Furcation perforation: current approaches and future perspectives

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During root canal treatment many procedural accidents may occur of which perforation of the root canal system plays a significant role. Perforation is defined by the American Association of Endodontics (AAE) Glossary of Endodontic Terms (2003) as a mechanical or pathological communication between the root canal system and the external tooth surface, which is caused by caries, resorption or iatrogenic factors. It has been identified as the second greatest cause of endodontic failure that accounts for 9.6% of all unsuccessful cases (Pitt Ford et al, 1995).

As a result of furcation perforation, destruction of the periodontal tissues may occur, which ultimately lead to loss of the tooth (Arens, Torabinejad, 1996; Tsesis, Fuss, 2006). The prognosis of the tooth depends upon several factors:

1. The severity of initial damage to the periodontal tissue
2. The location and size of perforations
3. The bacterial contamination
4. The sealing ability or cytotoxicity of the repair materials (Tsesis, Fuss, 2006; Sinai, 1977; Balla et al, 1991).

Even if a biocompatible material is used to treat a perforation, extensive injury may cause irreversible damage to the attachment apparatus at the furcation area (Sinai et al, 1989).

In large perforations, the complete sealing of the defect with a repair material is problematic and allows irritants to continuously penetrate into the furcation area (Balla et al, 1991). Perforations close to the gingival sulcus produce persistent inflammation and a down-growth of sulcular epithelium into the defect (Tsesis, Fuss, 2006). Sinai (1977) stated that coronally located perforations including furcal perforations were more serious than those in the middle and apical third of a canal. It is the objective of this review to collect and review the data that is available in the scientific literature and to reach a conclusion as to the best treatment options.

Methods

Retrieval of literature

An English-limited Medline search was performed of articles published from 2002 to 2015. The searched keywords included 'perforations and endodontics', 'furcation perforation', 'root canal and perforation', and 'perforation and mineral trioxide aggregate (MTA)'. Then, a hand search was done of the references of collected articles to determine if more papers relevant to the topic should be included.

Results

A total of 820 articles were found, which, in order of their related keywords, accounted for the following: perforations and endodontics: 285; furcation perforation: 92; root canal and perforation: 299; and perforation and mineral trioxide aggregate (MTA): 144.

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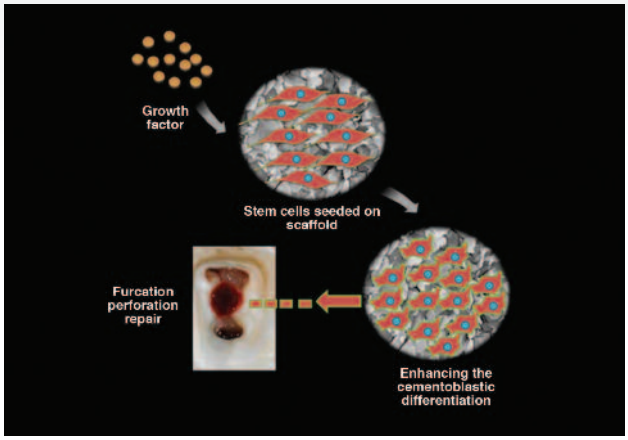

Figure 1: This illustration depicts a furcation perforation repair using stem cells, scaffold and growth factor. This method has the potential to open new avenues in furcation repair treatment in the foreseeable near future. This image relates to the text under 'future perspectives for the perforation repair' on page 40.

Perforation repair techniques and their prognosis

Surgical and non-surgical approaches have been utilised for periodontal tissue re-establishment at the perforation site. In both surgical and non-surgical approaches, two factors should be considered:

1. An appropriate material selection
2. The use of a matrix (Clauder, Shin, 2009).

The repair material should be selected based on the following criteria:

- Perforation site accessibility
- Biocompatibility (be nontoxic and noncarcinogenic)
- Ability to induce osteogenesis and cementogenesis
- Moisture control
- Easy handling
- Aesthetic considerations (Clauder, Shin, 2009; Bryan, Woollard, Mitchell, 1999; Yildirim et al, 2005; Samiee et al, 2010).

Matrix use

Controlling haemostasis and placement of the repair material in the perforation site without extrusion into surrounding periodontal structures are essential prerequisites for the success of a perforation repair. In order to achieve a fluid-tight seal, haemostasis has to be controlled (Clauder, Shin, 2009). Delayed perforation repair can lead to extrusion of repair materials as a result of breakdown of the surrounding periodontium that is replaced by granulation tissue. Thus, in an attempt to avoid extrusion of the repair material, internal matrices such as calcium sulphate, hydroxyapatite, collagen, demineralised freeze-dried bone and Gelfoam have been used (Clauder, Shin, 2009; Roda, 2001; Bargholz, 2005).

The internal matrix concept was introduced by Lemon (1992) in order to adequately seal the furcation perforation and avoid extrusion of the material. He also recommended the use of hydroxyapatite as a matrix under amalgam. Calcium sulphate and calcium hydroxide prevented extrusion of composite resin when used as a furcal repair material (Imura et al, 1998). In 1999, Jantarat and colleagues demonstrated that amalgam placed with plaster of Paris as a matrix for furcal perforation repair improved its sealing ability. Hapset (65% non-resorbable hydroxyapatite and 35% plaster of Paris) and hydroxyapatite showed similar healing responses when used as internal matrices under amalgam (Rafter et al, 2002). Rafter et al (2002) further reported that there was marked extrusion of amalgam into the underlying bone with an associated severe inflammatory response when used alone without a matrix.

Although it has been reported that without using an internal matrix the optimal strength and excellent sealability of MTA was achieved in the presence of moisture (Arens, Torabinejad 1996; Holland et al, 2001; Torabinejad et al, 1994), conflicting results have been reported by some authors regarding the use of an internal matrix under MTA. In 2004, Kratchman suggested that the perforation site should be soaked with sodium hypochlorite after haemostasis had been achieved and that a physical barrier such as collagen or calcium sulfate must be used at the perforation site to prevent MTA from being packed into the bone.

According to Bargholz (2005), excellent clinical results were achieved when collagen matrix was used under MTA. A study by Al-Daafas and Al-Nazhan (2007) showed that calcium sulfate prevented extrusion of the repair material. However, an unfavourable inflammatory reaction – epithelial tissue migration into the defected perforation and the inability to induce bone regeneration – were detected. Thus, the authors concluded that using calcium sulphate as an internal matrix for MTA is not recommended. When used as an internal matrix for furcal perforation repair, calcium sulfate and Collaplug (Calcitek, Carlsbad, CA) did not improve the sealing ability nor reduce the incidence of MTA overextension. Therefore, the authors concluded that these two materials are not recommended as an internal matrix for MTA (Zou et al, 2008). Furthermore, calcium sulfate and hydroxyapatite did not improve the sealing ability of MTA when used as internal matrices for furcation perforation repair (Taneja, Kumari 2011).

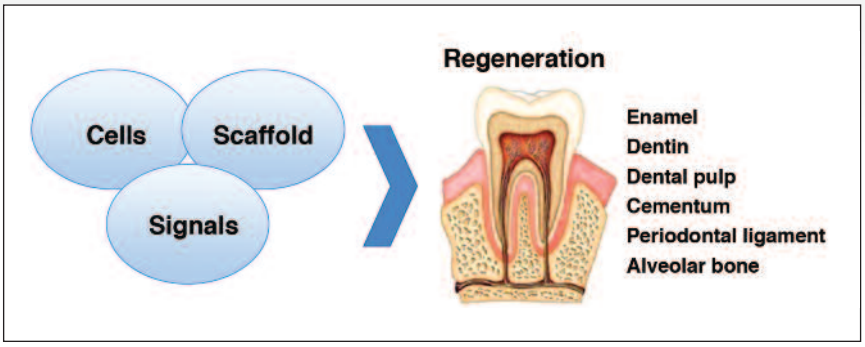

Figure 2: The three key elements of dental tissue engineering are stem cells, scaffolds and signals.

Materials used for furcation perforation repair

In an attempt to repair a furcation perforation, several materials such as amalgam, tricalcium phosphate (TCP), hydroxyapatite, gutta percha, calcium hydroxide, zinc oxide-eugenol-based cement (IRM and Super-EBA), glass ionomer cement, composite resins, resin-glass ionomer hybrids, demineralised freeze-dried bone and MTA have been used over the years (Arens, Torabinejad, 1996; Balla et al, 1995; Bryan, Woollard, Mitchell, 1999, Yildirim et al, 2005; Salman et al, 1999). However, none fulfil all requisite qualifications for an ideal biomaterial.

Balla et al (1991) reported that no hard tissue was formed at the furcation perforation defect site when treated with either tri-calcium phosphate, hydroxyapatite, amalgam or calcium hydroxide (Life); instead, the defect site was occupied by epithelium and acute inflammatory cells (Balla et al, 1991). MTA is water-based cement that is derived from Portland cement (type I). It was introduced as a root-end filling material in the early 1990s (Torabinejad, Watson, Pitt Ford, 1993; Torabinejad, Chivian, 1999). It was subsequently determined that it was a suitable material for various clinical applications such as pulp capping, repair of furcal perforations as well as root-end closure (Sinai et al, 1989; Torabinejad et al, 1995). MTA promotes periradicular tissue regeneration (Pitt Ford et al, 1995; Yildirim et al, 2005; Holland et al, 2001; Zhu, Xia, Xia, 2003; Noetzel et al, 2006) and it differs from other materials by its ability to promote cementum regeneration, thus facilitating the regeneration of the periodontal apparatus (Pitt Ford et al, 1995; Arens, Torabinejad, 1996). Its biocompatibility nature is suggested by its ability to form hydroxyapatite when exposed to simulated body tissue fluid (Sarkar et al, 2005).

Two commercial forms of MTA are available; Proroot MTA (Dentsply Tulsa Dental), which is available in both gray or white form, of which the latter contains a lower amount of iron, and MTA-Angelus (Angelus) (Asgary et al, 2005). MTA-Angelus was introduced to address the long setting time from two hours for Proroot MTA to 10 minutes for MTA-Angelus. MTA-Angelus contains 80% Portland cement and 20% bismuth oxide, with no addition of calcium sulfate, while Proroot MTA is composed of 75% Portland cement, 20% bismuth oxide, and 5% calcium sulfate dehydrate (Hashem et al, 2008). The constituents of the Portland cement are minerals, amongst which the most important are dicalcium silicate, tricalcium silicate, tricalcium aluminate, tetracalcium ironaluminate and dehydrated calcium sulfate (Oliveira et al, 2007; Asgary et al, 2009a). The only significant difference between the dominant compounds of white and gray MTAs and associated Portland cements is bismuth oxide, which is present in MTAs (Asgary et al, 2009a; Asgary et al, 2004).

It has been reported that the sealing ability of MTA (Loma Linda University, Loma Linda, CA) was significantly better compared to amalgam in preventing leakage of Fusobacterium nucleatum through furcal perforations (Nakata, Bae, Baumgartner, 1998). When used to seal a large furcation perforation, Proroot MTA with/without internal matrix and MTA-Angelus with internal matrix showed the lowest dye absorbance compared to zinc oxide-eugenol cement (IRM) with/without internal matrix and MTA-Angelus without internal matrix. Additionally, the authors reported that IRM without internal matrix had the highest dye absorbance (Hashem, Hassanien, 2008). However, white and gray MTA (Dentsply Tulsa Dental) showed no significant differences in microleakage when used for furcal perforation repair (Ferris, Baumgartner, 2004; Hamad, Tordik, McClanahan, 2006). Furcal perforations have been repaired with Proroot gray MTA (Dentsply) and Geristore (Denmat). Geristore has been used as a root end filling material and in the restoration of subgingival surface defects such as root surface caries and iatrogenic perforations, surgical repair of root perforations

and as an adjunct in guided-tissue regeneration (GTR) (Mehrvarzfar et al, 2010). It also leaked significantly less than amalgam (Mehrvarzfar et al, 2010). In the aforementioned study, the authors reported that the sealing ability of MTA and Geristore was reduced when bioglass was used as a matrix underneath.

Sluyk, Moon and Hartwell (1998) assessed the effect of time and moisture on setting, retention and adaptability of MTA when used for furcal perforation repair. Findings showed that MTA adaptation to perforation walls increased in the presence of moisture. They further suggested that a moistened matrix can be used under MTA to prevent under- or overfilling of the material. Furthermore, Main et al (2004) indicated that MTA provided an effective seal for root perforations.

Yildirim et al (2005) investigated the histologic response to MTA and Super EBA (Bosworth Company) when used in furcation perforation repair in dogs. In their study, less inflammation and new cementum formation was observed with MTA compared to Super EBA, which demonstrated connective tissue repair without inflammation. Similar abilities to seal furcal perforations were observed for both Portland cement and MTA (De-Deus et al, 2006; Noetzel et al, 2006) evaluated histologically the inflammatory reactions and tissue responses to experimental tricalciun phosphate (TCP) and MTA when used as repair materials in furcation perforations in dogs. Results showed no significant differences between MTA and TCP in terms of bone reorganisation or deposition of fibrous connective tissue.

Thus, MTA is considered the gold standard and material of choice for perforation repair and has demonstrated good potential for clinical success. However, it has some disadvantages, including the inability to degrade to allow for replacement with natural tissues, low resistance to compression over the long-term, extended setting time, poor handling, and difficult insertion into cavities because of its granular consistency, while additional moisture is required to activate the cement setting, and lastly, the high cost, despite its widespread use (Torabinejad et al, 1995; Chng et al, 2005; Kogan et al, 2006; Coomaraswamy, Lumley, Hofmann, 2007; Parirokh, Torabinejad, 2010). Many dental materials have been demonstrated in the literature to exhibit cytotoxic effects during setting. Low cell numbers were demonstrated in vivo with freshly mixed MTA (pH=10.2) compared to preset MTA (pH=12.5) (Tronstad, Wennberg, 1980). However, histologically, no difference in bone and cementum regeneration was observed after periradicular surgery in dogs between fresh and preset Proroot MTA (Apaydin, Shabahang, Torabinejad, 2004).

In 2006, Asgary and colleagues introduced a new endodontic cement, a calcium-enriched mixture (CEM) cement. Major components of CEM cement powder are 51.75 wt.% calcium oxide, 9.53 wt.% sulfur trioxide, 8.49 wt.% phosphorous pentoxide, and 6.32 wt.% silicon dioxide; whereas the minor essential constituents are aluminium oxide > sodium oxide > magnesium oxide > chlorine. CEM cement has a similar pH but an increased flow compared to MTA. However, working time, film thickness and price are considerably less (Asgary et al, 2008a). Unlike MTA, mixed CEM cement releases calcium and phosphate ions and forms hydroxyapatite not only in simulated body tissue fluid but also in normal saline solution (Asgary et al, 2009a; Amini et al, 2009).

Although the chemical composition of CEM cement and MTA are different, they have similar clinical applications (Asgary et al, 2008b; Asgary et al, 2008c; Asgary et al, 2009b; Asgary, Ehsani, 2009c). Similar to MTA, CEM cement had low cytotoxic effects on different cell lines (Asgary et al, 2009d). However, it showed a better antibacterial effect comparable to calcium hydroxide (Asgary et al, 2008d). Similar sealing ability was demonstrated by both Proroot MTA and CEM when used to repair furcal perforation of primary molar teeth (Haghgoo et al, 2014).

Non-surgical approach

When a perforation repair is indicated, it is recommended to first attempt an intracoronal approach (non-surgical) to preserve the periodontium thus increasing the chances of success (Regan, Witherspoon, Foyle, 2005). Generally, perforations coronal to the crestal bone fall into the category of a non-surgical approach. The use of a surgical microscope operated at high magnification and with ample illumination allows for better management of perforation repairs (Kratchman, 2004; Daoudi, Saunders, 2002).

A surgical approach may complicate the treatment and lead to loss of periodontal attachment, chronic inflammation and furcal pocket formation (Arens, Torabinejad 1996). Experience has shown that buccally located perforations are easier to repair than lingual or proximal lesions. Lingual located perforations, especially in the mandible, should be treated non-surgically or orthodontically. If they are not responding to treatment, the tooth should be extracted (Regan et al, 2005). If a tooth can be extruded orthodontically to a point where the perforation reaches a supragingival level, repair of the defect will be greatly facilitated (Smidt, Lachish-Tandlich, Venezia, 2005). Whether clinically practical or not, one case of intentional reimplantation was reported after repair of the perforation was performed on

the extracted tooth (Poi et al, 1999).

In cases of large perforations, bleeding should be controlled first using sterile saline. Alternatively, calcium hydroxide, calcium sulphate, or collagen has been used (Clauder, Shin 2009). For bleeding control, non-specific intravascular clotting agents should be avoided as they may lead to alveolar bone damage and delay in healing (Lemon, Steele, Jeansonne, 1993). In cases of perforations that are infected or perforation sites that need further enlargement and cleaning, burs or ultrasonic tips may be used. However, ultrasonic tips are preferable as they are gentler to the adjacent periodontium tissues (Pitt Ford et al, 1995; Arens, Torabinejad, 1996; Clauder, Shin, 2009). For cleaning of infected perforations, 2.5% sodium hypochlorite has been used (Arens, Torabinejad, 1996), however, sterile saline is indicated in large perforations (Clauder, Shin, 2009). To avoid blockage of the canals with repair material, gutta percha points, paper points, cotton pellets or an easily removable material (such as Cavit) should be placed over the canal orifices (Clauder, Shin, 2009).

A resin-bonded material such as Geristore (Denmat) is recommended to restore subgingival defects (Clauder, Shin, 2009), which also serves as an adjunct to GTR (Abitbol et al, 1996; Behnia, Strassler, Campbell, 2000). It is less sensitive to moisture than conventional glass ionomer cement while a drier environment improved the results (Cho, Kopel, White, 1995). Adhesive materials can be used in supracrestal perforations, whereas MTA is preferable in subcrestal perforations (Clauder, Shin, 2009). If a perforation defect involves bone destruction (intraosseus defect), a barrier is needed to facilitate controlled placement of the repair material. This is not necessaary if the defect does not include an intraosseus defect (Clauder, Shin, 2009). If MTA is used a moist cotton pellet should cover the material to allow setting of the material. After perforation repair the final restoration can be placed either after one day or one week. Once repair has been achieved the root canal(s) can be cleaned, shaped and filled (Pitt Ford et al, 1995; Arens, Torabinejad, 1996).

If a perforation is present in the middle third of the root, the canal(s) should be prepared first before closing the defect to avoid blocking the canal. With the aid of an operating microscope, obturation of the canal apical to the defect should be done first, followed by filling the remainder of the canal and the perforation site with MTA (Clauder, Shin, 2009). Alternatively, the root space beyond the perforation can be maintained by means of a file or gutta percha cone. In case a file is used, it should be loosened after finishing the repair procedure to allow easy removal before the MTA is fully set (Clauder, Shin, 2009). The other option is to use a gutta percha point and soften it with heat to the dentinal wall opposing the perforation. MTA is then placed at the defect site (Clauder, Shin, 2009). Perforations at the apical one-third are quite challenging and difficult to manage. Successful treatment cannot always be achieved for all cases necessitating apical surgery or extraction of the tooth to remedy the problem (Clauder, Shin, 2009).

Surgical approach

Surgical intervention (external approach) is indicated in areas that are not accessible by non-surgical means alone, cases that have not responded to non-surgical treatment or in repairing a perforating resorption (Regan et al, 2005). The surgical approach is performed by reflecting a flap at the perforation site followed by cleaning and preparing the perforated area and finally packing the repair material (Alhadainy, 1994).

During the surgical repair procedures, cortical bone damage is involved, which may result in reduced success of the corrective surgical procedure. Thus, a GTR technique has been recommended for successful treatment outcomes by using either non-resorbable or resorbable membranes as a barrier (Duggins et al, 1994; Barkhordar, Javid 2000; Rankow, Krasner, 1996; Dean et al, 1997; Leder et al, 1997). This barrier guides selected cells to populate at the perforation defect, ie, placing the barrier between the gingival tissue and the perforation defect will facilitate the repopulation of the defect by periodontal ligament cells and other osteogenic cells and prevents the colonisation by gingival cells (Linde et al, 1993; Sandberg, Dahlin, Linde, 1993). A resorbable membrane is generally preferable, as it does not need a second surgical procedure to remove it. However, in some cases, titanium-tented membrane or a supporting graft material is needed to prevent collapsing the membrane into the defect (Abitbol et al, 1996).

Cementum regeneration and role in the periodontium reconstruction

Cementum formation is very essential in the furcation perforation repair process (Pitt Ford et al, 1995; Clauder, Shin, 2009; Samiee et al, 2010; Zairi et al, 2012). Pitt Ford and colleagues (1995) evaluated the histologic response to experimentally induced furcation perforations in dog mandibular premolars repaired by either MTA or amalgam and found that most of the MTA samples showed no inflammation and cementum deposition, whereas with the use of amalgam, moderate to severe inflammation with no

cementum deposition was present.

Healing after intentional perforations in dogs' teeth was evaluated after repair with either MTA or Sealapex (Kerr) (Holland et al, 2001). Most samples sealed with MTA showed new cementum deposition and an absence of inflammation. In 2010, Samiee and colleagues reported that cementum-like hard tissue was formed using either MTA or CEM cement in the furcation perforation in dogs in the presence of a mild inflammatory response. The authors concluded that both materials showed a similar favourable biological response in furcation perforation repair.

Zairi et al (2012) compared the inflammatory reactions and tissue response of furcal perforations in dogs' teeth to growth factors, TGFβ1, basic fibroblast growth factor (bFGF), osteogenic protein-1 (OP-1) and IGF-I, with MTA or IRM as controls. The authors reported that a clear stimulatory effect on cementum formation and inhibition of collagen capsule formation was exerted by the growth factors. However, MTA exhibited better results than the growth factors. Based on that, the authors suggested a further study comparing the effects of application of growth factor mixture with MTA and MTA alone on tissue healing and regeneration.

In a case report, Bains et al (2012) used tissue engineering principles for the furcation perforation repair of the pulpal floor of the right mandibular first molar of 39-year-old male patient using MTA and platelet-rich fibrin (PRF). The authors reported that this combination was able to repair the perforation defect and regenerate the lost periodontium in the furcation area effectively. A case report (Eghbal, Fazlyab, Asgary, 2014) was published describing the nonsurgical endodontic management of an extensive perforation of the floor of the pulp chamber in a first mandibular molar of a 28-year-old Caucasian female using CEM cement. The authors reported that CEM was able to induce hard tissue formation, ie bone and cementum.

Cellular tissue engineering approach for cementum regeneration

A proposed therapeutic approach was reported by the

removal of autologous cells from the patient's periodontal ligament (PDL), culturing of the cells in vitro, which were then placed back onto the exposed root coated with chemo attracting factors, subsequently covering the area with an artificial basement membrane (Terranova, 1990). However, it is unknown whether this method produced the desired effect. Lekic and colleagues (2005) reported that rat periodontal and bone marrow cells were able to differentiate into periodontal ligament fibroblasts, osteoblasts and cementoblasts when transplanted into periodontal wounds in rats, thus contributing to periodontal regeneration.

Regeneration of cementum, PDL and alveolar bone have been observed using auto-transplantation of bone marrow derived mesenchymal stem cells (BMMSCs) (Kawaguchi et al, 2004) or periodontal ligament cell sheet (Akizuki et al, 2005) into periodontal osseous defects in dogs. However, the principle disadvantage of cell sheets is their delicate structure and difficult handling during surgery (Li, Jin, 2015). Furthermore, the harvest of bone marrow (BM) is a highly invasive and a painful procedure for the donor. Moreover, it has been reported that the number, proliferation and differentiation potential of BMMSCs decline with increasing age (Kern et al, 2006).

It has been reported that cementoblast-biodegradable poly(lactic-co-glycolic acid) (PLGA) polymer sponge-treated defects showed complete bone bridging and PDL formation, whereas minimal evidence of osteogenesis was exhibited by follicle cell-treated defects along the root surface of athymic rats (Zhao et al, 2004). Periodontal ligament stem cells (PDLSCs) have the ability to differentiate into cementoblast and osteoblast (Isaka et al, 2001; Seo et al, 2004) and have shown potential therapeutic applications in periodontium regeneration. However, the very low number of these cells residing in the PDL is indicative of the difficulty acquiring a sufficient number for regenerative treatment remains and is an issue that remains unresolved (Maeda et al, 2011). Primary cultures of PDLSCs yielded small cell numbers, therefore before application, PDLSCs must proliferate at least 12 population doublings (Zhu, Liang, 2015). Additionally, it has been found that the proliferation and migration ability and differentiation potential of PDLSCs decreased with increasing age (Zhu, Liang, 2015).

Apical tooth germ cells conditioned medium were able to provide the cementogenic microenvironment and induced the cementoblastic differentiation of PDLSCs (Yang et al, 2009). Hertwig's epithelial root sheath (HERS) cells, or their secreted products, were able to induce PDL cells differentiation along the cementoblastic lineage in vitro (Zeichner-David et al, 2003). Several in vivo studies have also shown the potential capability of PDLSCs to form cementum and PDL-like tissues (Yang et al, 2009; Liu et al, 2008; Feng et al, 2010; Park, Jeon, Choung, 2011).

Regenerative therapy

Tissue engineering is an interdisciplinary field that applies the principles of engineering and life sciences toward the development of biological substitutes that restore, maintain, or improve tissue function or a whole organ (Langer, Vacanti, 1993). Tissue engineering aims to stimulate the body either to regenerate tissue on its own or to grow tissue outside the body, which can then be implanted as natural tissue (Nadig, 2009).

Triad components

Regenerative endodontics can be defined as biologically based procedures designed to replace damaged structures, including dentine and root structures, as well as cells of the pulp-dentine complex (Murray, Garcia-Godoy, Hargreaves, 2007). This approach consists of the following interactive triad: 1) an appropriate cell source; 2) a supportive matrix (scaffold); and 3) inductive biological factors or signals (Figure 1). To create regenerative therapies, these disciplines are often combined rather than used individually (Murray, Garcia-Godoy, Hargreaves, 2007).

Future perspectives for the perforation repair

Reconstruction of the lost attachment via regeneration of the periodontium components, such as cementum, PDL and bone, is essential in the repair of perforated areas. Replacement of the lost cementum (cementogenesis) is very critical and enhances the reattachment of the fibres of the periodontal ligament. Several studies have been published that demonstrate the ability of different materials to repair furcation perforations, albeit with variable success rates.

However, during recent years, there has been a paradigm shift from conventional to regenerative endodontic therapy and repair of the periodontium is not an exception. To date, to the best of our knowledge, no studies have been published in the literature reporting on the effect of the triad application (stem cells, scaffold and growth factor) for furcal perforation repair and the response of surrounding tissues (cementum, PDL and alveolar bone). We propose a stem cell-based tissue engineering approach for furcation perforation repair through enhancing of stem cell differentiation along the cementoblastic lineage in association with scaffold and growth factor. The suggested biomimetic approach is illustrated in Figure 2. This will have the potential to open a

new era and strategy in endodontic and periodontal tissue engineering therapies.

Conclusions

Perforation of the pulp chamber floor of multi-rooted teeth constitutes a perplexing and frustrating problem. It is a major cause of endodontic treatment failure. A furcation perforation has to be regarded as an endodontic and periodontal problem. The inflammatory response in the periodontium, leading to irreversible loss of periodontal attachment in the area, can result in loss of the tooth if the perforation is not successfully repaired. To re-establish the periodontal tissue in the perforation site, surgical and non-surgical techniques have been utilised.

For furcation perforation repair, several materials have been used with varying results. However, the stem cell-based tissue engineering approach is very promising and is suitable for furcation perforation repair. This approach has the potential to revolutionise the practice of regenerative endodontics in the future and may therefore save many teeth that would otherwise have to be extracted due to a poor to hopeless prognosis.

Moreover, it will help and assist in designing regenerative therapies based on sound biological principles, which can be applied in both endodontic and periodontal specialties.

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