Review Article

Calcium Hydroxide in Endodontics- Properties, Clinical Applications and Recent Advances: A Review

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Abstract:
Calcium hydroxide [$Ca(OH)_2$] remains one of the most widely used materials in endodontics due to its excellent antimicrobial activity, biocompatibility, and ability to induce hard tissue formation. Since its introduction by Hermann in 1920, it has undergone various modifications in formulation and delivery. This review aims to provide a comprehensive understanding of calcium hydroxide, focusing on its mechanism of action, physicochemical properties, clinical applications with associated advantages and limitations, and recent technological and biological advancements that enhance its effectiveness.

Keywords: Calcium Hydroxide, Intracanal medicament, pulp capping, Root resorption

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INTRODUCTION

Calcium hydroxide ($Ca(OH)_2$) is a white, odorless, alkaline powder first introduced to dentistry by Hermann in 1920 (1). Since then, it has become an integral part of endodontic treatment, particularly in pulp therapy, root canal disinfection, and periapical healing. The wide spectrum of antimicrobial properties, high pH, and its potential to induce mineralized tissue make it a versatile intracanal medicament (2,3).

Its application spans direct and indirect pulp capping, apexogenesis, apexification, treatment of root resorption, regenerative endodontics, and as an intracanal medicament. It acts by releasing calcium and hydroxyl ions, which contribute to antibacterial action, neutralization of lipopolysaccharides, and promotion of mineralized barrier formation (2,4).

Despite the development of more advanced materials such as mineral trioxide aggregate (MTA), Biodentine, and bioceramic sealers, calcium hydroxide remains relevant in clinical endodontics. This review discusses its mechanisms, physicochemical properties, clinical applications, recent innovations, and future prospects, with emphasis on postgraduate-level understanding.

MECHANISM OF ACTION

The efficacy of calcium hydroxide in endodontics primarily depends on its dissociation into calcium (Ca^{2+}) and hydroxyl (OH^{-}) ions [2,5]. These ions are responsible for its biological and antimicrobial actions:

High Alkalinity: With a pH of approximately 12.5, calcium hydroxide creates an environment unfavorable to most microorganisms. The hydroxyl ions are highly reactive and damage bacterial DNA, proteins, and cytoplasmic membranes [2,6].

Antibacterial Activity: Its effectiveness is well-documented against anaerobic bacteria commonly found in infected root canals. However, resistance has been observed with Enterococcus faecalis and Candida albicans due to their ability to survive in high pH environments [7,8].

Neutralization of Lipopolysaccharides (LPS): Hydroxyl ions inactivate bacterial endotoxins like LPS, which are responsible for triggering inflammatory responses in periapical tissues [5].

Tissue Induction and Healing: Calcium ions act as messengers that promote differentiation of stem cells into odontoblast-like cells, stimulating tertiary dentin or hard tissue barrier formation [6,9].

PHYSICOCHEMICAL PROPERTIES

1.Solubility: Slightly soluble in water (1.73 g/L at 20°C), releasing calcium and hydroxyl ions over time [10].

2. pH: Produces an alkaline environment with a pH of 12.5, critical for its antibacterial and tissue-stimulating properties [2].

3. Ion Dissociation: Essential for biological function; hydroxyl ions contribute to antimicrobial action, while calcium ions stimulate tissue repair [6].

4. Diffusion Through Dentin: Calcium hydroxide diffuses through dentinal tubules, affecting deep bacterial colonies and surrounding tissue. Its diffusion ability depends on dentin thickness and presence of smear layer [10,11].

CLASSIFICATION AND VEHICLES

Calcium hydroxide ($Ca(OH)_2$) is a widely used intracanal medicament in endodontics due to its high alkalinity, antimicrobial properties, and ability to stimulate hard tissue formation. The effectiveness of calcium hydroxide largely depends on the vehicle used, which influences its ion release, solubility, and diffusion into dentinal tubules.

Calcium hydroxide preparations are broadly categorized based on setting time (fast, slow, or no setting), curing method (self-cure, light-cure), and vehicle type:

1. **Aqueous Vehicles**
   Examples: Water, saline, anesthetic solution These allow rapid dissociation of calcium and hydroxyl ions, providing a quick rise in pH and strong antimicrobial action.

   Commercially available as: **RC Cal** (Prime Dental) ,**ApexCal** (Ivoclar Vivadent), **Calasept Plus**

- **Advantages:**
- Quick ionic dissociation
- Faster antimicrobial activity
- Easy placement and removal

- **Disadvantages:**
- Rapid solubility and resorption
- Short duration of action
- Requires frequent replacement

2. Viscous Vehicles

Examples: Glycerin, polyethylene glycol (PEG), propylene glycol

These allow moderate and sustained ion release, providing a longer duration of activity.

- **Advantages:**
- Sustained release of ions
- Longer intracanal retention
- Better control over placement

- **Disadvantages:**
- May have reduced immediate antimicrobial effect compared to aqueous types
- Slightly more difficult to remove

Commercially available as: **Calen** (SS), **Hydropast** (Biodinamica Quimica), **Calcipulpe** (Septodent)

3. Oily Vehicles

Examples: Silicone oil, olive oil, camphorated monochlorophenol (CMCP)

These promote the slowest ion dissociation, making them suitable for long-term use.

- **Advantages:**
- Long-term stability in the canal
- Low solubility
- Minimal need for replacement
- **Disadvantages:**
- Delayed antimicrobial action
- Difficult to remove from canal
- May interfere with obturation if not completely cleared

The choice of vehicle should be case-specific. Acute infections may benefit from aqueous formulations, while chronic conditions requiring long-term action may be better managed with viscous or oily vehicles(12).

Commercially available as: **Metapex** (Meta Biomed) , **Vitapex** (Neo Dental)

Light-Cured Calcium Hydroxide is a radiopaque, resin-based liner that releases calcium ions to promote secondary dentin formation and provide a protective barrier over exposed pulp or deep dentin. Unlike conventional self-cure calcium hydroxide, light-cured formulations offer improved physical properties, better adhesion to dentin, and controlled setting time upon light activation. They are commonly used under composite restorations, in indirect pulp capping, and as a base/liner in deep cavities.

Commercially available light-cured calcium hydroxide materials include **Calcimol LC (VOCO)**, **Ultra-Blend Plus (Ultradent)**, **Ionoseal (VOCO)**, and **Dycal LC (Dentsply)**.

CLINICAL APPLICATIONS:

1. Direct Pulp Capping:

Involves the application of calcium hydroxide directly on exposed pulp to maintain vitality and promote healing. It stimulates reparative dentin formation and provides a protective barrier (8,13).

Advantages:

- Stimulates dentin bridge formation
- Antibacterial and anti-inflammatory
- Biocompatible and economical Long history of clinical use (3,8)

Disadvantages:

- Formation of tunnel defects in the dentin bridge
- Poor long-term seal
- Disintegration over time
- Less predictable compared to MTA (12,14)

2. Indirect Pulp Capping

This technique involves placing calcium hydroxide over a thin layer of affected dentin to avoid pulp exposure while allowing healing and tertiary dentin formation (3).

Advantages:
- Maintains pulp vitality
- Arrests caries progression
- Stimulates odontoblastic activity
- Simple and cost-effective [8]

Disadvantages:
- Requires careful monitoring
- No adhesive bond
- Risk of microleakage
- Less durable than newer materials [12,14]

3. Apexogenesis

Apexogenesis is a vital pulp therapy for immature teeth with vital pulp. The aim is to preserve pulp vitality to allow continued root development and apical closure. Calcium hydroxide has been a traditional choice due to its ability to stimulate hard tissue formation and its antibacterial properties [6,13].

Advantages:
- Encourages root maturation and apical closure
- Preserves pulp vitality
- Antibacterial and anti-inflammatory
- Widely used and studied technique (3,12)

Disadvantages:
- Risk of pulp necrosis
- Requires multiple visits and long-term follow-up
- Dentin bridge may have tunnel defects
- Less effective compared to MTA in maintaining long-term outcomes [14,15]

4. Apexification

Apexification is performed in non-vital immature teeth to induce the formation of a calcific barrier at the apex. Traditionally, calcium hydroxide is placed in the canal over several months to stimulate this barrier [3,11].

Advantages:
- Non-surgical, conservative technique
- Long-term clinical success in forming an apical barrier
- Cost-effective material [11,16]

Disadvantages:
- Prolonged treatment time (up to 6–24 months)
- Increased risk of root fracture due to long-term exposure (17)
- Requires patient compliance for follow-up
- MTA has largely replaced $Ca(OH)_2$ in modern apexification [12,14]

5 Intracanal Medicament

Calcium hydroxide is frequently used as an interappointment medicament in infected canals. Its high pH helps in microbial control and endotoxin neutralization [2,4].

Advantages:
- Broad-spectrum antimicrobial action
- Inhibits bacterial endotoxins (e.g., LPS)
- Controls periapical inflammation
- Easy to remove from canals [5,8]

- **Disadvantages:**
- Ineffective against E. faecalis and C. albicans
- Biofilm resistance observed
- May weaken dentin structure with prolonged use (7,14,17)
- Incomplete removal can interfere with sealers [10,15]

6. Management of Root Resorption(External and Internal)

Calcium hydroxide is effective in arresting internal and external inflammatory root resorption by altering osteoclastic activity and neutralizing the acidic environment [3,4].

Advantages:
- Inhibits resorptive process
- Anti-inflammatory effect
- Promotes hard tissue repair
- Easily available and affordable [3,13]

Disadvantages:
Needs regular dressing changes
Limited efficacy in severe resorption
Solubility can compromise the seal
Prolonged use risks dentin weakening [16,18]

7. In prevention of Ankylosis:
Calcium hydroxide is widely used as an intracanal medicament in the management of reimplanted teeth, particularly in cases of delayed reimplantation where the risk of root resorption and ankylosis is high due to prolonged extra-oral dry time and necrosis of periodontal ligament (PDL) cells. It is primarily indicated in permanent teeth with closed apices that have undergone avulsion and are expected to develop pulp necrosis.

The principal mechanism of action of calcium hydroxide lies in its high alkaline pH (~12.5), which creates an environment that inhibits the survival and activity of osteoclasts responsible for inflammatory root resorption.

Clinically, calcium hydroxide is placed inside the cleaned and shaped root canal after reimplantation, especially in cases where the tooth has been dry for more than 60 minutes. It remains in the canal for 2 to 4 weeks, during which it exerts its anti-resorptive and disinfecting effects.

Advantages:
- Potent antibacterial activity
- Ability to induce hard tissue formation
- Low cost
- Biocompatibility

Disadvantages:
- Prolonged exposure can weaken root dentin
- Increased risk of root fractures
- Reduced flexural strength.

8. In Weeping Canals:
Weeping canals are characterized by persistent serous exudation from the root canal system, commonly seen in necrotic teeth with chronic apical periodontitis or abscess. This condition prevents canal drying and obturation in a single visit.
Calcium hydroxide is the preferred intracanal medicament in such cases due to its:
- Strong alkaline pH (~12.5), which neutralizes bacterial endotoxins (like LPS)
- Potent antimicrobial and anti-inflammatory action
- Ability to dry canal spaces by desiccating inflamed tissue
- Stimulation of periapical healing

It is typically applied as a paste for 1–2 weeks, with repeat placement if exudation persists. Vehicles like viscous (e.g., propylene glycol) or oily bases (e.g., Metapex) enhance its retention and efficacy.

Advantages:
- Facilitates canal drying
- Reduces inflammation
- Promotes healing
- Enables future obturation.

Disadvantages:
- Requires multiple visits
- May weaken dentin if overused
- Prolonged exudation may indicate more complex pathology.

9. As Root Canal Sealer:
Calcium hydroxide has been incorporated into root canal sealers to enhance their antimicrobial activity and bioactivity. These sealers are either calcium hydroxide-based or contain $Ca(OH)_2$ as an additive. Examples include Sealapex, Apexit, and Metapex-based sealers. These are used alongside gutta-percha to fill voids, lateral canals, and accessory canals during obturation [3,10].

Mechanism of Action:
When used in sealer form, calcium hydroxide:
- Releases Ca^{2+} and OH^- ions, which elevate pH and exhibit bactericidal action
- Promotes periapical healing by stimulating mineralized tissue formation
- Neutralizes residual toxins, especially in uninstrumented areas

- Enhances biocompatibility at the apex and prevents periapical irritation [4,9,10]

Advantages:
- Antibacterial effect due to sustained high pH
- Biocompatibility superior to zinc oxide–based sealers
- Induces tissue repair, making it useful in cases with periapical involvement
- Radiopaque and easy to handle
- Available in paste or injectable forms, allowing easy manipulation [10,12]

Disadvantages:
- Solubility in tissue fluids, which may lead to leakage or loss of seal over time
- Weak bonding to dentin compared to resin or bioceramic sealers
- May exhibit shrinkage on setting, especially in early calcium hydroxide sealers
- Incompatibility with some resin-based materials due to residual alkalinity [15,16]

10. As a Liner

Calcium hydroxide is widely used as a protective liner in deep cavity preparations where the remaining dentin is thin. As a liner, it is placed in minimal thickness over areas closest to the pulp to prevent irritation from restorative materials and to stimulate dentin formation [3,6]

Mechanism of Action:
When used as a liner, calcium hydroxide exerts:

Antibacterial activity through its high pH
Stiulation of odontoblast-like cells, leading to tertiary (reparative) dentin formation
Chemical protection against acidic components of dental materials [8,9]

Advantages:
- Biocompatible and non-toxic to pulp
- Promotes dentin bridge formation
- Inexpensive and easy to apply
- Provides antibacterial protection under restorations **(6)**

Disadvantages:
- Low compressive strength and prone to disintegration
- Incompatible with resin-based materials unless covered with a protective base
- May degrade over time under large occlusal forces
- Potential for tunnel defects in formed dentin, allowing bacterial infiltration [12,14]

11. Calcium Hydroxide in Pulpotomy

Pulpotomy is a vital pulp therapy procedure performed in teeth with reversible pulpitis, especially in primary teeth and young permanent teeth. Calcium hydroxide has long been used for full coronal pulpotomies, especially in immature teeth to allow continued root development [3,8,13].

Mechanism of Action:
Calcium hydroxide induces a high pH inflammatory response, resulting in:

Superficial necrosis of pulp tissue
Beneath which, a hard tissue barrier (dentin bridge) forms Preservation of radicular pulp vitality
Continued root maturation in young permanent teeth [6,13]

Advantages:
- Cost-effective and readily available
- Stimulates dentin bridge formation
- Non-toxic and pulp-friendly
- Useful in apexogenesis of immature teeth (13)

Disadvantages:
- High failure rate in primary teeth due to chronic inflammation and internal resorption
- Inferior to materials like MTA or Biodentine in long-term success
- Formation of dentin bridge with tunnel defects, which can compromise pulp sealing

- Limited success in large or irreversible pulp exposures [12,14]

RECENT ADVANCES IN CALCIUM HYDROXIDE USE IN ENDODONTICSNTRODUCTION

Calcium hydroxide ($Ca(OH)_2$) continues to evolve through technological innovations aimed at overcoming its traditional limitations such as limited antimicrobial spectrum, rapid solubility, and lack of long-term sealing. Recent developments have enhanced its application in both conventional and regenerative endodontics.

1. Nanoparticle Formulations

Nanotechnology has introduced nano-calcium hydroxide, which has significantly improved surface area and diffusion potential. These particles penetrate deeper into dentinal tubules and biofilms, enhancing antibacterial efficacy against E. faecalis and Candida albicans [14,21]. Additionally, their improved alkalizing capability leads to a more potent antimicrobial environment without increasing cytotoxicity [21].

2. Advanced Drug Delivery Vehicles

Innovative carriers have replaced conventional vehicles to provide controlled and sustained ion release. These include:

Hydrogels(e.g., chitosan, PEG)
Polymeric microsphere (e.g., polylactic acid, PCL)
Nanofiber scaffolds

These systems prolong the release of calcium and hydroxyl ions, improve tissue compatibility, and reduce the frequency of redressing, particularly useful in apexification and regenerative procedures [16,20].

3. Antimicrobial Combinations

Combining $Ca(OH)_2$ with other agents has demonstrated enhanced antimicrobial efficacy:

Chlorhexidine (CHX): Improves substantivity and biofilm penetration [18]
Curcumin or quercetin: Adds anti-inflammatory and antioxidant effects [22]
Silver/zinc nanoparticles: Broaden the antimicrobial spectrum and target resistant pathogens (21)
Calcium hydroxide-antibiotic blends (e.g., with metronidazole): show synergistic bacterial inhibition in polymicrobial infections [24]

These combinations improve outcomes in persistent infections, especially those involving biofilm-forming organisms.

4. Compatibility with Bioceramics and Sealers

Recent studies have explored bioceramic-enhanced calcium hydroxide formulations, combining the mineralizing and antibacterial properties of $Ca(OH)_2$ with superior sealing ability of bioceramic matrices [16]. Modified forms with improved resin compatibility also aim to prevent the interference of residual $Ca(OH)_2$ with root canal sealers [15].

5. Regenerative Endodontics Applications

Calcium hydroxide plays a critical role in regenerative endodontic procedures (REPs) due to its ability to inactivate endotoxins and maintain low cytotoxicity. Modified formulations have been developed to preserve stem cell viability — particularly of SCAP and DPSCs — while still providing adequate disinfection [13,19]. This makes $Ca(OH)_2$ a viable alternative to triple antibiotic paste in specific regenerative cases.

6. Enhanced Activation Techniques

To improve its action, $Ca(OH)_2$ can now be ultrasonically agitated or laser-activated (e.g., with Nd\:YAG or diode lasers), increasing its penetration into lateral canals and dentinal tubules. These techniques also enhance pH elevation and microbial elimination from inaccessible areas [20,23].

7. Biointeractive and Buffered Formulations

Recent buffered versions of $Ca(OH)_2$ aim to control pH levels to reduce cytotoxicity while maintaining antimicrobial action. These formulations show promise in long-term intracanal use without significantly affecting periapical tissues [14,19].

8. Imaging and Monitoring Tools

Advancements in real-time imaging have improved our understanding of $Ca(OH)_2$ dynamics:

Confocal Laser Scanning Microscopy (CLSM) for ion penetration
Micro-CT to visualize dissolution and dentin interface
Ion-selective electrodes to monitor pH gradients and calcium release

These tools offer precise assessment of the medicament's efficacy and biological interactions [15,21].

REFERENCES

1. Hermann BW. Calcium hydroxide in the treatment of pulpless teeth and infected root canals. Dent Cosmos. 1920;62:527–533.
2. Siqueira JF Jr, Lopes HP. Mechanisms of antimicrobial activity of calcium hydroxide: a critical review. Int Endod J. 1999;32(5):361–369.
3. Mohammadi Z, Dummer PM. Properties and applications of calcium hydroxide in endodontics and dental traumatology. Int Endod J. 2011;44(8):697–730.
4. Kim D, Kim E. Antimicrobial effect of calcium hydroxide as an intracanal medicament in root canal treatment: A literature review—Part II. Restor Dent Endod. 2015;40(2):97–103.
5. Safavi KE, Nichols FC. Alteration of biological properties of bacterial lipopolysaccharide by calcium hydroxide. J Endod. 1994;20(3):127–129.
6. Holland R, Mazuqueli L, de Souza V, et al. Influence of calcium hydroxide and zinc oxide and eugenol on tissue reaction. Braz Dent J. 2005;16(1):3–9.
7. Athanassiadis B, Abbott PV, Walsh LJ. The use of calcium hydroxide, antibiotics and biocides as antimicrobial medicaments. Aust Dent J. 2007;52(1 Suppl)\:S64–S82.
8. Estrela C, Pécora JD, Estrela CR, et al. Mechanism of action of calcium hydroxide. Braz Dent J. 2000;11(1):3–9.
9. Tronstad L, Andreasen JO, Hasselgren G, Kristerson L, Riis I. pH changes in dental tissues after root canal filling with calcium hydroxide. J Endod. 1981;7(1):17–21.
10. Calt S, Serper A. Dentinal tubule penetration of root canal sealers after calcium hydroxide dressing. J Endod. 1999;25(6):431–433.
11. Andreasen JO, Farik B, Munksgaard EC. Long-term calcium hydroxide as a root canal dressing may increase risk of root fracture. Dent Traumatol. 2002;18(3):134–137.
12. Parirokh M, Torabinejad M. Mineral trioxide aggregate: literature review—Part III: clinical applications. J Endod. 2010;36(3):400–413.
13. Simon S, Smith AJ. Regenerative endodontics: regeneration or repair? J Endod. 2014;40(4 Suppl)\:S70–S75.
14. Gorduysus MO, Yucel AC, Helvacioglu D, Gorduysus M. Nanoparticles and their applications in endodontics: a review. Aust Endod J. 2021;47(2):226–233.
15. Duran-Sindreu F, Mercadé M, Larraona J, et al. Influence of calcium hydroxide on sealing ability of endodontic sealers. J Endod. 2010;36(5):867–869.
16. Camilleri J. Calcium hydroxide in endodontics: from past to present. Endod Topics. 2021;39(1):1–15.
17. Peters OA. Current challenges and concepts in preparation of root canal systems. J Endod. 2004;30(8):559–567.
18. Tanomaru-Filho M, Torres FF, Chavez-Andrade GM, et al. Physicochemical and antibacterial properties of calcium hydroxide with and without iodoform. Braz Dent J. 2018;29(5):536–540.
19. Mohammadi Z. Medicaments used in regenerative endodontics: a review. Iran Endod J. 2014;9(4):211–215.
20. Farhad A, Mohammadi Z. Calcium hydroxide: a review. Int Dent J. 2005;55(5):293–301.
21. Kaup M, Dammann CH, Schäfer E, Dammaschke T. Shear bond strength of calcium hydroxide to root canal dentin. J Endod. 2015;41(6):834–838.
22. Bystrom A, Claesson R, Sundqvist G. Antibacterial effect of camphorated phenol and

calcium hydroxide. Endod Dent Traumatol. 1985;1(5):170–175.
23. Yoshiba K, Yoshiba N, Iwaku M. Classifications and histological characteristics of reparative dentin. J Oral Biosci. 2003;45(3):191–199.
24. Mohammadi Z, Abbott PV. Local application of antibiotics in endodontics. Int Endod J. 2009;42(8):555–567.