RESEARCH ARTICLE

Comparative Evaluation of the Efficacy of Stepwise Caries Excavation vs Indirect Pulp Capping in Preserving the Vitality of Deep Carious Lesions in Permanent Teeth of Pediatric Patients: An *In Vivo* Study

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Abstract

Aims and objectives: To comparatively evaluate the clinical efficacy of stepwise caries excavation with indirect pulp capping (IPC) in managing the young permanent teeth in pediatric patients who have deep carious lesions.

Materials and methods: Eighty-eight teeth (first/second permanent molars) were included and randomly divided into two groups: group I (stepwise caries excavation) and group II (IPC). For group I, i.e., stepwise caries excavation, in the initial visit, bulk caries removal was done from walls of the cavity, however, soft and infected dentin was left untouched on the pulpal floor. The final excavation was performed after 2 months. The dentin parameters like the color, the consistency, and the humidity of dentin were noted at the first and second visits. A final follow-up to assess the primary outcome, i.e., sustained pulp vitality, was done after 1 year.

Results: When both the groups were compared with each other using the Chi-squared test, a highly significant difference was found ($p < 0.05$) between them. The success rate of stepwise caries excavation (97.3%) was found to be significantly greater than IPC (82.4%). After doing statistical analysis, a significant difference between stepwise excavation at baseline and at re-entry for parameters like the color, the consistency, and the humidity ($p < 0.05$), where dentin was observed to be darker in color, harder in consistency, and drier to touch at re-entry was found.

Conclusion: Stepwise caries excavation was considered a safer technique than IPC for preserving the vitality of young permanent teeth. Also, the clinical changes recorded during the re-entry in the case of stepwise caries excavation technique indicated the arrest of the carious process.

Clinical significance: Pulp preservation is of utmost importance especially in the case of young permanent teeth which have open apex to aid in apexogenesis. Failure to do so in maintaining the vitality of pulp before root completion may lead to the unfavorable crown to root ratio resulting in thin dentinal walls which are prone to fracture.

Keywords: Deep caries, Indirect pulp capping, Pulp conservation, Stepwise excavation.

International Journal of Clinical Pediatric Dentistry (2020): 10.5005/jp-journals-10005-1874

Introduction

The preservation of a tooth in a healthy functional state in the arch becomes an inevitable backbone for the longevity of the tooth and optimum health of the dynamic oral cavity. The agonizing fact is that once the vitality of the tooth is compromised, it leads us to a complicated treatment that is not so pocket-friendly. The definition of deep caries needs a special mention here as it points toward the potential exposure of the pulp.[1] The treatment of such lesions poses a significant challenge to the practitioner in terms of decision-making which is an interesting as well as debatable concept. The classic dental practitioner's approach aims at complete caries removal even if the procedure involves an associated risk of pulp exposure. However, the cariologist's opinion is focused more on the disease and remineralization therapy of carious dentin.[2]

The situation is further intensified while managing a deep carious lesion in a young permanent tooth with open apices. It is encouraging to understand that from a pediatric dentist's point of view the maintenance of pulp vitality is integral to aid in apexogenesis.[3] Hence, it is indeed true to say that it is extremely important to aim for the preservation of pulp as the primary goal while managing the young permanent dentition as endodontic management of such teeth arrests root development and the thin dentinal walls in the root canal are at an increased risk of root fracture.[4]

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How to cite this article: Manhas S, Pandit IK, Gugnani N, *et al.* Comparative Evaluation of the Efficacy of Stepwise Caries Excavation vs Indirect Pulp Capping in Preserving the Vitality of Deep Carious Lesions in Permanent Teeth of Pediatric Patients: An *In Vivo* Study. Int J Clin Pediatr Dent 2020;13(S-1):S92–S97.

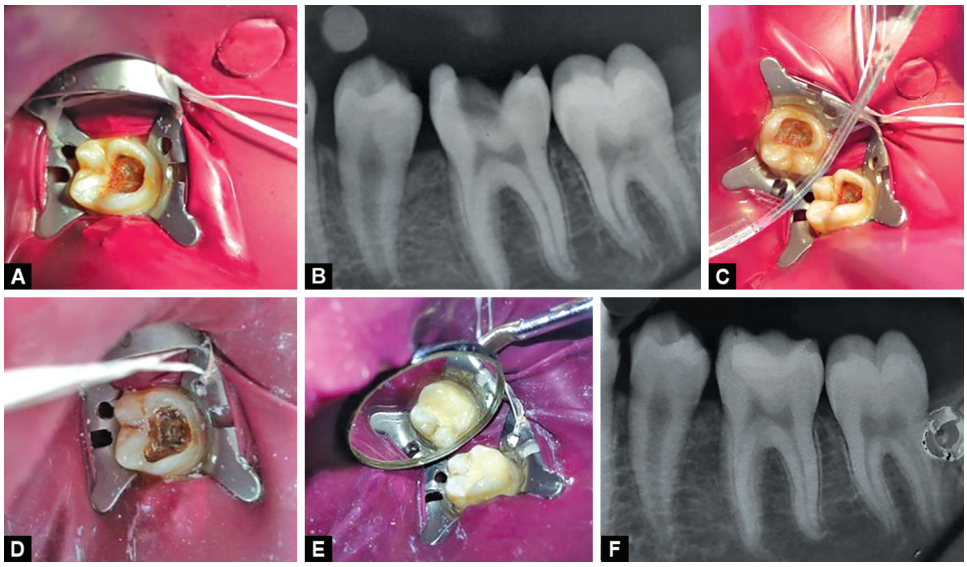
Source of support: Nil

Conflict of interest: None

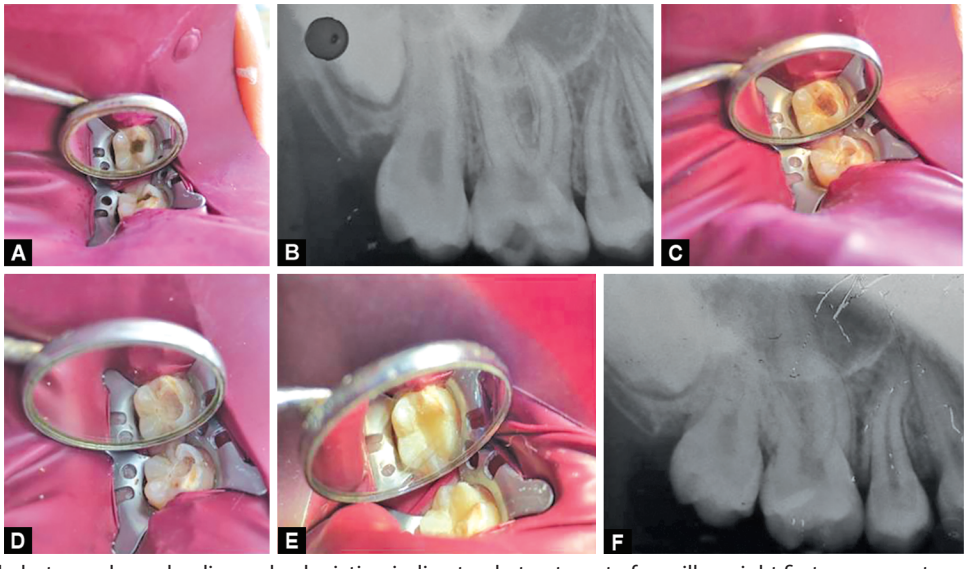
Not so very recently, but a paradigm shift towards the medical model of dental caries has begun the revolution in lesion management. Dental caries is defined as a dynamic disease process that takes place in dental plaque, and the microbial deposit (biofilm) on the surface of the tooth, which causes the formation of an equilibrium between the tooth structure and biofilm. With

a shift in the ecology of the dental plaque, the equilibrium gets disturbed, further disturbing caries balance, causing resultant demineralization. Such a simplified explanation of this complex dental caries process indicates that it is the metabolic activity taking place in the biofilm which is driving the caries process.[5] However, if such is the case, then the amount of caries removed becomes irrelevant, and the search behind the rationale of this very concept forms the basis of our study (Figs 1 and 2).

As we realize the need to change yesteryears' concepts and abreast with the newer perspectives, we head towards minimal sacrifice and maximum preservation of the natural tooth structure and pulp vitality. An established pulp capping procedure, "indirect pulp capping" has been time and again described for over 200 years, which involves almost complete removal of infected as well as affected dentin leaving behind only a thin layer of demineralized tissue.[6] However, this can be considered a rather radical approach, as it involves an inherent risk of pulp exposure, necessitating the need for endodontic treatment at times.[7] Therefore, another technique described by Magnusson and Sundell[8] and recently modified by Bjørndal et al.[9] "Stepwise excavation" seems more conservative wherein the first excavation includes removal of only the superficial necrotic part of the dentin that is already demineralized, not touching the floor of the lesion, leaving the infected, soft, discolored, and wet dentin centrally on the pulpal



Figs 1A to F: Clinical photographs and radiographs depicting stepwise caries excavation of mandibular right first permanent molar: (A) Pretreatment view of the tooth with a deep carious lesion; (B) The pretreatment radiograph shows no apical pathosis, but a deep carious lesion; (C) Clinical photograph showing the cavity preparation (all soft infected dentin left untouched on the pulpal floor); (D) The cavity re-entered at the end of 2-month interval period; (E) Tooth restored permanently; (F) Radiograph of the tooth at 1 year showing no apical pathosis



Figs 2A to F: Clinical photographs and radiographs depicting indirect pulp treatment of maxillary right first permanent molar: (A) Pretreatment view of the tooth with a deep carious lesion; (B) The pretreatment radiograph shows no apical pathosis, but a deep carious lesion; (C) Clinical photograph showing the cavity preparation (all soft infected dentin removed); (D) The cavity immediately after removal of temporary filling with a layer of dycal left behind, at the end of 2-month interval period; (E) Tooth restored permanently; (F) Radiograph of the tooth at 1 year showing no apical pathosis

floor, followed by a temporary restoration and second excavation, generally after a period of 8–12 weeks (Bjørndal)[10] before the final restoration, giving enough time for the left out bacteria to die down and let the process of reparative dentin formation and/or remineralization of the dentin to take place.[11] Hence, making it easier for the clinicians to re-enter the lesion and perform final excavation with less risk to the pulp so that the cavity can be filled permanently.[12]

Although many studies[9,13] have suggested when deep carious lesions were sealed following the incomplete removal of carious dentin, lesion progression was observed to be arrested. However, the prognosis of the remaining caries is considered to be suspicious by many therefore, it was considered worthwhile to compare the effectiveness of indirect pulp capping (IPC) with stepwise caries excavation in preserving the vitality of permanent teeth having deep caries with a follow-up of 1 year.

Materials and Methods

Eighty-eight teeth (maxillary/mandibular first/second permanent molars) with deep carious lesions were selected in the outpatient Department of Paedodontics and Preventive Dentistry at DAV (C) Dental College, Yamunanagar, Haryana. Ethical clearance was received from the Institutional Ethical Committee of J.N. Kapoor DAV (C) Dental College, Yamunanagar.

The inclusion/exclusion criteria for the study were: (1) Deeply carious tooth with the proximity of lesions to the pulp (caries progression should be 75% or more of the dentin thickness[9]) as confirmed by the IOPA radiograph. (2) A well-defined radio-opacity present between the pulp and the carious lesion. (3) Active caries lesion deep into dentin, characterized by a soft consistency. (4) Positive response to pulp vitality tests (electric pulp tester, thermal testing). (5) The absence of clinical symptoms of irreversible pulpitis such as spontaneous pain or pain persisting after the disappearance of the existing stimulus or sensitivity to pressure. (6) The absence of fistula, swelling in periodontal tissues, and abnormal tooth mobility.

The patients were included only based on signed informed consent provided by the parents/legal guardians for this study. The included teeth were then randomly assigned for the two treatment groups: group (I) stepwise excavation and group (II) IPC (Table 1). For the random selection procedure, a random sequence was generated from the computer software. Permuted block randomization was used to ensure an equal number of samples in both groups throughout the study, while allocation concealment was ensured by using sealed envelopes containing randomization code to allocate the treatment.

Treatment Procedure

After the rubber dam isolation, the tooth was thoroughly washed with saline and was dried using sterile cotton swabs. Clinically the first step in all the included teeth comprised of the opening of the cavity followed by removal of the unsupported enamel using airotor with copious air/water spray and diamond burs. Complete removal of caries from the walls of the cavity and at the dentino-enamel junction (DEJ) was done with the help of spoon excavators.

Table 1: The distribution of samples according to the treatment groups

Treatment groups	*No. of samples*	*Percentage*
Stepwise	44	50
IPC	44	50

The stepwise excavation was done on 44 teeth. The treatment procedure for the stepwise excavation group, i.e., (group I) was as follows: The necrotic dentin from the superficial part of the lesion was removed; however, soft carious dentin was left untouched on the floor of the cavity adjacent to the pulpal floor. Then, the remaining untouched soft carious dentin was covered with calcium hydroxide (Dycal) followed by sealing the cavity with reinforced zinc oxide eugenol cement (IRM), for a period of 2 months. The time period of 2 months was considered adequate for the effect of calcium hydroxide to take place and also for the possibility of tertiary dentin formation as a reactionary response from the pulp.

The same treatment protocols were carried out for the IPC group (group II); however, instead of leaving carious dentin behind, almost all of the infected as well as affected dentin was removed from the lesion leaving just a thin layer of affected dentin on the pulpal floor and restoring the tooth temporarily.

After a period of 2 months, the radiographic and clinical examinations were performed again. For clinical examination procedure, the history of pain, any sensitivity to percussion and palpation, tooth mobility, and any absence or presence of fistula or edema were noted. The pulp testing was done again to evaluate pulp vitality by means of the cold stimulation tester and electric pulp test. After the application of rubber dam, for the stepwise excavation group (group I), the temporary restoration was removed and the cavity was re-entered to check for any soft infected dentin, which if still present was further removed with the help of spoon excavators and then cavity floor was sealed with calcium hydroxide, and finally, the teeth were restored permanently. However, for group II (IPC), while removing temporary restoration, the remaining sealed dentin was neither exposed nor touched and a thin layer of dycal (placed during initial visit) was left back on the cavity floor and permanent restoration was carried out.

Clinical and Radiographic Evaluations

Several clinical parameters like the color, the consistency, and the humidity of dentin were recorded by means of standardized scales by Lars Bjorndal's criteria.[9] These clinical evaluations were done preoperatively, i.e., at baseline for both the groups. But for IPC (group II), the clinical evaluations were also done again after the excavation of caries, during the first visit only. While in the stepwise group (group I) apart from the baseline, clinical evaluation was done again at the re-entry stage before the final excavation was performed.

Reference cards depicting these colors were used to avoid subjective bias in judging the dentin color. Where, light yellow color (active progressing lesion), yellow color (actively progressing lesion), light brown color (slowly progressing lesion), dark brown color (slowly progressing arrested lesion), black color (slowly progressing arrested lesion). The consistency was assessed as: very soft (if the probe can penetrate the dentin followed by easy fragment loss of the demineralized tissue), soft (if the probe can penetrate the dentin without any resistance felt while removing the probe), medium-hard (if a slight amount of resistance felt while removing the probe), or hard (if the touch of the probe is comparable to sound or unaffected dentin). The humidity of the dentin was assessed as: wet (if the tissue oozed moisture on probing) and dry (if the tissue did not ooze moisture on probing).[4]

The radiographs were taken preoperatively before the start of the treatments, after 2 months interval, before performing the final excavation, and at the end of 1 year. Standardized IOPA radiographs

Table 2: Dentin color in the treatment groups

Treatment groups	*Light yellow (%)*	*Yellow (%)*	*Light brown (%)*	*Dark brown (%)*	*Black (%)*
IPC (baseline)	6 (13)	20 (46)	12 (27)	4 (9)	2 (5)
IPC (after excavation: same visit)	0 (0)	15 (38)	20 (52)	4 (10)	0 (0)
Stepwise (baseline)	1 (2.3)	24 (54.55)	11 (25)	5 (11.6)	3 (6.8)
Stepwise (re-entry: next visit)	0 (0)	0 (0)	15 (40.5)	14 (37.8)	8 (21)

Table 3: Dentin consistency in the treatment groups

Treatment groups	*Very soft (%)*	*Soft (%)*	*Medium-hard (%)*	*Hard (%)*
IPC (baseline)	2 (5)	39 (88)	3 (7)	0 (0)
IPC (after excavation: same visit)	0 (0)	0 (0)	0 (0)	39 (100)
Stepwise (baseline)	2 (4.5)	37 (84.09)	5 (11.36)	0 (0)
Stepwise (re-entry: next visit)	0 (0)	0 (0)	16 (43.2)	21 (56.8)

Table 4: Dentin humidity in the treatment groups

Treatment groups	*Wet (%)*	*Dry (%)*
IPC (baseline)	42 (95.5)	2 (4.5)
IPC (after excavation: same visit)	0 (0)	39 (100)
Stepwise (baseline)	38 (86)	6 (14)
Stepwise (re-entry: next visit)	0 (0)	37 (100)

Table 5: Primary outcome: sustained vitality at the end of one year for both the groups

Treatment groups	*Vital (%)*	*Non-vital (%)*
Stepwise	36 (97.3)	1 (2.7)
IPC	28 (82.4)	6 (17.6)

with the paralleling technique were used to diagnose and exclude teeth with apical pathology.

Patients were recalled after a period of 1 year after the completion of the final excavation, and patients were again assessed clinically for signs and symptoms of pulpal involvement and radiographically for any periradicular pathosis or pulpal involvement.

Statistical Methods

All data were processed by SPSS v 21.0, IBM®. The Chi-squared test was used to compare the primary outcome, i.e., sustained vitality at the end of 1 year for both the groups. The Wilcoxon signed-rank test was used to compare the clinical dentin parameters like the color, the consistency, and the humidity for each group at different steps and stages. The results were considered statistically significant if the *p* value was <0.05.

Results

Of the 44 teeth treated with IPC (group II), the most frequent color at baseline was yellow (46%) followed by light brown (27%), whereas after excavation, during the first visit only for the IPC group (group II), the most frequent color was light brown (52%) followed by yellow (38%). In the 44 teeth which were treated with stepwise excavation (group I), the most frequent color recorded at baseline was yellow (54.55%) followed by light brown (25%), whereas the most frequent color at re-entry after 2 months before final excavation was light brown (40.5%) followed by dark brown (37.85%) (Table 2).

The consistency and humidity in the IPC group (group II) were detected mostly as soft and wet at baseline (88%) and (95.5%), respectively. However, following excavation at the first visit, the most frequent consistency and humidity were observed to be hard and dry, both 100%. In the stepwise excavation group, the most frequent consistency and humidity at baseline were soft and wet, (84.09%) and (86%), respectively. But at re-entry, i.e., second visit (after 2 months) and before final excavation, the most observed frequency of the consistency and humidity was hard (56.8%) followed by medium-hard (43.2%) and dry (100%) (Tables 3 and 4).

The statistical analysis suggested a significant difference present among stepwise excavation baseline and re-entry in terms of the clinical parameters like the color, the consistency, and the humidity ($p < 0.05$).

While comparing a number of the teeth that remained vital at the end of 1 year, a statistically significant difference was observed ($p < 0.05$) between the success rate of group I and group II. The success rate of group I was found to be higher than that of group II, suggesting that the stepwise caries excavation technique has a higher success rate than that of IPC (Table 5).

Discussion

The main focus of a clinician, especially a pediatric dentist should be aimed at preserving the vitality of a tooth that has reversible pulpitis, but how much caries should be removed during vital pulp therapy remains unanswered. "Dental caries—When to stop?" has become the topic of interest and many researchers have aimed at providing an answer to this question. Indirect pulp capping aims at removing all of the soft and infected dentin and only leaving just a thin layer of hard affected dentin at the base; however, if the activity in the biofilm is believed to be the driving force for the caries process, then the amount of caries removed becomes irrelevant.[5] Stepwise excavation procedure is therefore an answer to the above question, where we leave caries untouched on the pulpal floor, seal the cavity, and re-enter the lesion after some time to check for any clinical signs of the arrest of the caries process. The biological rationale behind the stepwise excavation procedure could be attributed to the theoretical presumption that the first phase is responsible for inactivating the caries progression as reported by Bjørndal et al.[9] and hence the formation of tertiary dentin is stimulated. Therefore, over some time, the removal of carious dentin becomes easier posing a less risk for iatrogenic exposure of the pulp at the stage of the final excavation.[9]

The 9–16 years age group was appropriately selected as caries activity in this age group is observed to be high, also preserving the vitality of young permanent teeth is essential for the long-term survival of the tooth.[14]

All the previous studies have seldom shown the specific depth of the carious lesion, when, in this study to minimize the selection bias while including deep carious lesions a proper approach was undertaken with the help of an inclusion plate which is based on pictures of the radiographs that shows examples of the carious lesions which could be either included in the study or excluded from the study Bjørndal et al.[15,16]

In both the groups, the preoperative assessment of clinical parameters like dentin color, consistency, and humidity was carried out, suggesting that both the groups were comparable at baseline.

The treatment interval that we used in this study was 8–12 weeks and it might be argued that a longer treatment interval could have introduced the formation of more tertiary dentin; however, Orhan et al.[17] have reported that a period of approximately 3 months is considered adequately sufficient for the effect of calcium hydroxide to take place and for the possibility of the formation of tertiary dentin as a reactionary response from the pulp, thereby increasing its resistance to pulpal exposure. Also, Leksell et al.[18] in their study on deep caries in the case of young permanent posterior teeth showed that no significant difference was observed in the frequency of pulp exposures between teeth treated with calcium hydroxide for 8 to 10 weeks compared with those treated for a longer time.

For the stepwise excavation group, the dentin parameters, i.e., the color, the consistency, and the humidity showed a trend toward darker, harder, and drier dentin at re-entry. Such a clinical picture of dentin is usually suggestive of an arrested carious lesion which is characterized by a darkly pigmented dentin, having a hard or leather-like consistency, as defined by Miller and Massler.[19] The color change can be attributed to Maillard tissue reaction that takes place between carbohydrates from bacteria and proteins from dentin causing browning of the lesion, this color change is further associated with altered sensitivity to proteolytic degradation and hence a role in caries arrestment as reported by Kleter et al.[20] It was further described by Bjørndal[21] that in addition to the Maillard reaction, an increase in the inflow of external stain, plus an acidogenic environment were responsible for the darkening of the lesion.

The consistency parameter had shown a trend toward hardness, whereas the humidity status of the dentin had changed to all dry. The clinical changes in the remaining carious dentin, characterized with a darker color, harder consistency, and drier dentin after the interval period in the treatment protocol were in accordance with the findings by Miller and Massler,[19] Orhan et al.,[17] and Bjorndal et al.[9]

Moreover, in studies by Orhan et al.[17] and Bjorndal et al.,[9] they had also demonstrated that these clinical findings were accompanied by a countable reduction in the bacterial counts during the treatment stages. Therefore, according to them, both, the clinical changes in dentin parameters and a decrease in the numbers of bacterial counts in this group provide suggestive evidence of arrest in the caries process.

Therefore, these results support the hypothesis that sealing provides a way to arrest metabolic activity of bacteria in caries lesions and this stops further progression of caries. These results can be attributed to the fact that upon sealing, the bacteria are exposed to a significant environmental change and severe nutrient limitation which significantly affects bacterial survival.[22]

Also, during the study, the number of intraoperative exposures encountered for stepwise excavation was zero, whereas the number of intraoperative exposures was five while performing IPC. This was in accordance with Padmaja and Raghu[7] who has described IPC as a rather radical approach as compared to stepwise excavation technique, as the focus of the clinician while performing IPC is to remove all of the infected dentin to reach a dry and harder affected dentin,[17,19] whereas in stepwise excavation soft, wet, and infected dentin is left at the pulpal floor untouched, thereby decreasing the risk of pulpal exposure during initial excavation.[23]

When both the groups were compared with each other for the primary outcome, i.e., sustained vitality of the teeth at the end of 1 year, the success ratio of group I was found to be higher than that of group II, suggesting that the stepwise caries excavation technique has a higher success rate than that of IPC.

The final stage of excavation recorded no pulp exposures in any treated teeth. This finding was in alignment with the study by Bjorndal et al.[9] Moreover, it emerged out to be a very safe and pain-free technique, which can be easily used among young children, as no local anesthesia was required to be administered, as this outweighs the limitation of more than one visit required.

The main limitation of this study was that no microbiological assessment was done to support the changes in clinical parameters. However, on the contrary, employing certain measures like using standardized clinical procedures, the use of rubber dam, and similar restorative materials (composite) in both the groups for clinical procedures, have helped in increasing the quality of this study and have decreased the risk of performance bias.

However, advocates of the single visit approach may question the re-entry of the lesion if sealing caries causes the lesion to arrest eventually, but our aim behind re-entering was to compare the clinical changes occurring in dentin parameters and to make sure whether sealing caries lead to lesion arrest or not. Also, Hevinga et al.[24] in their study have tried to answer this question, where they highlighted that permanent restoration done over soft dentin leads to the generation of microfractures, characterized as "ice-cracks", therefore partial excavation in a single visit has a questionable prognosis and for now stepwise excavation technique seems like a safer option.

The superiority of the stepwise excavation study has been well established when compared to the complete excavation technique, as it can avoid more pulp exposures than the complete excavation.[25,26] But to remain within the boundaries of minimally invasive dentistry a comparison between two conservative strategies like indirect pulp capping and stepwise excavation was required.

Conclusion

In the present study, we found that both the caries excavation strategies were found to be effective means of restoring the tooth and protecting the pulp in deep carious lesions. However, the stepwise caries excavation technique was found to be a better and safer method of treating deep carious lesions than IPC because the number of intraoperative exposures encountered during the initial excavation in the stepwise excavation was nil. The clinical changes recorded during the re-entry in the case of stepwise caries excavation technique indicated the direction of caries progression was moving towards the arrest of the lesion.

The overall results of this present study in terms of sustained pulp vitality at the end of 1 year indicated that the success rate of

the stepwise excavation technique was significantly greater than IPC. Stepwise excavation technique, therefore, can be considered as a safer technique in comparison to indirect pulp capping. But to reach well-established evidence, more randomized controlled clinical trials are required in the future.

Clinical Significance

The principal motive in the management of young permanent teeth is mainly focused on preserving the vitality of the teeth and minimal possible trauma to the pulp. However, in young permanent teeth which have immature roots with open apices, pulp preservation becomes integral to aid in apexogenesis as loss of pulp vitality before root completion can lead to the unfavorable crown to root ratio resulting in thin dentinal walls which are prone to fracture. The longevity of a tooth depends on a favorable crown to root ratio and thick dentinal walls sufficient to withstand normal function.

References

1. Fitzgerald M, Heys RJ. A clinical histological evaluation of conservative pulpal therapy in human teeth. Oper Dent 1991;16(3):101–112.
2. Bjørndal L. The caries process and its effect on the pulp: the science is changing and so is our understanding. J Endod 2008;34(7 Suppl):S2–S5. DOI: 10.1016/j.joen.2008.02.037.
3. AAPD guideline on pulp therapy for primary and immature permanent teeth. Reference Manual V32/No.6 10/11.
4. Bergenholtz G, Axelsson S, Davidson T, et al. Treatment of pulps in teeth affected by deep caries – a systematic review of the literature. Singapore Dent J 2013;34(1):1–12. DOI: 10.1016/j.sdj.2013.11.001.
5. Kidd EA. How 'clean' must a cavity be before restoration? Caries Res 2004;38(3):305–313. DOI: 10.1159/000077770.
6. Al-Zayer MA, Straffon LH, Feigal RJ, et al. Indirect pulp treatment of primary posterior teeth: a retrospective study. Pediatr Dent 2003;25(1):29–36.
7. Padmaja M, Raghu R. An ultraconservative method for the treatment of deep carious lesions-step wise excavation. Adv Biolog Res 2010;4(1):42–44.
8. Magnusson BO, Sundell SO. Stepwise excavation of deep carious lesions in primary molars. J Int Assoc Dent Child 1977;8(2):36–40.
9. Bjørndal L, Larsen T, Thylstrup A. A clinical and microbiological study of deep carious lesions during stepwise excavation using long treatment intervals. Caries Res 1997;31(6):411–417. DOI: 10.1159/000262431.
10. Schwendicke F. Incomplete caries removal: a systematic review and meta-analysis. J Dent Res 2013;92(4):306. DOI: 10.1177/0022034513477425.
11. Thompson V, Craig RG, Curro FA. Treatment of deep carious lesions by complete excavation or partial removal: a critical review. J Am Dent Assoc 2008;139(6):705–712. DOI: 10.14219/jada.archive.2008.0252.
12. Maltz M, Garcia R, Jardim JJ, et al. Randomized trial of partial vs. stepwise caries removal: 3-year follow-up. J Dent Res 2012;91(11):1026–1031. DOI: 10.1177/0022034512460403.
13. Maltz M, Oliveira EF, Fontanella V, et al. Deep caries lesions after incomplete dentine caries removal: 40-month follow-up study. Caries Res 2007;41(6):493–496. DOI: 10.1159/000109349.
14. Suwansingha O, Rirattanapong P. Effect of fluoride varnish on caries prevention of partially erupted of permanent molar in high caries risk. Southeast Asian J Trop Med Pub Health 2012;43(3):808–813.
15. Bjørndal L, Reit C, Bruun G, et al. Treatment of deep caries lesions in adults: randomized clinical trials comparing stepwise vs. direct complete excavation, and direct pulp capping vs. partial pulpotomy. Eur J Oral Sci 2010;118(3):290–297. DOI: 10.1111/j.1600-0722.2010.00731.x.
16. Bjørndal L, Demant S, Dabelsteen S. Depth and activity of carious lesions as indicators for the regenerative potential of dental pulp after intervention. J Endod 2014;40(4 Suppl):S76–S81. DOI: 10.1016/j.joen.2014.01.016.
17. Orhan AI, Oz FT, Ozcelik B, et al. A clinical and microbiological comparative study of deep carious lesion treatment in deciduous and young permanent molars. Clin Oral Investig 2008;12(4):369–378. DOI: 10.1007/s00784-008-0208-6.
18. Leksell E, Ridell K, Cvek M, et al. Pulp exposure after stepwise versus direct complete excavation of deep carious lesions in young posterior permanent teeth. Endod Dent Traumatol 1996;12(4):192–196. DOI: 10.1111/j.1600-9657.1996.tb00513.x.
19. Miller WA, Massler M. Permeability and staining of active and arrested lesions in dentine. Br Dent J 1962;112:187–197.
20. Kleter GA, Damen JJ, Buijs MJ, et al. The Maillard reaction in demineralized dentin in vitro. Eur J Oral Sci 1997;105(3):278–284. DOI: 10.1111/j.1600-0722.1997.tb00212.x.
21. Bjørndal L. Dentin and pulp reactions to caries and operative treatment: biological variables affecting treatment outcome. Endodon Top 2002;2(1):10–23. DOI: 10.1034/j.1601-1546.2002.20102.x.
22. Paddick JS, Brailsford SR, Kidd EA, et al. Effect of the environment on genotypic diversity of actinomycesnaeslundii and *Streptococcus oralis* in the oral biofilm. Appl Environ Microbiol 2003;69(11):6475–6480. DOI: 10.1128/aem.69.11.6475-6480.2003.
23. Mertz-Fairhurst EJ, Curtis Jr JW, Ergle JW. Ultraconservative and cariostatic sealed restorations: results at year 10. JADA 1998;129(1):55–66. DOI: 10.14219/jada.archive.1998.0022.
24. Hevinga MA, Opdam NJ, Frecken JE, et al. Does incomplete caries removal reduce strength of restored teeth? J Dent Res 2010;89(11):1270–1275. DOI: 10.1177/0022034510377790.
25. Ricketts DN, Kidd EA, Innes N, et al. Complete or ultraconservative removal of decayed tissue in unfilled teeth. Cochrane Database Syst Rev 2006(3):CD003808. DOI: 10.1002/14651858.CD003808.pub2.
26. Bjørndal L, Simon S, Tomson PL, et al. Management of deep caries and the exposed pulp. Int Endodon J 2019;52(7):949–973. DOI: 10.1111/iej.13128.