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MANAGEMENT OF TEETH WITH OPEN APICES; A NARRATIVE REVIEW OF ETIOLOGY AND TREATMENT PLANNING

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ABSTRACT

Various pathological or iatrogenic causes may create wide open, blunderbuss root apices. When root canal therapy is indicated for these teeth such condition necessitates careful treatment-planning and management due to the delicate apical anatomy as well as its endodontic and restorative treatment challenges. This review article tends to discuss the nature of the problem and strategies for successful endodontic treatment as well as advantage, disadvantage and limitation of both conventional and contemporary available treatment methods. Techniques of vital pulp therapy such as apexogenesis, direct pulp capping, pulpotomy and treatment methods for a non vital tooth like apexification, modified gutta percha obturation technique and recent artificial apical barrier techniques using mineral trioxide aggregate (MTA) and calcium enriched mixture (CEM) cement, has been discussed with contemporary viewpoints. Regeneration and revascularization has offered newer insights and directions on treating canals with blunderbuss apical shape and will be discussed with perspective on the present understanding as well as future research trends. This review article will also give an evidence based treatment planning protocol based on literature available till date.

INTRODUCTION

According to the glossary of endodontic terminology given by American Association of Endodontists (AAE), the blunderbuss canal is defined as an incompletely formed root in which the apical diameter of the canal is greater than the coronal diameter [1]. Because of the specific apical anatomy it is difficult to achieve objective of endodontic treatment thorough debridement and three dimensional sealing of the root canal system [2]. The absence of apical seal predisposes the apical extrusion of irrigants and filling materials. Biomechanical instrumentation in such teeth with wide apical anatomy and thin dentinal walls may further compromise the strength of the root. Also the forces generated during obturation, especially by lateral condensation technique may also fracture the root. The treatment of teeth with blunderbuss anatomy presents unique endodontic and restorative challenges and requires careful assessment and treatment planning. The current literature provides us with wide variety of treatment options for managing teeth with wide open apex. The purpose of this article is to briefly discuss the various treatment options and techniques for vital immature teeth including revascularization and regeneration and to review the suggested treatment plans depending upon the pulpal status of the tooth.

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PATHOPHYSIOLOGY

Development of root continues up to 3 to 4 years after eruption of the tooth [3, 4]. Traumatic or carious exposure of the pulp during this time period may lead to cessation of root end development due to damage of Hertwig's epithelial root sheath and necrosis of the pulp that leads to a necrotic immature tooth with blunderbuss canal anatomy [5]. This morphology may also occur in mature and fully formed root in conditions like extensive resorption after orthodontic treatment or severe periapical inflammation. Iatrogenic factors like over instrumentation beyond the apex may also lead to formation of a wide open apex. Knowing the current stage of root development may aid in determining the correct treatment.

Cvek [6] classified the root development into five stages according to the width of the apical foramen and length of the root. Stage 1: Teeth with divergent apical opening and a root length estimated to be less than half of the total tooth length.

Stage 2: Teeth with wide divergent apical opening and a root length estimated to be half of the total tooth length.

Stage 3: Teeth with wide divergent apical opening and a root length estimated to be two thirds of the total tooth length.

Stage 4: Teeth with wide open apical foramen and nearly completed root length.

Stage 5: Teeth with closed apical foramen and complete root development.

Depend upon the stage, the diameter of root canal is also varies. In stage I the diameter is widest and it gradually decreases in diameter towards the next stage. According to the literature the wide apical diameter of root canal is favourable for regeneration and has good prognosis. So it is our opinion that the stages I, II, III are the good candidates for the regeneration procedure.

A critical step prior to providing a regenerative endodontic treatment for immature permanent teeth is determining the size of apical foramen. A small apical foramen can limit the pulpal blood flow. Teeth with restricted blood flow are not likely to revascularize and regenerate in response to regenerative endodontic procedures. Traumatized immature permanent teeth with $\geq$1.1 mm open apical foramen are the best candidates for regenerative endodontic procedures [7]. Staging of root development may therefore provide an important guideline for treatment planning especially while considering the option of regenerative endodontic treatment.

Diagnosing the pulpal status and stage of root development are the major factors in the selection of treatment plan [8]. The vitality status of the teeth also dictates the treatment planning in teeth with blunderbuss canal. Electric pulp testers (EPT) assess the neurovascular supply of the pulp and their responses must be interpreted with caution in traumatized young permanent teeth because of incompletely developed sensory nerves in such teeth. Lack of response to EPT may not therefore necessarily correlate with pulpal necrosis [9]. Using devices based on intra pulpal blood flow recordings like Laser Doppler Flowmetry and pulse oximetry provides more a more accurate pulp vitality assessment [10, 11].

Vital pulp therapy for immature permanent teeth

Apexogenesis

According to glossary of American Association of Endodontists (AAE) apexogenesis is defined as a vital pulp therapy procedure performed to encourage continued physiological development and formation of the root end [2]. Therapeutic apexogenesis or vital pulp therapy is the treatment of choice for traumatized or carious teeth with vital pulps and open apices. The major vital pulp therapy procedures are direct pulp capping and pulpotomy [12].

Direct pulp capping

Glossary of AAE for endodontic terminology defines direct pulp capping (DPC) as treatment of an exposed vital pulp by sealing the pulpal wound with a dental material such as calcium hydroxide or MTA to facilitate the formation of reparative dentin and maintenance of vital pulp [2]. Historically a variety of materials have been overlaid upon the exposed pulp like gold foil by Paff in 1756 [13], formaldehyde by Nitzel in 1874 [14], asbestos fibers, cork, bees wax, pulverized glass, eugenol based compounds, calcium compounds and various dental cements [15]. Datwyler conducted the first scientific clinical study to compare different capping materials in 1920 [13]. First used by Hermann in 1920, Calcium hydroxide used to be considered as the gold standard for direct pulp capping [5]. In recent years, Bone morphogenic protein (BMP) as a member of TGFβ superfamily[16], enamel matrix derivative (EMD) [17], and recently mineral trioxide aggregate (MTA) [18] have also been used for direct pulp capping. MTA has proved to be the new alternative gold standard replacing calcium hydroxide in vital pulp therapy. It has overcome some of the disadvantages of calcium hydroxide like resorption of capping material beneath the permanent restoration, mechanical instability and insolubility, slower pulp healing and subsequent inadequate long term sealing ability [18]. DPC is indicated in traumatized immature permanent teeth, and according to the guidelines of American Association of Pediatric Dentistry (AAPD), it can be also used in teeth with reversibly inflamed pulps and carious or mechanical exposure. After hemostasis the pulp covering (bio)material such as MTA or calcium hydroxide is placed directly over the exposed pulp to protect it from further damage and allow healing of the pulp-dentin complex [19, 20]. The tooth is then restored with a good sealing material to prevent microleakage [21]. In carious exposed permanent teeth, the long term success rate of pulp capping with calcium hydroxide ranges from 13% to 96% while the success rate of MTA pulp capping in within the range of 93% to 98% [22]. Apart from classic materials like calcium hydroxide and MTA, recently Calcium Enriched Mixture (CEM) cement has been used in DPC with promising results [23]. Recent outcomes of a prospective randomized clinical trial carried out on immunohistochemical examination of 32 permanent teeth that were orthodontically planned for extraction have shown that, thickness of dentinal bridge beneath CEM was higher than MTA at various time intervals; and pulp inflammation was also lower in the CEM groups [24]. In addition, expression of fibronectin/tenascin in the CEM samples were higher than teeth treated with MTA ; however, the aforementioned differences were not statistically significant [25]. Various other materials like bioceramics such as EndoSequence Root Repair Material (ERRM, Brassler, Savannah, GA, USA) putty and paste [26] and Biodentine (Septodont, Saint-Maur-des-Fosses, France) [27] have also been successfully used as direct pulp capping materials.

Pulpotomy

Pulpotomy is defined as "the removal of the coronal portion of a vital pulp to preserve the vitality of the remaining radicular portion; and it may be performed as an emergency procedure for temporary relief of symptoms in mature teeth or for or therapeutic purposes, as in the instance of a Cvek pulpotomy" [28]. Pulpotomy is most commonly used in primary or immature teeth with carious exposure of pulp and free of symptoms [18]. However its indication as a treatment in permanent mature teeth is relatively a new concept [29].

Pulpotomy may be either partial (*aka*. Cvek pulpotomy) or full pulpotomy. Partial/Cvek pulpotomy entails the surgical removal of approximately 2 mm of tissue underlying the pulp exposure in the coronal portion of a vital pulp as a means of preserving the vitality of the remaining coronal and radicular pulp tissues. in this procedure [30]. The procedure involves opening of access cavity followed by removal of inflamed segment of the coronal pulp. After arresting the hemorrhage, the remaining pulp surface is covered with a bioregenerative medicament .The cavity is then filled with a suitable cement to prevent micro leakage. During this procedure the formation of blood clot is avoided because the blood clot may compromises the prognosis [31].

Variety of materials have been used in pulpotomy procedures like formocresol introduced by Buckley (1904); which was popularized by Sweet even in extensively decayed teeth[32], ferric sulphate [33-39], glutraldehyde [40, 41], calcium hydroxide [42-45], MTA [46], laser [47], freeze dried bone [48], Bone morphogenic protein (BMP) [49, 50] and osteogenic protein [51].

Recently, a novel endodontic material known as calcium-enriched mixture (CEM) cement, has been developed [52]. Many *in vitro* studies on the sealing ability, biocompatibility and regenerative properties of CEM have been conducted [53], and *in vivo* vital pulp therapies in animals [54] and humans revealed comparable results between CEM and MTA.. CEM cement has been reported to form hydroxyapatite over material in normal saline [55] and exhibits characteristics similar to those of surrounding dentin when used as root-end filling [56].

In a recent randomized clinical trial conducted by Nosrat *et al*, CEM cement and MTA showed similar performance in pulpotomy of immature caries-exposed permanent molars [57]. In another randomized controlled trial conducted by Asgary *et al*. excellent treatment outcomes occurred in molar teeth with irreversible pulpitis undergoing pulpotomy with MTA and CEM biomaterials [58]. Recently a randomized controlled clinical trial on partial pulpotomy of sound human premolars, revealed no significant difference in pulp response to MTA or a bioceramic paste (iRoot BP, Innovative BioCeramix Inc, Vancouver, BC, Canada) in terms of inflammation and hard tissue formation.[59, 60]. The success rate of partial pulpotomy for traumatized teeth is in the range of 95% while it is unknown in case of carious exposed teeth [61]. Partial pulpotomy procedure should be selected as an alternative to direct pulp capping when the extent of pulpal inflammation is expected to be greater than normal, particularly in traumatic exposures longer than 24 hours and for mechanical exposure in teeth with deep caries [29].

Full pulpotomy is the removal of the entire coronal pulp to the level of the root orifices [62, 63]. . The success rate of full pulpotomy in a symptomatic reversible pulpitis is 90% at 6 months and 78% at 12 months [64].

Factors such as the size of exposure, its causes (traumatic, mechanical, or carious), and microbial contamination of the site have been described as the main determinants of successful vital pulp therapy [65].

Treatment options for nonvital, immature permanent teeth

Apexification

Apexification is defined as the method of inducing a calcific barrier in apical zone of a root with an open apex or the continued apical development of an incompletely formed root in teeth with necrotic pulp [2].

The hard tissue apexification barrier may be [66] as a cap, bridge or ingrown wedge composed of cementum, dentin, bone or 'osteodentin' [67]. Steiner and Van Hassel [68] demonstrated apical closure by calcific bridge that satisfied the histological criteria of cementum.

In 1964 Kaiser utilized the osteogenic potential of calcium hydroxide along with camphorated parachlorophenol for inducing the formation of hard tissue barrier. This technique was later popularized by Frank [69, 70]. Klein and Levy used Calcium hydroxide along with Crestin [71]. Exact mechanism for induction of hard tissue barrier by calcium hydroxide is unknown, however it is hypothesized that calcium hydroxide dissolves into calcium and hydroxyl ions in tissue fluids [72, 73]. Tronstad proposed that the hydroxyl ion elevates the local pH level and neutralizes the acidic environment due to inflammation[74]. Calcium hydroxide in root canal creates an environment that prevents migration of multi-potent undifferentiated mesenchymal cells into the canal and regeneration of dentin on the lateral dentinal walls [75]. Calcium hydroxide also disinfects the area and in conjunction with the elevated pH, it provides an environment conducive for calcification and closure of the wide apex. However, calcium hydroxide apexification can only induce a hard tissue barrier at the apex and cannot promote continued root development [70]. Also it is stated that long term intra canal calcium hydroxide can make the tooth brittle due to its hygroscopic [76] and proteolytic [77] properties that acts on the organic matrix of dentin.. Moreover, the length of the treatment may range between three to 24 months or longer. This may lead to poor patient compliance especially in young patients [75]. Weakening of the root structure, the ling time required for formation of hard tissue barrier, the porous, Swiss cheese appearance of the barrier that can cause over extrusion of the obturating materials [78], are the major drawbacks for calcium hydroxide which can be overcome by MTA. Moreover the temporary seal in teeth being treated with calcium hydroxide may be disrupted in the intervening treatment period resulting in reinfection and prolongation or failure of treatment [5].

Debridement of root canal, removal of necrotic pulp tissue and microorganisms along with a decrease in pulp space are the critical factors in apexification [79]. Dimension of periapical lesion in cases of apical periodontitis and patient's age may be inversely related to the time required for formation of apical barrier [80, 81].

Artificial apical barrier formation

Treatment of a non-vital open apex teeth aims at sealing the pathway(s) of communication between the root canal system and periapical tissues [82]. Obturation of the root canal system with gutta percha and sealer cannot offer a good long term prognosis in the absence of an apical stop [83]. To overcome the draw backs of apexification by stimulation of hard tissue barrier, inserting a non resorbable apical barrier with various materials, has been suggested against which the obturating materials could be packed. Single step apexification offers the advantage of overcoming such drawbacks of long term induction of apical closure by calcium hydroxide.

Morse in 1990 defined the one-visit apexification as the non-surgical condensation of a biocompatible material into the apical end of the root canal. The rationale behind this treatment is to establish an apical stop that would enable the root canal to be filled immediately. There is no attempt for root end closure, instead an artificial apical stop is created [84].

Obturation of the blunderbuss open apex canal may lead to apical extrusion of materials if the apical stop is not created. Varieties of materials have been used to create an apical stop. such as dentin chips [85], a mixture of dentin chips and $Ca(OH)_2$ [86], $Ca(OH)_2$ and hydroxyapatite powder [87], MTA, Demineralized freeze-dried bone (DFDB), tricalcium phosphate, IRM, super EBA, glass ionomer [88-91] .Calcium-enriched mixture (CEM) cement was also introduced as root-end filling biomaterial . It proved to have coronal as well as retro-sealing ability equal to MTA [53, 92]. New bioceramic materials are under research for this purpose such as Endo Sequence root repair material (ERRM) , Bio Aggregate, iRoot BP Plus, *etc.*[93].

Obturation techniques

Gutta percha is widely used for obturation of root canal system; however standard gutta percha points cannot have a snug fit in wide apices. Gutta percha cones can be modified into a large rod shaped cone using heat orvarious chemicals [94]. Preparation of tailor made gutta percha matching the approximate apical size of the canal [95] is done by rolled cone technique; a number of heated, coarse, gutta percha points are arranged butt to tip on sterile glass slab, points are then rolled with spatula into a single rod shaped mass by repeated heating and rolling.. No voids should exist in mass of rolled gutta percha and before its trial fit, it should be chilled with ethyl chloride spray or ice water [95]. The outer surface of the custom point may also be softened by heat flash or dipping the point in a solvent [95]. Gutta percha can also be inversely placed in the canal to get a snug fit. Obturating the canal system using a custom made resin block by means of heat cure polymethyl methacrylate (PMMA) resin has also been reported as tailor made endodontic obturator in literature [96].

Thermoplasticized gutta percha with different injection techniques such as Obtura system (Obtura II, Spartan/Obtura, Fenton, Missouri, USA), allows obturation of irregularly shaped canals such as those with internal resorption and curved canals, [97]. In cases of open apex (blunderbuss) teeth, back filling of the canal with injectable thermoplasticized gutta percha over the artificial apical plug, can predictably avoid fracture of the root with thin dentinal walls.

Regenerative Endodontics

Regenerative endodontics is defined as a biologicalprocedures designed to physiologically replace damaged tooth structures, including dentin and root structures as well as cells of pulp dentin complex [2]. More than 60 years ago, Hermann described the application of calcium hydroxide for vital pulp therapy and in essence pioneered the concept of regeneration of dental tissues. In 1961 Nygaard Østby performed the revascularization procedure for reestablishing the pulp dentin complex in non vital permanent teeth.

The potential of pulp for regeneration by means of scaffolds and stem cells is promising. Adult bone marrow stem cells mixed with embryonic epithelial cells have shown capacity to regenerate enamel by differentiation into ameloblasts while dissociated cells from tooth germs mixed in scaffolds of agar and collagen have formed crown, root and periodontal structures in host [98].

Pulp regeneration procedure includes application of scaffolds and growth factors like Platelet Rich Plasma (PRP) [99], Recombinant Human Bone Morphogenic

Protein (rhBMP) [100], fibroblast growth factor 2 (FGF-2) [101, 102], that has caused augmentation of pulp, bone and periodontal ligament (PDL) [103].

Over the last few decades, many clinical trials have focused on revascularization techniques which are based on the principles of regenerative tissue engineering. Revascularization can be defined as reestablishing the vascularity in a non-vascularized tissue or organ [104]. The use of this term has attracted controversy, as it does not completely address the desired outcomes of regenerative endodontic procedures, which is regeneration of the pulp-dentin complex, rather than just revascularization. Either “induced or guided tissue generation and regeneration” has been proposed as an alternative terminology [105].

Although the application of artificial apical plug and obturation of the remaining canal for non vital permanent teeth with immature apices, will eliminate the risk of week apical seal and over extrusion of the root filling, it does not strengthen the thin dentinal walls. In fact many of these teeth remain prone to future cervical fractures [106].

The first session of revascularization procedure involves disinfection of the root canal wall with sodium hypochlorite. Minimal instrumentation should be done to avoid further weakening of thin dentinal walls .Trope suggested the use of a triple antibiotic paste (mixture of equal amounts of ciprofloxacin, metronidazole and minocycline in a propylene glycol carrier) for at least 4 weeks to ensure optimal disinfection [63]. Bleeding is then induced in the disinfected root canal by lacerating the periapical tissues with #15 hand file inserted 2-3 millimeters beyond the apex. A thin layer of MTA with a moist cotton pellet can be placed in the coronal aspect of the canal. After one day the cotton can be removed and the cavity can be sealed using resin modified glass ionomer cement [107].

The mesenchymal stem cells of apical papilla are delivered into the root canal space from the induced bleeding of periapical tissues and are supposed to act as both growth factor and a scaffold, thus induce the formation of vital pulp [108]. PRP placed in the root canal, offers three to six fold increase in growth factors such as vascular endothelial growth factor (VEGF) and platelet-derived growth factor (PDGF) [109], which play a vital role in coordinating angiogenesis, development of loose connective tissue and increase the rate of wound healing [110].

The size of the apical foramen is a critical aspect prior to considering regenerative endodontic treatment in immature permanent teeth. A small apical foramen can limit blood flow into teeth. Pulp regeneration and revascularization is unlikely in teeth with restricted blood flow. Traumatized immature permanent teeth with an apex as wide as 1.1 mm or larger are the best candidates for regenerative endodontic procedures [7]. Cvek’s stages I, II and III of root development have open apices with large diameter that may be the good candidates for the revascularization procedures [6].

Till date only case series and case reports regarding regenerative endodontics are published but there is a need for randomized clinical trials for this procedure [102]. The Recent glossary of the American Association of Endodontists (AAE) revealed some factors to consider for case selection in endodontic regeneration. It proposed that regeneration could be used in compliant patient with necrotic immature teeth and the pulp space is not needed for post/core [111]. The etiology of pulp necrosis does not appear to be a factor in case selection because case studies have included teeth with pulps that became necrotic secondary to trauma [112], dental anomalies [113], and decay [114]. Gracia-Godoy F and Murray PE gave recommendations for using regenerative endodontic procedures in permanent immature traumatized teeth. They stated that in cases of traumatic teeth with immature apex revascularization/regeneration procedure should only be attempted if the tooth is not a good candidate for conventional root canal therapy, and treatments like apexogenesis, apexification, or partial pulpotomy are believed to have a poor prognosis [107].

Surgical Intervention

According to the current concepts all inflammatory periapical lesions should be initially treated with conservative nonsurgical procedures as the first treatment option [115], and surgical intervention is recommended only after nonsurgical techniques have failed [116].

This holds valid even in case of teeth with blunderbuss canal having periapical pathology where surgical intervention is a resort when other treatment modalities have failed. Surgery in such teeth can be undertaken if they are associated with large or long standing periapical lesion [117].

Several retro filling materials have been proposed among which MTA with several desirable properties is the most commonly used. . Recently CEM cement has shown considerable success rate and there are indications that CEM cement may be considered as an acceptable endodontic biomaterial for peri-radicular surgeries [118].

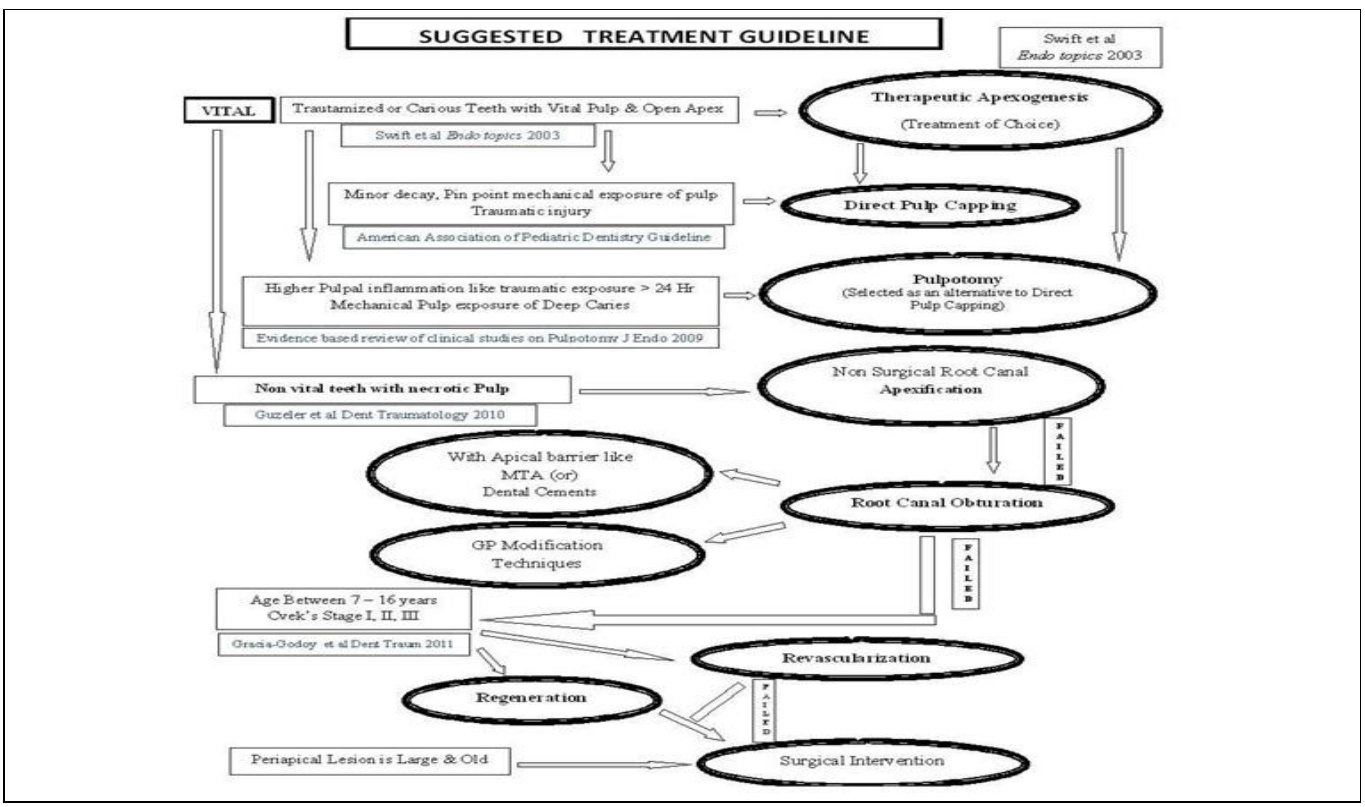
Flow Chart- Treatment Planning Protocol.

DISCUSSION

The delicate anatomy of the blunderbuss canal dictates selecting treatment option by careful weighing of the advantages and disadvantages of available treatment modalities. In a vital tooth, it is advisable to preserve the pulp. Therapeutic apexogenesis or vital pulp therapy is the treatment of choice for traumatized or carious teeth with vital pulps and open apices [12].. These modalities not only preserve the vital pulp but also increase the radicular dentinal wall thickness. The pulp capping option should be done in teeth with pinpoint mechanical pulp exposure encountered during cavity preparation or traumatic injury. Partial pulpotomy as an alternative to direct pulp capping should be selected when the extent of pulpal inflammation is expected to be greater than normal, particularly in traumatic exposure that has occurred for more than 24 hours and for mechanical exposure in teeth with deep caries.

Non vital blunderbuss canal can be managed by a variety of treatment options like apexification, artificial apical plug techniques, modified gutta percha obturation technique, and recently via revascularization and regeneration. Non surgical root canal apexification is the first treatment modality in non vital teeth with blunderbuss open apex [107]. Without creating a calcified apical barrier through apexification, obtaining an apical seal with gutta-percha and root canal sealer as obturation materials cannot offer a good long-term prognosis [83]. To avoid the challenges associated with long-term $Ca(OH)_2$ apexification procedures, a non-surgical, one-step alternative barrier technique with a variety of materials has been suggested [84, 87, 119, 120]. Minimizing the number of patient visits and providing a treatment that can ensure continuous hard tissue deposition to reinforce the fragile root canal walls have recently been reported with a high rate of success for open-apex teeth [121]. Mineral trioxide aggregate (MTA), calcium enriched mixture (CEM) and bioceramics have been used in recent years as an alternative to traditional calcium hydroxide apexification.

As a new approach, regeneration/ revas cularization of the necrotic pulp, offers the advantage of increasing the thickness of canal walls. A critical aspect prior to considering regenerative endodontic treatment in immature permanent teeth is the size of the apical foramen, with an apical size of 1.1 mm or larger to be considered the best candidates for regenerative endodontic procedures [7]. Large diameter immature apex may facilitate the ingrowth of mesenchymal stem cells from the the apical papilla (SCAP) [122, 123]. Patient's age may also be an important consideration, since some studies suggest that younger patients have a greater healing capacity or stem cell regenerative potential [124, 125]. Case reports of revascularization procedures have generally been limited to immaturely developed root apices in patients reaching adolescence (between 8 to 18 years old) [102]. According to AAE's suggestion, regeneration can be used for teeth with necrotic pulp and immature apex in which pulp space is not needed for post/core and the patient is compliant [111]. In case of traumatic teeth with immature apex, revascularization regeneration procedures should only be attempted if root canal cannot be suitably obturated or apexogenesis, apexification, or partial pulpotomy treatments have poor prognosis [107]. If there is large, long standing periapical lesion and other treatment modalities have failed, periapical surgery can be selected as treatment option. If the periapical lesion is large, long standing and other treatment modalities are failed, the surgical management option can be selected.



CONCLUSION

The treatment of blunderbuss canals has two different categories as management of vital and nonvital teeth.

Vital teeth management with open apices provides physiological development and dentinal reinforcement of root with closure of apex. Managing non vital teeth with blunderbuss canal via traditional apexification, tailor made obturation techniques and barrier techniques however only offer means of cleaning shaping and obturating the immaturely developed root. A need for paradigm shift in managing teeth with necrotic pulp and immature apices has been felt. This has led to exploration in the domains of regenerative endodontics which offers to regenerate the pulp dentin complex and consequently sustain the physiologic development and closure of immature open apex. However the current delivery of endodontic regenerative procedures needs to be effectively developed to replace the traditional apexification procedures.

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