Uttar Pradesh Journal of Zoology

Volume 44, Issue 10, Page 63-72, 2023; Article no.UPJOZ.2587
ISSN: 0256-971X (P)

Calcium Hydroxide Pulp Capping Agent: An Overview on Composition, Properties, and Clinical Applications

P. Venkata Karteek Varma [a++], Ganta Gopala Krishna [b#], Rama Krishna Alla [c†*], S. Sowmya [d^], K. N. Raghavendra Swamy [d‡] and Rani Sirisha Malkapuram [e†]

[a] *Department of Conservative Dentistry and Endodontics, Vishnu Dental College, Bhimavaram, Andhra Pradesh, India.*
[b] *Intercare Community Health Network, MI, USA.*
[c] *Department of Dental Materials, Vishnu Dental College, Bhimavaram, Andhra Pradesh, India.*
[d] *Department of Prosthodontics, Crown and Bridge, JSS Dental College and Hospital, JSSAHER, Mysuru, Karnataka, India.*
[e] *Department of Conservative Dentistry and Endodontics, Drs. Sudha and Nageswararao Siddhartha Institute of Dental Sciences, Chinnotapalli, Andhra Pradesh, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.56557/UPJOZ/2023/v44i103507

Editor(s):
(1) Dr. Ana Cláudia Correia Coelho, University of Trás-os-Montes and Alto Douro, Portugal.
Reviewers:
(1) Garima Rawat, Dharamshila Narayana Superspeciality Hospital, India.
(2) Anil Kumar Nagarajappa, Jouf University, Saudi Arabia.
(3) Mangesh G. Andhare, MUHS nashik, India.

Review Article

Received: 23/03/2023
Accepted: 25/05/2023
Published: 06/06/2023

[++] *Reader;*
[#] *Business Intelligence Analyst;*
[†] *Associate Professor;*
[^] *Assistant Professor;*
[‡] *Professor and Head;*
**Corresponding author: Email: rkdentalbiomaterials@gmail.com;*

ABSTRACT

Calcium hydroxide is a commonly used material in pulp capping procedures due to its favourable biological properties, including the ability to promote dentin bridge formation and stimulate reparative dentinogenesis. The mechanical properties of calcium hydroxide, including its compressive strength, flexural strength, and wear resistance, are relatively low, but they are not critical properties in pulp capping procedures. However, the composition and formulation of calcium hydroxide can vary depending on the manufacturer, and this can affect the material's physical and chemical properties, as well as its handling characteristics. Despite these variations, calcium hydroxide remains a popular choice for pulp capping due to its favourable biological properties and its long-standing history of use in dental procedures.

Keywords: Calcium hydroxide; pulp capping; apexification.

1. INTRODUCTION

Calcium hydroxide is a widely used pulp capping material that has been in use for many years. It is a white, odourless, and alkaline substance that is prepared by combining calcium oxide (quicklime) with water. In dentistry, calcium hydroxide is used as a direct pulp capping material due to its excellent biocompatibility and antimicrobial properties [1,2]. When applied to an exposed pulp, it can stimulate the formation of a dentin bridge, helping to protect the pulp and promote healing. Calcium hydroxide has several beneficial properties, including antimicrobial activity, alkalinity, and the ability to stimulate reparative dentin formation. It is typically used in cases of small pulp exposures, caries lesions, and traumatic injuries [1,2].

Compared to other dental cements, calcium hydroxide has several advantages as a pulp capping material, including its ability to promote the formation of a mineralized barrier over exposed pulp and its ability to stimulate the differentiation of odontoblast-like cells [3]. Additionally, calcium hydroxide is relatively easy to use and has a long history of successful clinical use in pulp capping procedures [4]. While other dental cements, such as mineral trioxide aggregate (MTA), have also been shown to have biocompatibility and stimulating effects on dentin formation, calcium hydroxide remains a popular choice for pulp capping due to its lower cost and ease of use [5]. Additionally, calcium hydroxide has been shown to have a longer track record of successful use in pulp capping procedures compared to MTA [6]. This article reviews the composition, properties, indications and contra-indications of calcium hydroxide cement.

2. COMPOSITION

Calcium hydroxide pulp capping materials are available in the form of a powder and liquid components, and 2-paste systems. The powder is composed of calcium oxide (CaO) and may contain other ingredients such as zinc oxide, magnesium oxide, and barium sulfate. The liquid component is usually distilled water or saline solution. When mixed, the powder and liquid components form a paste-like consistency [1,2,7].

The most widely used calcium hydroxide 2-paste system is Dycal (Dentsply Sirona), which consists of a base and the catalyst pastes. Base paste typically contains calcium hydroxide, Zinc oxide, polymeric fatty acid ester, Barium sulphate and titanium dioxide. The catalyst paste contains Dimethylammonium p-toluenesulfonate, Methyl-4-hydroxybenzoate, and Hydroxypropyl cellulose [8,9].

3. SETTING MECHANISM

The setting reaction of calcium hydroxide pulp capping agent is a complex process that involves several chemical reactions. Calcium hydroxide pulp capping material sets by a process called hydration. When water is added to the powder component, calcium oxide reacts with water to form calcium hydroxide ($Ca(OH)_2$) and the reaction is exothermic. The resulting calcium hydroxide paste sets by hardening due to the formation of calcium hydroxide crystals [1,2,9,10]. The setting reaction proceeds in two stages [11-13]:

Stage 1: Dissolution and Ionization

In the first stage, calcium hydroxide particles dissolve in water to form calcium and hydroxide ions:

$$Ca(OH)_2\ (s) \leftrightarrow Ca^{2+}\ (aq) + 2OH^-\ (aq)$$

This process is exothermic, which means that it releases heat. As the calcium hydroxide dissolves, the pH of the mixture increases, leading to the ionization of the water molecules:

$$H_2O\ (l) \leftrightarrow H^+\ (aq) + OH^-\ (aq)$$

The hydroxide ions produced by the dissolution of calcium hydroxide and ionization of water react with calcium ions to form calcium hydroxide complexes:

$$Ca^{2+}\ (aq) + 2OH^-\ (aq) \leftrightarrow Ca(OH)_2\ (aq)$$

Stage 2: Precipitation and Gelation

In the second stage, the calcium hydroxide complexes react with carbon dioxide from the air to form calcium carbonate and water:

$$Ca(OH)_2\ (aq) + CO_2\ (g) \rightarrow CaCO_3\ (s) + H_2O\ (l)$$

This reaction is also exothermic and leads to the formation of a solid precipitate of calcium carbonate. The calcium carbonate particles then aggregate and react with the residual calcium hydroxide complexes to form a gel-like material:

$$Ca(OH)_2\ (aq) + CaCO_3\ (s) \rightarrow Ca^{2+} + 2OH^-\ (aq) + CaCO_3\ (s)$$

This gel-like material provides a scaffold for the formation of reparative dentin and helps to seal the pulp chamber.

4. PROPERTIES

Calcium hydroxide pulp capping material has several desirable properties, including excellent biocompatibility, antibacterial activity, and the ability to stimulate dentin formation.

4.1 Biological Properties

Biocompatibility: Calcium hydroxide is a biocompatible material and does not cause any adverse reactions or toxicity in the surrounding tissues. It is safe to use on pulp tissue, and it does not interfere with the healing process [14,15]. The Calcium Hydroxide-Calcium Silicate mixtures exhibited good biocompatibility and osteogenic potential, making them a suitable material for dental pulp capping [16]. Shokouhinejad et al. (2021) reported that Calcium Hydroxide showed good biocompatibility and low cytotoxicity on dental pulp stem cells and is comparable to that of biodentine and MTA [17]. Also, $Ca(OH)_2$ demonstrated low cytotoxicity and genotoxicity when used as an intracanal medicament [18].

Antibacterial activity: Calcium hydroxide has been shown to have strong antibacterial activity against a wide range of bacteria, including those that are commonly found in infected pulp [19]. It works by disrupting the bacterial cell wall and membrane, causing the bacteria to die. This property is important for preventing or treating pulp infections [20]. However, the antimicrobial efficacy and bioactivity of calcium hydroxide are less compared to calcium silicate-based cements [21,22]. The calcium hydroxide was reported to be effective in preventing bacterial leakage in teeth with incomplete root formation [23].

Pulp regeneration: Zhang et al. (2021) found that calcium hydroxide had a positive effect on both pulpal and periodontal regeneration [24]. Calcium hydroxide has been shown to stimulate the formation of new dentin and promote pulp tissue regeneration. This is due to its ability to release calcium ions, which are important for the mineralization of new dentin [25].

Immunomodulation: Calcium hydroxide has been shown to modulate the immune response in the pulp tissue, which can help to reduce inflammation and promote healing. It can stimulate the production of cytokines and growth factors, which are important for tissue repair [26].

Arão et al. (2021) investigated the effect of calcium hydroxide associated with platelet-rich fibrin on the repair of rat calvarial defects. The study found that the combination of calcium hydroxide and platelet-rich fibrin resulted in better bone formation and faster healing compared to calcium hydroxide alone [27].

Various studies demonstrate that calcium hydroxide has several beneficial biological properties, including antimicrobial activity, biocompatibility, and osteogenic potential. However, other materials such as calcium silicate-based cements may offer better antimicrobial efficacy and bioactivity. More research is needed to fully understand the biological properties of calcium hydroxide and how it compares to other materials in different clinical scenarios, on gene expression and other aspects of dental pulp healing.

4.2 Chemical Properties

Solubility: Calcium hydroxide is highly soluble in water, which allows it to quickly dissociate and release calcium and hydroxide ions. This solubility also allows it to penetrate the dentinal tubules, where it can promote dentin bridge formation and stimulate reparative dentinogenesis [28].

pH: Calcium hydroxide has a high pH of approximately 12.5, which makes it alkaline that helps in neutralizing any residual acids in the dentin and pulp. This property is critical in protecting the pulp and preventing further inflammation or injury [7,29]. This alkalinity creates an environment that is unfavourable for bacterial growth and promotes the formation of mineralized tissue [30].

4.3 Rheological Properties

The rheological properties of calcium hydroxide cement are important for its handling, adaptation, and setting properties.

Viscosity: The viscosity of calcium hydroxide cement is an important rheological property that affects its handling and flow characteristics. Viscosity is a measure of a fluid's resistance to flow, and it is determined by the size, shape, and concentration of particles in the cement. The higher the viscosity, the thicker and more difficult to handle the cement will be. Calcium hydroxide cement typically has a high viscosity, which can make it difficult to apply and pack [31].

Thixotropy: Calcium hydroxide cement exhibits thixotropic behavior, which means that its viscosity decreases when it is subjected to mechanical stress or shear force. This property is important for facilitating the flow and adaptation of the cement to the cavity preparation. When the stress is removed, the viscosity of the cement increases again, preventing it from flowing out of the cavity [32].

Setting time: The setting time of calcium hydroxide cement is another important rheological property. It is the time it takes for the cement to solidify and harden after mixing with water. The setting time of calcium hydroxide cement is typically longer than other types of dental cements, ranging from 10 to 30 minutes. This property allows for adequate time for placement and adaptation of the cement to the cavity preparation [33].

The setting time of calcium hydroxide can vary depending on the formulation and manufacturer. Setting times can range from a few minutes to several hours [34]. The particle size distribution of calcium hydroxide cement can also affect its rheological properties. The cement typically contains particles of varying sizes, ranging from submicron to several microns in diameter. The larger particles contribute to the cement's overall viscosity, while the smaller particles improve its flow and setting properties [35].

4.4 Mechanical Properties

Compressive strength: Calcium hydroxide has relatively low compressive strength, which means it is not suitable for use in load-bearing applications. Compressive strength: The compressive strength of calcium hydroxide ranges from 10 to 40 MPa depending on the type and composition of the material [36-38]. However, in pulp capping, compressive strength is not a critical property since the material is not exposed to high compressive loads [39].

Flexural strength: The flexural strength of calcium hydroxide ranges from 3 to 10 MPa depending on the type and composition of the material [37,38]. Calcium hydroxide has low flexural strength, which limits its use in situations where high flexural loads are anticipated. However, in pulp capping, flexural strength is not a critical property since the material is not exposed to high flexural loads [40].

Elastic modulus: The elastic modulus of calcium hydroxide ranges from 2 to 6 GPa depending on the type and composition of the material [37,38].

Adhesion: Calcium hydroxide does not exhibit strong adhesion to dentin, which can limit its effectiveness in sealing the pulp chamber. However, it can still promote dentin bridge formation and stimulate reparative dentinogenesis [28].

Wear resistance: Calcium hydroxide has relatively low wear resistance, which can limit its durability in long-term use. The hardness of calcium hydroxide ranges from 7 to 22 Vickers hardness number (VHN) depending on the type and composition of the material [41,42]. However, in pulp capping, wear resistance is not a critical property since the material is typically covered with a permanent restoration [43].

The mechanical properties of calcium hydroxide as a pulp capping agent are not as critical as their biological properties. Although it has relatively low compressive and flexural strength, adhesion, and wear resistance, it can still effectively promote dentin bridge formation and stimulate reparative dentinogenesis.

4.5 Thermal Properties

Thermal properties of dental materials, including pulp capping agents such as calcium hydroxide, are important considerations for clinical use.

Thermal conductivity: Calcium hydroxide has relatively low thermal conductivity, hence, it acts as a poor conductor of heat. This property can be advantageous in pulp capping procedures, as it can help to minimize heat transfer to the pulp tissue during restoration placement [44].

Thermal expansion: Calcium hydroxide has a low coefficient of thermal expansion. Therefore, it is less likely to expand or contract in response to temperature changes. This property can be important for the stability of the restoration and the prevention of microleakage [45]. Jain P et al. reported a coefficient of thermal expansion of 16.4×10^{-6}/°C for a calcium hydroxide cement containing zirconium oxide [46].

Melting point: Calcium hydroxide does not have a true melting point, as it undergoes decomposition at high temperatures. The thermal stability of calcium hydroxide is important for its use in clinical procedures, as it needs to remain stable at the temperatures encountered during restoration placement [47].

The thermal properties of calcium hydroxide as a pulp capping agent are favorable for clinical use. Its low thermal conductivity can help to minimize heat transfer to the pulp tissue, while its low coefficient of thermal expansion can promote the stability of the restoration.

4.6 Optical Properties

The optical properties of dental materials, including pulp capping agents such as calcium hydroxide, can have important clinical implications for aesthetics and visibility during placement and follow-up examinations.

Colour: Calcium hydroxide is typically a white or off-white colour, which can help to blend with the colour of the tooth structure. However, discolouration over time can occur due to various factors such as degradation and exposure to oral fluids [48].

Translucency: Calcium hydroxide is relatively translucent, which can help to allow for adequate visualization during placement and follow-up examinations [49].

Opacity: Calcium hydroxide has low opacity, which can help to minimize the appearance of the material through the overlying restoration [50]. Calcium hydroxide is radiopaque, which makes it visible on radiographs. This property allows clinicians to monitor the progress of healing and ensure that the material is properly placed [51]. A recent study evaluated the clinical and radiographic success rates of calcium hydroxide as a pulp capping material and found a success rate of 80% after 3 years [6].

The optical properties of calcium hydroxide as a pulp capping agent can provide favourable clinical outcomes. Its colour and translucency can blend well with the tooth structure and provide adequate visibility during placement, while its low opacity can help to minimize its appearance through the overlying restoration.

5. MANIPULATION

The mixing ratio and setting time of calcium hydroxide pulp capping material can vary depending on the brand and type of material used. Generally, the powder and liquid are mixed to form a smooth paste, which is then placed onto the exposed pulp or onto a layer of dentin that has been removed to expose the pulp. The paste is then covered with a layer of glass ionomer cement or composite resin to protect it from saliva and bacteria [14].

5.1 Pulp Capping [52-55]

Direct and indirect pulp capping are commonly used techniques in restorative dentistry to manage dental caries and prevent further pulp damage.

5.2 Direct Pulp Capping Procedure

Access the pulp: The tooth is isolated and prepared for the procedure. The carious lesion is removed to expose the pulp chamber.

Control bleeding: Any bleeding from the pulp is controlled with sterile saline or by applying pressure to the bleeding site with a cotton pellet or a dampened piece of gauze.

Apply calcium hydroxide: A small amount of calcium hydroxide paste is applied directly onto the exposed pulp using a small spatula or a micro brush.

Cover with a temporary restoration: The calcium hydroxide is covered with a temporary restoration, such as a glass ionomer cement or a resin-modified glass ionomer cement, to protect the tooth and prevent bacterial contamination.

5.3 Indirect Pulp Capping Procedure

Access the pulp: The tooth is isolated and prepared for the procedure. The carious lesion is removed, leaving a thin layer of carious dentin over the pulp.

Control bleeding: Any bleeding from the pulp is controlled with sterile saline or by applying pressure to the bleeding site with a cotton pellet or a dampened piece of gauze.

Apply calcium hydroxide: A small amount of calcium hydroxide paste is applied to the remaining carious dentin using a small spatula or a micro brush. The calcium hydroxide should not come into direct contact with the exposed pulp.

Cover with a temporary restoration: The calcium hydroxide is covered with a temporary restoration, such as a glass ionomer cement or a resin-modified glass ionomer cement, to protect the tooth and prevent bacterial contamination.

6. INDICATIONS

Calcium hydroxide is a commonly used pulp capping material in dentistry, with various indications for clinical use.

Indirect pulp capping: Calcium hydroxide can be used as an indirect pulp capping material when the carious lesion has approached the pulp but without pulp exposure. Calcium hydroxide stimulates the formation of tertiary dentin, which acts as a protective barrier against bacterial invasion and pulp irritation [56].

Direct pulp capping: Calcium hydroxide can also be used as a direct pulp capping material when there is a small pulp exposure due to trauma or caries. Calcium hydroxide promotes the formation of a calcified bridge over the exposed pulp, which helps to protect the pulp from further damage and promotes healing [57].

Pulpotomy: Calcium hydroxide can be used as a pulp dressing material after pulpotomy, which involves the removal of the coronal pulp tissue due to irreversible pulpitis or traumatic injury. Calcium hydroxide acts as an antibacterial agent and promotes the formation of reparative dentin [58].

Apexification: Calcium hydroxide can be used in apexification procedures to promote the formation of an apical barrier in immature teeth with open apices. Calcium hydroxide stimulates the differentiation of stem cells into odontoblast-like cells, which helps to promote the formation of an apical barrier [59].

7. CONTRA-INDICATIONS

While calcium hydroxide is a commonly used pulp capping material in dentistry, there are some situations where its use is contraindicated.

Pulp necrosis: Calcium hydroxide is not indicated for use in teeth with pulp necrosis, as it cannot promote pulp healing and may lead to further pulp irritation [60].

Excessive bleeding: Calcium hydroxide should not be used as a pulp capping material in cases of excessive bleeding, as it may not effectively seal the exposed pulp and may lead to infection or inflammation [61].

Allergy: Patients with a known allergy to calcium hydroxide should not be treated with calcium hydroxide as a pulp capping material [62].

Large pulp exposure: Calcium hydroxide is not recommended for use as a pulp capping material in cases of large pulp exposure, as it may not effectively promote pulp healing and may lead to further pulp damage [63].

Teeth with compromised periodontal status: Calcium hydroxide should be used with caution in teeth with compromised periodontal status, as it may lead to increased resorption of the root structure [64].

The use of calcium hydroxide as a pulp capping material should be carefully evaluated based on the individual patient's clinical situation and with consideration of any contraindications.

8. RECENT ADVANCES

The formulation of calcium hydroxide pulp capping materials has recently improved. For example, calcium hydroxide can be combined with other materials such as resin-based materials, and nanohydroxyapatite to improve its physical and biological properties. The addition of antibiotics or other antimicrobial agents to the material can also enhance its antibacterial properties [65].

9. CONCLUSION

Calcium hydroxide is an effective pulp capping agent that can promote dentin bridge formation and stimulate reparative dentinogenesis, which is critical for maintaining the vitality of the tooth pulp. While it has relatively low compressive and flexural strength, adhesion, and wear resistance, these properties are not as critical for its use in pulp capping as its biological properties. The material can also exhibit antibacterial properties and has a low cytotoxicity, which further enhances its effectiveness as a pulp capping agent. However, the choice of the specific calcium hydroxide product should consider its composition, formulation, and clinical indications to achieve the desired outcome. It is always recommended to consult with a dental professional for specific treatment recommendations.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Anusavice KJ. Philips Science of Dental Materials. 11th Edition, Saunders, Elsevier, USA. 2004:491-92.
2. Alla RK. Dental Materials Science. 1st Edition. Jaypee Brothers Medical Publishers Pvt Ltd. India. 2013:129-130.
3. Akhlaghi N, Khademi AA, Mohammadi N. Calcium hydroxide in dental treatments: A review. J Cons Dent: JCD. 2013;16(2): 92–98.
4. Bakland LK. Long-term clinical effectiveness of treatment provided for pulpal therapy in primary teeth. J Endod. 1998;24(10):649–653.
5. Parirokh M, Torabinejad M. Mineral trioxide aggregate: a comprehensive literature review--Part II: Leakage and biocompatibility investigations. J Endod. 2010;36(2): 190–202.
6. Mente J, Hage N, Pfefferle T, Koch MJ, Dreyhaupt J. Treatment outcome of mineral trioxide aggregate or calcium hydroxide direct pulp capping: long-term results. J Endod. 2010; 36(5):806–813.
7. Lin J, Zuckerman O. Calcium Hydroxide. [Updated 2022 Sep 12]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2022. Available:https://www.ncbi.nlm.nih.gov/books/NBK499847/
8. Dycal [package insert]. Dentsply Sirona; 2018.
9. Luiz R, Vieira LCC, Araújo MAM, et al. Analysis of the Composition of Calcium Hydroxide Pastes Used for Endodontic Therapy. Int J Dent. 2018;2018:7875320.
10. Shahi S, Rahimi S, Yavari HR, et al. Success rate of formocresol pulpotomy versus mineral trioxide aggregate (MTA) pulpotomy in primary molars: a systematic review and meta-analysis. J Dent Res Dent Clin Dent Prospects. 2014;8(1):1-7.
11. Hilton TJ. Keys to clinical success with pulp capping: a review of the literature. Oper Dent. 2013; 38(suppl_1): E15-E25.
12. Shayegan A, Petein M. Vital Pulp Therapy In Endodontics: Part 1—Dental Pulp Anatomy and Physiology. Int J Dent; 2012.
13. Jalan AL, Warhadpande MM, Dakshindas DM.. Pulp capping agents: An overview. J Conserv Dent: JCD. 2013;16(6): 501-503.
14. Mahmoud SH, Elsaka SE. Calcium hydroxide as a pulp capping agent: literature review. Clin CosmetInvestig Dent. 2020;12:113-121.
15. Akhil AP, Rameshbabu AP, Thomas AJ, Venugopal L, Varma HK, Surendran S. Antibacterial and Biocompatibility Evaluation of Calcium Hydroxide Containing Dental Materials. Int J Dent, 2020:3920916.
16. Cvikl B, Moritz A, Bekes K, Ogris K, Windisch P, Marton D. Biocompatibility and Osteogenic Potential of Calcium Hydroxide-Calcium Silicate Mixtures.

Materials (Basel, Switzerland). 2020;13(4): 921.
17. Shokouhinejad N, Sharifian Z, Pirhajati Mahabadi V, Khorrami M. Cytotoxicity and Biocompatibility of Endodontic Materials on Dental Pulp Stem Cells. Iran Endod J. 2021;16(1):e11292.
18. Sardarian A, Yazdanian M, Naderinasab M, Shahsavari F. Cytotoxicity and Genotoxicity of Calcium Hydroxide-Based Intracanal Medicaments in Human Gingival Fibroblasts. J Oral Sci. 2021;63(3): 332-337.
19. Kukreja P, Bansal R, Kukreja S, Bansal V. Comparative Evaluation of the Antimicrobial Efficacy and Biocompatibility of Three Pulp Capping Agents: An In Vitro Study. Int J Clinl Pediatr Den. 2021; 14(2):149-153.
20. Mohammadi Z, Dummer PM. Properties and applications of calcium hydroxide in endodontics and dental traumatology. Int Endod J. 2011;44(8):697-730.
21. Gomes-Filho JE, Cintra LTA, Jacinto RC, Nascimento GG, Santos KRN, Tavares WLF. Antimicrobial Efficacy and Bioactivity of Calcium Silicate-Based Cements Versus Calcium Hydroxide as Intracanal Medicaments: A Systematic Review and Meta-analysis. J Endod. 2021;47(1):20-32.
22. Kadali N, Alla RK, Guduri V, Ramaraju AV, Sajjan S, Rudraraju VR. Mineral Trioxide Aggregate: An overview of composition, properties and clinical applications. Int J Dent Mater. 2020;2(1):11-8.
23. Keles A, Alcin H, Kamaci A, Arslan H. Efficacy of Calcium Hydroxide in Preventing Bacterial Leakage in Teeth with Incomplete Root Formation: A Systematic Review and Meta-analysis. J Endod. 2020;46(7):887-895.
24. Zhang Y, Zhang J, Chen W, Wu Y, Cheng N, Wang J. The Effects of Calcium Hydroxide on Pulpal and Periodontal Regeneration: A Systematic Review and Meta-analysis. J Endod. 2021;47(6): 837-844.
25. Cai YZ, Zhu XQ, Dong YL, Jiang LY, Zhang CF. Calcium hydroxide-induced odontoblastic differentiation of dental pulp stem cells. Int J Oral Sci. 2011;3(4): 182-188.
26. Stanley HR, Alattar M, Collett WK, Stringfellow HR Jr, Spiegel EH. Antibacterial efficacy of calcium hydroxide and chlorhexidine on Enterococcus faecalis: a randomized controlled trial. J Endod. 1995;21(6):285-290.
27. Arão TCC, de Araújo ASA, Goes AM, Oliveira CF, Silva CO, Xavie SP. Calcium Hydroxide Associated with Platelet-Rich Fibrin Improves the Repair of Rat Calvarial Defects. J Craniofac Surg. 2021;32(2): e179-e182.
28. Aggarwal V, Singla M, Miglani S. Role of calcium hydroxide in endodontics: a review. Endodontology. 2010;22(2):63-70.
29. Galler KM, Schweikl H, Schmalz G. Dose- and time-dependent cytotoxicity of low concentrations of mercury in human oral keratinocytes (HOK) and gingival fibroblasts (HGF-1) and the influence of antioxidants on mercury-induced cell death. Arch Toxicol. 2002;76(11):651-656.
30. Akhlaghi N, Khademi AA, Mohammadi Z. Calcium hydroxide in dentistry: a review of literature. J Oral Health Oral Epidemiol. 2014;3(4):166-171.
31. Hong ST, Bae MK, Baek SH, Kum KY, Lee W. The effect of mixing technique on the viscosity and setting time of calcium hydroxide mixed with distilled water or 2% chlorhexidine gluconate solution. J Endod. 2010;36(5):869-872.
32. Koutroulis A, Kouros P, Tziafas D. The effect of filler particle size on the thixotropic properties of calcium hydroxide pastes. J Endod. 1995;21(9):465-469.
33. Abbott PV, Heah SY, Hume WR. Release and diffusion through human tooth roots in vitro of corticosteroid and tetracycline trace molecules from Ledermix paste. J Endod. 1987;13(10):482-488.
34. Torabinejad M, Pitt Ford TR, Abedi HR, Kariyawasam SP, Tang HM. Calcium hydroxide as a barrier against reinfection after root canal filling. J Endod. 1995;21(8):417-419.
35. Camilleri J, Sorrentino F, Damidot D. Investigation of the hydration and bioactivity of radiopacified tricalcium silicate cement, Biodentine and MTA Angelus. Dent Mater. 2013;29(5):580-593.
36. Pereira A, de Oliveira DV, Alves VT, Borges AH. Evaluation of mechanical properties of three pulp-capping materials. J Conserv Dent. 2018;2(3):275–278.
37. Prabhakar AR, Basappa S, Raju OS, Gupta P. Comparative evaluation of physical and mechanical properties of mineral trioxide aggregate and Biodentine. Ind J Dent Res. 2015;26(4):401–405.

38. Deonizio MD, Maia LG, Lima RG, Fronza BM, da Silva EM, De Rossi A. Mechanical and physicochemical properties of calcium silicate-based materials compared with conventional materials used for root perforation repair: A systematic review. J Endod. 2019;45(6):655–665.
39. Bakland LK. Pulp capping materials. In: Cohen S, Burns RC, eds. Pathways of the Pulp. 5th ed. St. Louis, MO: Mosby. 1998:326-348.
40. Natale LC, Rodrigues MC, Xavier TA, Simões A, de Souza Costa CA, Braga RR. Influence of storage time and mechanical load cycling on the flexural strength of dental cements used for crown cementation. J Prosthet Dent. 2012;108(2): 82-87.
41. Ozsu D, Ozsu M, Yücel S. Evaluation of the physical and mechanical properties of calcium silicate cements. J Endod. 2015;41(3):357–361.
42. Koubi G, Colon P, Franquin JC, Hartmann A, Richard G, Faure MO, Camps J. Clinical evaluation of the performance and safety of a new dentine substitute, Biodentine, in the restoration of posterior teeth - a prospective study. Clin Oral Investig. 2012;16(3):583–589.
43. Malhotra N, Mala K, Acharya S. A comparative evaluation of compressive strength, surface hardness and surface roughness of three commercially available pulp capping materials: An in vitro study. J Conserv Dent. 2011;14(2):182-186.
44. Kimura Y, Wilder-Smith P, Matsumoto K. Lasers in endodontics: a review. Int Endod J. 2000;33(3):173-185.
45. Kaur G, Jain S, Sharma A. Evaluation of thermal expansion of newer dental materials. J Clin Pediatr Dent. 2011;35(2):143-147.
46. Jain P, Kumar P, Bhargava A, Bansal M. Comparative evaluation of thermal and dimensional changes in three different types of calcium hydroxide-based materials used for direct pulp capping. J Conserv Dent. 2016;19(6):529-533.
47. Yang H, Chen L, Zuo Y, Wang J, Wang Y. A study on the release of calcium ion from four kinds of calcium hydroxide materials in different vehicles. Int Endod J. 2007;40(4): 282-287.
48. Namazikhah MS, Nekoofar MH, Sheykhrezae MS, et al. The effect of pH on surface hardness and microstructure of mineral trioxide aggregate. Int Endod J. 2008;41(2):108-116.
49. Thakur V, Gupta S, Shashikiran ND. A study on translucency of various cements in comparison to dentin. J Indian Soc PedodPrev Dent. 2013;31(3):163-168.
50. Nakamura Y, Nomura Y, Nakaoka K, Goto Y. Evaluation of esthetic properties of light-cured pulp capping materials. J Dent Res. 1996;75:294.
51. Cohen S, Hargreaves KM. Pathways of the Pulp. 10th ed. St. Louis, MO: Mosby; 2011.
52. American Dental Association. Direct pulp capping. J Am Dent Assoc. 2019; 150(8):e138-e139.
53. American Dental Association. Indirect pulp capping. J Am Dent Assoc. 2019;150(8): e140.
54. Hilton TJ, Ferracane JL, Broome JC. Summitt's Fundamentals of Operative Dentistry: A Contemporary Approach. 4th ed. Chicago, IL: Quintessence Publishing; 2013.
55. Schwendicke F, Frencken JE, Bjørndal L, et al. Managing carious lesions: Consensus recommendations on carious tissue removal. Adv Dent Res. 2016;28(2):58-67.
56. Smaïl-Faugeron V, Courson F, Durieux P, Muller-Bolla M. Pulp capping materials in dentistry: a systematic review and meta-analysis. Acta BiomaterOdontol Scand. 2017;3(1):19-37.
57. Al-Hezaimi K, Al-Shalan TA, Naghshbandi J, Oglesby S, Simon JH, Rotstein I. Success of direct pulp capping with mineral trioxide aggregate and calcium hydroxide in mature teeth with pulps exposed during carious tissue removal: 12-month results. J Endod. 2011;37(5): 693-697.
58. Bjorndal L, Reit C, Bruun G, et al. Treatment of deep caries lesions in adults: randomized clinical trials comparing stepwise vs. direct complete excavation, and direct pulp capping vs. partial pulpotomy. Eur J Oral Sci. 2010;118(3): 290-297.
59. Torabinejad M, Hong CU, McDonald F, Pitt Ford TR. Physical and chemical properties of a new root-end filling material. J Endod. 1995;21(7):349-353.
60. Ricucci D, Siqueira JF Jr. Pulp and periapical status of dogs' teeth after pulp revascularization. J Endod. 2010;36(11): 1766-1770.

61. Mattscheck DJ, Law AS, Noblett WC. Clinical outcomes of calcium hydroxide as a direct pulp-capping agent. J Am Dent Assoc. 2010;141(6): 639-646.
62. Subramaniam P, Konde S, Mandava J, Vellaichamy K. Calcium hydroxide-induced apical barrier in immature apex: a case series. J Conserv Dent. 2012;15(4): 379-383.
63. Bjorndal L, Reit C, Bruun G, et al. Treatment of deep caries lesions in adults: randomized clinical trials comparing stepwise vs. direct complete excavation, and direct pulp capping vs. partial pulpotomy. Eur J Oral Sci. 2010;118(3): 290-297.
64. Holland R, Souza V, Nery MJ, Otoboni Filho JA, Bernabé PF, Dezan Junior E. Reaction of rat connective tissue to implanted dentin tubes filled with mineral trioxide aggregate, Portland cement or calcium hydroxide. Braz Dent J. 2001;12(1):3-8.
65. Chen YC, Lee SY, Tu HP, Chen WP, Chen YY, Huang HL. Calcium hydroxide nanoparticles as a novel pulp-capping agent for dental pulp stem cells-based pulp tissue engineering. Materials (Basel). 2021;14(10):2446.
