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ORIGINAL RESEARCH

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Vital pulp therapy following pulpotomy in immature permanent teeth with carious exposure

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Abstract

This prospective cohort study aimed to evaluate the clinical outcomes of vital pulp therapy (VPT) with the use of iRoot BP Plus (Innovative Bioceramics, Vancouver, Canada) for immature permanent teeth of patients aged from 6 to 10 years with pulp exposure resulting from dental caries and determine the impact of preoperative factors on VPT. Forty-six immature permanent teeth with dental caries underwent pulpotomy using iRoot BP Plus following a standardized protocol. Postoperative follow-ups were conducted on the first 3, 6 and 12 months post-surgery, then annually afterward. Successful treatment outcomes were defined based on clinical and radiographic evaluations. Statistical analysis was performed using the Fisher exact test, with $p < 0.05$ considered for statistical significance. Forty-four patients included in this study were 8.48 ± 1.49 years old and were followed up for 6 to 36 months. The overall success rate of pulpotomy was found to be 90.9% (40/44). None of the physical examination findings and symptoms significantly affected VPT prognosis ($p > 0.05$). Immature permanent teeth with caries-induced pulp exposed in patients aged 6 to 10 years can be effectively treated with pulpotomy using iRoot sBP Plus.

Keywords

Vital pulp therapy; Pulpotomy; Immature permanent teeth

1. Introduction

Young permanent teeth exposed to dental caries can cause irreversible damage to the underlying pulp tissues and inhibit the development of roots [1]. The standard treatment for such cases includes root canal therapy (RCT), which entails the complete removal of the pulp tissue [2]. However, the total removal of the vital pulp can negatively impact root growth and render the tooth more susceptible to fracture [3].

Vital pulp therapy (VPT) has been increasingly performed to retain more hard and soft tissues, thus partially preserving the vital pulp tissues. Pulpotomy is recognized as a promising personalized VPT, especially for immature permanent teeth, as it can prevent the unnecessary removal of pulp tissues [4]. Thus, the residual vital pulp tissues can promote the roots of young permanent teeth with incomplete apical foramen to achieve physiological growth [5]. Additionally, the presence of vital pulp can provide a protective effect, reducing the risk of root fractures in affected teeth. As such, when endodontic treatment is performed on immature permanent teeth, retention of vital pulp to the greatest extent possible is highly recommended. In a recent study, partial pulpotomy performed with calcium hydroxide (94.4%) and mineral trioxide aggregate (MTA) (95%) as the pulp-capping material showed favorable outcomes for carious pulp exposures in immature permanent teeth [6]. Similarly, another study demonstrated that direct pulp capping could achieve a success rate of 93% with evidence of continued root growth at 24 months [7].

Ideal pulp-capping agents should possess anti-inflammatory and antibacterial properties, as well as be nontoxic and exhibit favorable sealing properties. In addition, they should be capable of inducing dentin mineralization [8]. Calcium hydroxide is a traditional ingredient of pulp capping agents. MTA has been shown to be an effective pulpotomy agent in immature permanent teeth, and is considered a viable alternative to calcium hydroxide [9]. A randomized controlled trial reported that Biodentine (90%) and MTA (88%) had higher success rates compared to calcium hydroxide (CH) (82%) in carious-exposed immature permanent molars [10]. iRoot BP Plus (Innovative Bioceramics, Vancouver, Canada), a novel bioceramic material, has shown clinical outcomes consistent with MTA in promoting physiological development and maintaining the basic functions of immature permanent incisors with complicated crown fractures [11]. It was also shown to outperform MTA in clinical handling. Various studies have reported the high biocompatibility of iRoot BP Plus and its ability to induce odontoblast differentiation and mineralization [12]. iRoot BP Plus is now considered an appropriate alternative to calcium hydroxide in permanent teeth pulpotomy [13] and has promising clinical applications as a pulp-capping agent [14].

Dentists often encounter difficulties when managing young

permanent teeth exposed to dental caries, as their extraction at an early age could compromise occlusion and require further orthodontic treatments [15]. Endodontic management (*i.e.*, pulp extirpation and root obturation) can be significantly compromised because of incomplete root development [1]. Developments of newer biocompatible materials have allowed the removal of the inflamed part of the pulpal tissue and facilitated the healing of the remaining pulp and good coronal seal [16]. This approach can promote further root development, and even in cases where the treated teeth ultimately became non-vital, their endodontic management can be easier, leading to better long-term outcomes [17].

This present study aimed to prospectively investigate the clinical and radiographic success rates of vital pulp therapy in immature permanent molars using iRoot BP Plus as a pulp dressing agent and determine the impact of preoperative factors on VPT prognosis.

2. Materials and method

2.1 Design and participants

Fig. 1 illustrates the overall protocol for pulpotomy. To ensure proper reporting of our results, we adhered to the guidelines of the Strengthening the reporting of observational studies in Epidemiology (STROBE; https://www.strobe-statement.org/index.php?id=available-checklists). The study cohort comprised patients aged 6 to 10 years treated at The Second Affiliated Hospital of Zhejiang University School of Medicine (Zhejiang University District).

2.2 Inclusion criteria

In accordance with the American Association of Endodontics (AAE) guidelines (https://www.aae.org/specialty/newsletter/endodontic-diagnosis/) and Levin's research [18], patients were recruited for this study based on the following inclusion criteria:

(1) Children aged 6–10 years with asymptomatic/symptomatic disease and having vital immature permanent posterior teeth with clinical exposure to dental caries of the pulp and bleeding.

(2) Posterior teeth had deep caries with pulp exposure.

(3) Posterior teeth that exhibited preoperative symptoms, such as referred pain, spontaneous pain or pain induced during thermal and cold sensitivity tests, with a range of symptoms that can last from seconds to hours compared to the control teeth.

(4) Posterior teeth without prominent radiolucency in the furcation or periapical regions.

(5) The posterior teeth could be restored.

(6) Each participant provided one tooth. Multiple teeth were included in the VPT analysis to ensure that the samples were independent and suitable for statistical modeling. The teeth were selected in the following priority order: first molar, second molar, second premolar, and first premolar.

2.3 Exclusion criteria

(1) Patients with contraindications of the to-be-performed dental treatment.

(2) Teeth with completed VPT or RCT.

(3) Teeth with furcation, prominent radiolucency in the periapical regions, or external or internal resorption.

(4) Teeth with pulpitis attributed to tooth fracture, cracking, periodontitis or wedge-shaped defects.

(5) Teeth without any response to experiments of vitality.

(6) Teeth with formed root/closed apex.

(7) Teeth with edema, fistula and excessive mobility not associated with periodontal disease.

2.4 Interventions

A periapical radiograph was taken using the Sirona periapical machine (Germany) after completion of the clinical examination to make a preoperative diagnosis. Pain intensity in children 6 years and older was recorded postoperatively using the verbal numerical rating scale (vNRS) due to its strong reliability [19].

Following the same standardized protocol, all operations were performed by three endodontic postgraduate students under the supervision of an experienced instructor after the completion of clinical and radiographic evaluations. First, local anesthesia of the tooth was achieved using 4% articaine with 1:100,000 epinephrine (Ubistesin 4%—Espe Dental AG Seefeld, Berlin, Germany). Second, the tooth was isolated using a dental dam (Kerr, Germany) and a sterile high-speed diamond bur with water cooling was utilized for caries excavation. Non-selective removal of caries was performed under a microscope to reach the hard dentine, which could only be removed using a sharp instrument or dental drill. A harsh scratching sound could be heard when the probe was pressed across the dentin. Third, the tooth surface was disinfected using 5% sodium hypochlorite (NaOCl), and the cavity was rinsed using 2.5% NaOCl. Fourth, a new sterile high-speed diamond was adopted to remove the affected pulpal tissue at the exposure site until only healthy pulp tissue remained, as observed under a microscope.

Haemostasis was achieved by placing a 1% NaOCl-moistened cotton pellet gently over the amputated pulps for 5 min [20], followed by evaluation of the pulp state based on its appearance, color and consistency under a microscope. If hemostasis could not be achieved within 5 min or the pulp was necrotized (judged based on appearance), the treated tooth was excluded from the study and underwent further revascularization based on the status of the remaining pulp. Next, iRoot BP Plus was produced following the manufacturer's instructions and a 3-mm layer was arranged on the pulp tissue. Glass ionomer modified by resin (Vitrebond, 3M, ESPE, St Paul, MN, USA) was arranged as a protective base on the iRoot BP Plus layer after a cotton pellet was made to cover the iRoot BP Plus. Lastly, a stainless-steel crown or resin composite was adopted to restore the tooth, which was determined by the amount of the structure of the remaining tooth.

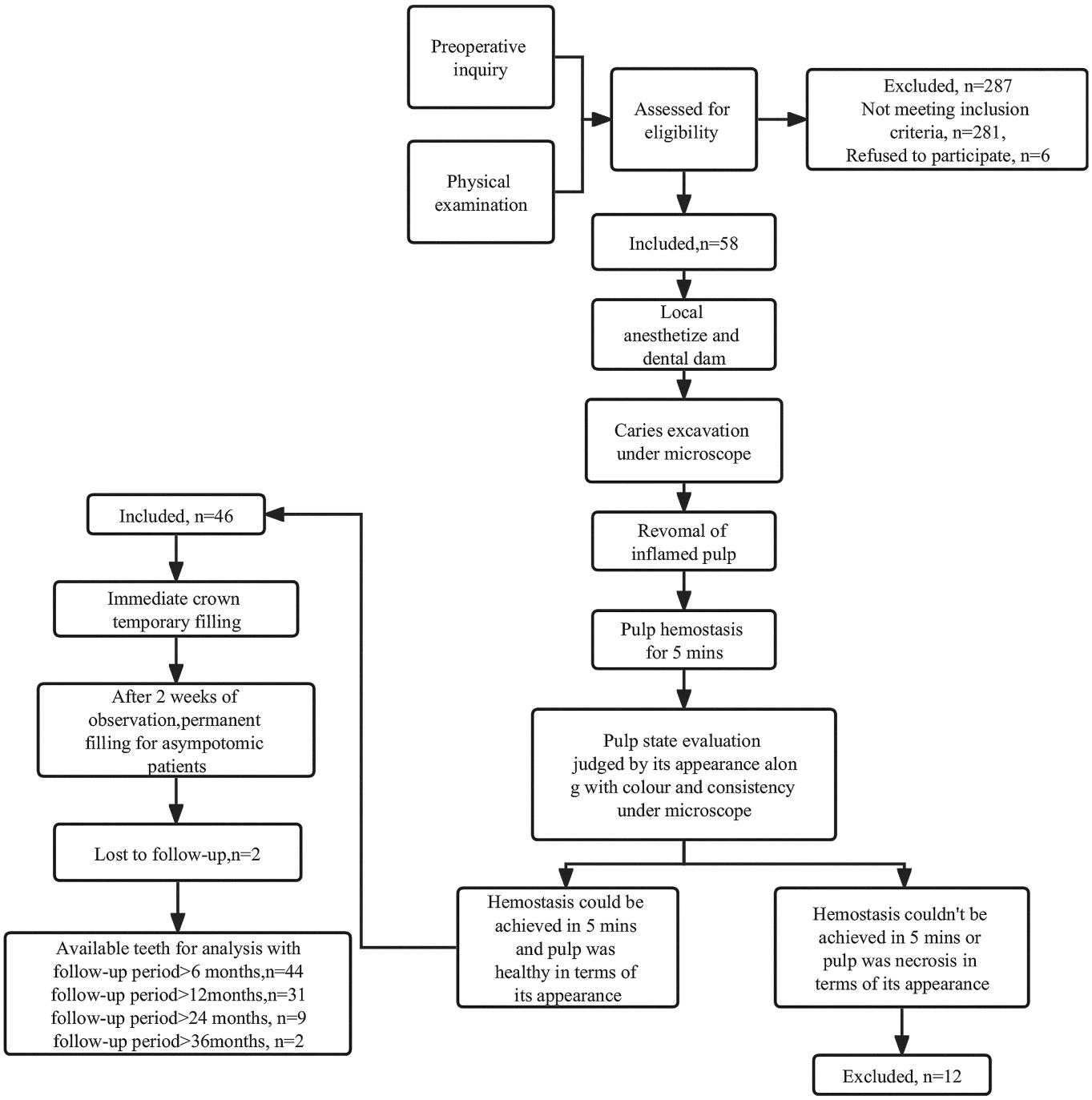

FIGURE 1. Illustration of the pulpotomy protocol of this present study and the number (n) of patients of respective stages.

2.5 Outcomes

The patients were scheduled to undergo clinical and radiographic assessments at 3, 6 and 12 months after the surgery and annually afterward. A pediatric dentist performed the follow-up clinical examinations using the criteria of clinical success, and an oral radiologist performed radiographic examinations. Clinical success was defined based on the following standards: (1) the teeth were functional with no signs/symptoms of pulp or peri-radicular inflammation/infection; (2) absence of pain related to the treated molars, including patient-reported pain or sensitivity to percussion/palpation; (3) no evidence of swelling of supporting soft tissue or presence of a sinus tract; (4) absence of abnormal mobility; (5) continued radiographic root growth in immature roots without signs of radicular, inter-radicular and peri-radicular radiolucency.

2.6 Statistical analysis

Statistical analyses were conducted using the Statistical Package for the Social Sciences software version 17.0 (SPSS Inc., Chicago, IL, USA). The outcomes between various baseline characteristics were compared using Fisher exact test. $p < 0.05$ was used to indicate statistically significant differences.

3. Results

The Cohen Kappa statistics indicated good intraobserver and interobserver agreement. The reliability of the observers was high, with scores ranging from 0.70 to 0.85.

A total of 46 immature permanent teeth with caries underwent pulpotomy using iRoot BP Plus. Of them, 44 permanent teeth (23 males and 17 females, aged 6–10 years) were evaluable for this study based on the inclusion and exclusion criteria, and the follow-up rate was 95.7% in the entire cohort. The mean age of patients that underwent pulpotomy was 8.48 ± 1.49 years. The follow-up period ranged from 6 to 36 months, with a mean of 15.92 ± 7.78 months.

During the follow-up, VPT achieved a success rate of 90.9% (40/44), 90.3% (29/31), 88.9% (8/9) and 100% (2/2) in patients with follow-up period more than 6 months, 12 months, 24 months and 36 months respectively. The typical cases of this study was presented in Figs. 2,3. And dentin bridge formation was detected in 14 of 44 teeth (31.8%).

The Fisher exact test showed that sex, age, maxilla or mandible, tooth position, restorations history, preoperative night pain, preoperative spontaneous pain, preoperative referred pain, percussion, temperature test result, electrical vitality test of the patients did not significantly affect patients' prognosis following pulpotomy ($p > 0.05$; Table 1).

4. Discussion

Advances in biological materials have materialized previously unattainable forms of treatment. However, due to the complexity of the root canal system and the complications associated with the treatment processes, there are still several limitations linked with root canal surgery in some clinical situations. Presently, the treatment of immature permanent first molars and damaged pulp remains challenging. Premature loss of the first permanent molars can hinder dentition development. In addition, the removal of permanent molars can lead to trauma to the treated child. From a developmental standpoint, the absence of the first permanent molars can negatively affect both arches [21]. Importantly, pulp treatment is based on maintaining tooth vitality and functions and making the tooth asymptomatic. During pulpotomy, the inflamed pulp is surgically removed, while the remaining root pulp, assumed to be non-inflamed and to have a continuous blood supply, is covered with a biocompatible material over the excised pulp tissue to establish a coronal seal, protecting the pulp from further damage and promoting healing [22]. Our results supported the application of VPT in immature permanent teeth exposed to caries and were similar to a recent systematic review supporting partial and full pulpotomy as definitive treatments for mature posterior teeth diagnosed with irreversible pulpitis [23].

It is worth mentioning that once root formation is complete, RCT is recommended [24]. However, with the introduction of new biomaterials, removing the inflamed pulp and using the above materials for covering the root pulp tissue may serve as a long-term treatment for improved root development, as well as root canal treatment and pulp extraction inevitably.

Proper preoperative evaluation is crucial as there are no standard guidelines describing the indications of VPT in immature permanent teeth. Anatomically molars and premolars have differences in terms of number of roots, thickness, floor of the pulp chambers [25]. The overall average length of the maxillary and mandibular premolar is 22.5 mm with an average crown length of 8~8.5 mm and an average root length of 14~14.5 mm, while the overall average length of the maxillary and mandibular molar is among 19~21.5 mm with an average crown length of 7~7.5 mm and an average root length of 12~14 mm [25]. However, tooth position, surfaces involved were not

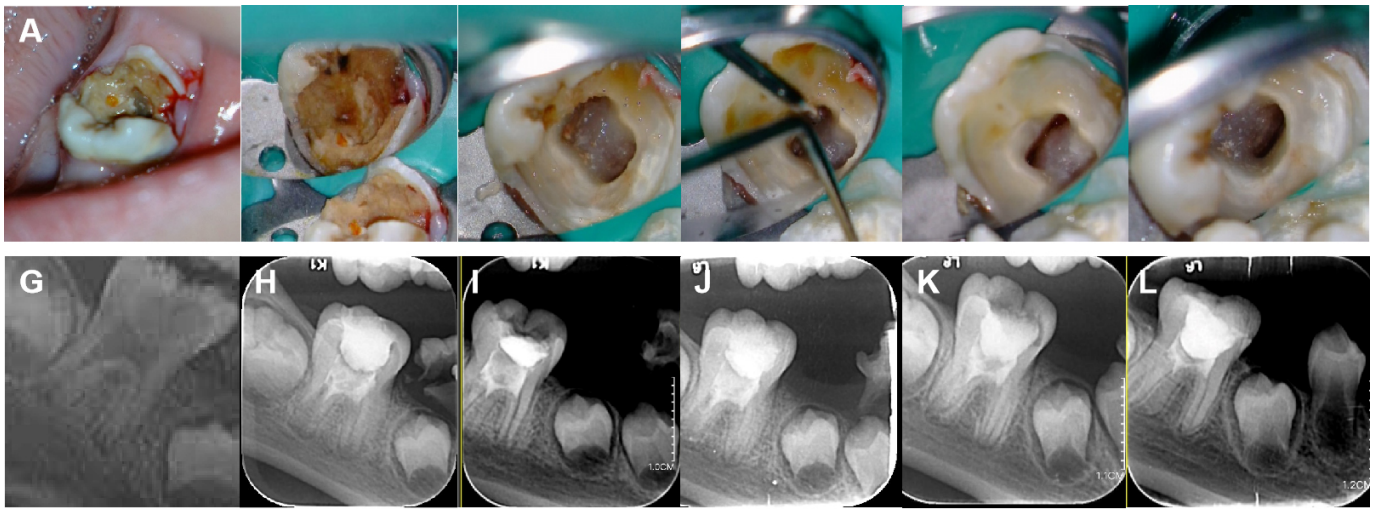

FIGURE 2. A typical case of a female patient aged 6 years who developed clinical symptoms attributed to exposure to dental caries, and immature roots. (A) Preoperative pictures of the lower right first molar in the female patient (B) Rubber dam isolation and caries excavation under a microscope. (C,D) Removal of inflamed pulp (E,F) pup state evaluation of mistal and distal root. (G) The preoperative periapical radiograph. (H) The postoperative periapical radiograph when pulpotomy was completed using iRoot BP Plus. (I) The 6-month follow-up. (J) 12-month follow-up. (K) 24-month follow-up. Partial loss of filling and secondary caries were observed and caries elimination and re-filling were performed. (L) 36-month follow-up indicating continuous root growth and dentin bridge formation.

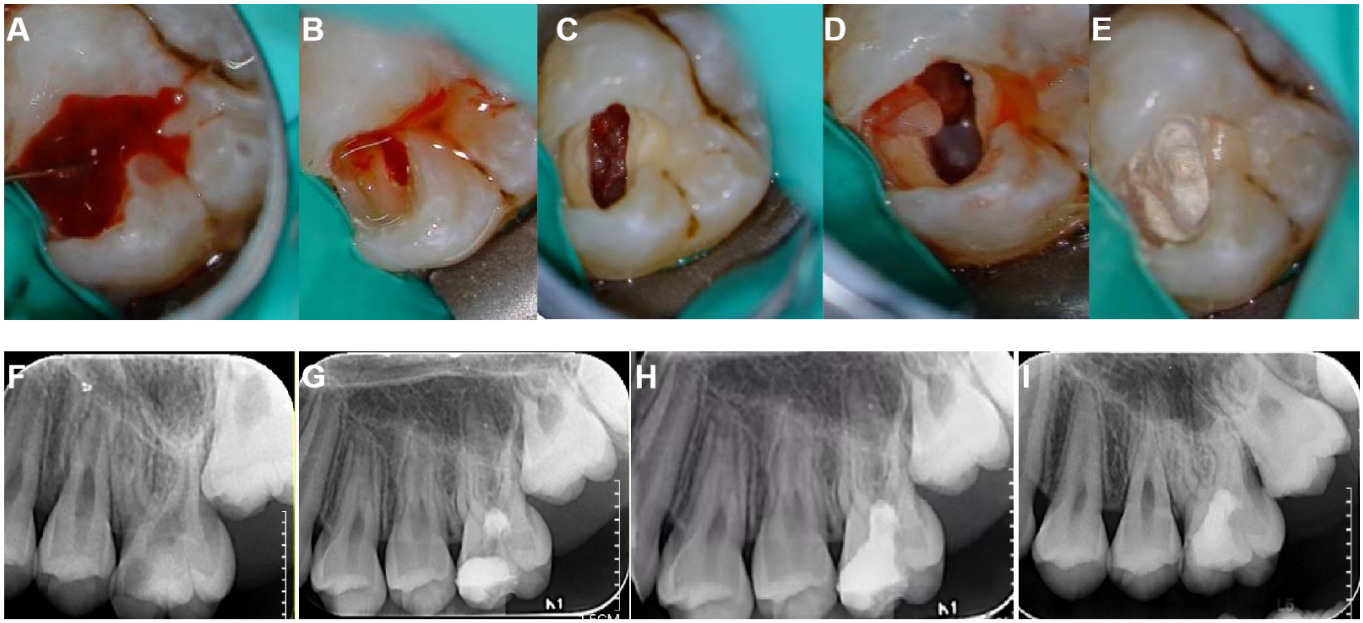

FIGURE 3. Typical case of a male patient aged 10 years with a maxilla left first molar exposed to dental caries with immature roots. (A) pulp exposure after caries excavation (B) Rubber dam isolation and caries excavation under microscope. (B–D) Removal of inflamed pulp and pulp state evaluation under microscope. (E) Pulp capping using iRoot BP Plus. (F) The preoperative periapical radiograph. (G) The postoperative periapical radiograph when pulpotomy was completed using iRoot BP Plus. (H) The 6-month follow-up. (I) 12-month follow-up indicating continuous root growth.

TABLE 1. Fisher exact test on outcomes based on patients' baseline characteristics.

	Prognosis						
	Number of Successful teeth	Success Rate (%)	Number of failed teeth	Failure Rate (%)	Effect Size	95% CI	*p* value
Sex							
Male	23	0.92	2	0.08			
Female	17	0.89	2	0.11	1.03	0.822–1.360	0.9999
Maxilla or mandible							
Maxilla	21	0.91	2	0.09			
Mandible	19	0.90	2	0.10	1.01	0.796–1.302	0.9999
Tooth position							
Premolar	6	0.86	1	0.14			
Molar	34	0.92	3	0.08	0.93	0.527–1.148	0.5135
involved surfaces							
Occlusal Surface Only	20	0.95	1	0.05			
Proximal Surface Involved	20	0.87	3	0.13	1.10	0.872–1.415	0.6086
Previous restoration							
Yes	8	0.89	1	0.11			
No	32	0.91	3	0.09	0.97	0.614–1.186	0.9999
Spontaneous pain							
Yes	36	0.92	3	0.08			
No	4	0.80	1	0.20	1.15	0.906–2.468	0.3941

TABLE 1. Continued.

	Prognosis						
	Number of Successful teeth	Success Rate (%)	Number of failed teeth	Failure Rate (%)	Effect Size	95% CI	*p* value
Nocturnal pain							
Yes	6	0.86	1	0.14			
No	34	0.92	3	0.08	0.93	0.527–1.148	0.5135
Referred pain							
Yes	8	0.80	2	0.20			
No	32	0.94	2	0.06	0.85	0.518–1.061	0.2176
Cold test							
Tenderness without delaying pain	4	1.00	0	0.00			
Tenderness with delaying pain <30 s	30	0.91	3	0.09			
Tenderness with delaying pain ≥30 s	6	0.86	1	0.14			0.6999
Pain level of cold test							
<5	27	0.93	2	0.07			
≥5	13	0.87	2	0.13	1.07	0.872–1.511	0.5962
Heat test							
Normal	15	1.00	0	0.00			
Tenderness without delaying pain	13	0.81	3	0.19			
Tenderness with delaying pain <30 s	9	0.90	1	0.10			
Tenderness with delaying pain ≥30 s	3	1.00	0	0.00			0.885
Pain level of heat test							
<5	36	0.92	3	0.08			
≥5	4	0.80	1	0.20	1.15	0.906–2.468	0.3941
Electrical vitality test difference							
<10	28	0.90	3	0.10			
≥10	12	0.92	1	0.08	0.98	0.798–1.368	0.9999
Percussion sensitivity							
(−)	31	0.94	2	0.06			
(+)	9	0.82	2	0.18	1.15	0.927–1.806	0.2565

CI: confidence interval.

associated with the success rate of VPT in present study, which was consistent with previous study [15]. Patients' clinical symptoms and reactions toward the test temperature can be used as an indication to determine the presence of pulpitis [26]. Irreversible pulpitis is typically characterized by referred pain, nocturnal pain or spontaneous pain based on the status of the pulp [27]. Liu *et al*. [28] and Kundzina *et al*. [29] previously reported that VPT prognosis was not dependent on the status of referred, nocturnal and spontaneous pain. Nevertheless, since their study had limited cases, it was imperative to clarify how preoperative symptoms might affect patients' prognosis following pulpotomy.

Existing research has shown that cold tests are the most effective examination for identifying necrotic pulp, especially prior to treating teeth with pulp-exposed lesions or deep caries [30]. Unintervened pulp exposure attributed to caries would eventually lead to the progressive spread of pulp inflammation, whereas the test result of pulp sensibility may not indicate this progression [31]. However, we found no significant association between pulpotomy outcomes, cold or heat test

results and pain index.

Existing research has suggested that pulp electrical vitality test data cannot precisely indicate the pulp status despite that it may indicate whether Aδ fibers can still have normal functions [31, 32]. The variable of this study was the differences in data of the control and affected teeth, and our results showed that pulpotomy outcome was not significantly affected even if the differences of the test of electrical activity exceeded 10.

A previous study showed that percussion results, a commonly used method for conducting oral physical examinations, can reveal periapical conditions and the depth of endodontic inflammation progression, with percussion pain being generated earlier than endodontic tissue necrosis [33]. Additionally, a one-year prospective study revealed that the percussion of teeth with irreversible pulpitis did not significantly affect the prognosis of crown pulp [15], as even patients with positive percussion still had successful outcomes. Moreover, the percussion results did not significantly affect the prognosis of pulpotomy. Therefore, a positive percussion result should not be considered a contraindication for pulpotomy.

Additionally, the choice of pulp capping material is of paramount importance for the prognosis of pulpotomy. Despite its widespread use, MTA has certain limitations when used for pulp capping. For instance, it requires regulation with normal saline immediately before application, which can make clinical operations more tedious. In addition, Bismuth Oxide (Bi_2O_3) coating on MTA can be toxic to dental pulp cells and cause teeth discoloration [34]. The iRoot BP Plus applied refers to a novel premixed material that exhibits high physicochemical characteristics and biocompatibility. Compared to MTA, mixing is not required, increasing clinical convenience [35]. The effect of iRoot BP Plus as a pulp capping agent in treating mature permanent teeth with pulp exposure attributed to caries has been previously studied, and the results indicated that at 1, 2 and 3 years or more after surgery, a success rate of 98%, 89% and 81% was achieved, respectively [28]. Pulpotomy with iRoot BP Plus as a pulp capping agent achieved a high success rate, suggesting that it can be used in VPT to treat immature permanent teeth exposed to dental caries.

A crucial factor affecting the adequate removal of pulp is the dentist's ability to determine the pulp state during pulpotomy. Although the hemostatic period has been used for pulp state evaluation, there is still no consensus on the optimal approach and duration. Whitherspoon *et al*. [36] suggested that regulating the hemostatic period to 10 min through irrigation with 1% NaOCl could achieve a reversible inflammatory state in the remaining pulp. Moreover, Taha *et al*. [32] directly contacted the exposed pulp with a cotton pellet moistened with 1% NaOCl to stop blood flow before VPT and reported a high rate of success (100%). Qudeimat *et al*. [37] revealed that a hemostatic period of up to 24 min could effectively treat teeth with irreversible pulpitis. A more stringent criterion was employed: for only teeth with pulp tissue directly contacted with a cotton pellet moistened with 1% NaOCl for a hemostatic period of 5 min yielded a high pulpotomy success rate of 90.9%, suggesting the hemostatic test as having a favorable clinical index in terms of pulp status. However, there is a lack of sufficient data to determine the optimal hemostatic period for pulpotomy.

The main limitation of this study was that we only investigated the associations between indicators and outcomes rather than establishing causality. To address this limitation, future research may include systematic reviews and meta-analyses or a randomized controlled trial to compare iRoot BP Plus and other different materials. Additionally, the sample size of this study was small, and thus, recruiting more patients may provide more definitive conclusions in the future.

5. Conclusions

In the light of findings from this prospective cohort study, iRoot BP Plus pulpotomy may be a viable option for cariously exposed permanent teeth in children aged 6 to 10 years who are unable to cooperate with or afford the cost of traditional RCT. However, more clinical studies on larger sample sizes are required to identify and assess the risks, costs and benefits of using iRoot BP Plus pulpotomy as a permanent endodontic procedure.

AVAILABILITY OF DATA AND MATERIALS

The datasets generated and/or analyzed during the current study are not publicly available due to possible compromise of individual privacy but are available from the corresponding author on reasonable request.

AUTHOR CONTRIBUTIONS

SH and QZ—designed the research study. SH—performed the research; analyzed the data; wrote the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The protocol of this study gained approval from the local Ethics Committee (The Second Affiliated Hospital of Zhejiang University School of Medicine, Zhejiang University District) and registered in the Chinese Trials Registry (No. ChiCTR2100044580). All patients' parents or legal guardian provided informed consent.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] Wigler R, Kaufman AY, Lin S, Steinbock N, Hazan-Molina H, Torneck CD. Revascularization: a treatment for permanent teeth with necrotic pulp and incomplete root development. Journal of Endodontics. 2013; 39: 319–326.

[2] Wong M, Shelley JJ, Bodey T, Hall R. Delayed root canal therapy: an analysis of treatment over time. Journal of Endodontics. 1992; 18: 387–390.

[3] Mello I, Michaud P, Butt Z. Fracture resistance of immature teeth submitted to different endodontic procedures and restorative protocols. Journal of Endodontics. 2020; 46: 1465–1469.

[4] Chen Y, Chen X, Zhang Y, Zhou F, Deng J, Zou J, *et al*. Materials for pulpotomy in immature permanent teeth: a systematic review and meta-analysis. BMC Oral Health. 2019; 19: 227.

[5] Sabeti M, Golchert K, Torabinejad M. Regeneration of pulp-dentin complex in a tooth with symptomatic irreversible pulpitis and open apex using regenerative endodontic procedures. Journal of Endodontics. 2021; 47: 247–252.

[6] Özgür B, Uysal S, Güngör HC. Partial pulpotomy in immature permanent molars after carious exposures using different hemorrhage control and capping materials. Pediatric Dentistry. 2017; 39: 364–370.

[7] Farsi N, Alamoudi N, Balto K, Al Mushayt A. Clinical assessment of mineral trioxide aggregate (MTA) as direct pulp capping in young permanent teeth. Journal of Clinical Pediatric Dentistry. 2007; 31: 72–76.

[8] Pedano MS, Li X, Yoshihara K, Landuyt KV, Van Meerbeek B. Cytotoxicity and bioactivity of dental pulp-capping agents towards human tooth-pulp cells: a systematic review of *in-vitro* studies and meta-analysis of randomized and controlled clinical trials. Materials. 2020; 13: 2670.

[9] Johnson WT. Comparison of mineral trioxide aggregate and calcium hydroxide as pulpotomy agents in young permanent teeth (apexogenesis). Yearbook of Dentistry. 2007; 2007: 228–229.

[10] Uyar DS, Alacam A. Evaluation of partial pulpotomy treatment in cariously exposed immature permanent molars: randomized controlled trial. Nigerian Journal of Clinical Practice. 2021; 24: 1511–1519.

[11] Hu X, Li Y, Xu J, Li Q, Wang R. Immature permanent incisors with complicated crown fractures treated with partial pulpotomy using white mineral trioxide aggregate and IRoot BP plus-a retrospective long-term study. Dental Traumatology. 2023; 39: 165–172.

[12] Rao Q, Kuang J, Mao C, Dai J, Hu L, Lei Z, *et al*. Comparison of iRoot BP plus and calcium hydroxide as pulpotomy materials in permanent incisors with complicated crown fractures: a retrospective study. Journal of Endodontics. 2020; 46: 352–357.

[13] Wu L, Xue K, Hu G, Du H, Gan K, Zhu J, *et al*. Effects of iRoot SP on osteogenic differentiation of human stem cells from apical papilla. BMC Oral Health. 2021; 21: 407.

[14] Azimi S, Fazlyab M, Sadri D, Saghiri MA, Khosravanifard B, Asgary S. Comparison of pulp response to mineral trioxide aggregate and a bioceramic paste in partial pulpotomy of sound human premolars: a randomized controlled trial. International Endodontic Journal. 2014; 47: 873–881.

[15] Taha NA, Abdulkhader SZ. Full pulpotomy with biodentine in symptomatic young permanent teeth with carious exposure. Journal of Endodontics. 2018; 44: 932–937.

[16] Fakhri E, Eslami H, Maroufi P, Pakdel F, Taghizadeh S, Ganbarov K, *et al*. Chitosan biomaterials application in dentistry. International Journal of Biological Macromolecules. 2020; 162: 956–974.

[17] Kim SG, Malek M, Sigurdsson A, Lin LM, Kahler B. Regenerative endodontics: a comprehensive review. International Endodontic Journal. 2018; 51: 1367–1388.

[18] Levin LG, Law AS, Holland GR, Abbott PV, Roda RS. Identify and define all diagnostic terms for pulpal health and disease states. Journal of Endodontics. 2009; 35: 1645–1657.

[19] Tsze DS, von Baeyer CL, Pahalyants V, Dayan PS. Validity and reliability of the verbal numerical rating scale for children aged 4 to 17 years with acute pain. Annals of Emergency Medicine. 2018; 71: 691–702.e3.

[20] NOSRAT A, SEIFI A, ASGARY S. Pulpotomy in caries-exposed immature permanent molars using calcium-enriched mixture cement or mineral trioxide aggregate: a randomized clinical trial. International Journal of Paediatric Dentistry. 2013; 23: 56–63.

[21] Çağlaroğlu M, Kilic N, Erdem A. Effects of early unilateral first molar extraction on skeletal asymmetry. American Journal of Orthodontics and Dentofacial Orthopedics. 2008; 134: 270–275.

[22] Gudkina J, Mindere A, Locane G, Brinkmane A. Review of the success of pulp exposure treatment of cariously and traumatically exposed pulps in immature permanent incisors and molars. Stomatologija. 2012; 14: 71–80.

[23] Santos JM, Pereira JF, Marques A, Sequeira DB, Friedman S. Vital pulp therapy in permanent mature posterior teeth with symptomatic irreversible pulpitis: a systematic review of treatment outcomes. Medicina. 2021; 57: 573.

[24] Ng YL, Mann V, Gulabivala K. Outcome of secondary root canal treatment: a systematic review of the literature. International Endodontic Journal. 2008; 41: 1026–1046.

[25] Mohammadi Z, Shalavi S, Jafarzadeh H. Extra roots and root canals in premolar and molar teeth: review of an endodontic challenge. The Journal of Contemporary Dental Practice. 2013; 14: 980–986.

[26] Ricucci D, Loghin S, Siqueira JF. Correlation between clinical and histologic pulp diagnoses. Journal of Endodontics. 2014; 40: 1932–1939.

[27] Rossi HL, See LP, Foster W, Pitake S, Gibbs J, Schmidt B, *et al*. Evoked and spontaneous pain assessment during tooth pulp injury. Scientific Reports. 2020; 10: 2759.

[28] Liu SY, Gong WY, Liu MQ, Long YZ, Dong YM. Clinical efficacy observation of direct pulp capping using iRoot BP Plus therapy in mature permanent teeth with carious pulp exposure. Chinese Journal of Stomatology. 2020; 55: 945–951. (In Chinses)

[29] Kundzina R, Stangvaltaite L, Eriksen HM, Kerosuo E. Capping carious exposures in adults: a randomized controlled trial investigating mineral trioxide aggregate versus calcium hydroxide. International Endodontic Journal. 2017; 50: 924–932.

[30] Mainkar A, Kim SG. Diagnostic accuracy of 5 dental pulp tests: a systematic review and meta-analysis. Journal of Endodontics. 2018; 44: 694–702.

[31] Alghaithy RA, Qualtrough AJE. Pulp sensibility and vitality tests for diagnosing pulpal health in permanent teeth: a critical review. International Endodontic Journal. 2017; 50: 135–142.

[32] Taha NA, About I, Sedgley CM, Messer HH. Conservative management of mature permanent teeth with carious pulp exposure. Journal of Endodontics. 2020; 46: S33–S41.

[33] Aguilar P, Linsuwanont P. Vital pulp therapy in vital permanent teeth with cariously exposed pulp: a systematic review. Journal of Endodontics. 2011; 37: 581–587.

[34] Alsubait S, Al-Haidar S, Al-Sharyan N. A comparison of the discoloration potential for endosequence bioceramic root repair material fast set putty and proroot MTA in human teeth: an *in vitro* study. Journal of Esthetic and Restorative Dentistry. 2017; 29: 59–67.

[35] Parirokh M, Torabinejad M, Dummer PMH. Mineral trioxide aggregate and other bioactive endodontic cements: an updated overview—part I: vital pulp therapy. International Endodontic Journal. 2018; 51: 177–205.

[36] Witherspoon DE, Small JC, Harris GZ. Mineral trioxide aggregate pulpotomies: a case series outcomes assessment. The Journal of the American Dental Association. 2006; 137: 610–618.

[37] Qudeimat MA, Alyahya A, Hasan AA. Mineral trioxide aggregate pulpotomy for permanent molars with clinical signs indicative of irreversible pulpitis: a preliminary study. International Endodontic Journal. 2017; 50: 126–134.

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