CLINICAL TREATMENT OUTCOMES OF DECIDUOUS MOLAR VITAL PULP THERAPY AT SCHOOL OF DENTAL SCIENCES, UNIVERSITI SAINS MALAYSIA

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by

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LIST OF ABBREVIATIONS

AAPD	American Academy of Paediatric Dentists
ALARA	As Low As Reasonably Achievable
ART	Atraumatic Restorative Technique
BMP	Bone Morphogenic Protein
CBCT	Cone Beam Computed Tomography
CEM	Calcium Enriched Mixture
CH	Calcium Hydroxide
CI	Confidence Interval
DM	Deciduous Molar
DPC	Direct Pulp Capping
ES	Electrosurgery
FC	Formocresol
FS	Ferric Sulphate
FSP	Ferric Sulphate Pulpotomy
GIC	Glass Ionomer Cement
ITR	Interim Temporary Restoration
IPT	Indirect Pulp Therapy
MC	Multi-collinearity
MTA	Mineral Trioxide Aggregate

NaOCl	Sodium Hypochlorite
OR	Odds Ratio
PC	Portland Cement
RCT	Root Canal Treatment
ROC	Receiver Operation Characteristics
SSC	Stainless-steel Crown
TTP	Tender to percussion
UG	Undergraduate
VIF	Variance Inflation Factor
VPT	Vital Pulp Therapy
ZOE	Zinc Oxide Eugenol

HASIL RAWATAN KLINIKAL TERAPI PULPA VITAL PADA GIGI SUSU MOLAR DI PUSAT PENGAJIAN SAINS PERGIGIAN, UNIVERSITI SAINS MALAYSIA

ABSTRAK

Terapi pulpa vital (VPT) adalah modaliti rawatan pemulihan yang bertujuan untuk merawat gigi dengan pulpa gigi yang terjejas akibat karies tanpa melibatkan tisu pulpa yang sihat. Ia bertujuan untuk mengekalkan gigi desidus sehingga masa eksfoliasi normal. Sehingga kini, terdapat kajian yang terhad dalam membandingkan hasil rawatan terapi pulpa tidak langsung (IPT) dan pulpotomi ferric sulphate (FSP) yang dilakukan pada gigi molar desidus (DM). Oleh yang demikian, kajian ini bertujuan membandingkan hasil rawatan klinikal IPT dengan FSP yang telah dilakukan pada gigi DM di kalangan pesakit pediatrik di Pusat Pengajian Sains Pergigian, Hospital Universiti Sains Malaysia. Sebanyak 590 rekod klinikal pesakit yang merangkumi 600 DM yang dirawat dengan IPT dan FSP telah diteliti dalam kajian ini. Sejumlah 342 DM dirawat dengan IPT dan 258 DM melibatkan FSP. Rekod pesakit yang lengkap dengan data berkaitan kajian, berumur di antara umur 4 hingga 8 tahun dan hanya rawatan melibatkan DM adalah disertakan dalam kajian ini. Data-data kajian merangkumi jenis rawatan (IPT / FSP), jenis gigi (DM pertama atau kedua), kedudukan DM berdasarkan rahang (maksilari dan mandibular) dan bilangan permukaan gigi yang terlibat telah dianalisis. Analisis regresi logistik digunakan dengan tahap signifikan ditetapkan pada $P < 0.05$. Sejumlah 278 DM pertama dan 322 DM kedua mempunyai rawatan IPT dan FSP. Berdasarkan lokasi rahang, 234 adalah DM maxillary dan 366 adalah DM mandibular. Dari segi permukaan gigi yang terlibat, 363 DM mempunyai karies pada satu permukaan dan 237 DM melibatkan karies banyak permukaan. Terdapat perbezaan

yang signifikan berdasarkan jenis rawatan yang dilakukan (P = 0.036), iaitu, kebarangkalian rawatan IPT berjaya adalah dua kali ganda berbanding dengan FSP. Selain itu, terdapat perbezaan yang ketara mengikut jenis gigi (P <0.05) dan lokasi rahang (P = 0.003), iaitu rawatan VPT pada DM kedua yang berjaya adalah 4 kali ganda berbanding DM pertama. Di samping itu, kebarangkalian molar maksilari untuk berjaya dirawat adalah 3 kali lebih tinggi berbanding molar mandibular. Walau bagaimanapun, tiada perbezaan yang signifikan bagi kadar kejayaan VPT berdasarkan permukaan gigi yang terlibat (P = 0.913). Kesimpulannya, IPT menunjukkan kadar kejayaan klinikal yang lebih tinggi daripada FSP, dengan DM kedua mempunyai prognosis keseluruhan yang lebih baik berbanding DM pertama. Maksilari DM mempunyai prognosis rawatan VPT yang lebih baik daripada DM mandibular.

CLINICAL TREATMENT OUTCOMES OF DECIDUOUS MOLAR VITAL PULP THERAPY AT SCHOOL OF DENTAL SCIENCES, UNIVERSITI SAINS MALAYSIA

ABSTRACT

Vital pulp therapy (VPT) aims to manage teeth with only part of the compromised dental pulp without the extirpation of the entire healthy pulp tissue. It targets at retaining deciduous teeth until their normal exfoliation. To date, very limited studies have compared the treatment outcomes of indirect pulp therapy (IPT) and ferric sulphate pulpotomy (FSP) carried out on deciduous molar(s) (DM). Thus, this retrospective study aimed to determine, the clinical treatment outcomes of VPT performed on paediatric DM at School of Dental Sciences, HUSM. Clinical records of 590 patients with 600 DM treated with IPT and FSP were reviewed. 342 DM underwent IPT and 258 FSP. All patient records which had information about DM treated with VPT, were included. Records of patients under 4 and above 8 years of age were excluded, along with those records in which VPT was performed on teeth other than DM. Association of treatment type (IPT/FSP), tooth type (1st or 2nd DM), arch location (maxillary/mandibular) and number of carious surfaces involved (one or multiple) to successful outcomes was analysed. Logistic regression analysis was used for statistical analysis with significance level set at $P < 0.05$. A total number of 278 1st DM and 322 2nd DM underwent IPT and FSP. Based on arch location, 234 were maxillary DM and 366 were mandibular DM. According to carious surfaces involved, 363 DM had one surface destroyed by caries and 237 DM had multiple surfaces destroyed. There was a significant difference based on the type of treatment performed ($P=0.036$), i.e., the odds of IPT being successful were two times more than those of FSP. Also, there was a

significant difference according to tooth type ($P<0.05$) and arch location ($P=0.003$), i.e., the odds of 2nd DM having successful outcomes were 4 times more than 1st DM. Additionally, the odds of maxillary molars having successful outcomes were 3 times more than when compared to their mandibular counterparts. However, there was no significant difference in success rates based on carious surfaces involved ($P=0.873$). In conclusion IPT showed a higher success rate than FSP, with 2nd DM having a better overall prognosis than 1st DM. Maxillary DM had a better prognosis than their mandibular counterparts, while comparing the two VPT.

CHAPTER 1

INTRODUCTION

Vital pulp therapy (VPT) aims to manage teeth with only part of the compromised dental pulp without the extirpation of the entire healthy pulp tissue (Ghoddusi *et al.*, 2014). It targets at retaining deciduous molar(s) (DM) until their normal exfoliation (Parisay *et al.*, 2015). VPT aims to treat reversible pulpal injury caused by deep caries, to maintain pulp vitality and also provide for residual/complete pulp function. It includes three therapeutic approaches: indirect pulp therapy (IPT) in cases of deep dentinal cavities, direct pulp capping (DPC) and pulpotomy in cases of pulp exposures (Dammaschke *et al.*, 2019). The most important factors in the success of VPT are the appropriate diagnoses of the pulp and the peri-radicular status, the preservation of pulp vitality and proper vascularization of the pulp (Parisay *et al.*, 2015).

However, non-vital pulp therapy on the other hand, is undertaken when VPT is not indicated, i.e., the infectious disease has spread to the root canals. Root canal treatment (RCT) is to be performed, where remaining pulp tissue is completely removed, the root canals are enlarged, disinfected and finally obturated with a filling material (Dammaschke *et al.*, 2019). Choice of therapy should be tailored to each particular patient according to multiple factors such as the vitality of the existing pulp, the extent of spread of the inflammation (e.g. only coronal versus coronal plus radicular portions), the presence or absence of reversible/irreversible pulpitis, the presence or absence of a necrotic pulp, the state of surrounding bones and soft tissues, and the presence or absence of infection, abscesses, fistulae, or underlying cysts (Al Baik *et al.*, 2018; Howley *et al.*, 2012).

Premature loss of deciduous teeth, in specific molars, can cause: malocclusion, aesthetic, phonetic, and functional problems; these in turn may be temporary or permanent. An attempt to preserve pulp vitality should be made whenever possible; however, when this is not feasible, the pulp can be eliminated without significantly compromising the function of the tooth (Fuks *et al.*, 2019).

Furthermore, in a recent local epidemiological study among 5-year-olds of the state of Kelantan; location of our current study as well; a caries prevalence of 88.7% was reported, which concludes that children in the state Kelantan continue to have the highest caries prevalence as compared to other states of Malaysia (Oral Health Division, 2015). The cause that leads to options like VPT and non-vital pulp therapies, is none other but dental caries. This highlights the importance, in our local setting, of further education regarding caries prevention for the local population, as well as the need to assess the clinical outcomes for the management of this highly prevalent disease in our hospital.

IPT can be defined as, the procedures or steps taken to protect or maintain the vitality of the carious tooth that, if completely excavated, the decay would result in a pulp exposure (Al-Zayer *et al.*, 2003). Before exposure and irreversible involvement of the pulp, IPT is the treatment of choice, but in the event of spread of inflammation within the pulp chamber and establishment of irreversible pulpitis, removal of inflamed/necrotic pulp tissue is the only option left and recommended (Parisay *et al.*, 2015).

Although there are no precise methods to determine how much carious dentin is to be removed, it was suggested previously that clinical judgment played a key role in the removal of dentin, that was necrotic and amorphic and leaving behind the dentin that was firmer and had the appearance of being intact (Anderson, 1982).

The rationale for IPT is that a few viable bacteria remain in the deeper dentin layers and after the cavity has been prepared and restored properly, the microbes are inactivated due to environmental changes (Parisay *et al.*, 2015). It was and still is considered very important to remove, all the remaining caries at the dentinal enamel junction before performing IPT (Fisher, 1981). The superficial layer of the carious dentin that is mandatory to be removed is called the infected dentin (Al-Zayer *et al.*, 2003). This layer contains majority of the microorganisms and their toxic products that are also the source of continuous insult to the pulp. The infected layer must be removed, to allow the healing of the dental pulp physiologically (Al-Zayer *et al.*, 2003). The deeper layer or the decalcified dentin, located underneath the superficial layer, is called the affected dentin; this layer has only a few microorganisms. The affected layer can be left in place without any adverse effect on the dental pulp and its remineralization is expected to occur (Al-Zayer *et al.*, 2003).

DPC can be defined as a wound dressing of exposed vital pulp tissue (Dammaschke *et al.*, 2010). It involves the application of a medicament, dressing or dental material to the exposed pulp in an attempt to preserve its vitality. The philosophy behind this treatment is to induce the pulp to initiate reparative tertiary dentin formation at the exposure site. The success rate of this treatment is not particularly high in deciduous teeth; therefore, it has limited application in this field of VPT (Tuna and Olmez, 2008). DPC in deciduous teeth has been associated with low success rates, especially concerning to the high incidence of internal resorption. However, as newer materials have been introduced, DPC success rates and complications have improved (Sujlana and Pannu, 2017).

Pulpotomy is one of the most widely accepted/recommended clinical procedures for treating cariously exposed pulps in symptom-free deciduous teeth. The rationale

depends solely upon the healing ability of the remaining radicular pulp tissue following surgical amputation of the affected or infected coronal pulp (Fuks *et al.*, 2019).

Pulpotomy for the deciduous teeth has been developed along three lines: devitalization, preservation, and regeneration (Ranly, 1994). Devitalization, where the intent is to completely destroy the vital tissue; is undertaken by formocresol (FC) or electrosurgery (ES). Preservation, which is the retention of the maximum vital tissue with no induction of reparative dentin, is exemplified by the use of glutaraldehyde and ferric sulphate (FS). Regeneration, which is the stimulation of a dentin bridge formation, has long been associated with calcium hydroxide (CH) (Ranly, 1994).

Pulpotomy can be performed using different techniques, which include non-pharmacotherapeutic treatments such as ES and laser or pharmacotherapeutic approaches by dressing the pulp tissue with different medicaments or biological materials such as FC, glutaraldehyde, FS, CH, mineral trioxide aggregate (MTA), freeze-dried bone, bone morphogenic protein (BMP), osteogenic protein, sodium hypochlorite (NaOCl), calcium-enriched mixture (CEM) cement, enriched collagen solutions, Portland cement (PC) and fully synthetic nanocrystalline hydroxyapatite paste. More recently introduced materials include MTA and biodentine which have excellent outcomes as pulpotomy agents (Parisay *et al.*, 2015).

Operational definitions defining success and failure in the current study were as follows: 1. Successful Treatment – a treatment outcome was labelled as successful, when there were no clinical signs of tenderness on percussion, no tooth mobility, no sinus tract or abscess formation around the treated tooth and no symptoms of spontaneous/nocturnal pain, within a time span of a year (follow-up after 1 week, 3 months, 6 months and 12 months). 2. Failed Treatment – a treatment outcome was labelled as failed, when there were clinical signs of failure, such as tenderness on

percussion, grade II or III tooth mobility, presence of sinus tract or an abscess around the treated tooth, along with radiographic evidence of PDL widening and symptoms of spontaneous/nocturnal pain, within a time span of a year (follow-up after 1 week, 3 months, 6 months and 12 months).

The objective of all VPT strategies is to create a state that enables the formation of a hard tissue barrier and the recovery of remaining tissue, preserving the functionality and therefore ensuring that a vital tooth remains in the oral cavity (Dammaschke *et al.*, 2019). However, the success of a treatment is very uncertain and likely depends upon many factors, including the experience of the operator, early diagnosis, clinical decision-making skills, availability of treatment materials, affordability of the patient and lastly, patient co-operation, particularly when treating paediatric patients. On the other hand, treatment dictated by episodes of nocturnal pain, pathologic mobility of the treated DM due to widening of the periodontal ligament space and sinus tract or abscess formation, eventually leads to extraction.

VPT plays a key role in saving cariously injured DM teeth. Hence, determining an association of the treatment outcomes of the two types of VPT is necessary, to narrow down the best possible option in terms of reliability and longevity of treatment success. Our study will be focusing on investigating clinical treatment outcomes of IPT and pulpotomy and their associations with factors that may be leading to the success or failure of treatment.

1.1 Problem statement

In most previous studies IPT has shown a success rate of 90% or above at the end of a follow-up period (Casagrande *et al.*, 2010; Fang *et al.*, 2019; Franzon *et al.*,

2007; Mathur *et al.*, 2016). Whereas ferric sulphate pulpotomy (FSP) has shown success rates ranging between 80-90% mostly (Chien *et al.*, 2001; Coll, 2008; Havale *et al.*, 2013; Ibricevic and Al-Jame, 2003; Odabas *et al.*, 2012). In the previous literature, to the best of our knowledge, there are only two studies that have compared IPT with FSP based on their treatment outcomes (Fang *et al.*, 2019; Lin and Lin, 2015). Al Zayer, et al. (2003) and Vij, et al. (2004) found the success rate of IPT to be 95%. But they observed that the technique was more likely to succeed if a base was used and even more likely to succeed if the tooth was restored with a stainless-steel crown (SSC). Another finding was that IPT was more likely to succeed in 2nd DM than 1st DM (Al-Zayer *et al.*, 2003; Vij *et al.*, 2004). IPT was found to have a lower cost, higher long-term success, better exfoliation pattern and better success rates in treating reversible pulpitis than pulpotomy (Coll, 2008).

In the human DM with exposure of vital pulp by caries or trauma, pulpotomy performed with either FC or FS was likely to have similar clinical and radiographic outcomes (Peng *et al.*, 2007). Due to the deleterious effect of FC, it was suggested that FS be recommended as a replacement (Peng *et al.*, 2007). A randomised controlled trial was done, comparing the effectiveness of four pulpotomy techniques. FSP had the highest percentage of success after 24 months (Huth *et al.*, 2005). Currently, there is limited published literature available, comparing outcomes of IPT with FSP. Furthermore, to the best of our knowledge, there are no published or accessible articles/studies available, regarding the comparison of IPT with FSP treatment outcomes in relation to the type of tooth, i.e. deciduous 1st and 2nd molar, as well as arch location and number of cariously involved tooth surfaces in a Malaysian population.

1.2 Justification of study

VPT for deciduous teeth, has been a remarkably good option for years and a lot of research has been carried out on different materials used for it and the various methods employed. But to the best of our knowledge, there is no published/accessible data found regarding comparisons of IPT with FSP based on different types of molars, arch location and number of cariously involved surfaces of the affected DM.

Furthermore, there is an amplitude of literature, that supports IPT to be a widely accepted method of VPT for DM teeth, but, to the best of our knowledge its treatment outcome comparisons with the pulpotomy treatment modality, have not been carried out in a paediatric population of Malaysia. The findings of this study will not only help to add to literature regarding the best treatment outcomes amongst IPT and FSP; but also, the associations of type of molars, arch locations and number of cariously involved surfaces with treatment outcomes of VPT. Also, our study will provide data that supports which treatment is better suited for a reversible pulpal injury in DM teeth and the efficacy and reliability of treatment performance and its outcomes by undergraduate (UG) dental students.

1.3 Research questions

1. Is there an association between clinical treatment outcomes and the type of VPT (IPT and FSP)?
2. Is there an association between clinical treatment outcomes of VPT and DM type (1^{st} and 2^{nd})?
3. Is there an association between clinical treatment outcomes of VPT and the arch location of DM (maxillary and mandibular)?

4. Is there an association between clinical treatment outcomes of VPT and the number of cariously involved surfaces of DM (one and multiple)?

1.4 Objectives

General Objective

To determine the association of treatment outcomes (success/failure) of VPT after a one-year of follow-up in deep carious DM teeth treated by UG dental students.

Specific Objectives

1. To determine the association between treatment outcomes of VPT and the type of treatment (IPT and FSP) after a one-year of follow-up in deep carious DM teeth treated by UG dental students.

2. To determine the association between treatment outcomes of VPT and the type of DM (1st DM and 2nd DM) after a one-year of follow-up in deep carious DM teeth treated by UG dental students.

3. To determine the association between treatment outcomes of VPT and the arch location (maxillary DM and mandibular DM) after a one-year of follow-up in deep carious DM teeth treated by UG dental students.

4. To determine the association between treatment outcomes of VPT and the number of cariously destroyed DM surfaces (one and multiple) after a one year of follow-up in deep carious DM teeth treated by UG dental students.

1.5 Research hypothesis

1. There is no association between treatment outcomes of VPT and the treatment type (IPT and FSP) after a one-year of follow-up.
2. There is no association between treatment outcomes of VPT and DM type (1^{st} and 2^{nd} DM) after a one-year of follow-up.
3. There is no association between treatment outcomes of VPT and the arch location of DM (maxillary and mandibular) after a one-year of follow-up.
4. There is no association between treatment outcomes of VPT and the number of cariously involved DM surfaces (one and multiple) after a one-year of follow-up.

CHAPTER 2

LITERATURE REVIEW

2.1 Vital pulp therapy

VPT is defined as, "a treatment which aims to preserve and maintain pulp tissue that has been compromised but not destroyed by caries, trauma, or restorative procedures in a healthy state" (Ghoddusi *et al.*, 2014). Dentists for a long time have believed the pulp to be capable of healing. The first pulp capping procedure is found to be dated back to 1756, when Philip Pfaff attempted to cap exposed pulps with a small piece of gold adapted carefully to the base of the cavity (Dammaschke, 2008). In 1826, Leonard Koeker cauterized the exposed portion of the pulp with a red-hot iron wire and covered the exposure site with a piece of lead foil. The earliest attempts to promote pulp healing consisted of different metallic foil placement against the site of exposure. According to the results of Glass & Zanders's study, no healing was seen in exposed pulps capped with zinc oxide eugenol (ZOE) however, when exposed pulps were capped with CH a rapid healing process was seen; which was relatively inflammation free. Within four weeks of CH placement, the original site of the exposure was completely walled off by a new odontoblastic layer and a new dentin barrier (Glass and Zander, 1949).

Clinical preliminary data gathering and interpretation must be focused on determining whether the DM pulp is normal, reversibly inflamed, irreversibly inflamed, or necrotic. If it is found to be vital or reversibly inflamed, only then the VPT techniques are indicated (Vidya *et al.*, 2015). But in cases of irreversibly inflamed and necrotic pulpal status, a successful IPT/pulpotomy cannot be accomplished so, a pulpectomy is indicated in order to achieve promising results. VPT is an expanding concept in

paediatric dentistry today, accredited to the potential of new biomaterials to stimulate regeneration of the pulp cells. Biocompatibility, bioactivity and dentin-like physical properties, as well as good handling, fast setting and the possibility to restore large cavities with a single biomaterial, are some of the ideal properties of materials aiming to heal traumatised and inflamed pulpal tissue (Todea *et al.*, 2018). A successful VPT requires a DM to be vital, which is achieved by a good seal against bacteria, no chronic inflammatory reactions, and stable haemodynamics within the pulp tissue. It also corresponds to the stimulation of the pulp-dentin complex, to promote the formation of a continuous dentin bridge at the pulp-dentin border, as part of the healing mechanism (Todea *et al.*, 2018).

When there is a need for a restoration, following should be kept in mind: to preserve healthy and remineralizable tissue, to achieve a good restorative seal, to maintaining pulpal health, and maximize restoration success. The purpose carious tissue removal is to purely create conditions for long-lasting restorations (Fejerskov and Kidd, 2009). Demineralized tissues close to the pulp do not need to be removed in every instance. There are mainly two types of lesions, namely deeper and shallow lesions. In teeth with vital pulps and deeper lesions, preserving health of the pulp should be prioritized, while in shallow or moderately deep lesions, restoration longevity is more important (Vij *et al.*, 2004).

There are multiple methods for caries removal in deciduous and permanent teeth. For DM with moderately deep cavitated lesions, carious tissue removal is performed according to "selective removal to firm dentine". In deep cavitated lesions, "selective removal to soft dentine" should be performed, although in permanent teeth, "stepwise removal" is an option (Bjorndal, 2008). There are evidences and recommendations, which support that less invasive carious lesion management and

delaying entry to the vital pulp by preserving tooth tissue and retaining teeth long-term are more favourable for successful outcomes (Schwendicke *et al.*, 2016). There are three treatment modalities for vital DM, which include IPT, DPC and pulpotomy.

2.1.1 Primary pulpal response to insult

Whenever a carious process takes place, the primary pulpal response to such an insult is the formation of tertiary dentine. Depending upon the intensity of the insult, the tertiary dentine may be reactionary or reparative (Coll *et al.*, 2013). Along with the tertiary dentine formation, there is an increase in number of inflammatory cells in the cell rich zone of the pulp, majorly constituting of fibroblasts and macrophages. This response is mutual to deciduous and permanent teeth (Fisher, 1981).

2.2 Indirect pulp therapy

IPT was previously known as "indirect pulp capping" and was explained by the American Academy of Paediatric Dentists (AAPD) as, "a procedure in which the caries closest to the pulp are left in place and covered with a biocompatible material, and the tooth is restored to prevent microleakage". The objective of IPT is to maintain the pulp health without adverse clinical signs or symptoms or radiographic evidence of internal or external root resorption, similar to a pulpotomy ("Guideline on pulp therapy for primary and young permanent teeth," 2005). Management of the cariously involved DM where the carious lesion approximates the pulp requires a knowledgeable approach to VPT and of course, a successful outcome depends on an accurate diagnosis of pulpal status prior to therapy (Vidya *et al.*, 2015).

The indications for IPT and pulpotomy are similar i.e., reversible pulpitis or a normal pulp where the pulp is judged to be vital from clinical and radiographic evaluation (Coll, 2008). The difference lies with the caries excavation. IPT purposely avoids an exposure by leaving behind residual deep decay in place while pulpotomy is undertaken when it results in a pulp exposure (Vidya *et al.*, 2015). Developed in the 1920s by Hermann, CH has been the gold standard in VPT for decades. Its use as a pulp dressing material in DPC or pulpotomies has shown both advantages and disadvantages. Previously, CH has shown imperative success, owing to the formation of a dentinal bridge, when used during DPC, IPT and even pulpotomy (Percinoto and Pinto, 2006). But due the current concepts of VPT along with introduction of more biocompatible materials, use of CH has decreased remarkably. Reasons for this drastic change are the recently evolving toxicity of CH to pulpal cells, when in direct contact, followed by internal/external root resorption (Arandi, 2017).

Following physiological stimulation/injury, such as caries or operative procedures, stem cells in pulp may be mobilised to proliferate and differentiate into odontoblasts (Tziafas *et al.*, 2000). IPT offers several advantages over pulpotomy such as fewer side effects, non-invasive, lesser chair time, child cooperation and cost-effectiveness (Vidya *et al.*, 2015). IPT usually shows success rates of 90% or greater irrespective of the method or medicament used (Coll, 2008).

2.2.1 Indications of IPT

Following indications should be kept in mind while performing IPT (Dentistry, 2009):

1. IPT is indicated in a DM with no pulpitis and deep carious lesions (Rabchinsky and Donly, 1993).
2. With reversible pulpitis, when the deepest carious dentin is not removed to avoid a pulp exposure (Fuks, 2002).
3. The pulp is judged by clinical and radiographic criteria to be vital and able to heal from the carious insult. So pulp should be vital (Fuks, 2002; Vij *et al.*, 2004).
4. There should be no radiographic evidence of pathologic external or internal root resorption or other pathologic changes.

2.2.2 Objectives of IPT

1. The restorative material should seal completely the involved dentin from the oral environment.
2. No posttreatment signs or symptoms such as sensitivity, pain, or swelling should be evident.
3. The tooth's vitality should be preserved.
4. There should be no harm to the succedaneous tooth.

2.2.3 Method/procedure

"The procedure, in which caries is allowed to remain adjacent to a vital pulp rather than risk pulp exposure, covered with a cavity sealer or liner and restored, is termed IPT" (Hilton, 2009).

IPT is carried out under rubber dam isolation by excavating the entire carious lesion, soft and hard, using a slow speed handpiece with a round bur and a spoon excavator. Only leaving behind, the deep, hard, arrested caries close to the pulp chamber. Copious amounts of saline are used for irrigation and then the cavity is dried with a cotton pellet. A sealing biocompatible liner is placed into this deep cavity, usually CH, which seals the open dentinal tubules and a temporary restoration is completed (Fang *et al.*, 2019). The patient is recalled after a few weeks for a permanent restoration, provided there are no signs or symptoms that indicate the persistence of reversible pulpitis or progression to irreversible pulpitis. Periodic follow-up is carried out to check for the success of the treatment and the patient is checked clinically for signs of suppuration/abscess, pathological tooth mobility and a positive TTP test (tender to percussion) and a brief history is taken for symptoms of nocturnal/spontaneous pain.

2.2.4 Materials

1. *Calcium hydroxide liners/cements*

CH has a high pH (approximately 12.5–12.8) and is chemically classified as a very strong base. Its mechanism of action is achieved through the ionic dissociation of Ca^{2+} and OH^- ions (Mohammadi and Dummer, 2011). They have effects not only on vital tissues but also cause induction of hard-tissue deposition and has antibacterial properties. The lethal effects that CH has on bacterial cells is probably due to protein denaturation and damage to the DNA and cytoplasmic membranes. It has a wide range of antimicrobial activity (Mohammadi and Dummer, 2011). It is a protective alkaline material placed on the unexposed pulp to maintain its health and stimulate defensive repair by tertiary dentin deposition (Arandi, 2017). CH liners protect the pulpal tissues

from chemical insults, stimulate dentinal bridge formation and serve as a protective barrier for pulp tissue not only by blocking patent dentinal tubules but also by neutralizing the attack of inorganic acids and leached products from certain types of cements (Lutfi *et al.*, 2010). CH has been reported as a liner of choice in clinical practice (Chisini *et al.*, 2015).

2. *Glass ionomer cements*

As the name indicates, glass ionomer cement (GIC) is formed by a reaction of calciumaluminofluorosilicate glass and polyacrylic acid. It tends to prevent demineralisation and promote remineralisation of carious enamel/dentin. These materials provide fluoride release which hinders bacterial growth, have a coefficient of thermal expansion and modulus of elasticity similar to dentin, bonds to both enamel and dentin and is biocompatible (Ogura *et al.*, 2005). Due to their high fluoride release, biocompatibility, antimicrobial properties and induction of tertiary dentin formation, they have been suggested to be an excellent agent for IPT (Korwar *et al.*, 2015).

3. *Stannous fluoride*

Stannous fluoride is an inorganic salt of tin and fluoride. It has an antibiotic effect and has the ability to modify the microorganism composition of the dental biofilm. Stannous fluoride reacts with the demineralized enamel and dentin to convert the calcium mineral apatite into fluorapatite, which in turn makes enamel and dentin more resistant to bacteria generated acid attacks (Groeneveld *et al.*, 1976). The use of stannous fluoride has two advantages. Firstly, DM treated with stannous fluoride

show harder remineralised dentin and secondly, DM show greater radiodensity than teeth treated with CH (Nordstrom *et al.*, 1974).

2.2.5 Retrospective studies

Al-Zayer et al., in 2003 retrospectively assessed the clinical and radiographic success rates of IPT using a layer of CH as a protective liner over the dentin/pulp complex, performed on 187 DM based on the influence of caries risk, operator skill, and type of permanent restorative material used. IPT performed on 1st DM failed more frequently than 2nd DM. There was no significant difference between maxillary and mandibular DM. Since the IPT success rate was 95%, the authors suggested that, it was a successful technique and should be considered as an alternative to other pulp therapy procedures (Al-Zayer *et al.*, 2003). This study compared IPT performed by UG and postgraduate dental students which is not very suitable since the UG students lack the clinical experience and expertise of the postgraduates. Also, the age for the inclusion criteria ranged from 18 months to 12 years. A patient coming at age 12 is very close to shedding their last remaining second DM, so it is not guaranteed that they would be able to complete the required follow-up duration.

A retrospective study examined clinically and radiographically the 3-year survival of 125 DM and 45 permanent teeth with IPT using resin-modified glass ionomer as a protective layer over the dentin/pulp complex. The survival rate for DM was 96% (mean survival time, 146 weeks) and 93% for permanent teeth (mean survival time, 178 weeks). The authors concluded that IPT in DM and permanent teeth of young individuals may result in a high 3-year survival rate (Gruythuysen *et al.*, 2010). Due to the long-term follow-up of 3 years, there was a high dropout rate. In the end, only 86

out of 125 DM and 34 out of 45 permanent teeth were available for both clinical and radiographic evaluation.

Even though these studies were carried out retrospectively, the success rates were more than 90% with IPT as choice of VPT. Indicating that IPT had a long-term successful outcome even over a period of three years.

2.2.6 Clinical trials

Clinical and radiographic changes in DM that underwent IPT was evaluated over a 48-month period in a study. 27 DM with deep caries, but without preoperative signs of irreversible pulpits, were treated with IPT. The teeth were randomly divided into two groups, according to the material used for capping over the dentin-pulp complex: (1) CH and (2) GIC. After 48 months, the CH group showed a success rate of 88.8% and the GIC group 93%. No significant difference was seen between the groups. The results of this study suggested that IPT in DM arrested the progression of the underlying caries, regardless of the material used as a liner over the pulp-dentin complex (Marchi *et al.*, 2007). But the sample size was extremely small to detect a significant difference between the two materials used and also, due to a long-term follow-up, the dropout rate was high.

A study evaluated the clinical and radiographic changes in 39 DM that underwent IPT over a 36-month period. The molars were randomly divided into two groups, according to the material used for capping/base over the dentin-pulp complex i.e., a CH liner or a gutta percha sheet. Both groups were restored with a Z250 resin-based composite. The overall success rate was 79.3%, with no significant difference between the groups (Franzon *et al.*, 2007). The results of this study suggested that IPT

of DM restored with a resin-based composite may arrest the progression of the underlying caries, regardless of the material used as a liner. But this study showed a lower success rate of IPT as compared to other studies performed.

A study on DM was carried out to compare a self-etching primer with a CH as a protective layer used over the remaining carious dentin during an IPT. This was carried out to evaluate the clinical and radiographic outcomes (24 months) of IPT. No significant difference was seen after 2 years of clinical and radiographic follow-up between the two groups. The overall success rate reached 87%. These results demonstrated that IPT had a high clinical and radiographic success rate in DM and was not dependent on the capping material (Casagrande *et al.*, 2008). Since this was a randomised clinical trial over a long-term duration, the dropout was high and a very small sample size was evaluated.

A study evaluated the clinical and radiographic outcomes of IPT using a self-etching adhesive system as an experimental capping material and CH as a control capping material in 40 DM after long-term function (up to 60 months). The results showed an overall success rate of 78%. There was no significant difference between the two groups of IPT treated DM. Surprisingly, in this study more cases of IPT failures were recorded in 2nd DM, and in occlusal restorations compared to the 1st DM and occluso-proximal restorations, but without significant differences (Casagrande *et al.*, 2010). Again, as this was a very long-term study, the dropout was high and the sample size was small. Also, this study showed a very low success rate of IPT in comparison to the usual reported 90% above success rate.

In a prospective study performed on 60 DM with deep caries, IPT using 2% chlorhexidine disinfecting solution and resin-modified glass ionomer as liner/base was used as a pulp cap. The treatments were successful in 50/50 (100%), 41/42 (~98%), and

31/32 (~97%) teeth at the 3-, 6-, and 12-month follow-up visits, respectively. Failures included one at 6 months in a 2nd DM with a composite restoration and another at 12 months in a 1st DM with a SSC. IPT was effective in DM, although appropriate case selection and an adequate marginal seal were essential for a successful outcome (Rosenberg *et al.*, 2013). Since this was a randomised clinical trial, even with a follow-up duration of 12 months, there was a high dropout rate and a very small sample size.

A split-mouth design trial evaluated the clinical and radiographic outcomes of bioactive tricalcium silicate-based dentin substitute and a light-activated CH based liner for IPT in 120 vital DM with carious lesions approaching the pulp. There were no significant differences in success rates between the two study groups. The combined success rate for the two groups was 96.7 percent (Garrocho-Rangel *et al.*, 2017). These results suggested that the IPT procedure with either material may be considered a suitable treatment with a high rate of success, to achieve acceptable therapeutic results when applied on deeply carious DM without degenerative symptoms.

Most of the clinical trials also revealed similar results as retrospective studies. IPT showed an amazing long-term success rate irrespective of choice of material used as liner, as temporary or permanent restoration. Pointing in the direction of minimally invasive dentistry, IPT serves by far as the best available option today in the field of paediatric dentistry, and CH as the most ideal capping material.

2.3 Pulpotomy

A pulpotomy can be defined as, "the procedure involving removal of the coronal pulp and maintenance of the radicular pulp" (Rodd *et al.*, 2006). Decades ago, "pulpotomy" and "partial pulpectomy" were used interchangeably to refer to the excision/amputation of the pulpal contents of the coronal portion of the pulp without disturbing the contents of the radicular pulp (Gardner, 1950). According to the AAPD

guidelines, the aim of a pulpotomy is to retain a functional, symptom-free DM until it reaches the age of its normal exfoliation, i.e., to keep the remaining pulp healthy without any adverse clinical signs/symptoms or radiographic evidence of internal/external root resorption (AG, 2005).

Pulpotomy is suitable for DM when, only the coronal portion of a pulp is cariously involved while pulpectomy can be used when both the coronal and radicular portions are affected. Pulpectomy is the treatment of choice in the presence of local infections, abscesses, or fistulas since pulpotomy is contraindicated (Al Baik *et al.*, 2018).

2.3.1 **Indications of Pulpotomy** (Rodd *et al.*, 2006)

1. Asymptomatic DM with only transient pain.
2. A carious or mechanical exposure of vital coronal pulpal tissue with reversible pulpitis.

2.3.2 **Objective of pulpotomy**

1. To remove the reversibly inflamed coronal pulp, leaving behind possibly healthy radicular pulp.
2. No post-treatment signs or symptoms such as sensitivity, pain, or swelling should be evident.
3. The tooth's vitality should be preserved.
4. There should be no harm to the succedaneous tooth.

2.3.3 Method/procedure

Vital pulpotomy in DM is performed under rubber dam isolation, and the coronal pulp tissue is completely removed with a spoon excavator. Bleeding is controlled by applying cotton pellets soaked in 15.5% FS solution/or a pulpotomy agent on the pulpal stumps for a time duration, in accordance with the manufacturer's instructions. Subsequently, the coronal pulp space may be filled with ZOE cement or other materials. Restoration is then performed with a permanent restorative material like amalgam, composite or SSC (Fang *et al.*, 2019).

2.3.4 Materials

1. *Ferric sulphate*

FS is a sulphate of trivalent iron. It is yellow in colour with a rhombic crystalline salt and is soluble in water at room temperature. It is produced on a large scale by the reaction of sulphuric acid, a hot solution of ferrous sulphate, with an oxidizing agent (Bandi *et al.*, 2017). FS has been commonly used as a pulpotomy medicament to control pulpal bleeding in VPT for three decades now. It induces haemostasis by forming a sealing membrane at the damaged vessels of pulpal tissue by agglutinating the blood proteins with ferric and sulphate ions (Fei *et al.*, 1991; Rodd *et al.*, 2006). It has the advantages of not only being a haemostatic agent but of also possessing antibacterial properties. One of the major reported disadvantage with FS is internal/external root resorption over a longer period of time, when used as a pulpotomy agent. Also, as pulpotomy agent, it hinders the formation of a dentinal bridge over the radicular pulp (Bandi et al., 2017).

The most important function of FS is minimal devitalization and preservation of the pulp tissue (Fuks *et al.*, 1997). The metal-protein clot at the surface of the amputated pulp stumps may probably act as a barrier to the irritative components of the sub-base and functions passively (Ranly, 1994).

2. *Zinc oxide eugenol*

ZOE is a very commonly used material in dentistry, owing to its sedative and palliative properties, in cases of pulpal pain. Mainly its use is restricted as an intermediate restoration or an insulating base over pulpotomised DM. This restriction is due to its reported diverse toxic effects, when in direct contact with the pulp, majorly inducing a chronic inflammatory response and inhibiting the defensive pulpal immune reaction (Chien *et al.*, 2001).

3. *Sodium hypochlorite*

NaOCl is a chlorine compound composed of sodium and hypochlorous acid. It acts as a bleaching agent and a disinfectant. It works as a solvent for organic and fat degrading fatty acids. Hypochlorous acid, a substance present in NaOCl solution, acts as a solvent. Hypochlorous acid (HOCl) and hypochlorite ions (OCl^-) lead to amino acid degradation and hydrolysis (Estrela *et al.*, 2002). Another promising alternative to haemostatic agents is NaOCl. It is not only an effective haemostatic agent but also a valuable antibacterial agent with no adverse effects on pulpal repair, healing, and tertiary dentinogenesis (Hafez *et al.*, 2002). The current literature supports the use of NaOCl at various concentrations ranging from 0.12% to 5.25% as a safe and appropriate haemostatic agent in VPT procedures (Demir and Cehreli, 2007; Hilton, 2009). Once haemostasis is obtained, the remaining pulp tissue should be covered with a biocompatible material (Atasever *et al.*, 2019).

4. *Formocresol*

FC is a mixture of 19% formalin and 35% cresol in an aqueous glycerine used in dentistry for pulpotomy procedures to fix and disinfect pulpal tissue. The use of FC as a pulpal medicament was first introduced by Sweet in 1904 (Sweet, 1955), and has since been a popular choice for use in the pulpotomy procedures, mainly because of its ease of use, clinical success and cost-effectiveness. Even though the use of this pulpotomy medicament is common and produces very successful results, concerns regarding its mutagenic properties have led investigators to search for a safe and effective alternative (Avram and Pulver, 1989; Fulton and Ranly, 1979; Messer *et al.*, 1980; Vidya *et al.*, 2015).

5. *Calcium hydroxide*

CH is another pulpotomy dressing material with a clinical success rate ranging from 31% to 100% (Waterhouse, 1995). It has an alkaline pH which both neutralizes lactic acid formation from osteoclasts and activates alkaline phosphatases which play an important role in the formation of hard tissue (Atasever *et al.*, 2019). However, based on the possibility of internal resorption caused by pulpal inflammation or bleeding, there is no consensus on the use of CH in DM pulpotomy (Percinoto and Pinto, 2006; Sonmez and Durutürk, 2008; Tunc *et al.*, 2006).

6. *Glutaraldehyde*

Glutaraldehyde is a bifunctional reagent, which has the ability to form strong intra- and intermolecular protein bonds, leading to fixation. This rapid fixation as well