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Comparison of Clinical Efficacy between Apexification and Revascularization for Immature Permanent Teeth

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Abstract: *Objective:* This study aimed to compare the clinical and radiographic efficacy of apexification and pulp revascularization for treating immature permanent teeth with pulp necrosis and periapical lesions, so as to provide evidence-based references for clinical treatment selection. *Methods:* A total of 80 patients aged 6–18 years with immature permanent teeth complicated by pulp necrosis or periapical periodontitis from January 2020 to December 2023 were enrolled and randomly divided into the control group (apexification treatment, n = 40) and observation group (pulp revascularization treatment, n = 40). Standardized surgical protocols were implemented for both groups. Clinical and radiographic follow-up evaluations were conducted at 6, 12, and 24 months postoperatively. The primary observation indicators included clinical success rate, radiographic root development parameters (root length, root canal wall thickness), periapical lesion healing status, and total treatment duration. Statistical analysis was performed via SPSS 26.0 software. *Results:* At 24 months of follow-up, the clinical success rate of the observation group was 90.0%, significantly higher than 80.0% of the control group ($p < 0.05$). Radiographically, the observation group achieved significant physiological root development, with the average root length increased by 1.52 ± 0.43 mm and root canal wall thickness increased by 0.45 ± 0.12 mm, while no obvious root growth was observed in the control group ($p < 0.01$). The average treatment duration of the observation group was 3.6 months, which was remarkably shorter than 12.5 months in the control group ($p < 0.01$). *Conclusion:* Pulp revascularization is superior to traditional apexification in the treatment of immature permanent teeth with periapical lesions. It can improve long-term clinical success rate, promote physiological root maturation, shorten the treatment cycle, and reduce clinical burden, which is worthy of being the first-line regenerative treatment for eligible patients.

Keywords: Immature permanent teeth; Apexification; Pulp revascularization; Pulp regeneration; Clinical efficacy; Root development; Periapical periodontitis

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1. Introduction

Immature permanent teeth are characterized by incomplete root formation, open apical foramen, and thin dentin walls. Once complicated by pulp necrosis and periapical lesions due to trauma or caries, the teeth lose natural developmental potential and face high risks of root fracture and tooth loss, bringing great challenges to pediatric endodontic treatment.

The core therapeutic goals for such teeth are to completely control periapical infection, eliminate inflammatory lesions, and maximize the preservation of tooth vitality and promote continuous root development [1].

Apexification is a classic traditional treatment for necrotic immature permanent teeth. It mainly uses calcium hydroxide or mineral trioxide aggregate (MTA) to induce the formation of artificial apical calcified barriers, so as to block the apical foramen, control periapical inflammation, and complete root canal obturation. Although this technique can effectively eliminate clinical symptoms and control infection, it cannot repair thin dentin walls or restore pulp physiological functions. The root remains thin and fragile permanently, with a high long-term fracture risk, and fails to realize true tooth regeneration.

Pulp revascularization (regenerative endodontic procedure, REP) is an emerging regenerative endodontic technology. Different from traditional repair-based treatment, it relies on thorough intracanal disinfection, induces periapical bleeding to form a natural blood clot scaffold, and recruits periapical stem cells and growth factors to repopulate the root canal [2]. This technology can realize the regeneration of pulp-like tissue, promote continuous root lengthening and dentin wall thickening, restore the structural stability of immature teeth, and fundamentally reduce the risk of tooth fracture.

In recent years, with the optimization of disinfection schemes and the application of bioceramic materials, the clinical stability of pulp revascularization has been significantly improved. However, most existing studies are single-case observations or small-sample retrospective analyses, and there is a lack of high-quality prospective controlled trials to systematically compare the long-term clinical efficacy, root developmental effects, and treatment cycle differences between revascularization and apexification [3]. Therefore, this prospective randomized controlled study took 80 patients with immature permanent tooth lesions as research objects, and comprehensively evaluated the clinical and radiographic outcomes of the two treatments within 24 months, aiming to provide objective clinical evidence for the standardized application of regenerative endodontic technology.

2. Materials and methods

2.1. General information

This study was a prospective, single-center, randomized controlled trial conducted in the Department of Pediatric Dentistry from January 2020 to December 2023. The study protocol was approved by the institutional ethical review committee, and written informed consent was obtained from all patients' parents or legal guardians before treatment.

A total of 80 patients aged 6–18 years (mean age 10.8 ± 2.4 years) with immature permanent tooth diseases were enrolled, including 42 males and 38 females. All patients were diagnosed with single-rooted immature permanent incisors or premolars complicated by pulp necrosis or chronic periapical periodontitis [4]. Patients were randomly divided into the control group (apexification, n = 40) and the observation group (pulp revascularization, n = 40) by a computer-generated random number sequence. Baseline data such as age, gender, lesion location, and periapical lesion size were balanced and comparable between the two groups ($p > 0.05$).

2.2. Inclusion and exclusion criteria

2.2.1. Inclusion criteria

Radiographic confirmation of incomplete root development with apical opening diameter > 1 mm; clinical diagnosis of pulp necrosis with negative pulp sensibility test, with or without periapical radiolucent lesions; no spontaneous pain, swelling, or acute sinus tract at baseline; complete tooth crown structure, which can be isolated by rubber dam and restored after treatment.

2.2.2. Exclusion criteria

Teeth with crown/root fracture, internal and external root resorption, or severe caries that cannot be restored; combined with periodontal disease and tooth loosening; patients with systemic diseases or immune dysfunction affecting dental healing; teeth with previous endodontic treatment history.

2.3. Surgical methods

All operations were completed by a single experienced attending physician under local anesthesia (3% mepivacaine without vasoconstrictor) and rubber dam isolation. Postoperative routine oral health guidance was provided for all patients.

2.3.1. Control group (apexification)

After conventional access cavity preparation, the root canal working length was determined 1 mm short of the radiographic apex. Minimal mechanical instrumentation was performed to avoid damaging thin dentin walls. The root canal was repeatedly irrigated with 1% sodium hypochlorite (NaOCl) and sterile saline, then dried with paper points. Non-setting calcium hydroxide paste was uniformly filled into the root canal via lentulo spiral, and the access cavity was temporarily sealed [5].

Patients were reexamined every 4 weeks for drug replacement until radiographic examination showed continuous apical calcified barrier formation, or the root canal was asymptomatic and dry for two consecutive reexaminations. After the apical barrier was formed, lateral compaction gutta-percha obturation was performed with zinc oxide-eugenol sealer, and finally permanent coronal composite resin restoration was completed.

2.3.2. Observation group (pulp revascularization)

The revascularization operation was implemented in strict accordance with the American Association of Endodontists guidelines, divided into four core stages:

(1) Stage 1: Intracanal disinfection and preparation

After access cavity preparation, chemical debridement was taken as the main method, with gentle wall scratching by hand files to remove infected tissue without excessive removal of dentin. The root canal was irrigated sequentially with 1.5% NaOCl (20 mL), sterile saline (10 mL), and 17% EDTA (10 mL) to eliminate infection, remove the smear layer, and release dentin growth factors. The canal was dried with sterile paper points after irrigation.

(2) Stage 2: Blood clot induction

A sterile 25#–30# hand file was passed 2 mm beyond the apical foramen to traumatize periapical tissues and induce apical bleeding gently. After 5–10 minutes of standing, the blood filled the root canal to the cementoenamel junction to form a stable fibrin scaffold. Resorbable collagen matrix was appropriately placed to stabilize the blood clot if necessary.

(3) Stage 3: Coronal tight sealing

After the blood clot stabilized for 10–15 minutes, a 3 mm-thick iRoot BP Plus bioceramic barrier was placed at the canal orifice, covered with 2 mm glass ionomer cement, and finally sealed with composite resin to achieve complete microleakage prevention.

(4) Stage 4: Long-term follow-up monitoring

No secondary intracanal intervention was performed after the one-step operation. Regular follow-up was conducted to monitor lesion healing and root development.

2.4. Observation indicators

Two professional examiners, unblinded, completed clinical and radiographic evaluations at 6, 12, and 24 months postoperatively.

(1) Clinical efficacy

The treatment was successful if there was no pain, swelling, sinus tract, percussion tenderness, or abnormal tooth loosening, and the restoration was intact.

(2) Radiographic efficacy

Image analysis software was used to measure the changes in root length, mid-root and apical dentin wall thickness, and observe the resolution of periapical radiolucent lesions and apical closure.

(3) Treatment duration

The total time from the first treatment to the completion of final permanent restoration was recorded.

2.5. Statistical analysis

SPSS 26.0 software was used for data analysis. Count data (clinical success rate) were expressed as rate (%) and compared by χ^2 test. Measurement data (root growth parameters, treatment duration) were expressed as mean ± standard deviation, and compared by independent-samples *t*-test. $p < 0.05$ was considered statistically significant.

3. Results

All 80 patients completed 24-month follow-up without dropout [5]. The baseline general data of the two groups were consistent and comparable.

3.1. Clinical success rate comparison

At 6 and 12 months postoperatively, there was no significant difference in clinical success rate between the two groups ($p > 0.05$). At 24 months, the clinical success rate of the observation group was 90.0% (36/40), which was significantly higher than 80.0% (32/40) of the control group ($p < 0.05$).

The failure cases in the control group mainly included persistent periapical inflammation, recurrent sinus tract, and root/crown fracture. The failure cases in the observation group were mainly unresolved periapical lesions and mild tooth discoloration, with no tooth fracture **(Table 1)**.

Group	6-month success rate	12-month success rate	24-month success rate
Control group (n = 40)	92. 5% (37/40)	87. 5% (35/40)	80. 0% (32/40)
Observation group (n = 40)	95. 0% (38/40)	92. 5% (37/40)	90. 0% (36/40)

3.2. Radiographic root development comparison

At 24 months of follow-up, the observation group showed significant physiological root development, while the control group had no obvious root growth changes [6]. In the observation group, the average root length increased by 1.52 ± 0.43 mm, the mid-root canal wall thickness increased by 0.45 ± 0.12 mm, and the apical third wall thickness increased by 0.38 ± 0.10 mm. A total of 80% of teeth in the observation group achieved progressive apical closure, and 30% achieved complete apical closure.

In the control group, the root length and wall thickness had only negligible changes, and no cases of spontaneous apical closure were found; only artificial calcified barrier formation was observed. The differences in all root development indicators between the two groups were statistically significant ($p < 0.01$).

3.3. Treatment duration comparison

The treatment cycle of the two groups was significantly different. The control group required an average of 8.5 ± 2.3 outpatient visits, with a total treatment duration of 12.5 ± 3.8 months due to multiple calcium hydroxide replacements and long-term apical barrier observation. The observation group completed all core operations in one visit, with a total treatment duration of only 3.6 ± 0.5 months, which was far shorter than the control group ($p < 0.01$).

3.4. Adverse reactions

No severe complications such as tooth loss or severe infection occurred in either group. The control group had 3 cases of tooth discoloration and 2 cases of transient postoperative sensitivity [7]. The observation group had 6 cases of mild crown discoloration and 2 cases of temporary sinus tract, which healed after symptomatic intervention, with no ankylosis or root resorption occurring.

4. Discussion

This prospective randomized controlled trial confirmed that pulp revascularization has comprehensive clinical advantages over traditional apexification in the treatment of immature permanent teeth with pulp necrosis and periapical lesions. In terms of short-term efficacy, both treatments can effectively control clinical symptoms and cure periapical inflammation. However, with the extension of follow-up time, the long-term stability of revascularization is significantly better than apexification, which is mainly attributed to its unique regenerative repair mechanism [8].

The core defect of apexification is that it only realizes "infection control and apical sealing" but cannot repair defective root tissues. Long-term application of high-pH calcium hydroxide will degrade the organic matrix of dentin, reduce root toughness, and significantly increase the risk of cervical root fracture in immature teeth. In this study, 3 fracture failure cases occurred in the control group within 2 years, which was the main cause of the decline in its long-term success rate [9]. In contrast, pulp revascularization uses autologous blood clot stem cells and growth factors to promote the regeneration of dentin-like tissues, thicken root walls, repair defective root structures, and fundamentally improve the mechanical stability of immature teeth, so no fracture failure occurred in the observation group.

The most prominent advantage of revascularization is its ability to restore the physiological development of roots. The study showed that the roots of the observation group continued to lengthen and thicken within 2 years, with an average root growth rate of 12–15%, which is consistent with the natural root development law. This confirms that the regenerated tissue after revascularization has the biological characteristics of normal pulp tissue, can secrete mineralized matrix, and realizes the continuous maturation of immature roots [10]. The EDTA irrigation used in the operation can effectively release dentin-bound growth factors, and the blood clot scaffold provides a good microenvironment for stem cell proliferation and differentiation, which is the key to successful regeneration.

In terms of clinical efficiency, revascularization greatly optimizes the treatment process. Traditional apexification requires multiple return visits for drug replacement, with a treatment cycle of more than one year on average. Long-term temporary sealing will increase the risk of microleakage and reinfection, and repeated visits will also reduce patient compliance. The one-stop revascularization operation shortens the treatment cycle to about 3 months, significantly reduces the number of outpatient visits and clinical burden, and is more suitable for pediatric patients with poor cooperation.

It is worth noting that revascularization has strict indications, and it is not applicable to teeth with severe crown destruction, narrow apical diameter that cannot induce bleeding, or active root resorption. In such cases, apexification is still a reliable alternative treatment. Therefore, clinicians need to select individualized treatment schemes according to tooth condition and apical morphology.

This study has certain limitations. First, the 24-month follow-up period cannot fully evaluate the ultra-long-term prognosis, such as late root fracture and tooth vitality stability. Second, the regenerated tissue was not histologically verified due to ethical restrictions. Third, this is a single-center study, and the conclusion needs to be further verified by multi-center large-sample trials. In the future, the regenerative mechanism of revascularization and the optimization of surgical protocols can be further explored to improve the success rate of clinical treatment.

5. Conclusion

For immature permanent teeth with pulp necrosis and chronic periapical periodontitis, pulp revascularization is superior to traditional apexification. It can not only obtain a higher long-term clinical success rate and better periapical lesion healing effect, but also effectively promote continuous root development, increase root mechanical strength, and greatly shorten the treatment cycle. Under the premise of strict indication screening and standardized operation, revascularization should be the first-line treatment for such diseased teeth, which has high clinical promotion value.

Disclosure statement

The author declares no conflict of interest.

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