CHAPTER 2

REVIEW OF THE LITERATURE

The review is divided into four parts as follows:

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2.1 Dental caries

Dental caries is the destruction of tooth structure by bacteria acid. Three major factors of dental caries are recognized as susceptible host (tooth in the oral environment), fermentable carbohydrates, and cariogenic microorganisms (bacteria)[23]. The current concept in dental caries process begins with fermentation of

carbohydrates by cariogenic bacteria in the biofilm or dental plaque producing acid. This acid causes a drop in pH. And when the pH drops below 5.5, the critical pH, the demineralization process which is a loss of mineral from the tooth occurs. This process potentially destroys tooth structure leading to the breaking down and carious formation in tooth[24].

The early stage of dental caries process begins in enamel surface. The first clinically visible sign of enamel change is called white spot lesion. This initial change is not due to bacterial invasion, but due to bacterial acid attack on tooth causing subsurface demineralization and more porosity in the enamel lesion. The shape of this lesion is conical spreading along enamel prisms[6, 15, 16].

The advance stage begins when carious lesion progresses into dentin. The initial change in non-cavitated lesion is dentin demineralization that occurs prior to bacterial contamination. In rapidly progressing lesions, the odontoblastic processes are destroyed causing dead tract appearance in dentin. When enamel breaks down, the cavity is created now bacteria can invade into empty dentinal tubules[6, 15, 25]. Dentin caries lesion can be classified as an infected and an affected dentin layers. The superficial carious dentin is called infected layer. The color and consistency of infected dentin layer is yellowish light-brown and soft due to dead tissue. This layer is contaminated with the majority of microorganisms and their toxic products. The dentinal tubules with both organic and inorganic components in the infected layer are destroyed and nonremineralizable. The inner carious dentin below the infected dentin layer is the affected dentin layer that has a similar structure to sound dentin. The consistency of affected dentin layer appear more harden. This layer has only a few microorganisms and the dentinal tubules are intact and able to remineralize[25, 26].

2.1.1 Defense reaction and pulpal response

Every tooth has its defense mechanism against bacteria and bacteria products. In non-cavitated lesions, odontoblast process in dentinal tubule will be stimulated by bacterial product passing through microporous enamel. The defense reaction to this stimulus is deposition of mineral within dentinal tubule, called hypermineralized dentinal tubules or tubular sclerosis, to decrease their permeabilities. In addition, the odontoblast cells in dental pulp produce a dentin-like matrix, called tertiary dentin which acts as a barrier to protect the pulp tissue. This defense reaction occurs before enamel lesion reaches the dentinoenamel junction (DEJ)[6, 15, 16, 25].

In cavitated lesions, quality of the tertiary dentin is different in patterns and related to progressive rate of carious lesion. There are two subtypes of tertiary dentin: reactionary and reparative dentin. In slowly progressing carious lesions, primary odontoblasts produce reactionary dentin which is tubular in shape similar to primary and secondary dentin. But in rapidly progressing lesion, the odontoblast cells may be destroyed and turn to necrosis. Mesenchymal cells will differentiate into odontoblast-like cells producing reparative dentin. The dentinal tubules of reparative dentin have atubular matrix and are more irregular in structure, less mineralized and have a higher content of organic material[6, 16, 25, 27].

The tooth that has not received early and adequate dental care will develop into deep carious lesions.

2.2 Deep dentin carious lesion

The definitions of "deep" dentin carious lesion varied. Generally, the deep dentin carious lesion has been described as the lesion that involves demineralized dentin close to pulp and possibly exposes the pulp after total caries removal[17, 18].

In fact, it is hard to specify the penetration depth of the deep carious lesion clinically. The bitewing radiograph is a measurable aid tool to approximate the depth of lesion. The penetration depth is the ratio between the maximum depth of carious dentin and the total dentin thickness[3]. In Bjorndal et al.'s opinion[3, 17, 28], the criterion to determine the depth of deep carious lesion is when the demineralized dentin penetrating into three fourths of the entire dentin thickness or more when evaluated radiographically. Similarly, Gruythuysen et al.[18] defined the depth of deep carious lesion as the demineralized dentin penetrating greater than the two thirds of the entire dentin thickness when evaluated radiographically.

One of the challenges in treating deep carious lesion is to gain accurate diagnosis. Then, the treatment will be chosen accordingly.

2.3 Vital pulp diagnosis

In deep dental caries with vital pulp, pulp conditions may be described as normal pulp or reversible pulpitis[5, 7].

1. Normal pulp means tooth has no symptoms and normally responsive to vitality testing.
2. Reversible pulpitis means pulp is capable of healing and teeth exhibit provoked pain from noxious stimulus (thermal, chemical, or mechanical irritants).

Both normal pulp and reversible pulpitis are clinical diagnoses of pulp status that must be obtained from a careful pre-operative evaluation including of subjective symptoms, clinical and radiographic examinations[5, 7, 28, 29].

The subjective symptoms for vital pulp diagnosis are as follows: absence of spontaneous or recurrent pain; presence of provoked pain only with existing stimulation.

The clinical criteria for vital pulp diagnosis are as follows: absence of abnormal tooth mobility; absence of sensitivity to percussion and palpation; absence of fistula and swelling of periodontal tissues.

The radiographic criteria for vital pulp diagnosis are as follows: absence of radiolucencies at the inter-radicular or periapical regions; absence of thickening of the periodontal spaces; absence of pathological internal and external root resorption; absence of calcification.

Nevertheless, cautions must be taken when making the final clinical diagnosis, the absence of clinical symptoms sometimes may be the result of silently developing pulp necrosis. Furthermore, clinical diagnosis may not always relate to its histological findings (cited in McDonal et al.)[29].

Currently, there is no practical diagnostic device to evaluate the histological pulpal status and estimate severity of pulp inflammation. Therefore, diagnostic data with subjective symptoms, clinical and radiographic findings, represent the best criteria possible to determine the pulp status[25, 28]. Accurate diagnosis of the pulp condition and selection of the appropriate treatment for a tooth are essential for its long-term prognosis.

2.4 Treatment of deep carious lesion

When treating primary teeth with deep carious lesions diagnosed as normal pulp or reversible pulpitis, the American Academy of Pediatric Dentistry (AAPD), in 2011-2012, recommends the guideline using vital pulp therapy such as protective liner, IPT, direct pulp capping and pulpotomy[5]. From all the treatments available, they can be grouped into 2 main categories by the concepts of complete and incomplete caries removals. However, these two concepts of caries removal have long been controversial since the early era of modern dentistry. Black in 1908 chose the complete caries removal because he believed that "…it is better to expose the pulp of a tooth than to leave it covered with softened dentin…" while Tomes in 1859 preferred the incomplete caries removal because he believed that "…the remaining dentin can reduce risk of pulp exposure…"(cited in Bjorndal)[16].

In a recent pulp symposium, when asking the endodontists and pediatric dentists of which is the best treatment option for the deep carious lesion diagnosed with normal pulp and reversible pulpitis in primary teeth; the survey findings showed that 58% of endodontists and 47% of pediatric dentists chose IPT whereas the rest chose pulpotomy with various materials[30]. The results of this survey imply that there is no consensus of the best treatment for managing deep carious lesion in primary teeth. And both IPT (incomplete caries removal) and pulpotomy (complete caries removal) are acceptable for treating deep carious lesions.

2.4.1 Complete caries removal technique

It has long been assumed that this traditional concept, complete caries removal technique, can eliminate total bacteria and prevent further cariogenic activity[1].

However, there are some confusions in its definition. Thompson et al.[31] defined the definition of complete caries removal technique as the removal of all infected and affected dentin. In contrast, Bjorndal et al.[3] defined it as the removal of the superficial necrotic dentin including the peripheral and central demineralized dentin leaving only yellowish or grayish hard dentin that equal to the hardness of sound dentin. After total or complete caries removal, the tooth will be treated according to the exposure status.

In case of no pulp exposure, AAPD recommends using a protective liner, such as calcium hydroxide, dentin bonding agent, or glass ionomer (GI) cement to cover exposed dentinal tubules. These materials act as barriers between the restorative material and the pulp[5].

In case of pulp exposure, direct pulp capping or pulpotomy in primary teeth are the treatment options that may be chosen[5-7]. As for direct pulp capping, the biocompatible material such as calcium hydroxide or mineral trioxide aggregate (MTA) is placed directly on pinpoint and/or small mechanical or traumatic exposures[5-7]. At present, this technique is not recommended for carious pulp exposure in primary teeth because it has had less success than that of IPT or pulpotomy[32]. The failure of direct pulp capping may result in internal root resorption[5, 7]. However, in carious exposure tooth of older children which have only 1-2 years before its normal exfoliation, this technique may be used[7].

In pulpotomy, the most common treatment for cariously exposed pulps in primary teeth, the procedure involves the amputation of coronal pulp and treating the remaining vital radicular pulp with medicament[5, 7]. The popular gold standard medicament in primary tooth pulpotomy is formocresol (FC). The mechanisms of

actions of FC are fixing and denaturing the radicular pulp[7, 13]. Despite the long-term use of FC as a pulpotomy agent, there are several reasons for clinicians and researchers have kept searching for its alternatives. Firstly, long-term success rates of FC pulpotomy decreased with time[8-10]. Secondly, 38% of FC-treated teeth in one study resulted in 6 months or more earlier exfoliation or exhibited early root resorption[8]. Thirdly, the poor histological responses of pulp treatment with FC showed zone of necrosis, area of inflammatory infiltrate, zones of atrophy, area of fibrous tissue formation in pulp[7, 33]. Finally and probably the most important reason, formaldehyde, the major component in FC, has been increasingly questioned in its toxicity and potential carcinogenicity that may cause nasopharyngeal cancer in humans[7, 13]. Recent survey reported that majority of dentists has turned away from formocresol use[30]. From these disadvantages of FC, the alternative medicaments such as ferric sulfate (FS) and MTA have been recently recommended[13].

FS is a hemostatic agent that can form clot barriers between the remaining pulp and the sub-based material[13]. However, FS may not be an ideal pulpotomy agent because the results of using FS were not different from that of FC in pulpotomy treatment. FS pulpotomies have shown no difference in success rate when compared with FC[7, 9, 10]. From the retrospective study of Vargas and Packham[11] in 2005, they found that 11% of FS pulpotomy treated teeth also early exfoliated, similar to that of teeth treated with FC pulpotomy. Moreover, the histological study showed inflammatory pulp response and pulpal destruction similar to that of FC medicament[33]. As for MTA, it has many favorable features when used as a pulpotomy agent. MTA pulpotomy appears to have higher long-term clinical and radiographic success rates compared to that of FC pulpotomy even though not

statistically significant[7, 12, 34]. MTA showed to create dentin bridge formation while maintain normal pulpal histology[33]. However, the high cost of MTA makes it not cost-effectiveness when treating primary teeth[7, 12].

It is generally accepted that complete caries removal of deep carious lesion may result in a pulp exposure that endangers the pulp's vitality and pulp survival rate. From table 2.1, the percentage of pulp exposure after using the complete caries removal technique was obviously more than that of the incomplete caries removal technique[2-4]. Moreover, in a recent randomized clinical trial of treating deep caries lesion in permanent teeth, Bjorndal et al.[3] found a lower overall pulp survival (approximately 30%) in the group of pulp exposure than the teeth with no pulp exposure (nearly 70%) at the 1-yr follow-up.

Table 2.1 Articles comparing the percentage of pulp exposure between complete and incomplete caries removal.

Study	Tooth type	Lesion depth	Pulp exposure	
			Complete caries removal	Incomplete caries removal
Lula et al., 2009[4]	Primary molar (N=36)	Inner half of dentin	N= 4 (25%)	Partial removal; N=0 (0%)
Bjorndal et al., 2010[3]	Permanent molar and premolar (N=314)	75% or more of the dentin	N=43 (28.9%)	Stepwise excavation; N=25 (17.5 %)
Orhan et al., 2010[2]	Primary molar (N=94) and first permanent molar (N=60)	Three fourths or more of the dentin	N= 12 (22%)	1-visit IPT; N=3 (6%) 2-visit IPT; N=4 (8%)

According to several weak points of the complete caries removal technique mentioned above, the alternative approach has been proposed as an incomplete caries removal technique to preserve the teeth's vitality and maintain an unbroken dentin barrier against the pulp.

2.4.2 Incomplete caries removal technique

Some researchers have recently changed their caries removal method from the traditional complete caries removal to the more conservative technique, incomplete caries removal, when managing deep carious lesion. In the traditional complete caries removal technique, the caries lesions are drilled and removed by surgical approach. In contrast, the incomplete caries removal technique focuses more on biological approach by trying to change caries environment and the most important key to success is to seal, isolate and separate it from biofilm[35], the crucial factor of caries process[14-17]. Incomplete caries removal is a generalized term used for various excavation methods ranging from no or minimal excavation to maximal excavation very close to the pulp leaving only minimal carious dentin to avoid pulp exposure. The aims of this technique are to reduce the number of pulp exposure, preserve pulp vitality and arrest caries progression[3, 4, 14, 17, 28, 35-37]. Moreover, pulp survival in teeth with an unexposed pulp was much higher than that of the teeth with exposed pulp[3]. The rationale for this approach is that the caries process of any remaining carious dentin will stop or slowly progress when the lesion is sealed from biofilm.

Biofilm is believed to play an important role in driving the caries process[14, 15]. However, this dynamic process of dental caries progression can be modified and arrested by an elimination of biofilm such as brushing or changing the environment of

the cavitated lesion into an open ecosystem which is more convenient for biofilm removal[14-16]. For example, root carious lesion can be simply converted into inactive lesion by cleaning together with fluoride application. However, all biofilm can be difficult to remove in some types of carious lesions such as a closed occlusal and/or proximal cavity. In these closed ecosystem cavities, it is almost impossible to eliminate biofilm. Therefore, the caries process continues and restorative dentistry has a role to play in caries management in these types of caries.

To prevent biofilm contamination, good sealing is the main key to success of incomplete caries removal technique and the amount of remaining carious dentin in the cavity before restoration does not seem to play a role on the success[14]. When the lesion is sealed, the numbers of residual bacteria are decreased; the clinical residual carious dentin change into arrested caries during a treatment interval and pulpo-dentin reaction can form tertiary dentin to protect dental pulp[14-17, 25].

Cavity sealing of carious tissue can modify microbiological features. Common types of bacteria in carious lesion consist of *Streptococcus spp, Streptococcus mutans, Lactobacillus spp, Actinomyces spp,* etc.[4, 38-42] Both of *Streptococcus mutans* and *Lactobacillus spp* play an important role in caries process because they can ferment carbohydrates and produce low pH acid. *Lactobacillus spp* has been related to caries progression and *Streptococcus mutans* are also acid-producing bacteria that can maintain metabolic activity in low-pH environment[38]. Many studies showed that cavity sealing can isolate the exogenous nutrient supply on which the aciduric bacteria such as *Streptococcus mutans* and *Lactobacillus spp* use to produce acid[4, 38-40, 42]. Therefore, the microbial stop proliferating; then, the numbers of microbial reduce and may also die (Table 2.2). The environment of caries lesion now has changed to the

condition with smaller quantity of bacteria and less acidic. So the lesion clinically arrests[4, 38-40, 42, 43].

Table 2.2 Changes in microbiology in deep carious lesion after incomplete caries removal.

Study	Tooth type	Procedure	Re-entry time	Changes in microbiology				
				SP	SM	LS	AS	TB
Malz et al., 2002[38]	Permanent teeth (N=32)	Remove all surrounding carious tissue. Application of calcium hydroxyl on a layer of soft dentin at bottom of cavity. Restored with IRM (intermediate restorative material).	6-7 months	—	↓	↓	—	↓
Wambier et al., 2007[39]	Primary molar (N=32)	Remove superficial layer of infected dentin and cover large layer of decayed dentin with RMGI.	30 and 60 days	↓	↓	↓	↓	↓
Orhan et al., 2008[40]	Primary (N=83) and young permanent molar (N=52)	Two visit IPT: Caries at the lateral wall of the cavity and the DEJ was completely removal. Then, remaining innermost layer of carious dentin was covered with calcium hydroxide.	3 months	—	↓	↓	—	↓
Lula et al., 2009[4]	Primary molar (N=36)	Removal of superficial necrotic dentin at lateral walls and DEJ but maintain the deeper layer of carious dentin. Application of calcium hydroxide and restoration with composite resin.	3-6 months	↓	↓	↓	—	↓
Duque et al., 2009[42]	Primary molar (N=27)	Removal of superficial necrotic dentin from DEJ and laterals walls, leaving a layer of soft dentin on the cavity floor. Application of calcium hydroxyl cement or RMGI and restored with IRM.	3 months	—	↓	↓	—	↓
Kneist et al., 2011[41]	Primary molar (N=70)	Stepwise treatment: Remove all soft dentin and base with calcium hydroxide. Restored with IRM.	8 and 11 weeks	—	—	↓	—	↓

SP: *Streptococcus spp*, SM: *Streptococcus mutans*, LS: *Lactobacillus spp*, AS: *Actinomyces spp*, TB: Total bacteria

Moreover, clinical observation of dentin caries after sealing reveals that the color and consistency of the demineralized dentin in actively progressing lesion can change from soft yellowish, light-brown into the darker, harder, and drier dentin resembling a slowly progressing lesion[25, 31, 39, 43, 44]. When active carious lesion changes to slowly progressing lesion, the pulp-dentin complex also produces its defense mechanisms. Wambier et al.[39] found that the clinical residual carious dentins have more compact collagen fibers and narrower dentinal tubule after re-entry. Good sealing of the cavity after treatment stimulates the formation of tertiary dentin and sclerosis of dentinal tubules, thus preventing unnecessary pulp exposure[14].

To date, there are controversial opinions regarding the re-entry of lesions treated with incomplete caries removal technique. In permanent dentition, Bjorndal[28] recommended re-entry to remove all remaining carious dentin before carrying out the final restoration because he believed that remaining carious dentin might stimulate obliteration of the root canals. Nevertheless, there are arguments in the most appropriate time of re-entry. The shortest and the longest times of re-entry that have been reported are 3 weeks and 2 years[14]. In primary dentition, Coll et al.[13] recommended using GI as "caries control", an important diagnostic tool for deeply carious primary teeth, for 1 to 3 months. Vij et al.[9] also found that success rate of IPT increased from 79% to 92% if caries controls were used before the definitive treatment.

In contrast, many researchers believed re-entry is unnecessary especially in the treatment of primary dentition[2, 4, 21]. There are evidences showing that dentin becomes darker in color, harder and drier in consistency after re-entry[38, 40, 43, 45, 46]. Microbiological analysis also showed a significant reduction in cultivable micro-

organisms. These findings would imply that re-entry of the cavity is not necessary[43]. From the study of Orhan et al.[2], no statistically significant difference was found between 1- and 2-visit IPT in terms of pulp exposure and success rate. The success of that study suggested that IPT performed in one appointment is viable in the primary dentition. Furthermore, re-entry have many disadvantages such as loss of temporary fillings between the treatment stages, pulp exposures during the final excavation of residual caries, loss of patients in the second visit and increasing of treatment cost and chair time[2, 4, 47].

No matter what techniques are used, one important factor to gain high success rate is choosing proper permanent restoration that provides a good marginal seal and limits the nutrient influx necessary to maintain bacterial metabolism and proliferation. These good properties can help the healing of healthy pulp itself by protect the cavity from contamination of biofilm. In deep and large carious lesion, the cavity after caries removal may be left with a little amount of surrounding wall of cavity making it prone to fracture. So these teeth require a strengthening property of the final restoration material to protect weak tooth structure. Accordingly, stainless steel crown (SSC) is the best restoration of multisurface or extensive carious lesion in primary dentition. It is more durable and has long lifespan more than other restorative materials[48-52]. SSC was believed to seal the dentin tubule from any subsequent microleakage and improved the chance of the IPT success[8]. Al-Zayer et al.[19] showed that SSC had higher success rate than amalgam when they were used with IPT. Moreover, Sonmez and Duruturk[49] also found that restoration failure rate of amalgam (14.3%) was statistically significant higher than that of SSC (2.4%). It may be concluded that SSC is the best available restoration providing long-term success of

pulp therapy. However, some authors chose GI or RMGI as an alternative restorative material in the case that teeth nearly exfoliate within 2½ years. However, failures of margin in these restorations were found and close monitoring was highly recommended[53-55].

Moreover, the selection of the luting cement is also important because it influences marginal leakage and retention of SSC restorations. The ideal luting cement should bond to tooth structure and restorative materials, have high compressive and tensile strengths, provide adequate film thickness and viscosity to ensure complete seating, exhibit adequate working and setting time, and more importantly have a low solubility in the oral cavity[56]. There are several luting cements that have been used for SSC cementation including zinc phosphate, polycarboxylate and GI cement. Zinc phosphate and polycarboxylate luting cements have high solubility and low hardness[56]. GI and zinc phosphate luting cements occasionally cause postoperative sensitivity[56-58]. At present, RMGI luting cement seems to be the closest to the ideal cement and is widely used because it has fluoride ion release, molecular bonding to tooth structure, low solubility of cement margin, simplicity of its use, medium material strength and low postoperative sensitivity[57, 59-61].

At present, there are several incomplete caries removal techniques described in literature. In this review, several incomplete caries removal techniques will be described as follows: (1) IPT; (2) Stepwise excavation; (3) Ultraconservative treatment; and (4) Hall technique.

2.4.2.1 Indirect pulp treatment (IPT)

IPT was previously known as indirect pulp capping which has been advocated for more than 200 years[19]. The basic definition of conservative IPT in treating deep decay in primary teeth is "the procedures taken to protect or maintain the vitality of the carious tooth that, if completely excavated, the decay would result in a pulp exposure"[29]. AAPD described IPT as the incomplete removal of carious dentin in order to avoid a pulp tissue exposure, and treating the decay process with a biocompatible material[5].

Despite its high clinical and radiographic outcomes reported in several studies[18-22], IPT is still not widely used as much as it should be by pediatric dentists. More recent results of study by Dunston and Coll[62] reported that 83% of the US dental schools taught IPT and 71% of the diplomates reported IPT use. But when giving a clinical scenario of primary teeth with deep caries near the pulp—which AAPD guidelines state are candidates for IPT or pulpotomy—however, only 30% of the US dental school representatives and 19% of diplomates would use IPT.

One of the reasons that IPT is not as popular as it should be is the ambiguous definition of the IPT itself. IPT has been defined in many different ways by many different authors (Table 2.3). The confusion remains whether which type of caries and how much it should be removed and left in cavity.

Table 2.3 The varied definitions of IPT.

Authors	IPT definition
Farooq et al., 2000[8]	"The carious dentin was removed, but some was left to avoid a clinical pulp exposure"
McDonald, 2004[48]	"The gross caries is removed from the lesion and the remaining thin layer of caries over the pulp is covered with a radiopaque biocompatible material"
Bjorndal and Kidd, 2005[17]	"Almost completely removes the demineralized and discoloured dentin, leaving a thin layer of residual caries, and re-entry is not undertaken"
Bjorndal, 2008[28]	"Almost complete removal of the affected dentin, leaving a thin layer of demineralized dentin"
Gruythuysen et al., 2010[18]	"Leaving infected carious dentin at the center of the cavity"
AAPD, 2010-2011[5]	"The caries surrounding the pulp is left in place to avoid pulp exposure and is covered with a biocompatible material"

In clinical procedures, it is quite difficult and very subjective to distinguish the types of caries that should be removed and left in cavity from varied definitions described above. Although we have known that removing infected dentin is painless but removing affected dentin may be painful, it is hard to ask pediatric patients about their feelings because pediatric dentists usually provide local anesthesia prior to most treatments[63]. Some authors recommend observing the dentin color, consistency and humidity as well as feeling through an explorer, a spoon excavator or a slowly revolving bur to determine the types of dentin. The softened, humid, yellow or light-brown dentin, that does not offer resistance to the manual excavation should be removed, while the less softened, darker and harder consistency, coming out in scales

or chips, can be left[19, 26, 63]. In fact, these sensations to discoloration and hardness are also subjective and depend mostly on dental experiences of each operator. Some researchers used caries-disclosing dyes to stain only the outer infected dentin[64, 65] but recent study has revealed that these dyes stain sound as well as carious dentin, leading to clinically significant overpreparation of cavities[18]. This caries removal step is the difficult part of the IPT procedure and requires considerable attention.

Besides the variation in definitions of IPT, there is also a debate about the essential of the lining or base materials used in IPT. Falster et al.[20] recommended that none of base materials is necessary. However, various bacteriostatic/ bacteriocidal base materials including calcium hydroxide[19, 20], GI[8, 9], RMGI[18] have been widely used. Calcium hydroxide is traditionally the material of choice because of its alkaline biocompatible properties and its ability of the induction of pulpodentin remineralization. GI and RMGI were also found to be biocompatible comparable to calcium hydroxide[66, 67]. At present, RMGI is widely used in pediatric dentistry because it has several good properties such as adhesion to dentin, reduce leakage, fluoride release, bacteriostatic, thermal protection, stress release, enhanced strength, less acidic at the initial stage of placement, less post-operative sensitivity, prevent microleakage, stimulate reparative dentin formation and simplicity of use[68]. In study of Coll et al.[13], using GI in caries control resulted in a higher success of both IPT and pulpotomy compared to that of using zinc oxide eugenol The authors believed that the cause of this higher success was better sealing ability. Nevertheless, many studies showed overall success rate of IPT to be more than 90% and the role of the lining material is not essential[13, 18-22] (Table 2.4).

Table 2.4 Success rates of IPT with different biocompatible materials.

Study	Study design	Tooth type	Intervention	Follow-up period	Success rate
Falster et al., 2002[20]	PST	Primary molars (N=48)	G1: 10%phosphoric acid + Scotchbond MultiPurpose G2: Calcium hydroxide liner + 10%phosphoric acid + Scotchbond MultiPurpose	2 years	G1:96% G2:83% Not significant between 2 groups.
Al-Zayer et al., 2003[19]	RST	Primary molars (N=225)	G1: Calcium hydroxide liner G2: Calcium hydroxide liner + base material (zinc oxide eugenol or RMGI).	2 weeks to 73 months	The survival rate was 95%. Using base material with calcium hydroxide liner increased the success rate than use Calcium hydroxide liner alone
Marchi et al., 2006[21]	PST	Primary molars (N=27)	G1: Calcium hydroxide liner G2: RMGI	48 months	G1:88% G2:93% Not significant between 2 groups.
Casagrande et al., 2009[22]	PST	Primary molars (N=48)	G1:Scotchbond MultiPurpose G2: Calcium hydroxide liner	4 – 5 years	G1:93% G2:80% Not significant between 2 groups.
Gruythuysen et al., 2010[18]	RST	Primary molars (N=125) and permanent teeth (N=45)	RMGI	3 years	96% for primary molars 93% for permanent teeth
PST = Prospective stydy, RST = Retrospective study, G1 = group 1 , G2 = group 2					

Another argument widely discussed about IPT is the matter of re-entering. Some described IPT as a procedure which can be performed as a 1- or 2 visit treatment[2, 69]

while others referred to 1-visit procedure as IPT and the 2-visit procedure as a stepwise excavation[14, 28, 47]. However, the literatures consisted of both approaches, only difference is in the 1-visit procedure, a permanent restoration is performed in the same visit. In the 2-visit procedure, an intermediate restoration is done in the first visit; then, the reopening is followed with variation in time period[14]. After the cavity is reopened, the final excavation is performed. In this final excavation, the operator may remove all remaining carious dentin or left some affected dentin in the cavity before permanent restorations are placed.

In the treatment of primary teeth, most studies have been heading toward 1-visit procedure or in another word "no re-entering"[18-21]. There may be many reasons behind this approach. Re-entering results in repeated treatment which may not be suitable for young children with primary teeth when considering both behavior management and cost-effectiveness. Moreover, SSCs are often chosen as restorations of large carious lesions of primary teeth and usually results in good seal and function until tooth exfoliation. Therefore, re-entering may not be suitable for primary tooth treated with IPT.

In contrast of primary teeth, treatment of deep carious lesions in permanent teeth may have some different details that needed some attentions. The purpose of treating permanent teeth may be more complicated than that of primary teeth. More conservative approach to ensure the long-term treatment success is essential. The restorations of young permanent teeth with large carious lesions vary from fillings to intermediate full coverage. With longer longevity of permanent teeth, there may be some leakage or failures of restorations which may result in reactivation of the caries

that has been left under restoration. Therefore, re-entering to remove all carious lesions may be more essential when treating permanent dentition.

2.4.2.2 Stepwise excavation

Stepwise excavation is the technique that caries excavation is performed in 2 visits. The stepwise excavation can be further classified into two different techniques as traditional and modified stepwise excavation. These two techniques have only minor differences that will be further discussed.

Traditional stepwise excavation

The traditional stepwise excavation resembles 2-visit IPT. In the first visit of the traditional stepwise excavation, the superficial necrotic dentin including soft and easily removed caries are excavated, while the excavating of residual caries close to the pulp is avoided. The lesion is then sealed with a biocompatible material, such as calcium hydroxide, and a temporary restoration is placed. After 8 week to 2 years, the cavity is re-entered and the remaining carious dentin is removed leaving only central yellowish or grayish hard dentin (equal to the hardness of sound dentin, as judged by gentle probing)[3, 17, 31].

Because the potential risk of iatrogenic pulpal exposure following IPT or traditional stepwise excavation, the less rigid criteria of caries excavation in the first visit has been recommended as “the modified stepwise excavation”.

Modified stepwise excavation

To reduce the risk of creating iatrogenic pulpal exposure following either IPT or during the first step of stepwise excavation, Bjorndal[16, 28] recommends to use the modified stepwise excavation.

In the modified stepwise excavation, the goal for the first excavation is to change the caries environment and avoid pulp exposure. So the thicknesses of residual carious dentin left in the modified technique is more than that of the traditional technique. Then, a provisional restorative material is selected on the basis of the length of the treatment interval, ranging between 6 and 8 months. The final step is to verify that the arrest of caries lesion has taken place. Then, the slowly progressing lesion of demineralized dentin is removed prior to the placement of final restoration[17, 28].

The advantage of this technique is to reduce the number of iatrogenic pulp perforations during the first excavation step. This technique has high long term success rate of 92% at 3½-4½ years[25].

2.4.2.3 Ultraconservative treatment

Mertz-Fairhurst et al.[70] published a controlled clinical study, four-celled design to compare sealed composite restoration (CompS/C) with sealed amalgam (AGS) or unsealed amalgam (AGU) in Class I lesion of permanent teeth. The lesions were screened with bitewing radiographs to confirm that each lesion had no penetration more than half of the total dentin thickness. In both AGU and AGS groups, all soft demineralized dentin was completely removed. In the AGU group, cavity preparation was extended into noncarious fissures to prevent future caries activity. In the AGS

group, the cavity preparation was not extended into unaffected fissures for prevention but sealant was applies over the amalgam restoration and all pits and fissures of the tooth. In the CompS/C group or Ultraconservative treatment and cariostatic sealed restoration, the preparation was done only 1 mm in the enamel and the caries below was left untouched. Then, composite restorations were placed over caries and sealants were applied over the restoration and the fissures. After 10-year follow up, the results of this study showed that both AGS and CompS/C groups remained good sealed restoration superior to the AGU group. Good seal in all groups prevented recurrent occlusal caries. There was no progression of caries in the sealed restoration. This 10-year study confirms that good bonded and sealed restoration will cut off the nutrients from the oral cavity to cariogenic bacteria in the lesion and prevent any further progress of carious process. Therefore, complete dentin caries removal may not be a prerequisite to arrest carious progression.

However, this technique is not suitable for all carious lesions. It may be quite difficult to seal the proximal lesions in the same way that was done on occlusal lesions. Moreover, all teeth that are treated by this technique should be closely followed to early detect marginal leakage or restoration loss. Careful case selection and long term follow-up are necessary when using this technique.

Besides Ultraconservative treatment, a recently published new technique for managing carious primary molar without any caries removal named Hall technique will also be described.

2.4.2.4 Hall technique

The more extreme example of the incomplete caries removal technique has been published from a group of dentists from Scotland. The technique was named after Dr. Hall who began using this new simple technique because of the overwhelming numbers of patients in her practice. Many authors have shown that this technique provides less invasive procedure and reduces treatment-induced distress or anxiety[71-73]. The novel technique was simply performed with no caries removal, no tooth preparation and no local anesthesia. The tooth was isolated from oral environment by sealing them with SSC cemented by GI luting cement. From 13 years period of Dr Hall's practice records, the results of survival analysis were 73.4% for three year, and 67.6% for five years[73].

Innes et al.[72] used a split-mouth randomized controlled clinical trial to compare Hall technique and the conventional restorations in primary molars done by general practitioners. One-hundred and thirty-two children ranging from age 3 to 10 years old were selected for their study (128 teeth in control restoration and 132 teeth in Hall technique). The restorative materials chosen in control groups are as follows: GIC (69%), amalgam (8%), compomer (5%), composite (11%), SSC (1%) and fissure sealant (2%). Nevertheless, the inclusion criteria was ambiguous such as various depth of lesion, no standard radiographic information prior to the treatment, GI base material was used in only some teeth, and different caries removal technique in the control group. The outcomes at minimum period of 23 months showed that the major failures (signs and symptoms of irreversible pulpal disease) were found 15% in the control restorations and 2% in Hall technique. The minor failures (loss of restoration, caries progression) were found 46% in the control restorations and 5% in Hall

technique. The authors concluded that Hall technique was a more successful method for managing caries in primary molars than the control restoration after two years and caries will arrest in the right circumstances[72].

Foley[74] surveyed the treatment options to manage carious primary molar teeth in UK postgraduates in pediatric dentistry by online questionnaire. He found that Hall technique appeared to be a favored option for treatment of an asymptomatic carious primary molar tooth in dentally-anxious child patient.

However, Hall technique has many limitations. Some children did not cooperate to bite a rigid SSC through tight contact point without local anesthesia. Without tooth preparation, occlusion showed 1-2 mm high in vertical dimension[72, 73]. Moreover, there are some big size teeth or teeth with anatomical variation and low margin of carious lesion that the SSC would not be able to cover when teeth are not prepared before SSC cementation.

Even though Hall technique has proved that only SSC with luting cement is sufficient in caries treatment of primary teeth, there are several issues that should be further inverstigated. The higher success rate may be expected if the SSC is prepared with the conventional method (with local anesthesia and preparation) which should result in better SSC adaption and sealing.

It can be concluded from the entire review literature as follows:

1. There is a wide range of amount of caries removal in the incomplete caries removal techniques. In IPT and stepwise excavation, maximal caries is removed. While in Ultraconservative treatment and Hall technique, none to minimal caries is removed.

2. There are controversial opinions of re-entry concept in the incomplete caries removal techniques. In 2-visit IPT and stepwise excavation, cavity is reopened to ensure that all carious dentin are removed. While in 1-visit IPT, Ultraconservative treatment and Hall technique, cavity is not reopened as long as it has a good sealing from biofilm.
3. There is a variation in the base material use in the incomplete caries removal techniques. In IPT and stepwise excavation, some studies used biocompatible base materials while other studies found that success rate of IPT does not depend on base material. Whereas in Ultraconservative treatment and Hall technique, base materials were not used but also have high success rate.

In our study, MCR with $RMGI_{B/L}$ or MCR with $RMGI_{L}$ technique was used for managing deep carious lesion in primary teeth. Minimal caries removal (MCR) was modified from all knowledge in this literature review. This technique has minimal caries removal resembling Ultraconservative treatment that had been studied only in permanent dentition and use SSC restoration to seal residual caries similar to Hall technique.