



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

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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].

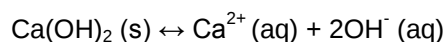
The most widely used calcium hydroxide 2-paste system is Dycal (Dentsply Sirona), which consists of a base and the catalyst pastes. Base paste typically contains calcium hydroxide, Zinc oxide, polymeric fatty acid ester, Barium sulphate and titanium dioxide. The catalyst paste contains Dimethylammonium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

3. SETTING MECHANISM

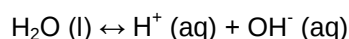
The setting reaction of calcium hydroxide pulp capping agent is a complex process that involves several chemical reactions. Calcium hydroxide pulp capping material sets by a process called hydration. When water is added to the powder component, calcium oxide reacts with water to form calcium hydroxide (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

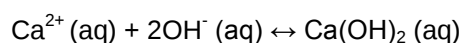
In the first stage, calcium hydroxide particles dissolve in water to form calcium and hydroxide ions:



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:

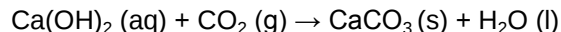


The hydroxide ions produced by the dissolution of calcium hydroxide and ionization of water react with calcium ions to form calcium hydroxide complexes:

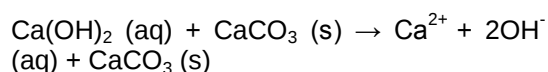


Stage 2: Precipitation and Gelation

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



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:



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 $16.4 \times 10^{-6}/^{\circ}\text{C}$ 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.

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