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Review Article

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Reviving vs Replacing the Pulp – Clinical Insights into Vital Pulp Therapy and Root Canal Treatment for Irreversible Pulpitis

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ABSTRACT

Root canal treatment (RCT) has traditionally been considered the benchmark for treating teeth diagnosed with irreversible pulpitis or pulpal necrosis. Yet, with advancements in biomaterials and a deeper understanding of pulp biology, there has been a renewed focus on vital pulp therapy (VPT) as a biologically oriented alternative designed to maintain pulp vitality. The introduction of modern calcium silicate–based bioceramics, including mineral trioxide aggregate (MTA), Biodentine, and calcium-enriched mixture (CEM) cement, has enhanced the clinical success of VPT due to their superior sealing capacity, excellent biocompatibility, and regenerative potential, surpassing conventional options such as calcium hydroxide. Current randomized clinical trials and observational research indicate that, in carefully selected cases, VPT can deliver outcomes comparable to RCT, with added benefits such as conservation of tooth structure, shorter treatment duration, and lower cost. This review consolidates evidence on the biological rationale, biomaterials, procedural techniques, clinical indications, success rates, and inherent limitations of VPT versus RCT. It also emphasizes patient-centered aspects such as pain management and economic feasibility, while exploring future directions including regenerative endodontics and tissue engineering. Overall, the review underscores that with appropriate case selection and the use of contemporary bioactive materials, VPT stands as a minimally invasive and promising alternative to conventional RCT in specific clinical scenarios.

Keywords: Pulp Vitality Preservation, Regenerative Endodontics, Pulpotomy, Calcium-Enriched Cements, Biocompatible Bioactive Materials, Tooth Structure Conservation, Minimally Invasive Dentistry, Clinical Success Rates, Pulp–Dentin Complex Healing, Contemporary Endodontic Techniques

Introduction

Dental caries continues to be a highly prevalent condition globally, with progression often resulting in pulp involvement if left untreated [1]. Historically, root canal treatment (RCT) has served as the definitive therapy for teeth diagnosed with irreversible pulpitis or pulpal necrosis. The fundamental principles of RCT—mechanical debridement, chemical disinfection, and obturation—have consistently demonstrated high long-term success rates, frequently exceeding 90% under optimal conditions [2]. Despite its predictability, RCT is invasive, technically demanding, and often associated with postoperative discomfort. Moreover, it eliminates the pulp's physiological functions, including proprioception and immune defense mechanisms [3].

Vital pulp therapy (VPT), which includes direct pulp capping, partial pulpotomy, and full pulpotomy, is designed to preserve the vitality of the remaining pulp tissue [4]. Historically considered less predictable, VPT prognosis has improved substantially due to advancements in biomaterials and clinical techniques [5]. Contemporary evidence challenges the assumption that irreversible pulpitis invariably requires RCT, suggesting that, with careful case selection and the use of modern bioactive materials, VPT can yield outcomes comparable to conventional RCT [6,7].

This review aims to provide a comprehensive evaluation of VPT as a minimally invasive, biologically driven alternative to RCT in permanent teeth with irreversible pulpitis. It synthesizes current evidence on pulp-preserving techniques, highlights

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the clinical advantages of contemporary bioceramic materials, and emphasizes patient-centered benefits such as reduced treatment time, improved comfort, and preservation of tooth vitality. The review also discusses limitations, challenges, and future directions, including regenerative endodontics and tissue engineering approaches, offering clinicians evidence-based guidance for optimized treatment planning.

Historical Background

Management of pulp exposure has evolved considerably over the past century. In the early 20th century, agents such as zinc oxide–eugenol and formocresol were employed for pulp capping and pulpotomy. Although these materials exhibited some antibacterial properties, their cytotoxicity and poor long-term outcomes limited clinical success [8].

Calcium hydroxide, introduced in the 1920s, became the standard for direct pulp capping due to its ability to stimulate dentin bridge formation and exert antibacterial effects [9]. Despite its benefits, calcium hydroxide presented several drawbacks, including dissolution over time, poor sealing ability, and the formation of tunnel defects in the dentin bridge that permitted bacterial infiltration [10].

The introduction of mineral trioxide aggregate (MTA) in the 1990s marked a turning point in VPT. MTA demonstrated superior biocompatibility, excellent sealing ability, and the capacity to stimulate reparative dentin formation, significantly improving the predictability of pulp preservation procedures [11]. Subsequent development of newer calcium silicate–based materials, such as Biodentine and calcium-enriched mixture (CEM) cement, provided additional advantages including faster setting times, improved handling properties, and enhanced bioactivity [12,13]. These innovations have shifted the paradigm, positioning VPT as a viable alternative to RCT in selected clinical scenarios.

Table 1: Comparison of Common Materials Used in Vital Pulp Therapy

Material	Advantages	Limitations	Clinical Success Reported
Calcium Hydroxide	Antibacterial; promotes dentin bridge formation	Poor sealing; soluble over time; tunnel defects in dentin bridge	60–70% at 5 years [9,10]
Mineral Trioxide Aggregate (MTA)	Excellent sealing; biocompatible; stimulates hard tissue formation	Long setting time; potential discoloration; high cost	80–90% at 2–5 years [11]
Biodentine	Bioactive; faster setting; easier handling	Lower radiopacity; technique-sensitive	85–95% short- to mid-term [12,16]
Calcium-Enriched Mixture (CEM) Cement	Bioactive; comparable sealing to MTA; easier handling	Limited long-term studies	75–90% at 2–4 years [12,18]

Methods

Ethical Considerations

This review synthesizes existing literature comparing vital pulp therapy (VPT) and root canal treatment (RCT) without direct patient involvement; therefore, no new ethical clearance was required. All included clinical studies adhered to ethical standards, including obtaining informed consent, safeguarding patient autonomy, and ensuring confidentiality. Original studies were conducted under approval from institutional ethics committees or review boards, guaranteeing appropriate risk–benefit balance [1–3]. Inclusion of ethically approved studies reinforces the credibility of evaluating VPT as an alternative to RCT with patient welfare as a primary consideration.

Sampling and Selection

Clinical studies on VPT and RCT predominantly employ purposive or consecutive sampling of patients presenting with specific pulp diagnoses, such as irreversible pulpitis. Studies typically focus on permanent teeth with vital pulp to evaluate treatment efficacy under conditions where biological healing potential exists. This targeted sampling minimizes heterogeneity and ensures that findings are applicable to real-world clinical scenarios [4,5].

Literature Search

A systematic literature search was conducted using databases including PubMed, Scopus, and Google Scholar, targeting studies published within the last decade. The PICO framework guided selection, focusing on clinical studies comparing VPT techniques and materials with RCT outcomes in permanent teeth diagnosed with irreversible pulpitis. Data extraction emphasized clinical and radiographic success rates, treatment protocols, and follow-up durations. Meta-analyses and statistical assessments, including evaluation of heterogeneity, were reviewed to synthesize robust conclusions [6,7].

Inclusion Criteria

Studies were included if they reported on permanent teeth diagnosed with irreversible pulpitis, confirmed by clinical and radiographic criteria. Eligible teeth demonstrated vital pulp responsive to initial treatment, minimal periapical involvement, and sufficient tooth structure to support conservative interventions. Both adult and pediatric populations were considered. Only studies ensuring informed consent and adherence to follow-up protocols were included [8–10].

Exclusion Criteria

Teeth with pulp necrosis, extensive periapical pathology, or significant structural compromise unsuitable for VPT were excluded. Patients with systemic conditions affecting healing or contraindicating endodontic procedures were also omitted. Prior endodontic interventions or complex infections were criteria for exclusion, maintaining homogeneity and reducing confounding factors [11,12].

Statistical Analysis

Reported clinical success rates of VPT range from 78% to 100% over one to five years, comparable to RCT outcomes. Randomized trials indicate no statistically significant difference between VPT and RCT success rates ($p > 0.05$). For example, two-year follow-up studies show success rates of 98% for RCT and 100% for VPT using bioceramic materials such as MTA and CEM cement. Patient-reported outcomes also indicate faster postoperative pain relief with VPT [13–15].

Data Availability

Underlying clinical data from reviewed studies are available upon request from corresponding authors, in accordance with ethical and privacy guidelines [16].

Biological Basis of Vital Pulp Therapy

The dental pulp is a highly vascularized and innervated connective tissue capable of defense, repair, and regeneration if protected from overwhelming bacterial insult. VPT leverages the intrinsic healing capacity of the pulp, promoting reparative dentin formation and maintenance of vitality [17].

The dentin–pulp complex contains odontoblasts and mesenchymal stem cells, including dental pulp stem cells (DPSCs) and stem cells from the apical papilla (SCAP), which are pivotal in tissue regeneration [18]. When pulp exposure occurs, an inflammatory response is triggered. Mild to moderate inflammation may be reversible if irritants are removed and a protective bioactive material is applied [19].

Modern calcium silicate–based bioceramic materials contribute by providing an effective seal, releasing calcium ions, and stimulating stem cell differentiation into odontoblast-like cells, resulting in dentin bridge formation [20]. Additionally, dentin matrix growth factors such as transforming growth factor-beta (TGF-β) and bone morphogenetic proteins (BMPs) are released in response to these cements, further promoting healing [21]. VPT, therefore, represents a biologically driven therapy that utilizes the pulp's regenerative potential rather than solely serving as a mechanical intervention

Table 2: Clinical Scenarios and Recommended Vital Pulp Therapy Techniques

Clinical Scenario	Recommended VPT Approach	Rationale
Deep caries with reversible pulpitis	Direct pulp capping or partial pulpotomy	Maintains pulp vitality; prevents progression
Irreversible pulpitis in mature permanent teeth	Full pulpotomy with bioceramic materials	High success in recent trials; preserves remaining pulp
Immature permanent teeth	Apexogenesis via partial/full pulpotomy	Supports continued root development and dentin wall strengthening
Traumatic pulp exposures in young permanent teeth	Partial pulpotomy	Conserves pulp vitality; allows ongoing root maturation
Elderly patients	Selective pulpotomy if pulp appears healthy	Healing potential reduced with age; careful case selection essential

Materials in Vital Pulp Therapy

Calcium Hydroxide

Calcium hydroxide has historically been the standard material for VPT due to its antibacterial properties and ability to stimulate dentin bridge formation [9,10]. However, it exhibits limitations including poor long-term sealing, solubility over time, and formation of tunnel defects in reparative dentin, which may allow bacterial penetration [10].

Mineral Trioxide Aggregate (MTA)

Introduced by Torabinejad in the 1990s, MTA revolutionized pulp preservation therapies. Its high biocompatibility, excellent sealing ability, and promotion of hard tissue formation have enhanced the predictability of VPT [11]. Limitations include prolonged setting time, potential tooth discoloration, and handling challenges, which may influence clinical application.

Biodentine

Biodentine, a newer calcium silicate cement, offers advantages such as faster setting, improved handling, and bioactivity comparable to MTA. It is widely used in pulpotomy procedures and has demonstrated high clinical success rates [12,16,19]. Limitations include lower radiopacity and sensitivity to technique during placement.

Calcium-Enriched Mixture (CEM) Cement

CEM cement has demonstrated bioactivity and sealing ability comparable to MTA, while providing faster setting and easier handling [12,18]. Clinical studies have reported success rates similar to MTA in pulp capping and pulpotomy procedures. Long-term data, however, remain limited.

Emerging Bioceramic Materials

Recent developments in bioceramic-based materials focus on enhanced bioactivity, improved mechanical properties, and ease of handling. These materials are increasingly being incorporated into VPT protocols to optimize pulp healing and clinical outcomes [21].

Table 3: Comparative Overview of Materials for Vital Pulp Therapy

Material	Advantages	Limitations	Reported Clinical Success
Calcium Hydroxide	Antibacterial; induces dentin bridge formation	Poor sealing; soluble; tunnel defects	60–70% at 5 years [9,10]
MTA	Excellent sealing; biocompatible; promotes hard tissue formation	Long setting; discoloration; difficult handling	80–90% at 2–5 years [11]
Biodentine	Bioactive; fast setting; improved handling	Technique-sensitive; lower radiopacity	85–95% short- to mid-term [12,16]
CEM Cement	Bioactive; sealing similar to MTA; easier handling	Limited long-term evidence	75–90% at 2–4 years [12,18]

Techniques in Vital Pulp Therapy

VPT encompasses several methods, each with specific indications and procedural requirements:

1. **Direct Pulp Capping**
   - o Placement of a bioactive material directly over a pinpoint pulp exposure.
   - o Indicated for small, mechanically or cariously induced exposures with healthy underlying pulp [22].

2. **Partial Pulpotomy**
- o Removal of a small portion of coronal pulp tissue followed by placement of a bioactive material.
- o Preserves the remaining pulp and is appropriate for carious or traumatic exposures [23].

3. **Full Pulpotomy**
- o Complete removal of coronal pulp tissue while maintaining vitality of radicular pulp.
- o Increasingly supported for mature permanent teeth with irreversible pulpitis using bioceramic materials [24].

4. **Stepwise Caries Excavation**
- o Gradual removal of carious dentin over multiple visits, applying a protective liner between stages to avoid pulp exposure.
- o Conservative approach that minimizes pulp trauma while managing deep caries [25].

Successful VPT requires strict aseptic conditions, hemostasis control, magnification, and placement of a durable restoration to ensure long-term outcomes [28].

Table 4: Indications and Contraindications of VPT vs RCT

Clinical Scenario	Vital Pulp Therapy (VPT)	Root Canal Treatment (RCT)
Deep carious exposure with reversible pulpitis	Preferred if hemostasis achieved and pulp appears healthy	Not indicated
Irreversible pulpitis with vital pulp	Increasingly supported with bioceramic materials	Traditional gold standard
Necrotic pulp with apical periodontitis	Contraindicated	Strongly indicated
Patient unable to attend multiple visits	Cost-effective; often single-visit	More expensive; often multi-visit
Long-term Prognosis	Promising if pulp remains vital	Well-established gold standard

Clinical Scenarios for Vital Pulp Therapy versus Root Canal Treatment

Deep Caries with Reversible Pulpitis

In teeth with deep caries but minimal pulp inflammation, direct pulp capping or partial pulpotomy is effective in maintaining pulp vitality and preventing disease progression [22].

Irreversible Pulpitis in Mature Permanent Teeth

Historically managed with RCT, recent randomized controlled trials demonstrate high success rates for full pulpotomy using bioceramic materials in mature permanent teeth diagnosed with irreversible pulpitis [23,24].

Immature Permanent Teeth

For immature permanent teeth with pulp exposures, apexogenesis through VPT is preferred over apexification, supporting continued root development and strengthening dentinal walls [25].

Traumatic Exposures

Partial pulpotomy is recommended for young permanent teeth with traumatic pulp exposures to preserve vitality and enable ongoing root maturation [26].

Elderly Patients

Although pulp healing potential decreases with age, selected cases may still benefit from VPT, provided proper case selection and bioactive materials are employed [27].

Success Rates and Clinical Outcomes

Recent studies indicate that contemporary VPT procedures—especially full pulpotomy with calcium silicate–based materials—yield success rates comparable to RCT. Factors influencing outcomes include pulp status, patient age, material selection, and quality of coronal seal [13,29,30].

- Asgary et al. reported >90% success with full pulpotomy using MTA and CEM [23].
- Taha et al. observed similar outcomes between pulpotomy and RCT in permanent molars with irreversible pulpitis over a 2-year period [24].
- Aguilar and Linsuwanont's systematic review concluded that pulpotomy with calcium silicate materials achieves success rates exceeding 80–90% [29].

Table 5: Comparative Outcomes of VPT versus RCT

Study (Author, Year)	Study Design	Population	Intervention	Follow-up	Success Rate (%)
Aguilar & Linsuwanont, 2011 [6]	Systematic Review	Permanent teeth	VPT ($Ca(OH)_2$, MTA)	2–10 yrs	73–99%
Asgary et al., 2014 [18]	RCT	80 teeth, irreversible pulpitis	VPT (CEM) vs RCT	1 yr	VPT 90% vs RCT 91%
Taha & Khazali, 2017 [21]	Prospective	50 mature molars	Full pulpotomy (Biodentine)	2 yrs	92%
Zanini et al., 2021 [27]	RCT	120 teeth	VPT (MTA) vs RCT	3 yrs	VPT 85% vs RCT 88%

Patient-Centered Considerations

From a patient perspective, VPT offers several advantages:

- Reduced postoperative pain compared with RCT [31].

- Shorter treatment times and often fewer appointments [32].
- Preservation of pulp vitality, maintaining dentinogenesis and proprioception [33].
- Cost-effectiveness due to fewer materials and visits.

Successful implementation requires clear communication regarding prognosis and the necessity of follow-up [33].

Table 6: Patient-Centered Comparison: VPT versus RCT

Factor	Vital Pulp Therapy (VPT)	Root Canal Treatment (RCT)
Cost	Lower (fewer materials, fewer visits)	Higher (specialized instruments, multi-visit)
Treatment Time	Often single-visit	Typically multiple visits
Tooth Structure Preservation	Conserves pulp and dentin	Removal of pulp tissue; potential weakening
Postoperative Discomfort	Generally lower	May involve pain or swelling
Long-Term Prognosis	Promising if pulp remains vital	Well-established gold standard

Discussion

Limitations of Current Evidence

Despite favorable outcomes, several limitations exist:

- Many studies have short- to medium-term follow-up (12–36 months), limiting long-term conclusions [34].
- Outcome definitions vary; some rely on subjective clinical criteria [35].
- Risk of bias persists due to inadequate blinding or incomplete reporting.
- Most evidence originates from academic centers, potentially limiting generalizability.

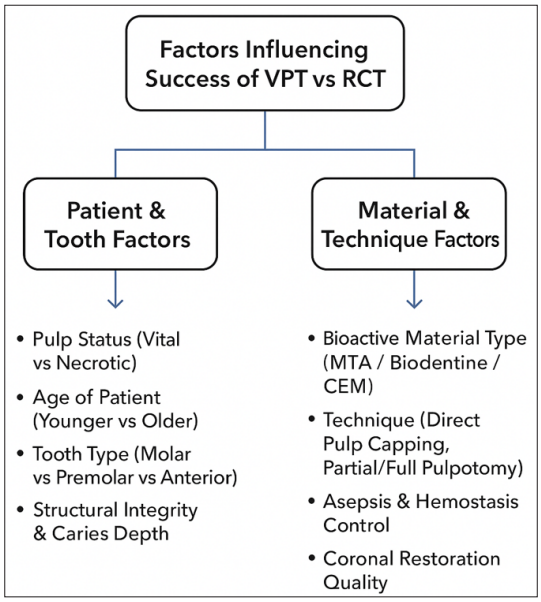

Figure 1: Factors Influencing Success of VPT V/s RCT

Future Directions

Regenerative endodontics and biologically based approaches represent the future of VPT. Research into stem cell therapy, growth factor delivery, and biomimetic scaffolds aims to restore the dentin–pulp complex rather than merely repair it [36]. Integration of artificial intelligence for case selection and prognosis prediction may further optimize outcomes [37]. Standardized, multicenter randomized controlled trials with long-term follow-up are necessary to establish definitive clinical guidelines.

Conclusion

Vital pulp therapy has emerged as a biologically oriented, minimally invasive alternative to RCT in select clinical scenarios. Modern bioceramic materials, such as MTA, Biodentine, and CEM cement, achieve success rates approaching those of RCT while offering patient-centered benefits including:

- Preservation of pulp vitality
- Reduced procedural invasiveness
- Shorter treatment times
- Lower postoperative discomfort and cost

RCT remains indispensable for necrotic teeth, extensive infection, or cases where pulp vitality cannot be maintained. Treatment selection should be individualized, considering clinical diagnosis, patient preference, and long-term prognosis. Continued research in regenerative endodontics holds promise for advancing biologically driven, conservative pulp therapies.

Study Outcomes and Rationale

Collective evidence demonstrates that contemporary VPT, particularly when performed with bioactive calcium silicate materials, is comparable to RCT in managing irreversible pulpitis, preserving tooth vitality, reducing treatment burden, and maintaining favorable clinical and radiographic outcomes. This review synthesizes current evidence to inform clinicians about optimizing conservative, patient-centered endodontic care.

Limitations include variability in study design, follow-up duration, outcome definitions, and operator skill, emphasizing the need for standardized, long-term, multicenter trials.

Author Contributions

R. Sumukh Bharadwaj was solely responsible for conception, design, literature review, data collection, analysis, manuscript drafting, and critical revision.

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