et al., 1999).**

  Harris et al. (1997) reported higher susceptibility to ESR among siblings.

- **Habits** :Nail-biting habit was also found to be associated with a greater risk of ESR during orthodontic treatment **(Odenrick & Brattstr◌m, 1985)**.
- ESR is more likely to occur with **fixed appliance orthodontic** treatment compared with removable **appliances (Linge & Linge, 1983; Yassir et al., 2021)**.

4.1.2.Histopathology

The pathogenesis of ESR is attributed to damage to the precementum due to the pressure from impacted teeth, cysts, tumours or orthodontic treatment. It has been reported that this pressure can compress and/or damage the blood vessels in the PDL, leading to hypoxia, anoxia and eventually the death of cementoblasts, odontoclasts then start to resorb the root surface **(Martins et al., 2019).**

4.1.3Clinical features

1. Surface resorption is usually asymptomatic and diagnosed as an incidental radiographic finding.
2. The clinical findings are usually unremarkable, with no signs of endodontic disease.
3. The affected teeth respond normally to pulp sensitivity tests.

4.1.4Radiographic features

- Asymmetric loss of external root surface adjacent to the source of pressure from an impacted tooth, cyst or tumour is a common radiographic presentation .
- Surface resorption associated with orthodontic treatment may cause flattening or blunting of the root apices .
- The use of CBCT has resulted in increased detection and more accurate determination of the extent and nature of surface resorption **(Marmulla et al., 2005; Moze et al., 2013; Sondeijker et al., 2020).**
- Active and stable ESR may be differentiated by the disappearance and re-establishment of the periodontal ligament .

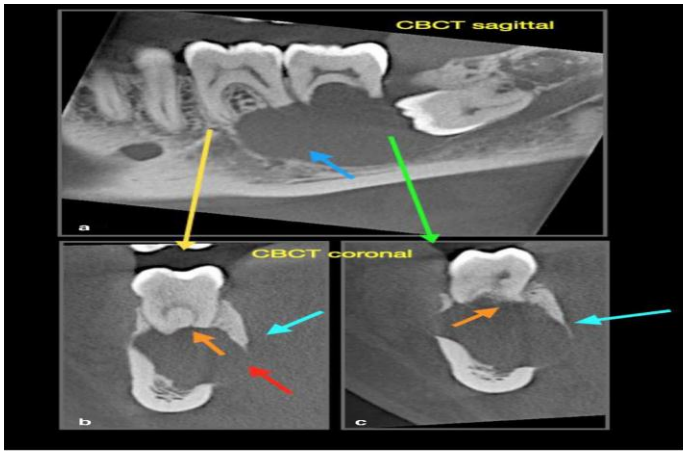

FIGURE 4 : **External surface resorption**.

4.1.5Management

1. ESR is managed by the appropriate elimination of the aetiological factor, i.e. excessive pressure, for example, removal of an impacted tooth.
2. A temporary pause of 3 months in active orthodontic treatment has been suggested to allow the resorbed cementum **(Mehta et al., 2017; Roscoe et al., 2015).**
3. Termination of orthodontic treatment may be indicated when there is significant ESR **(Artun et al., 2009; Levander & Malmgren, 1988)**. It is

good clinical practice to take a panoramic radiograph 6–12 months after placement of the fixed appliance **(Sondeijker et al., 2020)**.

4.2External cervical resorption

ECR usually occurs in the cervical region of the tooth immediately below the epithelial attachment **(Mavridou et al., 2016)**. In advanced cases, ECR can progress into the mid and apical thirds of the root.

4.2.1Aetiology and prevalence

The precise aetiology of ECR is poorly understood. Studies have shown that ECR could be multifactorial, with

- orthodontic treatment being the most commonly associated factor .
- The history of trauma, parafunctional habits, poor oral hygiene, periodontal treatment etc **(Mavridou et al., 2017).**
- Extraction of adjacent teeth **(Gunst et al., 2013**),
- herpes zoster virus infection **(Solomon et al., 1986**)and feline viruses **(von Arx et al., 2009)**,
- Playing wind instruments **(Gunst et al., 2011),**
- The use of bisphosphonates **(Patel & Saberi, 2015)** and
- Intracoronal bleaching **(Friedman et al., 1988).**

All the suggested aetiological factors are considered predisposing factors or association rather than causative, to date, there is no evidence of the cause and effect relationship **(Patel, Mavridou, et al., 2018**).

The prevalence of ECR is poorly reported. Some epidemiological and retrospective studies reported a 0.02%–2.3% prevalence rate for **ECR (Gulsahi, 2014; Heithersay, 1999a; Irinakis et al., 2020)**.

4.2.2.Histopathology

The pathogenesis of ECR is not fully understood. Damage to the protective unmineralized cementum allows the odontoclastic cells to resorb the underlying dentine. Pathogenesis involves a three-stage process **(Mavridou et al., 2016).**

- Initially, the osteoclastic cells from the adjacent periodontium invade the exposed root surface through the breach in the cementum (initiation stage).
- The resorptive lesion resorbs the tooth structure and consists of fibrovascular tissue (resorption phase). The pulp space is protected from the ECR front by the pericanalar resorption-resistant sheet, resulting in the lesion spreading circumferentially and apico-coronally **(Figure 5).**
- Only in advanced cases does the ECR lesion perforate into the root canal. Bone-like tissue is deposited into the resorption cavity in advanced cases of ECR (reparative phase; **Figure 6).**

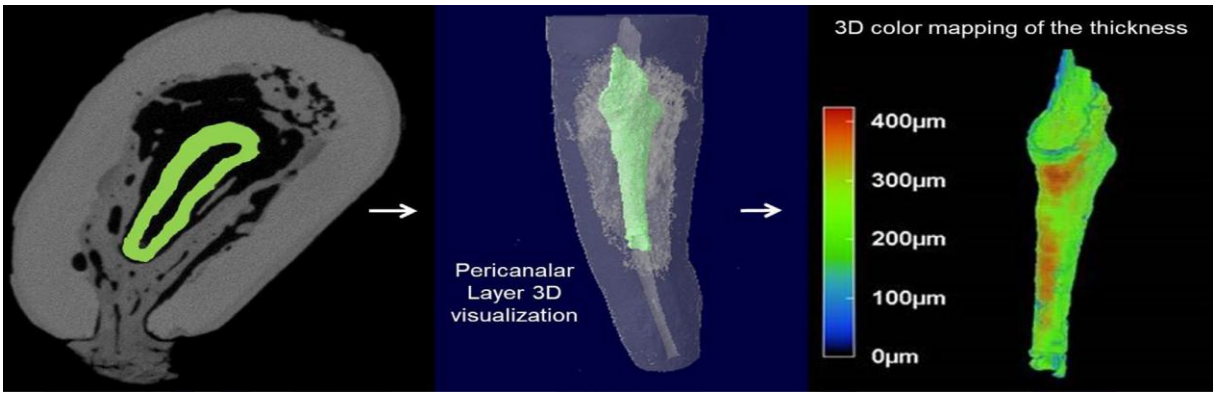

FIGURE 5: External cervical resorption

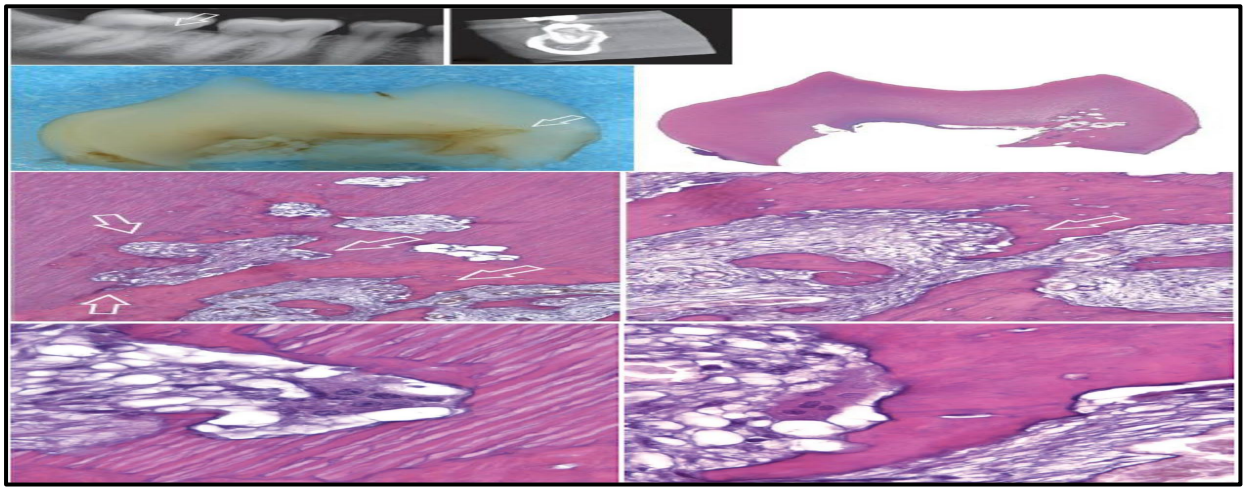

FIGURE 6 : External cervical resorption (reparative phase).

4.2.3.Clinical features

The clinical findings can be variable depending on the severity and nature of the resorptive defect, tooth type and stage of ECR **(Patel, Mavridou, et al., 2018).** **(Figure 7)**

- It is often asymptomatic in the early stage **(Liang et al., 2003).**
- A 'pink spot' may develop in the cervical region of the tooth and it can be detected as an incidental finding if it occurs at the labial/buccal or lingual/palatal surface. The pink discolouration is due to the fibrovascular granulation tissue occupying the resorptive cavity **(Heithersay, 2004).**
- Loss of periodontal attachment and profuse bleeding due to disturbing the vascular granulation tissue upon probing of the resorptive defect are among the other clinical features of ECR. **(Patel, Kanagasingam, et al., 2009).**
- In advanced cases, the resorption may eventually perforate the root canal wall and enter the pulp.
- The affected tooth usually respond to pulp sensitivity tests, except if the ECR has perforated the pulp chamber and pulp necrosis has ensued **(Frank & Torabinejad, 1998; Patel, Kanagasingam, et al., 2009).**

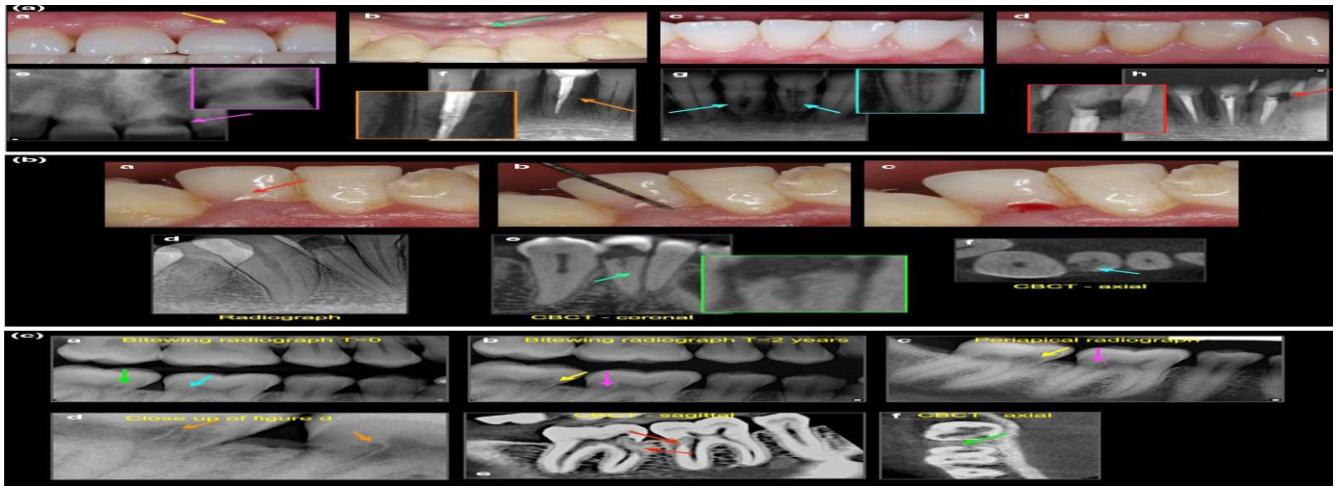

FIGURE 7: External cervical resorption .

4.2.4.Radiographic features

ECR can have varying radiographic features depending on

- ❖ the location,
- ❖ severity and
- ❖ phase of the lesion, i.e. resorptive or reparative .

- There is no 'classical' radiographic appearance of ECR.
- ECR often presents as a radiolucency in the resorptive phase; however, in moderate to advanced cases, the lesion may have mottled radiographic appearance as a result of the deposition of fibro osseous tissue within the resorptive as the body attempts to repair the resorptive defect (reparative phase; **Gunst et al., 2013; Patel, Kanagasingam, et al., 2009).**
- The border of the resorptive defect may be well defined or have a ragged, irregular appearance.
- The root canal outline is visible as long as there is no perforation of the root canal wall. It can be difficult to distinguish ECR from IRR especially when the tooth is asymptomatic (**Durack & Patel, 2016).**
- Parallax radiographs aid in differentiating ECR from IIR, as well as determining the location of the ECR **(Durack & Patel, 2016).**
- The 2-dimensional Heithersay classification has been used to assess the extent of ECR detected on radiographs **(Heithersay, 1999b).** Four stages are described:

i. class I lesion manifests as a shallow lesion in the coronal dentine.

ii. class II lesion extends deeper into the coronal dentine and close to the pulp.

iii. class III lesion penetrates the coronal third.

iv. class IV penetrates beyond the coronal third of the root.

Due to the limitations of (2-dimensional) periapical radiographs, only the proximal surface (mesial and distal) extent of ECR can be appreciated, whilst the approximal (buccal and palatal/lingual) extent of ECR cannot

be accurately determined. **Vaz de Souza et al. (2017)** compared the diagnostic accuracy of radiographs and CBCT in diagnosing the location with the Heithersay classification of simulated ECR lesions.

CBCT should be considered prior to managing ECR **(ECR Position statement, European Society of Endodontology, 2018).**

A 3D classification system has been proposed by taking into account the lesion height, circumferential spread and proximity to the root **canal (Patel, Foschi, Mannocci, et al., 2018)**.

In the future, it is anticipated that the classification will allow for an objective assessment of the treatment outcome in relation to the nature and extent of ECR **(Patel, Foschi, Mannocci, et al., 2018).**

4.2.5.Management

Management of ECR depends on the nature and accessibility of the lesion.

Preoperative CBCT is essential in the treatment planning and explanation of treatment options to the patient.

The treatment options of ECR include :-

- **External repair with(out) root canal treatment (RCT):-** External repair involves surgical exposure of the resorptive defect, complete excavation of the defect and restoration of the defects with composite, glass ionomer cement or Biodentine . Trichloroacetic acid (TCA) has been suggested to promote the coagulation necrosis of the resorptive tissue **(Heithersay, 1999c).**
- **Internal repair along with RCT**:- Internal repair is indicated when ECR is close to or has perforated the root canal system, and a surgical approach is not possible due to poor accessibility, or if surgical access will lead to an excessive amount of sound, tooth structure removal and the portal of entry cannot be located **.** RCT is completed, and the access cavity is restored together with the resorptive defect. Long shank burs and ultrasonic tips are useful in removing the resorptive lesion under a dental

operating microscope **(Frank, 1981; Patel, Foschi, Condon, et al., 2018).** Biodentine may be used to repair resorbed dentine, and its high pH may help to arrest the osteoclastic action of any residual osteoclastic remnants. **Irinakis et al. (2018)** identified the location of ECR in the mouth and the Heithersay class awarded as two local determinants that could significantly affect the failure rate. Posterior teeth with ECR had 70% failure rate at up to a 10-year follow-up period, compared to below 30% in anterior teeth. A retrospective assessment of 542 teeth diagnosed with ECR reported a mean 5-and 10-year survival rate of 70.3% and 28.6%, respectively, using a 3-step management strategy **(Mavridou et al. (2022).**

- **Intentional replantation (IR):-** Intentional replantation has been described in several case (series) reports to successfully repair ECR defects **(Krug et al., 2019; Patel, Foschi, et al., 2016).** This treatment option is indicated when ECR cannot be accessed and repaired by an external or internal approach, for example, ECR located interproximally in the middle or apical third of the root. Contemporary IR protocols (<15-min extraoral time, restoration with bioactive material) have been reported to result in higher survival rates **(Cho et al., 2016).** Clinical procedures of IR have been described in detail in the position statement of the **European Society of Endodontology (2021a). Irinakis (2018)** concluded that there was no statistically significant difference between repairing ECR defects versus no active treatment. Vital pulp treatment rather than RCT may also be indicated in specific cases. In certain situations, i.e when the tooth is unrestorable in the developing dentition, decoronation and intentional submerging of the root may be indicated to preserve, and allow the alveolar bone to develop **(Asgary et al., 2019).**

- **Extraction** is the treatment option for unrestorable, symptomatic ECR lesions. ECR tends to predispose the affected tooth to fracture during extraction due to the weakened and cavitated tooth structure and the infiltration of bone-like tissue in the resorptive cavity, and therefore, this needs to be carefully considered when ECR affects teeth in the aesthetic zone, a multidisciplinary approach is recommended **(Patel, Foschi, Condon, et al., 2018).**

4.3.External inflammatory resorption (EIR)

External inflammatory resorption (EIR) is present on the external surface of the root of majority of the teeth diagnosed with chronic apical periodontitis **(Laux et al., 2000; Tronstad, 1988; Vier & Figueiredo, 2002)**. EIR also affects teeth that suffer severe dental traumatic injury . In dental trauma injury (DTI) cases, EIR occurs as a result of injury to the root surface and adjacent periodontium.

4.3.1.Aetiology and prevalence

The root canal microbiome from infected necrotic root canals due to caries, microleakage and/or failed existing RCT results in EIR in the majority of teeth with radiographic signs of chronic apical periodontitis **(Laux et al., 2000; Vier & Figueiredo, 2002).** Pulp necrosis and subsequent infection of root canals of teeth affected by dental trauma injury (for example, avulsion and luxation) may result in bacteria traversing the dentinal tubules to the resorbed region of the external aspect of the root, resulting in EIR continuing. EIR rarely occurs in mild dental trauma, with no EIR case seen in concussion injuries and only one EIR case was seen in subluxation injuries **(Andreasen & Pedersen, 1985).**

4.3.2.Histopathology

- The pathogenesis of EIR after DTI commences following contusion injuries to the PDL, resulting in a breach in the protective nonmineralized precementum. Odontoclasts/ osteoclasts and macrophages migrate to the

injury site and bind to the underlying mineralized hard tissue and resorb the root surface **(Fuss et al., 2003; Tronstad, 1988).**

- Histologically, EIR appears as a saucer or bowl shaped area of resorption, with associated inflammation in the adjacent PDL **(Andreasen & Hjŏrting-Hansen, 1966b).**
- Resorption cavities contain *Howship lacunae*, which are occasionally occupied by odontoclasts. The inflamed area consists of mixed inflammatory cells infiltrate such as polymorphonuclear leukocytes, lymphocytes and plasma cells (Figure 8).
- The proliferation of capillaries is also a feature of inflammation **(Andreasen & Hjŏrting-Hansen, 1966b).**

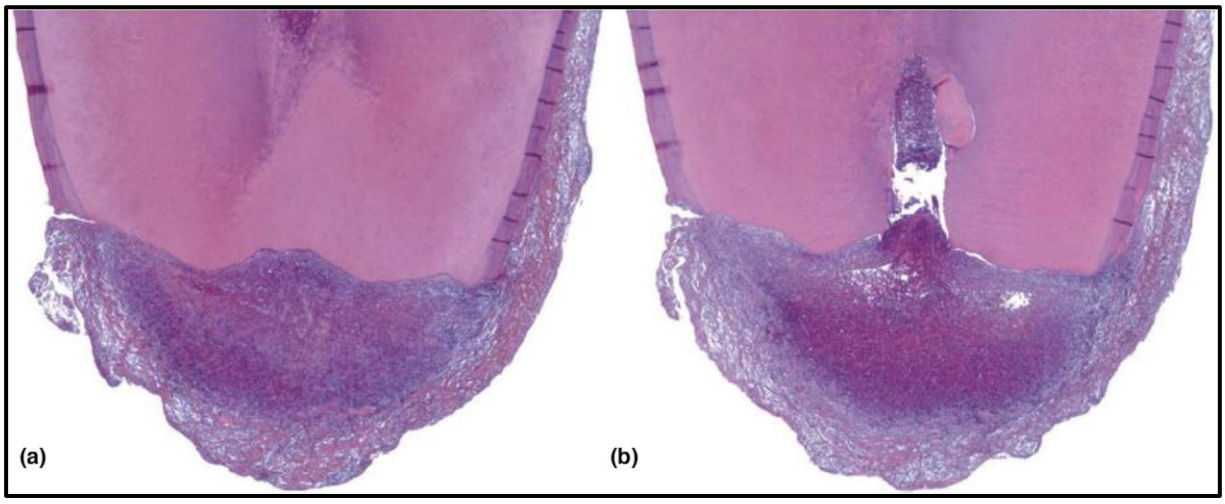

FIGURE 8: External inflammatory resorption

4.3.3.Clinical features

The clinical features of EIR are:-

- Irreversible pulpitis and/ or apical periodontitis such as pain.
- Swelling and sinus tract.
- Tenderness to percussion or palpation and discoloration.
- The affected tooth usually has a negative response to pulp sensitivity test **(Andreasen & Hjŏrting-Hansen, 1966a; Tronstad, 1988).**

4.3.4.Radiographic features

The diagnosis of EIR is confirmed on radiographic findings.

- EIR due to solely infected necrotic pulp contents may appear to be shorter or stunted in appearance than normally expected and sometimes have a ragged margin at the root end and associated with periapical radiolucency adjacent to the affected root .
- The root end may also have a ragged appearance. EIR associated with a history of moderate to severe DTI will usually have ragged bowl-shaped indentation along the lateral border of root surface with an adjacent periradicular radiolucency **(Andreasen & Hjŏrting-Hansen, 1966a, 1966b)**.
- Loss of lamina dura can also be seen in the region affected by the EIR and may be detected as early as 3–4 weeks after DTI. The root canal outline should be intact in the earlier stage of EIR.
- Perforation of the root canal wall can occur in advanced stages where the EIR is diagnosed and treated late. EIR may be aggressive in nature, and the progression of the root resorption can be rapid after onset, for example, resorption of an entire root can occur within months. Conventional radiography is the initial imaging technique of choice for diagnosis of root resorption after DTI. Radiographs are not sensitive enough to detect small-sized resorptive defects, CBCT was more accurate at detecting small simulated EIR lesions compared to parallax radiographs **(Durack et al., 2011; Estrela et al., 2009).** Root canal perforation in root resorption cases may not be diagnosed on a radiograph even if the root resorption is extensive, but the perforating resorption defect can be clearly visible on CBCT images **(Bhuva et al., 2011).** Therefore, CBCT is now considered a valid and reliable method for the assessment of moderate to advanced EIR defects.

4.3.5.Management

The objective in the management of EIR cases is the disinfection to eliminate the aetiological factor, therefore RCT for the treatable cases and extraction for the unsalvageable cases **.** Root canal treatment will eliminate the stimulating factors (microbes and their toxins) and arrest the resorptive process, thus preventing further damage on the root, at the same time allowing hard tissue repair of the damaged root surface **(Fuss et al., 2003; Tronstad, 1988).**

- When EIR is associated with DTI it is important to commence RCT as soon as possible due to the potentially rapidly progressing nature of EIR.
- In avulsion injuries of teeth with closed apices, the replanted tooth should be root treated 7–10 days after the reimplantation, even when there are no radiographic signs of EIR due to the small chance of pulp vitality being maintained and a high risk of EIR **(Fouad et al., 2020).** Enhanced protocols for root canal disinfection using intra-appointment medicaments have been suggested for the management of EIR associated with **DTI (European Society of Endodontology, 2021b; Krastl et al., 2021).**
- An intracanal calcium hydroxide dressing for 4 weeks to several months has been suggested **(Haapasalo & Endal, 2006; Mohammadi & Dummer, 2011; Trope, 2002).**
- It has also been suggested to place calcium hydroxide dressing until the resorption process is under control radiographically; however, there is limited evidence to support the use of intracanal medicaments **(Patel et al., 2020).**
- An alternative to calcium hydroxide dressing is the use of antibiotic corticosteroid paste such as Ledermix (Riemser) or Odontopaste (Australian Dental Manufacturing) followed by calcium hydroxide **(Krastl et al., 2021).**

- The combination of antibiotic-corticosteroid intracanal medication aims to reduce the inflammation in the periodontal membrane by directly inhibiting odontoclasts and detaching the resorptive cells from the damaged root surface **(Heithersay, 2007; Pierce et al., 1988; Pierce & Lindskog, 1987)**.

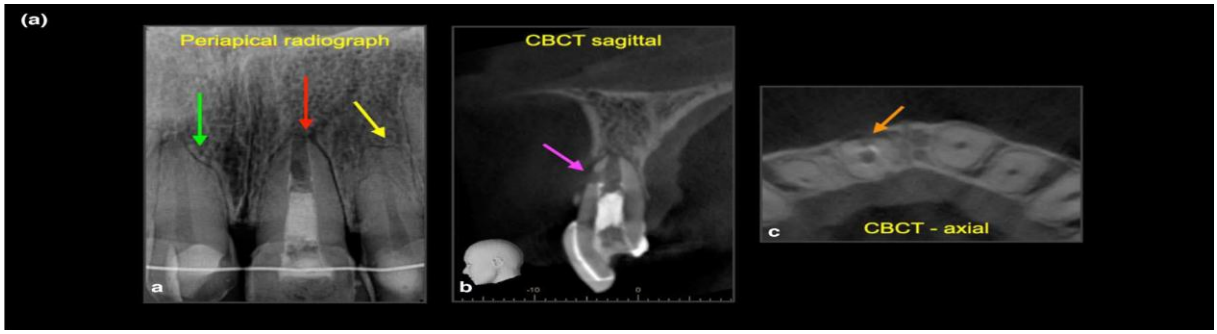

FIGURE9 : External inflammatory resorption, external surface resorption.

4.4.External replacement resorption (ERR)

ERR refers to the resorption on the root surface and subsequent replacement by bone tissue, which may result in ankylosis.

4.4.1.Aetiology and prevalence

ERR is associated with severe luxation such as intrusion and avulsion injuries. A retrospective study by **Soares et al. (2015)** revealed that replacement resorption was seen more frequently in cases of avulsion (87.2%), followed by intrusive luxation (57.1%). A meta-analysis revealed 51% of replacement root resorption in avulsion cases **(Souza et al., 2018).**

4.4.2.Histopathology

Depending on the nature of the injury:-

- the periodontal ligament may tear, become crushed and degenerate due to desiccation resulting in the periodontal ligament cells undergoing necrosis and together with damaged cementum and dentine, become resorbed via osteoclastic action and then ultimately replaced with alveolar bone laid down by osteoblasts as part of the repair process(**Andersson et al., 1984**).

- The osteoblastic activity may then gradually replace the radicular dentine with bone in the process of remodelling. ERR may be self-limiting and/or localized.
- **Andreasen (1980)** reported total mineralization of PDL as the most common finding in ERR after tooth replantation in monkeys.
- Deposition of bone tissue was found on the root surface and socket wall with soft connective tissue zone in early ankylosed area **(Andreasen, 1980).**

4.4.3.Clinical features

Clinical features of ERR include

- A lack of physiological mobility **(Andersson et al., 1984; Andreasen, 1975)**.
- The tooth may also be infraoccluded if ERR occurs in developing dentition, especially before the pubertal growth spurt of the patient.
- The tooth should respond normally to pulp sensitivity testing unless there is tertiary dentine formation, which delays or masks the response to sensitivity testing.
- A lack of response to sensitivity testing is not an indication for RCT in the affected tooth, as this pathological entity is entirely driven by the affected periodontium.

4.4.4Radiographic features

- Conventional radiographic examination will reveal the absence of periodontal ligament space where the resorbed root surface appears to fuse with the surrounding bone **(Figure 10).**
- The root dentine will have an irregular or 'moth-eaten' appearance as the dentine is replaced by bone **(Andreasen & Hjörting-Hansen, 1966b)**. Radiographs will only reveal the extent of ERR on the proximal aspects of the root.

- As with the types of root resorption described above, CBCT may be indicated to accurately assess the true nature and extent of ERR **(Durack & Patel, 2016).**

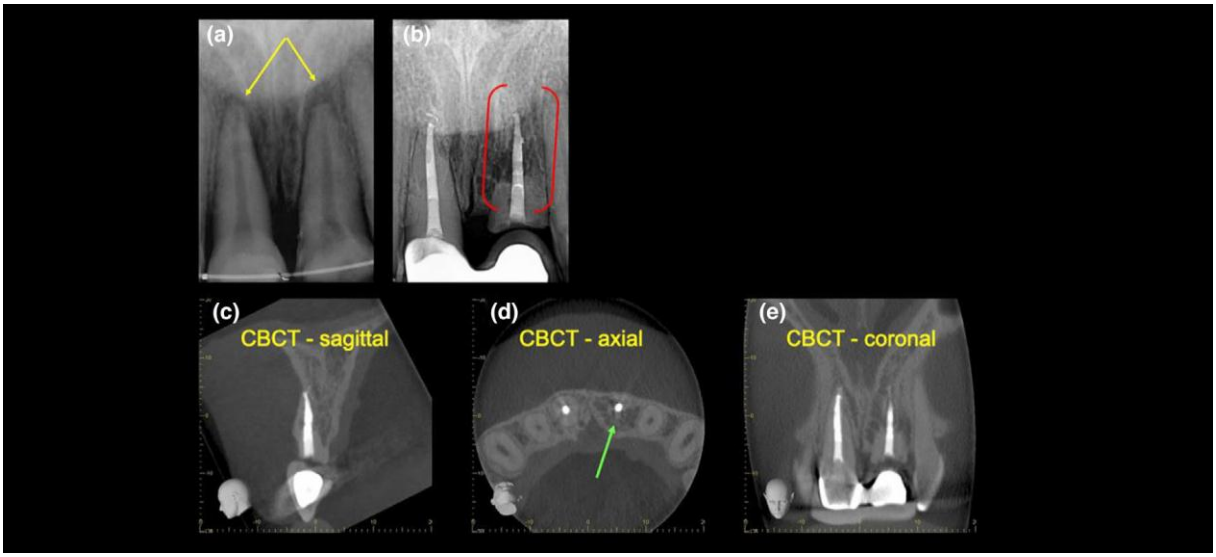

FIGURE 10: External replacement resorption.

4.4.5.Management

Presently, there is no treatment to arrest ERR.

- It may be self-limiting or continue to resorb the root and replace it with bone-like tissue for years, eventually resorbing the entire root. ERR may be reviewed periodically **(Finucane & Kinirons, 2003).**
- In the older patient, the progression of ERR may be slow, and the tooth can remain functional for many years without the need for any active intervention **(Andersson et al., 1989).**
- The early detection and management of ERR and ankylosis are crucial in children and adolescents before or during their pubertal growth spurt. This is because ankylosed teeth will arrest the development of the alveolar ridge on that region whilst the adjacent alveolar ridge continues to grow, causing the affected tooth to become infraoccluded and the alveolar ridge to underdeveloped **(Andersson & Malmgren, 1999).** This

will compromise the aesthetics, phonetics, function of the patient and further complicate future restorative or prosthetic treatment **(Malmgren, 2013; Malmgren et al., 2006). Malmgren (2013)** has advocated that ankylosed, infraoccluded tooth is intentionally decoronated below the level of cementoenamel junction in children and adolescents. In this technique, a mucoperiosteal flap is raised, and the tooth is decoronated to 2 mm below the marginal bone level, the decoronated root is allowed to fill with a blood clot and sealed with the mucoperiosteal flap.

- Once the patient is an adult, in their early 20's, permanent restorative treatment such as dental implant treatment may be considered. Other possible management strategies include composite build-up on the infraoccluded tooth to maintain a satisfactory appearance. This option is a short-to medium-term solution to improve the aesthetics. **(Andersson & Malmgren, 1999).**
- Autotransplantation with a premolar has been suggested as a treatment option **(Andreasen, Paulsen, Yu, Ahlquist, et al., 1990; Andreasen, Paulsen, Yu, Bayer, et al., 1990).** The donor tooth may require additional treatment procedures including RCT (depending on maturation status of the root apex) and reshaping the premolar to incisor shape **(Abella et al., 2018; Tsukiboshi et al., 2019).**
- Surgical repositioning involves extraction that breaks the bony contact with the root and replantation into the socket at a correct vertical and horizontal relationship with the adjacent teeth **(Takahashi et al., 2005).**
- Distraction osteogenesis has also been used to restore the correct vertical position and aesthetics of the infraoccluded tooth and the associated bone **(Isaacson et al., 2001). Filippi et al. (2006)** treated 15 ankylosed teeth (early stage) with IR after extraction and application of Emdogain (Straumann; gel containing enamel matrix derivative aimed to induce the

development of periodontium) on the root surface. Their 6-year recall revealed success in only seven out of the 15 teeth **(Filippi et al., 2006).** Another clinical study reported failures with all cases when Emdogain was used **(Schjȍtt & Andreasen, 2005).**

- Extraction of the tooth with ERR is indicated if a pathological root fracture occurs or is likely to occur. It is also indicated in extremely compromised aesthetics. Extraction of an ankylosed tooth often requires a surgical approach and can result in a considerable amount of bone loss, complicating future implant placement.
- A case series by **Yoshpe et al. (2020)** demonstrated the management of three ERR case with REP. They used platelet-rich fibrin instead of induced blood clot as a scaffold to promote stem cells differentiation and then placed Biodentine on top of the scaffold. These cases were followed up to 3 years, and the ERR were arrested and even reversed in some cases **(Yoshpe et al., 2020).** The success of REP offered a promising potential solution for ERR to avoid decoronation or extraction. However, more clinical trials are required to provide definitive evidence.
- In general, the management of ERR depends on the growth status of the patient. ERR in adult should be managed conservatively. Periodic review and/or composite build-up to restore the aesthetic appearance is usually sufficient. If the affected tooth is extensively resorbed, extraction and replacement with prosthesis are recommended. However, the ERR in children/adolescents require more active intervention such as decoronation or REP.
- If the tooth is severely resorbed and extraction is unavoidable, autotransplantation or orthodontic space closure could be more relevant as permanent restorative or implant treatment is contraindicated in growing patient.

4.5 .Transient apical breakdown

Transient apical breakdown is resorption of the apical portion of the root in healthy teeth with a recent history of DTI **(Boyd, 1995).** TAB appears to be related to the type of injury and the stage of root development **(Andreasen, 1986).**

4.5.1. Aetiology and prevalence

- The prevalence of transient apical breakdown is rarely reported, and to date, there is only one comprehensive study on TAB, which reported a 4.2% prevalence in 637 teeth affected by DTI **(Andreasen, 1986)**.
- TAB was associated with moderate DTI, such as extrusion and lateral luxation and rarely associated with minor DTI (such as concussion and subluxation) and usually absent in severe dental traumatic injuries **(Andreasen, 1986).**
- A diagnosis of TAB was reached when an existing periapical radiolucency attributed to the dental injury resolved during the review appointment without any intervention. TAB was diagnosed based on the transient change in the size of apical PDL space ranging from a minimum of twice the normal width of PDL space up to semicircular radiolucency in the radiograph.
- The colour change and the sensitivity testing of the teeth with TAB were then recorded. TAB was found in 2.2% of subluxated teeth, 11.3% of extruded teeth and 12.3% of laterally luxated teeth. Most of the transient changes in radiograph, colour and sensitivity were resolved by the 1-year follow-up.

4.5.2.Histopathology

The exact pathogenesis of TAB is unknown.

- It has been suggested that TAB is a sequela of moderate dental traumatic injuries where the necrotic or damaged tissue undergoes a repair process; the injured tissue is removed and then is replaced with healthy tissue after some time.
- It has been speculated that a transient bacterial infection may also be the cause of TAB.
- It usually has no permanent effect on the pulp and tends to resolve within a year. The histological features of TAB are unknown as there are no human or animal studies that have examined the histological healing events after luxation injuries **(Andreasen, 1986).**

4.5.3. Clinical features

Clinical features of TAB include :-

- mild tooth discolouration and delayed or no response to pulp sensitivity testing.
- A return to a positive response to sensitivity testing occurs within 12 months of TAB being diagnosed.
- Delayed or the absence of response to sensitivity testing can be observed if there is pulp obliteration secondary to tertiary dentin formation.
- The discolouration in TAB usually resolves within a year **(Andreasen, 1986; Boyd, 1995).**

4.5.4.Radiographic features

Radiographic examination of the affected tooth may reveal

- widening of the periodontal ligament space and
- blurry appearance or loss of apical lamina dura.
- The radiographic appearance of the periodontal ligament and lamina dura

may return to a normal state within a year **(Andreasen, 1986; Cohenca et al., 2003).**

- Surface resorption and pulp canal obliteration almost consistently occur after the resolution of TAB **(Andreasen, 1986).**
- The resolution of the radiolucency may also be in part due to the affected tooth being subtly displaced at the time of the dental injury, and over time as it seats down completely into the socket, the radiolucency disappears **(Figure 11).** It is well established that conventional radiographs, even with a beam aiming device, have limited capabilities to accurately replicate the same angulation and view **(Rudolph & White, 1988).**
- Any minor alteration in angulation may result in the disappearance of the periapical or PDL changes; therefore, TAB may be a radiographic artefact due to the limitation of the radiographic technique **(Patel & Saberi, 2018).**
- An extrusive luxation can appear as a uniform expansion of the PDL space, which will then be misdiagnosed as TAB **(Andreasen, 1986)**. Intraoral radiographic examination at different angulations (parallax technique) or with bisecting angle technique may create more confusion and complicate the diagnosis **(Brynolf, 1970).**

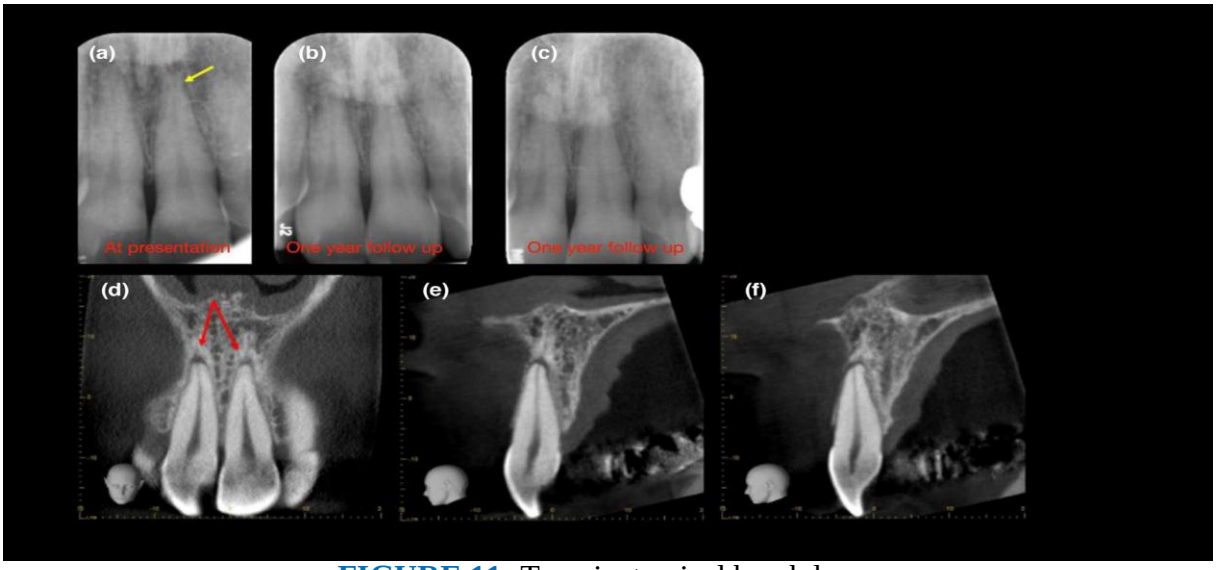

FIGURE 11 : Transient apical breakdown

4.5.5 Management

Understanding the aetiology and clinical features of TAB in traumatized or orthodontically treated teeth is important.

- If the risk of pulpal necrosis is low (concussion, subluxation and orthodontic forces), a no-treatment and wait approach may be indicated. Reversal of signs and symptoms should be observed within 1 year.
- The disappearance of initial radiographic changes in the periapical region and PDL does not confirm the initial diagnosis of TAB as a slight change in angulation during radiographic examination could mask minor periapical radiolucency or widening of PDL space.
- It is critical to evaluate the risk of pulp necrosis for traumatized teeth. **Andreasen (1985)** reported that with more extensive injuries (intrusion and lateral luxation), the risk of pulp necrosis increased, whereas concussion and subluxation had the best prognosis.
- Tenderness to percussion or on buccal palpation are more frequently associated with pulp necrosis than sensitivity tests (**Andreasen, 1988).**
- Doppler flowmetry or pulse oximetry can assess pulpal blood flow and thus be used to determine the vitality following trauma, more accurately than cold or electric tests **(Cohenca et al., 2003; Roeykens et al., 2002; Schnettler & Wallace, 1991).**

5.Differences between internal and external resorption

Internal resorption			External resorption				
Type of resorption	Internal inflammatory resorption	Internal replacement resorption	External surface resorption	External cervical resorption	External inflammatory resorption	External replacement resorption	**Transient apical resorption**
Clinical features	Asymptomatic (early), symptoms of pulpitis and/or apical periodontitis (advanced)	Asymptomatic (early), symptoms of pulpitis and/ or apical periodontitis (advanced)	None	Asymptomatic (early), symptoms of pulpitis and/or apical periodontitis (advanced), ± probeable periodontal defect with profuse bleeding	Symptoms of apical periodontitis	Variable, none or ankylosis and/or exhibit high-pitched metallic sound on percussion in advanced cases.	None
Clinical appearance	Healthy (vital), discoloured (necrotic), pink spot (rare)	Healthy (vital), discoloured (necrotic), pink spot (rare)	Healthy	Healthy (vital), discoloured (necrotic), pink spot (rare)	Healthy (vital), discoloured (necrotic)	Healthy	Discoloured, usually resolve within 1 year
Location on root	Anywhere	Anywhere	Adjacent to impacted tooth/cyst/ tumour, apical in orthodontically treated teeth	Cervical third (early) but can extend to middle or apical third (advanced)	Anywhere	Anywhere	Apical third
Pulp sensibility Testing	+ve in (partially) vital cases, −ve in necrotic cases	+ve in (partially) vital cases, −ve in necrotic cases	+ve	Usually +ve, −ve in advanced necrotic cases	−ve	Usually +ve, may exhibit −ve/delayed response due to tertiary dentin formation	−ve or delayed response, usually returns to normal within 1 year
Radiographic Features	Oval/round ballooning of root canal	Oval/round ballooning of root canal but with cloudy/ mottled inclusions	Flattened/blunted root apex, asymmetrical loss of root, intact root canal	(A)symmetrical radiolucency in early cases, mottled radiopaque appearance in advanced cases. Perforation of root canal in advanced cases	Ragged saucer-shaped indentations along the root surface, adjacent bone loss, periapical radiolucency, Perforation of root canal in advanced cases	Asymmetrical bony replacement of root surface, absence of PDL space, root appears 'fused' to adjacent bone. Intact root canal	Widened PDL space, blurred/loss of apical lamina dura. Intact root canal

TABLE 1 Salient clinical and radiographic features of internal and external root resorptions, adapted from **Patel and Saberi (2018)**

6.Conclusion

Robust clinical research is required to gain a deeper knowledge of the aetiology and pathogenesis of the various types of root resorption. The diagnosis and management of root resorption can be challenging for clinicians resulting in misdiagnosis, and a greater appreciation of this area of Endodontology is required. Identification of root resorption in clinical practice requires detailed past medical history, information of tooth involved, previous endodontic treatment, and associated diseases. The importance of a thorough and systematic clinical and radiographic examination is paramount to ensure appropriate management. The prognosis of root resorption is dependent on an accurate and early diagnosis. Increasingly, CBCT is being used to confirm the diagnosis and aid management.

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