

CLINICAL DILEMMA OF SELECTIVE CARIES REMOVAL IN PRIMARY TEETH: A SCOPING REVIEW

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ABSTRACT

Despite growing evidence supporting selective caries removal in managing deep caries, many practitioners still prefer to manage caries in a more invasive way. Although proven to be beneficial in preserving pulp vitality, there is a concern that leaving soft dentin behind will compromise the adhesion of dentin to restoration. This paper aimed to review the evidence supporting selective caries removal of deep dentin caries on primary teeth, and the arguments against the technique using a scoping review method. Various outcome parameters were applied to define and evaluate treatment success, including pulp and dentine responses, dentin micro-hardness, bacterial load of dentin under restoration, and restoration survival. A structured literature search of PubMed and Scopus databases was performed for relevant articles, using specific key words and based on a PICO-structured question: Does selective caries removal in carious deep dentin primary teeth show better results in terms of pulp exposure risk, restoration integrity, micro-hardness, and bacterial load of sub-restorative dentin compared with complete caries removal?

Selective caries removal is a minimally invasive approach that evidently protects teeth from the risk of pulp exposure. Several aspects must be considered before making the clinical decision to selectively remove carious tissue in managing deep caries. All dental practitioners are expected to possess a thorough knowledge about pros and cons of selective caries removal to deliver evidence-based treatments to their patients.

Key words: primary teeth, selective caries removal, non-selective caries removal, restoration quality, pulp exposure.

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INTRODUCTION

Selective removal is an approach, in which carious tissue at the pulpal wall are removed until leathery or firm dentin is reached, while in the periphery wall, caries are removed until the hard dentin (Figure 1) [1]. The International Caries Consensus Collaboration (ICCC) recommended this method in 2016, based on the concept change of dental caries pathology, from caries as an infectious disease caused by cariogenic bacteria, to caries as a biofilm-mediated disease driven by human behavior [1]. This brings a change in the way of managing dental caries. Previously, when caries was thought to be an infection, all contaminated or de-mineralized dentin had to be removed (Figure 1). However, current evidence suggested that when the tooth is vital and asymptomatic, leaving soft dentin in the pulpal walls of deep cavities is desirable [2]. This is because cariogenic bacteria need particular conditions to survive. Therefore, when a cavity is sealed by restoration, any remaining bacteria will either die or become dormant. The abundance of evidence has made complete caries removal risking, and pulp exposure seemed unethical [2, 3].

The father of operative dentistry, G.V. Black, stated more than 100 years ago that: “The day is surely coming when we will be engaged in practicing preventive rather than reparative dentistry” [4]. Today, despite growing evidence supporting selective removal in managing deep

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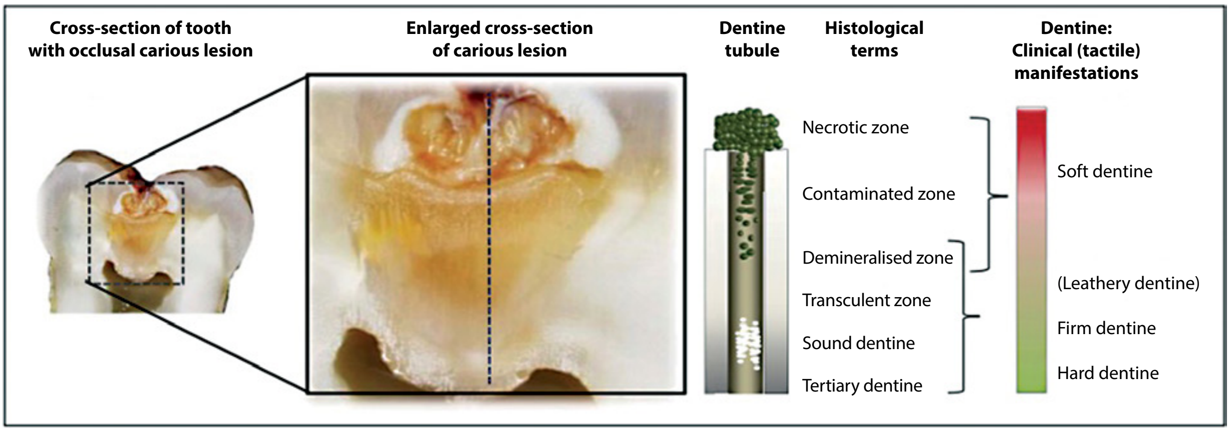

FIGURE 1. Clinical manifestations and histopathological terminology of caries zones [18]

carious lesions, dentists around the world are still managing caries more invasively. One of the reasons for this is (although selective removal is proven beneficial in preserving pulp vitality) that it does compromise adhesion of dentin to restoration. The soft dentin left on the cavity pulp wall may influence the restorations bond strength and marginal stress. According to Schwendicke *et al.* [1], the only reason why caries is removed today might be to create a larger surface for restoration to bond to.

Until today, numerous studies have investigated the effectiveness of selective caries removal in primary and permanent teeth [5-11]. However, various outcome parameters were used to define and evaluate treatment success, including the response of dentin and pulp, presence of complications, and/or restoration survival. Other authors also investigated micro-hardness of sub-restoration of dentin and bacterial load under restoration after selective caries removal [5, 12]. Furthermore, other factors, such as patient oral hygiene and socio-economic factors play important roles in determining treatment success.

The aim of the current paper was to review the evidence supporting selective caries removal of deep dentin caries on primary teeth and the arguments against it, considering factors, such as risk of pulp exposure, microhardness of dentin under restoration, microbial load of dentin sub-restoration, and restoration integrity, using a systematic scoping review method. This review followed the systematic, transparent, and reproducible search strategy used in a systematic review. However, since there were different parameters applied to evaluate outcomes, this scoping review did not draw any conclusion as it would in a systematic review, but aimed to provide understanding on the advantages and disadvantages of selective caries removal, so that clinicians can make better decisions regarding best management strategy prior to restoring primary teeth.

MATERIAL AND METHODS

This review was done based on the scoping review framework by Arksey and O'Malley [13] and the preferred reporting items for systematic reviews and meta-analysis (PRISMA) guidelines [14]. Two authors independently performed a structured literature search of PubMed and Scopus databases for articles published from January 1, 2012 to February 1, 2022 (Figure 2). Specific key words were applied based the following PICO-structured question: Does selective caries removal show better results in terms of pulp response, restoration quality, sub-restorative dentin hardness, and bacterial count compared with non-selective caries removal in primary teeth?

1. Patient: deep dentin carious primary teeth.
2. Intervention: selective caries removal (SCR) and adhesive restoration.
3. Comparison: stepwise (SW) vs. complete removal (CCR) and adhesive restoration.
4. Outcome: marginal integrity, secondary caries, discoloration, pulp response, presence of pain, pulp and dentin response, hardness and bacterial count of sub-restorative dentin *in-vitro*.

The literature search included all randomized clinical trials, which compared selective and non-selective caries removal in primary teeth, published within the last 10 years. Studies would be excluded if they were conducted on permanent teeth, those that did not include complete caries removal as an intervention/control group, and/or studies that did not include adhesive restoration as part of caries management (Table 1).

RESULTS

Sixty-four potential articles were identified through the initial database search. After eliminating duplicates, 53 articles remained. Abstracts and titles were screened by two reviewers independently, resulting in exclusion of 28 irrelevant abstracts. Twenty-five articles were included for full-text evaluation. After this process, 18 articles were excluded for the following reasons: subjects with permanent teeth (n = 4), research on a group "no caries excavation at all", previous research that had been updated with a longer follow-up period (n = 2), investigated costs and

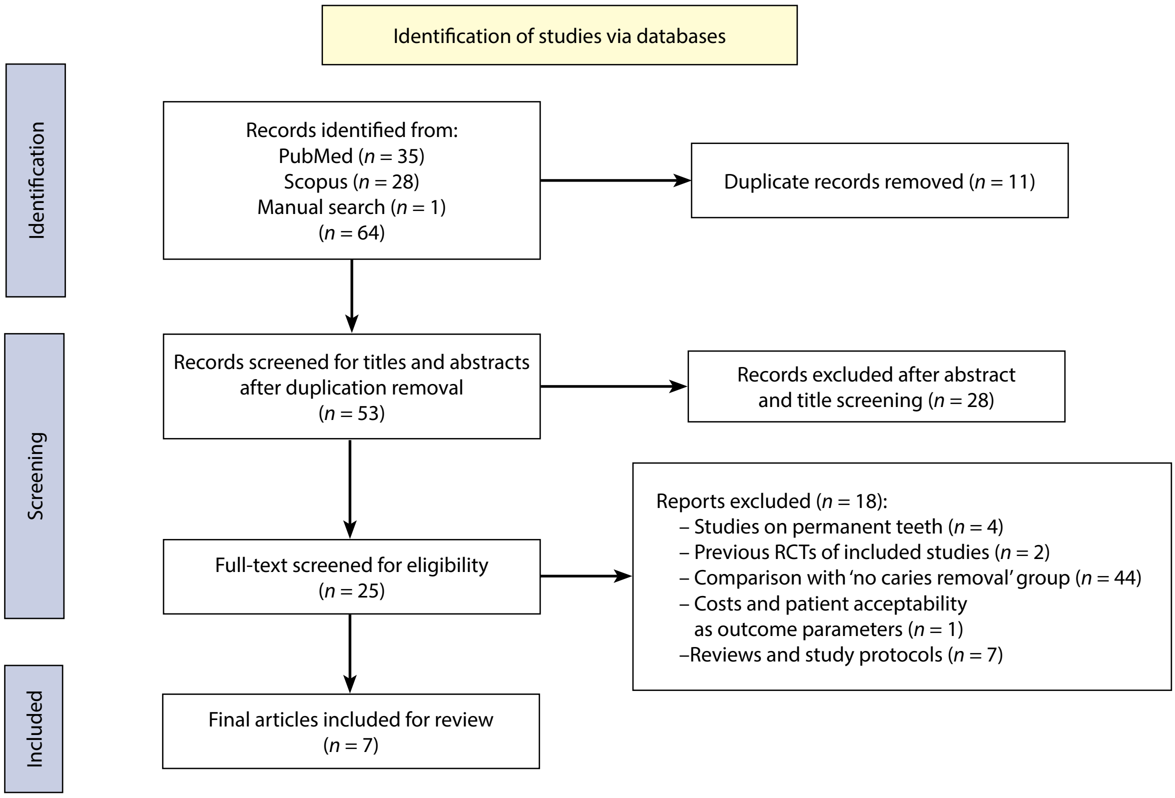

FIGURE 2. Flow diagram of the literature search based on the preferred reporting items for systematic reviews and meta-analysis extension for scoping reviews (PRISMA – ScR) [8]

patient acceptance as parameters (*n* = 1), and reviews or study protocols (*n* = 7). Figure 2 describes PRISMA diagram of the article search and reasons for exclusion.

CHARACTERISTICS OF INCLUDED STUDIES

In total, there were 7 studies included, out of which 4 were conducted in Brazil [7, 9, 15, 16], 1 study was from Uruguay [8], 1 from Thailand [12], and 1 from Germany [6]. Five studies were published within 2017-2021, while two other studies were published in 2014 and 2009, respectively [15, 16]. The authors manually searched the reference lists [8, 12] and included an article from 2009 [15], since there were no other studies investigating bacterial count as a parameter after selective excavation in primary teeth within 10 years. There was only one study measuring bacterial count after selective removal within that period [5], but the subjects had permanent teeth, hence the study was excluded. This paper used the scoping review design, because it aimed to review the effectiveness of selective caries removal based on several different aspects of outcome measures. Of the seven studies, four studies evaluated pulp complications and restoration quality [6, 7, 9, 16], one study assessed restoration quality only [8], one study investigated dentin hardness [12], and one study measured bacterial count in dentin before and after selective removal of caries [15]. Regarding isolation methods, five studies used rubber dams [7-9, 15, 16] and two other studies used cotton rolls [6, 12] as a method for isolation. Most studies used composite resin and only few studies used GIC [12], RMGIC [8, 9], and compomers [6] as a final restoration material. Table 1 summarizes the characteristic of the included studies.

RISK OF BIAS ASSESSMENT

All articles in this review went through a risk of bias assessment according to their respective study designs to determine the quality of the research conducted. Randomized clinical trials were evaluated using Cochrane risk of bias tool [17], while retrospective cohort trials were estimated with Newcastle-Ottawa quality assessment for cohort studies [18]. The six included randomized clinical trials demonstrated a low-risk of bias. In some clinical trials, it was not possible to blind the operators or patients; however, the patients were asked not to inform the examiners about the treatment allocation during follow-up examination [6, 16]. The results of the risk of bias assessment are presented in Table 2.

DISCUSSION

Selective removal is a caries removal strategy based on the change in caries etiopathological concept, which

TABLE 1. Main characteristics of included studies (*n* = 7)

No.	Study, year [Ref.]	Study design	Comparison groups	Isolation method	Use of liners	Outcome parameters	Restoration	Follow-up period	Conclusions
1	Elhennawy *et al.*, 2020 [6]	Randomized clinical trial	SCR, SW	Cotton rolls	No	Endodontic complications, restoration quality (USPHS criteria)	Compomer	24 months	SCR and SW showed similar efficacy after a 24-month follow-up period
2	Pereira *et al.*, 2021 [7]	Randomized clinical trial	SCR, NSCR	Rubber dam	Yes, calcium hydroxide	Restoration quality (FDI criteria), pulp vitality	Composite	33 months	SCR and NSCR showed comparable restoration quality after a 33-month follow-up period
3	Phonghanyudh *et al.*, 2021 [12]	Randomized clinical trial, experimental laboratory	SCR to soft and firm dentin, NSCR	Cotton roll	No	Dentin microhardness (KHN), signs and symptoms of pulpitis	GIC	3-6 months	SCR and NSCR resulted in similar dentin micro-hardness after GIC restorations in 3-6 months follow-up period
4	Liberman *et al.*, 2020 [8]	Randomized clinical trial	SCR, NSCR	Rubber dam	Yes, calcium hydroxide	Restoration quality (USPHS criteria)	RMGIC/composite	36 months	Restorations after SCR were 3.44 times more likely to fail compared to after NSCR
5	Melgar *et al.*, 2017 [9]	Retrospective cohort	SCR	Rubber dam	Yes, calcium hydroxide	Restoration failure defined as the need to repair or replace restorations, pulp therapy or extraction	RMGIC/composite	36 months	SCR resulted in 48.8% failure rate in a 3-year period, 20% of restoration failure, and 4% of pulp complications
6	Franzon *et al.*, 2015 [16]	Randomized clinical trial	SCR, NSCR	Rubber dam	Yes, calcium hydroxide	Restoration quality (USPHS criteria), pulp complications	Composite	24 months	SCR prevents pulp complications (2% vs. 27%), but resulted in lower restoration failure rate (66%) compared with NSCR (86%) in 24 months
7	Lula *et al.*, 2009 [15]	Randomized clinical trial, experimental laboratory	SCR, NSCR	Rubber dam	Yes, calcium hydroxide	Bacterial count before and after restoration	Composite	3-6 months	SCR and NSCR groups did not show differences in bacterial growth after restoration

SCR – selective caries removal, SW – stepwise caries removal, NSCR – non-selective caries removal, CFU – colony forming unit; KHN – Knoop hardness, USPHS – United States Public Health Service, FDI – World Dental Federation

believe that bacteria are not the only cause of disease [3]. According to this concept, the risk of exposing the pulp of a vital tooth with deep dentinal caries is greater than the need to remove all of the soft dentin from the cavity. This raised new questions: Is it acceptable to leave a part of the carious tissue in the cavity to avoid exposing the pulp? Will the left behind bacteria cause caries activity in the future? How does leaving soft dentin affect the quality of the restoration? In this study, we discussed four aspects that need to be considered in conducting selective caries removal, including pulp response, success rates of restorations, dentin hardness, and number of bacteria in dentine based on the seven included studies.

PULP RESPONSE

Pulp responses are the most widely used clinical parameters to evaluate the success or failure of selective caries removal and its restoration. The literature showed that leaving contaminated dentin under restorations does not affect the caries termination process, while being able to maintain pulp vitality [16]. Exposure of the pulp will cause irreversible damage to the palisade layer of odontoblasts and kill many primary odontoblasts [6]. Apart from causing irreversible damages, pulp complications have the potential to cause longer treatment times, increased number of visits, higher costs, and discomfort, especially in pediatric patients. Studies evaluating this parameter after a specified follow-up period defined pulp exposure as pathological immobility, edema, fistula, spontaneous pain, and sensitivity on palpation [7].

A study with a follow-up period of two years showed no differences between pulpal complications in the selective and stepwise removal groups [6]. Exposed pulp was found only in the stepwise group, and all occurred in the second stage when the cavity was re-opened and excavation was carried out in a non-selective manner [6]. Pereira *et al.* [7] found that the non-selective excavation group had more pulp complications, but the difference in pulp response between the two groups was not significant [7]. Another study comparing selective and non-selective removal in terms of pulp complications reported that in the selective removal group, only 2% had pulp exposure [16], whereas in the non-selective excavation group, approximately 27% had exposed pulp. This may be due to the fact that among the three studies, this study used the deepest caries depth as a criteria that was at least ¼ of the inner dentin. The caries depth, dentin hardness criteria for removal, and instruments applied are all factors, which can affect pulp exposure [6, 7, 16].

The measures for caries excavation and how much soft dentine can be left is an issue in any study of caries excavation, because these criteria are highly subjective. Nonetheless, the success of selective excavation is believed to be determined more by the accuracy of pulp diagnosis and good restoration quality, apart from the presence of a layer of soft dentin at the bottom of the cavity. Given the technical definitions of selective and non-selective excavation, it is reasonable for studies comparing complications between the two groups to show a lower risk in the non-selective group. Studies that reported no significant differences in pulpal complications between the two techniques indicated that selective excavation is less invasive in terms of pulp response compared with more conventional non-selective excavation [6, 7, 9, 16].

RESTORATION QUALITY

Restoration quality is another outcome parameter that was extensively researched in studies on selective caries removal. The criteria widely used to evaluate restorations are the United States Public Health Service (USPHS) and FDI (Fédération Dentaire Internationale/World Dental Federation) guidelines. In addition to no difference in pulp complications, clinical trials comparing selective excavation with stepwise also reported no differences in restoration quality between the two groups. The selective excavation group showed failure in terms of color, marginal integrity, and anatomical shape in compomer restorations based on the USPHS criteria, and the stepwise group also showed similar types of failures [6]. Moreover, Pereira *et al.* [7] used FDI criteria and found that majority of restoration failures occurred in marginal adaptation, but these failures and other four criteria occurred equally in the two caries removal groups.

Conflicting results were reported by Franzon *et al.* [16], where restoration success in the selective group (66%) was significantly lower than in the non-selective group (86%) after a 24-month follow-up period. However, when pulp complications were combined with restoration success as a parameter, the two groups showed similar treatment success, namely 61% for selective and 64% for non-selective excavation [16]. It is critical to note the criteria for restoration failures in this discussion. Criteria, such as marginal integrity and loss of partial/total restorations are relevant when it comes to caries excavation; however, criteria, such as marginal discoloration and anatomical shape may be less relevant, because they are not directly related to the method of excavation. Liberman *et al.* reported similar results [8] that composite restorations after selective removal showed a lower success rate compared to the non-selective group. In this study, complex cavities and poor oral hygiene were reported as contributing factors to restoration failure. Therefore, it is important to underline that restoration failure is not necessarily caused by the excavation process, but is strongly influenced by various other factors [8].

Different types of restorative materials were applied, including compomers, composite resins, and RMGIC. RMGIC is generally used in cases, where there were

TABLE 2. Quality assessment of included studies ($n = 7$)

Study, year [Ref.]	Randomization	Allocation concealment	Blinding of participants	Blinding of operators	Blinding of outcome assessment	Incomplete outcome data	Selective reporting
Randomized controlled trials							
Elhennawy *et al.*, 2020 [6]	Low	Low	High	High	High	Low	Low
Pereira *et al.*, 2021 [7]	Low	Low	High	Low	High	Low	Low
Phonghanyudh *et al.*, 2021 [12]	Low	Low	Low	Low	High	Low	Low
Liberman *et al.*, 2020 [8]	Low	Low	High	High	High	Low	Low
Lula *et al.*, 2009 [15]	Low	Low	Low	Low	High	Low	Low
Franzon *et al.*, 2015 [16]	Low	Low	Low	High	High	Low	Low

Study, year	Cohort studies: Selection				Comparability	Outcome		
	Representativeness of exposed cohort	Selection of non-exposed cohort	Ascertainment of exposure	Outcome of interest was not present at start of study	Comparability of cohorts on the basis of design or analysis	Assessment of outcome	Was follow-up long enough for outcomes to occur?	Adequacy of follow-up of cohorts
Melgar *et al.*, 2017 [9]	*	*	*	*	*	*	*	*
							Yes, follow-up period was 3 years	Follow-up rate of 79%, 21% patients without follow-up

A maximum of one star (*) is given for each numbered item within the selection and outcome categories. A maximum of two stars can be given for comparability based on Newcastle-Ottawa quality assessment scale for cohort studies difficulties with isolation, humidity control, and in uncooperative children. The only retrospective cohort design study in this review concluded that RMGIC and composites exhibited equally good restorative stability [9]. Additionally, GIC with its fluoride release feature was considered superior to composites in inhibiting de-mineralization, increasing re-mineralization, and in having anti-microbial effect, eradicating bacteria in soft dentin [12]. Regarding the restorative material choices, there is no scientific evidence to support that certain materials are better than others as post-selective caries removal restorative materials.

Any discussion on the pros and cons of removing all caries (or not ultimately) leads to the quality of final restoration. Remaining contaminated and de-mineralized carious tissue is believed to reduce the adhesive ability of restorative materials and support from the mastication pressure, which in turn causes stress on the material and reduce the integrity of restoration. An *in-vitro* study [19] found thin cracks in restorations after selective removal, indicating that the restorations collapsed onto the underlying dentin. This is because the soft dentine base at the bottom of the cavity is not strong enough to withstand the mastication pressure. The study was carried out in a laboratory design, so its clinical application is very limited. However, in practice, restoration failure usually occurs at least a few weeks after excavation and restoration [19]. Another interesting finding is that clinical failure of restorations due to decreased strength of the dentine complex and restorative material, generally takes at least 24 months. This is a clinical advantage of the treatment of primary teeth, which have a limited biological cycle until the time of exfoliation [9].

BACTERIAL COUNT IN DENTIN

Bacterial count in dentin under restoration is another parameter that can be used to determine changes in the micro-environment after selective caries removal. The concept of selective and stepwise technique is based on the understanding that cariogenic bacteria left between the restoration and the pulp will lose their source of nutrition, and hence are unable to survive. The only study evaluating the number of bacteria as a parameter concluded that the bacteria in the cavity were still viable and able to proliferate, but no caries activity was found due to the decreased number of mutans streptococci and *Lactobacillus* spp. The decrease in the number of these two aciduric bacteria probably occurred because the dentine environment experienced a decrease in the acidity level after the restoration. The number of micro-organisms in the selective group was significantly higher compared with the control group, but the bacterial growth rate did not show any significant difference before and after caries removal in the 3-6 months observation period [15].

It has long been known that the histological difference between active and arrested carious lesions is that the dentinal tubules are exposed in active lesions. Meanwhile, in an inactive carious lesion, a calcio-traumatic zone is seen covering the tubules and separating the secondary dentin from the tertiary dentin. Bacteria and irritants cannot pass through it, so that this zone becomes a very effective barrier to protect the pulp [5]. However, in a previous study, no severe pulpal inflammatory changes were found in all the specimens, and none of the teeth showed any painful symptoms during the observation period prior to extraction. How long will this process take? Can the pulp remain vital in the presence of bacteria? Will the pulp eventually experience necrosis? These three questions remain unanswered because the response of the pulp greatly depend on the amount of cariogenic bacteria remaining as well as on the extent of virulence and host resistance. As long as the quality of restoration is good, residual bacteria will not be able to multiply to the amount needed, causing caries and inflammatory activity. Similarly pulpal necrosis can occur when host resistance is decreased or when the densities of restoration margins are compromised.

Based on the concept of caries and biofilm etiopathogenesis, the caries process is driven by bacteria in the biofilm, not by bacteria in soft dentin. Therefore, if the caries process in the biofilm is stopped, the caries lesion that is a reflection of the biofilm will stop or become inactive. A similar process occurs in arrested caries, where plaque removal and regular application of fluoride can gradually change the active lesion, turning the surface of the lesion smooth, shiny, and hard upon probing [2].

DENTIN HARDNESS

A survey revealed that most dentists agree that dentine hardness is the criterion used in caries removal [20]. Research using dentin hardness as a parameter is expected to convince clinicians that the left behind soft dentine will increase in hardness after restoration. In this literature review, only one study evaluated the micro-hardness of dentine after selective caries excavation and restoration [12]. This study compared the micro-hardness of dentin under restoration between three distinct groups: selective excavation to soft dentin, firm dentin, and hard dentin. The mean micro-hardness value of dentin under restoration for the three groups was 16-23 Knoop hardness (KHN), while healthy dentin in the same sample had a micro-hardness value of 20-27 KHN. Analysis of the micro-hardness values in this study showed no differences between the selective to soft dentin, firm dentin, and hard dentine groups after a follow-up period of 3 to 6 months. Measuring the baseline micro-hardness value was a limitation in the design of this study, because the micro-hardness of dentine at different depths in different teeth and individuals would also be different [21].

Therefore, researchers measured the micro-hardness of healthy dentine at the same depth and the same tooth as a control. In this study, the micro-hardness of dentin increased post-restoration with GIC, but the increase did not reach the micro-hardness of healthy dentine. This may be due to re-mineralization to the level of micro-hardness of healthy dentin, which requires a longer time. The same outcomes were found in the selective and non-selective groups [12].

The results of this study indicate that the process of repair and re-mineralization in dentin continues, regardless of how much carious tissue is left behind. The micro-hardness of dentin is a histological evidence that indirectly indicates mineral content of hard tooth tissue and describes physical properties of dentin. Another study showed that after selective excavation and restoration, dentin showed good clinical and histological changes as seen from dentin inter-tubular thickening, compaction of collagen tissue, and decreased bacterial counts. These changes were also radiographically confirmed by the appearance of tertiary dentine formation.

OTHER FACTORS AFFECTING CARIES MANAGEMENT SUCCESS

It is important to consider that failure in restoration or pulpal response is not caused by caries excavation alone. Several other factors that can increase the risk of restoration failure include patient age, caries activity, socio-economic status, number of tooth surfaces that experience caries, and individual dental and oral hygiene maintenance aspects. Factors, such as visual plaque index (VPI) are closely related to the durability of restoration. Patients with a higher percentage of plaque were found to have more restoration failures [9]. Gingival bleeding is another feature contributing to restoration failure, which is a clinical sign of gingivitis caused by poor mechanical control of the biofilm. The presence of biofilm around the restoration has a potential to cause secondary caries that can eventually damage the restoration [8].

The use of a liner in a cavity prior to restoration is recommended because it protects the pulp, has a re-mineralizing and anti-bacterial effect, especially after selective excavation [22]. RMGIC and calcium hydroxide can stimulate odontoblasts to produce reparative dentin and re-mineralize the remaining dentin [23]. Materials that can be used as liners are bonding agents, RMGIC, calcium hydroxide, or MTA, and according to a meta-analysis, no liner material has been proven to be superior to other materials [24]. The use of pulp protectors was also concluded not to affect the quality of selective post-excavation restoration [9]. Clinically, the excavation of carious tissue and quality of the restoration are believed to be more critical to the success of caries management than the use of any material to protect the pulp.

Intervention in the caries process must be performed not only at the lesion level through non-restorative and restorative treatments, but also at the patient level to modify behavior, which consists of dietary counseling and strengthening maintenance of dental and oral hygiene at home. The combination of these two approaches will avoid the start of "restoration cycle", where restorations tend to be repaired and replaced every 5-10 years, which causes the cavity to expand and the tooth structure becomes weaker. Subsequently, the tooth needs a crown restoration and when the crown fails, the tooth is eventually planned for extraction [2]. Both of these approaches suggest treating caries not just as a "lesion", but also as a "disease", which would be more effective in halting the cariogenic process and restoring mineralization balance.

CONCLUSIONS

The review of the four parameters of treatment success indicated that selective caries removal is a minimally-invasive procedure with relatively similar clinical and histological success, compared with non-selective removal. Selective removal was shown to reduce the risk of pulp exposure, thereby avoiding discomfort and anxiety of pediatric patients. One of the disadvantages of selective excavation is the reduced adhesion capacity of the dentine to the restorative material, but the literature shows that the success rate of restorations is good as long as there is optimal support of peripheral walls. Finally, apart from excavation and restoration factors, the success of caries management is also largely determined by patient condition history and individual biofilm control at home. Education regarding the maintenance of oral hygiene should be strengthened as part of caries management at the patient level to complement restorative treatment as caries management at the lesion level.

CONFLICT OF INTEREST

The authors declare no potential conflicts of interest concerning the research, authorship, and/or publication of this article.

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