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Vital Pulp Therapy: Contemporary Concepts, Materials, and Clinical Outcomes — A Narrative Review

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Abstract
Vital pulp therapy (VPT) encompasses a spectrum of biologically based, minimally invasive procedures — including indirect pulp capping, direct pulp capping, and partial or full pulpotomy — that aim to preserve the vitality of a pulp exposed to, or threatened by, caries, trauma, or iatrogenic injury. Over the past two decades, VPT has undergone a substantial conceptual shift, moving away from the traditional paradigm in which any sign of pulp exposure or symptomatic pulpitis mandated root canal treatment, toward an evidence-based, tissue-preserving philosophy supported by the introduction of bioactive calcium silicate-based materials. This narrative review synthesizes current literature on the biological rationale, diagnostic criteria, clinical techniques, and material science underlying VPT, and appraises reported outcomes across primary and permanent dentitions. Calcium hydroxide, long regarded as the historical gold standard, has been progressively superseded by hydraulic calcium silicate cements such as mineral trioxide aggregate (MTA), Biodentine, and related bioceramic formulations, which demonstrate superior sealing ability, biocompatibility, and induction of reparative dentinogenesis. Contemporary evidence, including recent systematic reviews and clinical practice guidelines from the American Academy of Pediatric Dentistry and the European Society of Endodontology, indicates that indirect pulp treatment, direct pulp capping, and pulpotomy achieve comparably high success rates in teeth with normal pulp or reversible pulpitis, and that full pulpotomy can be a predictable option even in select cases of symptomatic irreversible pulpitis. Factors influencing prognosis include accurate pulpal diagnosis, hemorrhage control, selection of a bioactive capping material, and coronal seal integrity. Persisting controversies include the classification of pulpal disease based on clinical symptoms alone, the optimal depth of caries removal, material-related tooth discoloration, and the long-term fate of retained pulp tissue. This review concludes that VPT represents a scientifically sound, minimally invasive alternative to root canal treatment for appropriately selected cases and outlines directions for future research, including regenerative and bioactive material development.

Keywords
Vital Pulp Therapy; Pulp Capping; Pulpotomy; Calcium Silicate Cements; Mineral Trioxide Aggregate; Biodentine.

Introduction

Preservation of pulp vitality has re-emerged as a central objective in restorative and endodontic practice. For much of the twentieth century, a carious or traumatic pulp exposure — particularly one accompanied by pain — was widely regarded as an indication for pulpectomy and root canal treatment, based on the assumption that an inflamed or exposed pulp could not reliably heal. This assumption has been challenged by a growing body of histological, microbiological, and

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clinical evidence demonstrating that the dental pulp possesses considerable reparative and regenerative capacity when the causative irritant is removed, hemorrhage is controlled, and an adequately sealing, bioactive material is placed over the wound.

Vital pulp therapy (VPT) is the collective term for the family of procedures designed to protect and preserve pulp tissue that has been exposed to, or is at risk from, caries, trauma, or operative intervention. These procedures include stepwise/selective caries excavation, indirect pulp capping (IPC), direct pulp capping (DPC), partial pulpotomy (Cvek pulpotomy), and full (cervical) pulpotomy, applied across both the primary and permanent dentitions. The unifying biological principle is the retention of healthy, vital pulp tissue capable of continued dentinogenesis, proprioception, and, in immature permanent teeth, ongoing root development (apexogenesis), in contrast to root canal treatment, which sacrifices the pulp entirely.

The clinical resurgence of VPT has been driven by three converging developments. First, an improved understanding of pulp biology has shown that the outward clinical signs traditionally used to diagnose irreversible pulpitis — such as lingering pain — correlate only imperfectly with the true histological state of the pulp[1], meaning that some clinically "irreversible" cases nonetheless retain reparative potential. Second, the introduction of hydraulic calcium silicate cements, beginning with mineral trioxide aggregate (MTA) in the 1990s and followed by tricalcium silicate-based materials such as Biodentine and a range of bioceramic putties and resin-modified formulations, has provided materials with superior sealing, biocompatibility, and bioactivity compared with the calcium hydroxide preparations that dominated twentieth-century practice[2]. Third, updated clinical practice guidelines issued by bodies such as the American Association of Endodontists (AAE), the American Academy of Pediatric Dentistry (AAPD), and the European Society of Endodontology (ESE) have formally endorsed VPT — including pulpotomy in mature teeth with signs of irreversible pulpitis — as a legitimate, evidence-supported alternative to root canal treatment in appropriately selected cases[3-5].

Despite this progress, considerable variability remains in clinical decision-making, terminology, technique, and material selection, and areas of genuine scientific uncertainty persist. The objective of this narrative review is to synthesize the current evidence base on the biological rationale, diagnostic framework, clinical techniques, and materials used in vital pulp therapy, and to critically appraise reported treatment outcomes in both the primary and permanent dentitions, with a view to informing contemporary evidence-based clinical practice.

Materials and Methods

Review Design

This article is structured as a narrative review of the peer-reviewed dental and endodontic literature on vital pulp therapy. As a narrative (rather than systematic) review, no formal protocol was registered; however, a structured and transparent search and selection process was followed to minimize selection bias and to ensure the currency and relevance of the evidence discussed.

Literature Search Strategy

A literature search was conducted across major biomedical and dental databases, including PubMed/MEDLINE, Scopus, and the Cochrane Library, supplemented by hand-searching of key endodontic and pediatric dentistry journals and review of clinical practice guidelines issued by professional bodies (American Association of Endodontists; American Academy of Pediatric Dentistry; European Society of Endodontology). Search terms included combinations of: "vital pulp therapy," "pulp capping," "pulpotomy," "indirect pulp treatment," "calcium hydroxide," "mineral trioxide aggregate," "calcium silicate cement," "Biodentine," "bioceramic," "reversible pulpitis," "irreversible pulpitis," and "apexogenesis." Reference lists of identified articles, systematic reviews, and meta-analyses were screened to identify additional relevant sources.

Eligibility Criteria

Priority was given to systematic reviews, meta-analyses, randomized controlled trials, prospective cohort studies, and consensus/position statements published within approximately the last fifteen years, supplemented by foundational historical studies of recognized importance to the development of the field. Articles addressing diagnosis, technique, material properties, or clinical/radiographic outcomes of IPC, DPC, or pulpotomy in primary or permanent teeth were considered eligible. Case

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reports, non-peer-reviewed sources, and studies not published in English were generally excluded unless of particular historical or conceptual significance.

Data Synthesis

Given the narrative format, data were synthesized qualitatively and thematically rather than through formal statistical pooling. Findings are organized around diagnosis and case selection, clinical technique, capping/pulpotomy materials, and reported outcomes, with quantitative results from systematic reviews and meta-analyses cited where available to support key claims.

Ethical Considerations

As this is a narrative review of previously published literature involving no direct patient contact, data collection, or intervention by the authors, formal ethical approval and informed consent were not required. Where original studies discussed within this review involved human participants, readers are directed to the cited primary sources for details of the ethical approvals and consent procedures obtained by those investigators.

Results and Discussion

Biological Rationale for Vital Pulp Therapy

The dental pulp is a richly vascularized, innervated connective tissue capable of mounting a defensive and reparative response to injury. Following a carious or mechanical insult, odontoblasts and pulpal progenitor cells can be stimulated to deposit tertiary (reactionary or reparative) dentine, forming a mineralized barrier that isolates the pulp from further irritation. This reparative capacity underpins the biological rationale for VPT: if the causative irritant (bacterial biofilm, in most cases) is adequately removed, hemorrhage is controlled, and the wound is sealed with a biocompatible, bioactive material that prevents microleakage, the pulp can heal, remain vital, and continue to function.

A central and long-debated issue is the reliability of clinical pulpal diagnosis. Traditional diagnostic categories — normal pulp, reversible pulpitis, symptomatic or asymptomatic irreversible pulpitis, and pulp necrosis — are derived largely from patient-reported symptoms (spontaneous pain, nocturnal pain, lingering thermal sensitivity) rather than direct histological assessment[6], and correlation between clinical symptomatology and actual pulp histopathology has historically been shown to be imperfect[1]. This mismatch is clinically important because it implies that pulps clinically labeled "irreversibly" inflamed may, in a proportion of cases, retain sufficient healthy tissue at the site of exposure to heal following partial or full pulpotomy — a finding that underlies the more conservative pulpotomy-first approach now advocated in several contemporary guidelines for mature teeth with symptoms of irreversible pulpitis[7,8].

Diagnostic Framework and Case Selection

Appropriate case selection is widely regarded as the single most important determinant of VPT success. A comprehensive diagnostic work-up should incorporate:

- Patient history: nature, duration, and pattern of pain (spontaneous vs. stimulus-evoked; lingering vs. transient); history of trauma or previous restorative intervention.
- Clinical examination: depth and extent of caries or fracture, quality of remaining tooth structure, restorability, periodontal status, and mobility.
- Pulp sensibility and vitality testing: cold, electric pulp testing, and, where available, adjunctive tests such as laser Doppler flowmetry or pulse oximetry.
- Radiographic assessment: periapical radiographs (and cone-beam computed tomography where indicated) to evaluate caries depth, root development stage, periapical status, and the presence or absence of internal/external resorption.
- Intraoperative assessment: the character and duration of hemorrhage from an exposed pulp is increasingly regarded as a more reliable real-time indicator of the true inflammatory status of the pulp than preoperative symptoms alone; hemostasis achieved within a few minutes using an appropriate irrigant is generally considered a favorable prognostic sign.

Contemporary guidelines converge on the principle that normal pulp and reversible pulpitis represent favorable indications for the full spectrum of VPT procedures, while symptomatic irreversible pulpitis

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in mature permanent teeth is increasingly recognized as amenable to full pulpotomy in carefully selected cases, provided hemostasis is achieved and no radiographic or clinical evidence of pulp necrosis or apical periodontitis is present[4,5,9]. Pulp necrosis remains a contraindication to VPT, warranting either root canal treatment or, in immature permanent teeth, regenerative endodontic procedures.

Clinical Techniques

Vital pulp therapy comprises several distinct, technique-specific modalities spanning stepwise excavation through to full pulpotomy, each with its own clinical protocol and evidence base[10].

Stepwise and selective caries excavation. In deep caries approaching, but not yet involving, the pulp, selective (partial) caries removal — leaving a thin layer of caries-affected (but not infected) dentine over the pulp to avoid exposure — followed by restoration has been shown to reduce the risk of iatrogenic pulp exposure compared with complete caries removal, without compromising caries arrest, provided the restoration achieves an adequate coronal seal[11].

Indirect pulp capping (IPC/IPT). A bioactive liner or cement is placed over the residual thin dentine layer left after selective excavation, in either a one-stage or, historically, a two-stage (stepwise) protocol, followed by a well-sealed definitive or provisional restoration.

Direct pulp capping (DPC). Following a small, localized pulp exposure in an otherwise asymptomatic or minimally symptomatic tooth, hemorrhage is controlled — sodium hypochlorite irrigation is now strongly recommended over saline for hemostasis in several guideline documents[4] — and a bioactive capping material is placed directly over the exposure site, followed by a definitive restoration.

Partial pulpotomy (Cvek pulpotomy). A limited volume (typically 2–4 mm) of coronal pulp tissue immediately adjacent to and including the exposure site is removed under copious irrigation to reach non-hemorrhagic, healthier tissue, which is then capped with a bioactive material; this technique is particularly well established for traumatic crown fractures with pulp exposure in young permanent teeth, and has also shown favorable outcomes when applied to mature teeth with clinical signs of irreversible pulpitis[12].

Full (cervical) pulpotomy. The entire coronal pulp is removed to the level of the root canal orifices, hemostasis is achieved, and the remaining radicular pulp stump is capped with a bioactive material before restoration. Full pulpotomy is the technique most extensively studied for mature permanent teeth presenting with symptoms of irreversible pulpitis, and for cariously exposed primary molars[13,14]. Across all techniques, meticulous attention to asepsis (rubber dam isolation), atraumatic tissue handling, adequate hemorrhage control, and a coronal restoration capable of providing a long-term bacteria-tight seal are consistently identified in the literature as critical determinants of outcome, arguably of comparable or greater importance than the specific capping material selected.

Materials Used in Vital Pulp Therapy

Calcium hydroxide. Calcium hydroxide ($Ca(OH)_2$), introduced to clinical dentistry in the early twentieth century, was for decades the material of choice for pulp capping and pulpotomy owing to its high pH, antibacterial activity, and ability to stimulate a calcific (dentine bridge) barrier. However, calcium hydroxide-formed dentine bridges are frequently porous and discontinuous, the material is soluble and can degrade over time, and it has
relatively poor long-term sealing ability against microleakage — limitations that have been associated with comparatively higher long-term failure rates than newer bioactive alternatives[15].

Mineral trioxide aggregate (MTA). MTA, a hydraulic calcium silicate cement introduced in the 1990s, set a new benchmark for VPT materials[2]. It exhibits excellent biocompatibility, induces the formation of a more continuous and homogeneous hard-tissue (dentine) bridge than calcium hydroxide, and provides a superior long-term seal. Its principal clinical drawbacks include a long

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setting time, handling difficulty, relatively high cost, and — importantly — a well-documented propensity to cause coronal tooth discoloration, largely attributed to its bismuth oxide radiopacifier[13], which is a significant concern in anterior aesthetic zones.

Biodentine and other tricalcium silicate cements. Biodentine, a fast-setting tricalcium silicate-based material developed to address the handling limitations of MTA, offers comparable or superior biological performance, including stimulation of odontoblast-like cell differentiation and biomineralization[16], with a substantially shorter setting time and, notably, an absence of bismuth oxide, which has been associated in comparative studies with markedly less tooth discoloration than MTA[15].

Resin-modified calcium silicate materials. More recently, light-curable resin-modified calcium silicate materials (e.g., TheraCal LC and its successor formulations) have been introduced to combine bioactivity with the convenience of immediate light-curing and improved handling. Evidence on their biological performance remains more contested than for MTA or Biodentine, with some studies reporting greater inflammatory response and reduced biocompatibility relative to non-resin-modified calcium silicate cements; current systematic reviews suggest more cautious use, favoring indirect pulp capping applications over direct pulp capping or pulpotomy pending further clinical evidence[17].

Other and emerging materials. Additional bioceramic putties, nanomaterial-enhanced formulations, and adhesive/self-etch systems combined with resin-based capping materials have also been investigated, alongside continued interest in growth factor- and stem cell-based regenerative approaches, although these remain predominantly at the preclinical or early clinical research stage[18].

Clinical Outcomes

Contemporary systematic reviews and meta-analyses, including those underpinning recent GRADE-based clinical practice guidelines from the AAPD covering evidence through mid-2024, report consistently favorable outcomes for VPT in teeth diagnosed with normal pulp or reversible pulpitis: at approximately 24 months, indirect pulp treatment, direct pulp capping, partial pulpotomy, and full pulpotomy have each demonstrated success rates in the region of roughly 90–97%, without statistically significant differences between techniques in this diagnostic category[4,9]. In permanent teeth undergoing direct pulp capping with calcium silicate cement, indirect pulp treatment has shown success broadly comparable to direct pulp capping at 36 months[9]. Encouragingly, full pulpotomy has also been reported as a successful treatment option for teeth diagnosed with symptomatic irreversible pulpitis, supporting the more conservative, pulp-preserving approach increasingly reflected in current guidance[7,19], although partial and full pulpotomy have generally shown significantly higher success than direct pulp capping specifically for traumatic pulp exposures[20]. Comparative outcome data across different bioactive capping agents further support the broadly favorable prognosis associated with contemporary VPT protocols[21,22].

Material choice influences both biological and aesthetic outcomes. Comparative data indicate that MTA is associated with substantially more tooth discoloration than Biodentine[23], a clinically meaningful consideration when treating anterior teeth or young patients. Root maturity does not appear to significantly influence pulpotomy success in teeth with normal pulp or reversible pulpitis, supporting the applicability of VPT across both immature and mature permanent teeth[9]. Sodium hypochlorite irrigation for hemostasis prior to capping has strong guideline support over saline irrigation, reflecting both its hemostatic and antimicrobial properties[4].

In the primary dentition, indirect pulp treatment, direct pulp capping, and pulpotomy similarly demonstrate high success rates in teeth with normal pulp or reversible pulpitis, with evidence favoring pulpotomy using calcium silicate cement as a particularly reliable option over longer follow-up periods[24].

Areas of Controversy and Limitations of Current Evidence

Despite this generally favorable evidence base, several areas remain unresolved. First, heterogeneity in outcome definitions (clinical success, radiographic success, and their

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combination), follow-up duration, and diagnostic criteria across studies complicates direct comparison and pooling of results. Second, while short- to medium-term outcomes are well documented, high-quality long-term data (beyond 5–10 years) remain comparatively limited, particularly for full pulpotomy in cases of irreversible pulpitis. Third, professional bodies differ somewhat in recommended approach — for example, in the extent of caries removal recommended prior to VPT and in specific technique selection — reflecting genuine areas of low-certainty evidence rather than settled consensus[5,8]. Fourth, the biological performance of newer resin-modified calcium silicate materials remains incompletely characterized and is an active area of ongoing investigation. Finally, questions remain regarding the long-term histological fate of pulp tissue retained after pulpotomy, including the potential for asymptomatic pulp canal obliteration, internal resorption, or delayed necrosis[25], underscoring the continued importance of long-term clinical and radiographic follow-up for all patients undergoing VPT.

Conclusion

Vital pulp therapy has evolved from a historically conservative, narrowly indicated procedure into a well-supported, first-line treatment option for a broad range of clinical presentations, spanning selective caries excavation and indirect pulp capping through to direct pulp capping and partial or full pulpotomy in both primary and permanent dentitions. This evolution has been driven principally by improved understanding of pulp biology and by the introduction of hydraulic calcium silicate-based bioactive materials, which offer superior sealing, biocompatibility, and dentinogenic potential compared with traditional calcium hydroxide. Current high-quality evidence supports comparably high success rates across VPT modalities in teeth with normal pulp or reversible pulpitis, and increasingly supports full pulpotomy as a viable, pulp-preserving alternative to root canal treatment even in selected cases of symptomatic irreversible pulpitis. Careful case selection, meticulous clinical technique — particularly hemorrhage control and coronal seal integrity — and judicious material selection remain the principal determinants of long-term success. Continued long-term clinical research, standardization of outcome reporting, and further characterization of emerging bioactive and regenerative materials will be essential to refining evidence-based protocols and further expanding the appropriate role of vital pulp therapy in contemporary restorative and endodontic practice.

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Conflict of Interest

The authors declare that they have no known competing financial, professional, institutional, or personal interests that could have appeared to influence the work reported in this manuscript.

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