The Incidence of Pulp Exposure in Primary Molars with Extensive Active Proximal Caries and Marginal Ridge Breakdown

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Abstract

This study sought to evaluate the incidence of pulp exposure in primary molars with extensive active proximal caries and marginal ridge breakdown. Children with a mean age of 6 years presenting with extensive active proximal caries and marginal ridge breakdown were included. The percentage loss of interproximal distance (IPD) in the ratio between the extent of the carious lesion in buccolingual/palatal distance and the IPD was measured. The samples were divided into two groups (≤ 50% and > 50% marginal ridge breakdown). The caries were removed and judged by two calibrated examiners (Cohen's Kappa = 0.8). The data was analyzed by Fisher's exact test.

The incidence of pulp exposure after receiving caries removal was 44.2%. In the group of ≤ 50%,, marginal ridge breakdown had pulp exposure at 37.1% and no pulp exposure at 62.9%. While, in the group of > 50% marginal ridge breakdown found pulp exposure 48.3%, and no pulp exposure 51.7%. There was no statistically significant difference between the two groups *(p=0.392)*. The quality of demineralized dentin reported pulp exposure between soft and leathery to firm dentin in 77.1% and 10.6%, respectively. There was a statistically significant difference between the two groups (p=0.000). Interestingly, the second primary molars with proximal caries at the mesial surface had a high incidence of pulp exposure. Consequently, there were several factors affecting pulp exposure, including the extent of marginal ridge breakdown and the quality of demineralized dentin.

***Keywords*:** *Primary molar, Marginal ridge breakdown, Proximal caries, Pulp exposure*

1. Introduction

Children aged 4-9 years were found to have the most proximal caries lesions in posterior teeth. At these ages, the study reported that the number of proximal caries lesions from clinical findings was 62.7% in males and 58.9% in females. If radiographic examination was included, the number of proximal caries increased in males and females by 80.6% and 72.9%, respectively (Dhar et al., 2018). Primary teeth occur more proximal caries than permanent teeth due to the anatomy of primary teeth; the contact area between molars, which have a border and flatter contact area, leads to a reduction of the self-cleansing area, providing greater plaque accumulation and limited salivary access (Kirthiga et al., 2018).

According to a 4-year prospective study of the progression of proximal caries in the mixed dentition, the progression of the outer half of enamel in the first permanent molar was a slow process for the first 3 years and became faster afterwards. On the other hand, the proximal caries progression in primary teeth is more rapid in any stage of progression as long as the tooth is exposed to cariogenic factors. The progression of proximal caries in primary teeth differs from permanent teeth, because the primary molar has thinner enamel, which leads to less calcification and easier for cavitation. Thus, when caries progress from enamel into dentin, the progression of proximal caries will be faster. Moreover, less dentin thickness leads to more permeability, and the large pulp chamber causes rapid progression to broken marginal ridge with pulp involvement (Mortimer et al., 1970).

In primary teeth, very few studies investigated the correlation between the extent of proximal caries and the degree of pulpal inflammation. A literature review of the current development in pulp therapy for primary teeth has stated that primary teeth with carious marginal ridge breakdown may be indicators of pulp

involvement (Fuks et al., 2010). Presently, only two studies have studied the relationship between marginal ridge breakdown and pulpal involvement in primary molars with extensive active proximal caries.

Duggal and colleagues have studied the relationship between the extent of proximal caries in relation to the buccolingual intercuspal distance (ICD) of the primary molar and the histological status of the pulp. The results revealed that most primary molars had evidence of pulp inflammation, with the pulp horn being involved in most teeth with < 1/2 or > 1/2 ICD involved in the caries process of proximal caries. Moreover, the authors suggested and concluded that inflammation of the pulp in primary molars may occur at an early stage of proximal caries attack, and once proximal caries involvement presents clinically with marginal ridge breakdown, pulp inflammation is usually extensive (Duggal et al., 2002).

A study conducted by Kassa et al. (2009) compared the histological pulpal inflammation in extracted primary molars according to the site (occlusal versus proximal caries) and the depth of the dentin carious lesion. The researchers concluded that primary teeth with proximal carious lesions extending more than 50% through the dentin thickness appear to have more extensive inflammatory pulpal changes than teeth with occlusal caries of a similar depth. Moreover, the authors explained that the overall dentin thickness of the proximal surface is less over the pulp horn region than on the occlusal surface, as primary teeth have prominent pulp horns. Therefore, for a proximal caries lesion, potential irritants are closer to the pulp tissue than for an occlusal caries lesion. (Kassa et al., 2009).

Nowadays, there is limited evidence in clinical research that studies the correlation between the extent of extensive active proximal caries presenting with marginal ridge breakdown and the incidence of pulp exposure. Accordingly, the previously mentioned literature review has recommended that the operative diagnosis with direct evaluation of pulp tissue (direct pulp inspection) can be the final diagnosis of pulp involvement and the decision about treatment (Fuks et al., 2010). Therefore, the remaining dentin thickness or the incidence of pulp exposure in our study was investigated by the operative diagnosis of the routine clinical practice.

Our research was a prospective clinic study. To investigate the incidence of pulp exposure after caries removal in primary molars with extensive active proximal caries and marginal ridge breakdown between less than or equal fifty percent marginal ridge breakdown and more than fifty percent marginal ridge breakdown.

2. Objectives

1) To evaluate the incidence of pulp exposure in primary molar with extensive active proximal caries and marginal ridge breakdown.
2) To investigate the pulp exposure after caries removal in primary molar with extensive active proximal caries with marginal ridge break down between less than or equal fifty percent marginal ridge breakdown and more than fifty percent marginal ridge breakdown.

3. Materials and Methods

The study protocol was approved by the Research Ethics Committee, Research Institute of Rangsit University, Thailand (RSU-ERB20242015.2501).

The parents of all the participants in this study have explained the objectives of the study and any possible treatment outcomes, and they signed a written informed consent form.

Sample Selection

The study included healthy children aged 4 to 9 years who received comprehensive treatment at pediatric dental clinics. The subjects met the following inclusion and exclusion criteria. A total number of 95 sample teeth were recruited from 73 children consisting of 32 boys and 41 girls. The mean age of participants was 6 years old.

Inclusion criteria

1) Teeth will be recruited from healthy children with no sign of any medical systemic condition.

2) The primary molars had only one extensive active proximal caries and marginal ridge breakdown that was restorable.
3) The radiographic revealed the progression of caries extending from the middle ⅓ to the inner ⅓ of dentin or superimposed pulp involvement.

Exclusion criteria

1) The children present with lacking cooperative behavior according to Gerald Wright's behavior classification for dental treatment.
2) The children present with relevant medical conditions that can affect pulp inflammation, such as immunocompromised diseases or complex congenital heart diseases.
3) The primary molars with dental anomalies such as amelogenesis imperfecta, dentin dysplasia, dentinogenesis imperfecta, taurodontism or hypomineralized teeth.

Pre-operative Procedure

The study began by selecting healthy children aged 4 to 9 years who presented with primary molars exhibiting extensive active proximal caries and marginal ridge breakdown on either the occlusomesial surface (OM) or occlusodistal surface (OD) where the samples were 95 teeth from 73 children. A flow chart of the study design is shown in Figure 1.

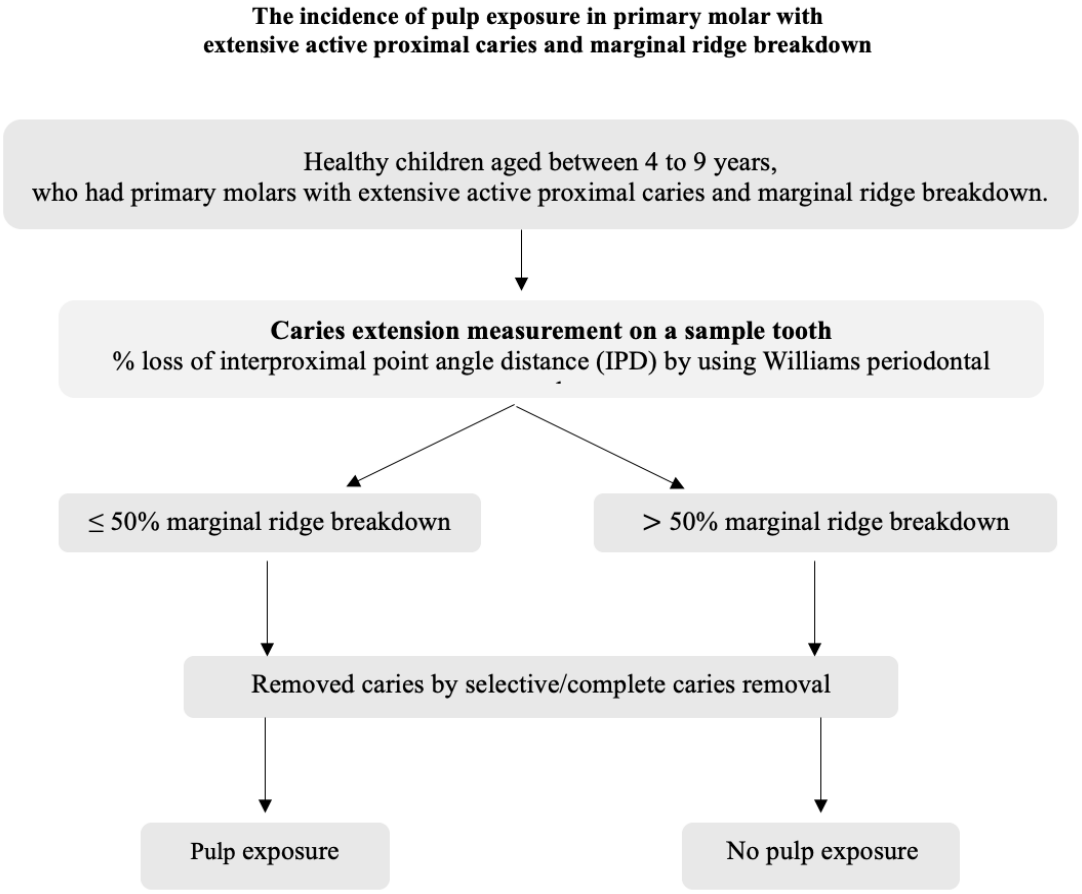

Figure 1 The study designed flowchart

Caries Extension Measurement

The interproximal point angle distance (IPD) of different primary molars was measured anatomically, as shown in Figure 2. The IPD for each primary molar and surface was measured from the mesiobuccal point angle to the mesiolingual/palatal point angle on the mesial surface. The distal surface was measured from the distobuccal point angle to the distolingual/palatal point angle.

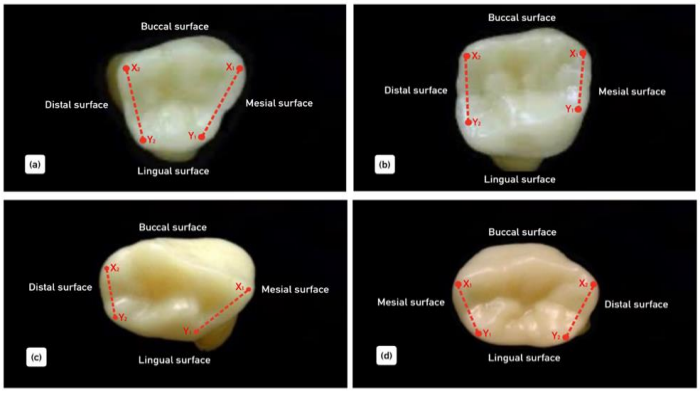

Figure 2 Measurement of buccolingual/palatal interproximal point angle distance in different primary molars and surfaces.

X_1: Mesiobuccal point angle
Y_1: Mesiolingual/palatal point angle
X_2: Distobuccal point angle
Y_2: Distolingual/palatal point angle

a: primary maxillary first molar
b: primary maxillary second molar
c: primary mandibular first molar
d: primary mandibular second molar

$$\% \text{ loss of interproximal distance} = \frac{\text{The extent of carious lesion in bucco-lingual/palatal distance}}{\text{Bucco-lingual/ palatal IPD}} \text{ X } 100$$

The extension of the caries was measured on the occlusal surface of the primary molar with proximal caries and marginal breakdown, using a Williams periodontal probe; the extent of the caries was calculated as the percentage loss of interproximal point angle distance. This was measured from the largest extent of the carious lesion in the buccolingual/palatal dimension. The largest distance of the carious lesion was then divided by the buccolingual/palatal IPD of the respective tooth to obtain a ratio, as described in Figure 4. Two independent evaluators measured the clinical evaluations. Inter-reliability and intra-reliability were assessed with Cohen's kappa = 0.8.

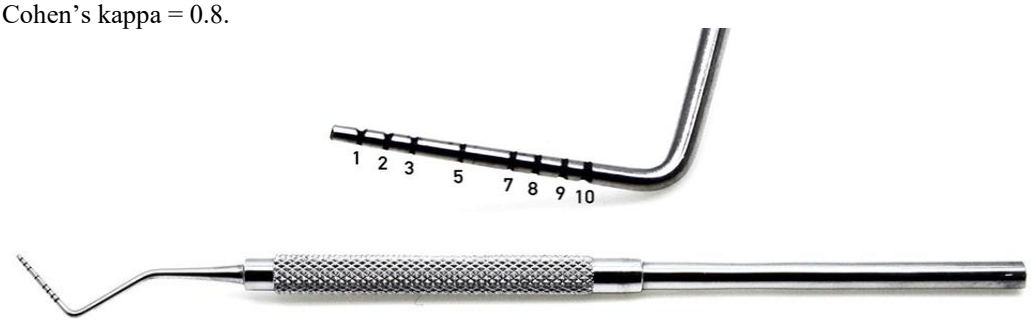

Figure 3 Williams periodontal probe

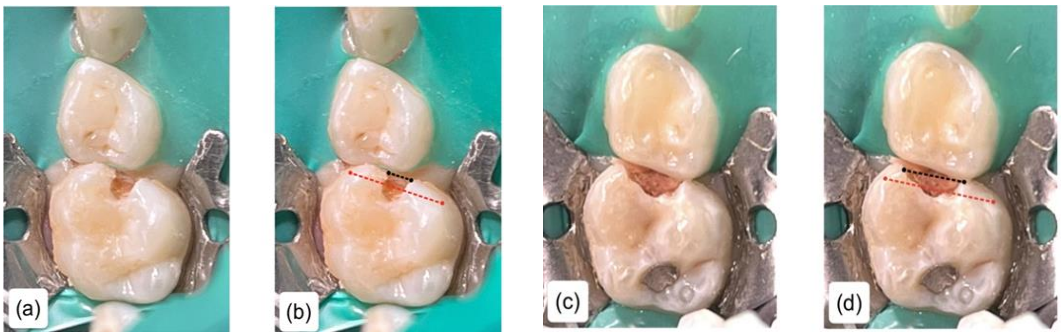

Figure 4 Comparison of sample teeth exhibiting ≤ 50% and > 50% marginal ridge breakdown, as assessed using a Williams periodontal probe. (a: Sample tooth with ≤ 50% marginal ridge breakdown, b: Measurement comparison between the IPD (red dashed line) and caries extension (black dashed line) in a tooth with ≤ 50% marginal ridge breakdown, c: Sample tooth with > 50% marginal ridge breakdown, d: Measurement comparison between the IPD (red dashed line) and caries extension (black dashed line) in a tooth with > 50% marginal ridge breakdown)

After measuring caries as mentioned above, the sample teeth were categorized into two groups based on the percentage loss of buccolingual/palatal IPD. Teeth with ≤ 50% loss of IPD were classified as having ≤ 50% marginal ridge breakdown. On the other hand, teeth with > 50% loss of IPD were classified as having > 50% marginal ridge breakdown.

The Operative Procedure

All caries removal procedures were performed by dental students under the supervision of two calibrated instructors (Kappa = 0.8) from the Department of Pediatric Dentistry, College of Dental Medicine, Rangsit University. The local anesthesia was injected, and a rubber dam was applied to the sample tooth. Before caries removal, the quality of the carious dentin was evaluated and classified as soft (easily excavated with hand and rotary instrumentation), leathery (does not deform upon pressure from an instrument but can be excavated with hand instrument without much pressure), or firm (resistant to hand excavation and can only be removed by exerting pressure), as shown in Figure 5.

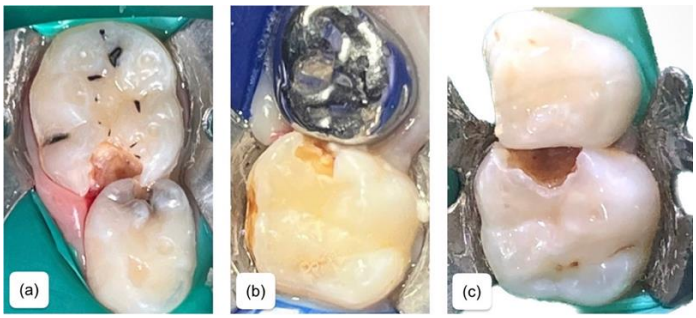

Figure 5 The sample tooth with soft carious dentin on the 85 OM surface (a), leathery carious dentin on the 55 OM surface (b) and firm carious dentin on the 55 OM surface (c)

Selective caries removal was performed for teeth with normal pulp tissue or reversible pulpitis. The procedure began by removing carious dentin from the superficial and peripheral walls using a spoon excavator and a low-speed round steel bur until sound dentin was reached. The carious dentin closer to the pulp was then selectively removed with a spoon excavator, stopping when firm, leathery, or soft carious dentin was encountered. For teeth diagnosed with irreversible pulpitis or pulp necrosis, complete caries removal was performed. The carious dentin was entirely removed until sound dentin was reached, prior to any pulpal exposure.

Figure 6, the sample tooth 55 (example 1) has active extensive caries with marginal breakdown and is preoperatively diagnosed as deep caries with normal pulp and classified in the group of > 50% marginal ridge breakdown. The operative treatment with selective caries removal is performed until firm dentin is reached. Also, the remaining dentin thickness was detected, and there was no pulp exposure. The operative diagnosis for this sample is judged as normal pulp status.

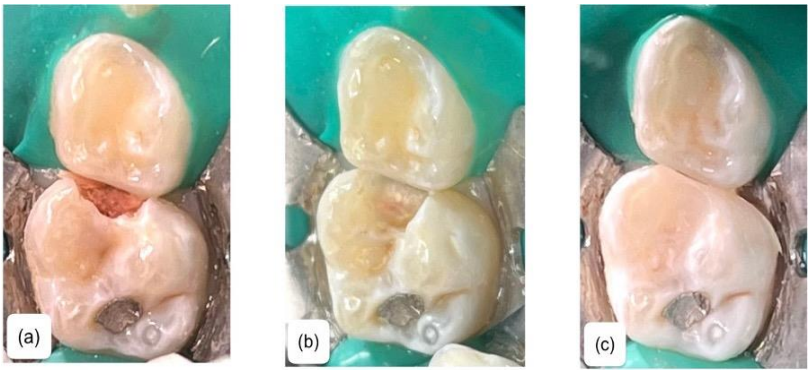

Figure 6 Preoperative clinical finding (a), Clinical finding after receiving a selective caries removal procedure (b), After receiving restoration (c)

Figure 7, the sample tooth 55 (example 2) has active extensive caries with marginal breakdown and is preoperatively diagnosed as deep caries with normal pulp and classified in the group of > 50% marginal ridge breakdown. The operative treatment with selective caries removal is performed. Pin-point pulp exposure is detected with easily stopped bleeding. The operative diagnosis for this sample is judged as reversible pulpitis.

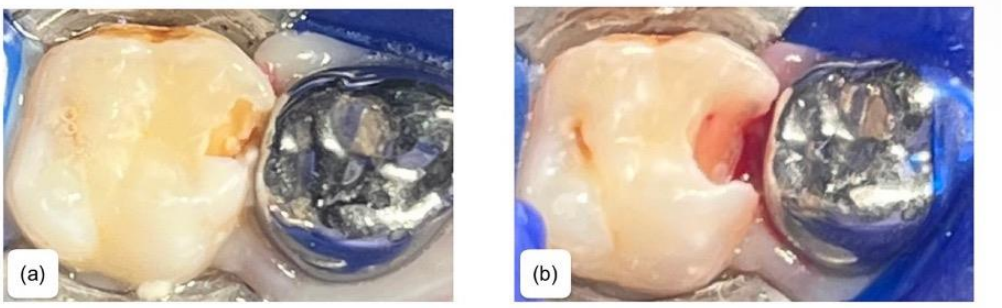

Figure 7 Preoperative clinical finding (a), After receiving a selective caries removal procedure (b)

Figure 8, the sample tooth 55 (example 3) has active extensive caries with marginal breakdown and is preoperative diagnosed as irreversible pulpitis and classified in the group of > 50% marginal ridge breakdown. The operative treatment with complete caries removal is performed. Caries exposure is detected with excessive bleeding. The operative diagnosis for this sample is judged as irreversible pulpitis.

Figure 9, the sample tooth 5 (example 4) was diagnosed as pulp necrosis and classified in the group of ≤ 50 % marginal ridge breakdown. The operative treatment with complete caries removal is performed. Caries exposure with no bleeding is detected. The operative diagnosis for this sample is judged as pulp necrosis.

Figure 8 Complete caries removal

Figure 9 Caries exposure with no bleeding

4. Results and Discussion

4.1 Results

Among the 95 sample teeth with extensive active proximal caries and marginal ridge breakdown found, 47 were first primary molars, there were 46 teeth (97.87%) affected at the distal surface, and only one tooth (2.13%) affected at the mesial surface. While the second primary molars found 48 teeth affecting the mesial surface in 46 teeth (95.83%) and the distal surface in 2 teeth (4.17%).

The total number of proximal carious teeth was categorized by the extent of marginal ridge breakdown that, revealed 35 primary molars showing extensive active proximal caries with ≤ 50% marginal ridge breakdown, while 60 primary molars showed extensive active proximal caries with > 50% marginal ridge breakdown. The extent of the broken marginal ridge and clinical evaluations were measured by two independent evaluators. Inter-reliability and intra-reliability were assessed with Cohen's kappa = 0.8.

The incidence of pulp exposure after receiving caries removal was 44.2% in 42 out of 95 sample teeth. Moreover, in the group of primary molars with extensive active proximal caries with ≤ 50% marginal ridge breakdown and > 50% marginal ridge breakdown,37.1% (13 out of 35) and 48.3% (29 out of 60), respectively, as shown in Figure 10. There was no significant difference between the two groups (P=0.392)

In addition, the incidence of pulp exposure was compared by the evaluation of the quality of demineralized dentin between soft and leathery to firm demineralized dentin showed that 37 out of 48 teeth (77.1%) of soft demineralized dentin were pulp exposed, while leathery to firm demineralized dentin had pulp exposure 10.6% (5 out of 47 teeth), as shown in Figure 11. There was a significant difference between soft and leathery to firm demineralized dentin in the incidence of pulp exposure (P=0.000).

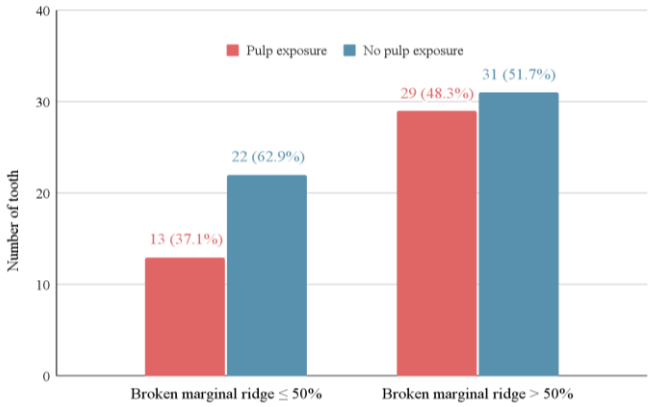

Figure 10 The incidence of pulp exposure in the primary molars with extensive active proximal caries according to the extent of marginal ridge breakdown

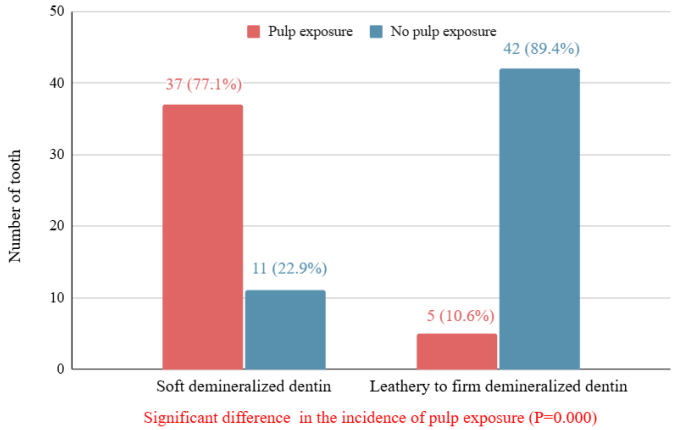

Figure 11 The incidence of pulp exposure of primary molars with extensive active proximal caries according to the quality of demineralized dentin

Table 1 The distribution of tooth samples and the incidence of pulp exposure according to the extent of marginal ridge breakdown and the quality of demineralized dentin.

Percentage loss of IPD	**Soft demineralized dentin**		**Leather to firm demineralized dentin**	
	Pulp exposure	No pulp exposure	Pulp exposure	No pulp exposure
≤ 50 %	13 (65.0%)^{aA}	7	0 (0%)^{bB}	15
> 50 %	24 (85.7%)^{aA}	4	5 (15.6%)^{bB}	27
N = 95	37	11	5	42

IPD = Interproximal distance

a, b the same small superscript letters present within the column are not statistically significant differences between percentage loss of IPD groups at $p > 0.05$ with Fisher's exact test.

A, B the different capital superscript letters present within the rows are statistically significant differences between soft and leathery to firm demineralized dentin at $p \leq 0.05$ with Fisher's exact test.

Furthermore, the comparison in the incidence of pulp exposure between extensive active proximal caries with ≤ 50% marginal ridge breakdown and those with > 50% marginal ridge breakdown, characterized by the quality of demineralized dentin (soft vs leathery to firm demineralized dentin), revealed that the number of pulp exposure in tooth samples with soft demineralized dentin and ≤ 50% marginal ridge breakdown was 13 out of 20 (65.0%). While the pulp exposure in the sample teeth of > 50% marginal ridge breakdown with soft demineralized dentin was 24 out of 28 (85.70%). Regarding leathery to firm demineralized dentin, there was no pulp exposure in sample teeth with extensive active proximal caries with ≤ 50% marginal ridge breakdown, while pulp exposure was found in 5 out of 32 (15.60%) sample teeth with > 50% marginal ridge breakdown. (As shown in table 1) Therefore, the incidences of pulp exposure were high in soft demineralized dentin and had statistical differences in both groups (P=0.000)^{AB}

Interestingly, the incidence of proximal caries in second primary molars most frequently occurred at the mesial surface, as mentioned above. This study revealed that the chance of pulp exposure in extensive active proximal caries with a broken marginal ridge of the mesial surface was 28 out of 46 sample teeth (60.87%). While the distal surface of the first molar was most likely to occur proximal caries with a chance of pulp exposure in 13 out of 46 sample teeth (28.26%).

Moreover, the history of pain was divided into two categories, one for each subject being compared with active extensive proximal caries. There were 14 out of 95 sample teeth with spontaneous pain and 81 cases with non-spontaneous pain. In addition to non-spontaneous pain, 9 cases were reported as experiencing provoked pain, with 4 of them being exposed (44.44%). On top of that, 11 out of 14 sample teeth with

spontaneous pain had marginal ridge breakdown > 50%, and 3 sample teeth had marginal ridge breakdown ≤ 50%. Incidence of pulp exposure was found in all 14 sample teeth with spontaneous pain. From 81 out of 95 sample teeth that had no reporting spontaneous pain, 28 sample teeth had pulp exposure while receiving caries removal (34.57%), and 53 sample teeth had no pulp exposure (65.43%).

4.2 Discussion

This research was the first prospective clinical study and investigated the incidence of pulp exposure in primary molar with extensive active proximal caries and marginal ridge breakdown. The result of our study showed that the incidence of pulp exposure was 44.2%, which was lower than that of a few previous studies. A previous study has studied the histological pulpal inflammation in primary molars with proximal caries and marginal ridge breakdown clinically according to the extent of carious lesion in relation to buccolingual intercuspal distance (ICD), categorized as < ½ ICD and > ½ ICD. Findings from this study revealed that 80% of tooth samples manifested histological pulp inflammation, while histological pulp inflammation was found in 63% and 83% of sample teeth with marginal ridge breakdown < ½ ICD and > ½ ICD, respectively.

Moreover, most teeth of both groups showed inflammation extending to the pulp horn (Duggal et al., 2002). Additionally, the latest study has compared the sites of occlusal versus proximal caries and the depth of dentinal carious lesions. The findings indicated that the group of proximal caries had 74.2% histological pulpal inflammation. When comparing between proximal and occlusal caries as in a similar depth extending more than fifty percentages through the dentin thickness, the authors concluded that the proximal caries had more severe inflammatory pulpal changes. The two mentioned studies showed a high incidence of pulpal involvement in the primary molar with extensive proximal caries and marginal ridge breakdown because these studies investigate the histological status of the pulp (Kassa et al., 2009). In general, it is well acknowledged that inflammation of pulp in the histology aspect manifests well before the pulp is found to be clinically exposed (Raoof et al., 2022).

The result of our study revealed that primary molars with proximal caries and marginal ridge breakdown extending more than 50% resulted in clinical pulp exposure in 48.3%, while 37.1% in the group of marginal ridge breakdown extended less than 50%. There was no statistically significant difference, regardless of the proximal carious extension in bucco-lingual width. Thus, the extent of marginal ridge breakdown alone did not fully explain the likelihood of pulp exposure, cleanability of the cavitated carious lesions and the quality of demineralized dentin might be a related factor. This finding may be attributed to the fact that wider carious lesions allow for easier access during the cleansing process. The exposed cavity may promote self-cleansing (Innes et al., 2016). Regular removal and redistribution of biofilm can slow the carious process and contribute to the transition of dentin quality to an inactive state (Van Strijp, & van Loveren, 2018). These explanations might be the reason for the lack of significant differences in the incidences of clinical pulp exposure according to the extent of marginal ridge breakdown. Therefore, cavitated carious lesions in the group of marginal ridge breakdown extending more than 50% can be self-cleaned more than the group of marginal ridge breakdown extending less than 50%.

The quality of demineralized dentin in our study that were classified into three categories of soft, leathery and firm demineralized dentin. The incidence of pulp exposure was high in soft demineralized dentin compared with leathery to firm demineralized dentin, which occurs in both groups of marginal ridge breakdown ≤ 50% and > 50%. Because soft dentin was referred to as infected dentin, characterized by the presence of bacteria, low mineral content and irreversibly that the caries process can be stilled (Warreth et al., 2023). Therefore, the carious lesion with soft demineralized dentin and extensive active caries probably had a chance of pulp exposure, whereas leathery to firm demineralized dentin occurred less.

Moreover, our study found that 44.2% of teeth had pulp exposure after caries removal. The highest predictor of pulp exposure was soft demineralized dentin (77.1%) rather than just the amount of marginal ridge breakdown. This is important for a more careful approach to caries removal, where only the most infected dentin is taken out, while the deeper layers are left to protect the pulp and keep the tooth healthy. Along with the advancements in caries management, the approach has shifted from completely removing caries to partially removing them. In the past, fully removing carious dentin often led to a higher risk of pulp

exposure. Now, partial caries removal helps preserve more dentin, lowering the chance of pulp damage while still stopping caries from progressing. This new method has important clinical benefits and offers a more conservative approach to dentistry.

Based on our study, it could be observed that the most affected areas of proximal caries were at the distal surface of the first primary molar (95.83%) and the mesial surface of the second primary molar (97.87%). Moreover, the result revealed that the extensive active proximal caries with marginal ridge breakdown at mesial surfaces of the second primary molars tend to be more related to the incidence of pulp exposure compared to the proximal caries at distal surfaces of the first primary molars. It is well acknowledged that the anatomical pulpal horns of primary molars are positioned relatively high, especially at the mesiobuccal pulp horn of the second primary molar, making it more susceptible to pulp exposure (Puddhikarant, 1983).

Furthermore, all the primary molars with extensive active proximal caries and marginal ridge breakdown that reported a history of spontaneous pain had pulp exposure. This may be related to the dentin-pulp complex, when pathological processes such as caries occur in dentin, it affects pulp nociceptors to undergo a process of sensitization and pulp inflammation (Yu, & Abbott, 2018). The history of having spontaneous pain implies irreversible pulpitis and/or pulp necrosis; the pulp is already injured and must be treated with non-vital pulp therapy (IAPD Foundational Articles and Consensus Recommendations, 2021). Thus, this supported the reason for the high incidence of pulp exposure in spontaneous pain teeth.

On the other hand, less than 50% of the non-spontaneous pain cases had pulp exposure, which depended on the quality of demineralized dentin, especially in soft demineralized dentin. In addition, 44.44% of the provoked pain cases found pulp exposure. It can be concluded that not only the quality of demineralized dentin but also the history of pain was related to the chance of pulp exposure.

This study has significant implications for dental public health and health systems, particularly in the prevention and management of primary molars with extensive active proximal caries and marginal ridge breakdown. The study highlights that soft demineralized dentin is more likely to result in pulp exposure compared to leathery or firm demineralized dentin, which is crucial information for refining preventive and treatment strategies for dental caries in children. Encouraging dentists to adopt selective caries removal could help minimize the risk of pulp exposure while preserving as much tooth structure as possible. When compared with previous international research. This study was different due to variations in assessment methods, as earlier studies focused on histological analysis while this study is a clinical investigation. However, the findings show a similar trend, indicating that pulp involvement is strongly associated with the extent of caries and dentin quality.

5. Conclusion

The primary molars with extensive active proximal caries and marginal ridge breakdown showed clinical pulp exposure in almost half of all tooth samples after receiving caries removal. However, the extent of marginal ridge breakdown might not be the only determining factor for pulp exposure. The cleanability of the cavitated carious lesions and the quality of demineralized dentin during the operative procedure must be considered. The uncleanable cavitated carious lesion with soft demineralized dentin resulted in more chance of pulp exposure, especially extensive active proximal caries with marginal ridge breakdown at mesial surfaces of the second primary molars.

Even though there was no difference in the incidence of pulp exposure according to the extent of marginal ridge breakdown. However, it still can be used as a potential diagnostic tool for predicting proper treatment by concerning the quality of demineralized dentin, anatomy of primary molars, and pain history.

Further study should exclude the extensive active proximal caries with marginal ridge breakdown that was diagnosed as irreversible or pulp necrosis and the sample sizes should increase for more reliability of evidence.

6. Acknowledgements

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