INTRODUCTION

Pulp exposures may result from caries removal during restorations, large caries, or trauma such as a sports injury. A pulp exposure could cause inflammation of the dental pulp (pulpitis), which may become irreversible, causing pain, pulp necrosis, and eventually may require an extraction or root canal treatment. Clinically, the treatment of a pulp exposure includes a direct pulp capping or pulpotomy. A direct pulp capping is the placement of a dental material directly over an exposed pulp, to protect the dental pulp and preserve its vitality; a pulpotomy involves the removal of a portion of the pulp before the placement of a material. The goal of direct pulp-capping is to prevent the dental pulp from dying and avoid the need for root canal treatment.

A number of materials, such as zinc oxide eugenol, glass ionomer/resin-modified glass ionomer, and adhesive systems, have been used in direct pulp capping, but they normally have poor clinical outcomes due to the cytotoxicity to the dental pulp. Calcium hydroxide has a long track record of clinical success, and is considered the “gold standard” of direct pulp capping materials. In recent years, calcium silicates, such as mineral trioxide aggregates (MTA) have been developed with the advantages of precise placement, command set, and superior physical strength. Resin-modified calcium hydroxide and calcium silicates have been used in direct pulp capping materials, particularly resin-modified materials.

Keywords: Cytotoxicity, Pulp capping, Calcium hydroxide, MTA, Calcium silicates

CALCIUM HYDROXIDE AND RESIN-MODIFIED CALCIUM HYDROXIDE

Calcium hydroxide was introduced in dentistry in 1920s, and has been used with great clinical success as a direct pulp capping material for several decades. Calcium hydroxide is a strong base with a high pH of approximately 12. It is slightly soluble in water, releasing Ca2+ and OH− ions through the ionic dissociation. The high pH of OH− ion provides excellent antibacterial properties, minimizing bacterial penetration to the pulp. On the other hand, the high pH causes irritation of the pulp tissue and develops a superficial three-layer necrosis on exposed pulp, stimulating and forming mineralization directly against the necrotic zone. The Ca2+ ion provides a source of calcium for initiating and stimulating mineralization. Three types of calcium hydroxides have been used for direct pulp capping, including one-paste non-setting calcium hydroxide, two-paste self-setting calcium hydroxide, and resin-modified calcium hydroxide.

Historically, calcium hydroxide was used in a powder form directly on exposed pulp. Currently,
Table 1 Compositions of representative direct pulp-capping materials

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Materials</th>
<th>Compositions</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-paste non-setting calcium hydroxide</td>
<td>UltraCal XS</td>
<td>Calcium hydroxide, water, barium sulfate</td>
<td>Ultradent Products, South Jordan, UT, USA</td>
</tr>
<tr>
<td></td>
<td>Calcicur</td>
<td>Calcium hydroxide, water, cellulose derivatives and barium sulfate</td>
<td>Voco, Cuxhaven, Germany</td>
</tr>
<tr>
<td>Two-paste self-setting calcium hydroxide</td>
<td>Dycal</td>
<td>Base paste: calcium phosphate, calcium tungstate, zinc oxide, iron oxide pigments, 1,3-butylene glycol disalicylate Catalyst paste: calcium hydroxide, zinc oxide, zinc stearate, titanium oxide, iron oxide pigments, N-ethyl-o/p-toluene sulphonamide</td>
<td>Dentsply Tulsa Dental, Johnson City, TN, USA</td>
</tr>
<tr>
<td></td>
<td>Life</td>
<td>Base paste: calcium hydroxide, zinc oxide, calcium oxide, zinc stearate, N-ethyl-o(or p)-toluenesulphonamide Catalyst paste: titanium dioxide, barium sulfate, methyl salicylate</td>
<td>Kerr, Orange, CA, USA</td>
</tr>
<tr>
<td>Resin-modified calcium hydroxide</td>
<td>Prisma VLC Dycal</td>
<td>Calcium hydroxide, barium sulfate, UDMA, TEGDMA</td>
<td>Dentsply Tulsa Dental</td>
</tr>
<tr>
<td></td>
<td>Ultra-Blend Plus</td>
<td>Calcium hydroxide, tricalcium phosphate, diurethane dimethacrylate, TEGDMA</td>
<td>Ultradent Products</td>
</tr>
<tr>
<td></td>
<td>Calcinol LC</td>
<td>Calcium hydroxide, fumed silica, UDMA, TEGDMA</td>
<td>Voco</td>
</tr>
<tr>
<td>Calcium silicates/MTA</td>
<td>ProRoot MTA</td>
<td>Portland cement, bismuth oxide</td>
<td>Dentsply Tulsa Dental</td>
</tr>
<tr>
<td></td>
<td>MTA-Angelus</td>
<td>Tricalcium silicate, dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite, bismuth oxide</td>
<td>Angelus, Londrina, PR, Brazil</td>
</tr>
<tr>
<td></td>
<td>Biodentine</td>
<td>Powder: tricalcium silicate, calcium carbonate and zirconium oxide Liquid: water, calcium chloride (accelerator) and modified polyacrylic acid</td>
<td>Septodont, Saint-Maurdes-Fosses, France</td>
</tr>
<tr>
<td>Resin-modified calcium silicates</td>
<td>TheraCal LC</td>
<td>Portland cement (calcium silicates), fumed silica, Bis-GMA, polyglycol dimethacrylate</td>
<td>Bisco, Schamburg, IL, USA</td>
</tr>
</tbody>
</table>

TEGDMA: Triethylene glycol dimethacrylate; Bis-GMA: bisphenol A diglycidyl methacrylate; UDMA: urethane dimethacrylate
68.0 and 58.7% after 1, 5 and 9 years, respectively. Because of the disadvantages of high solubility and the lack of setting of one-paste calcium hydroxide systems, a curable two-paste calcium hydroxide system has been developed and widely used in clinical practice. Commercial products include Dycal (Dentsply Tulsa Dental, Johnson City, TN, USA) and Life (Kerr, Orange, CA, USA) (Table 1). Two-paste calcium hydroxide systems normally contain a base paste and catalyst paste. One of the pastes contains active ingredient calcium hydroxide, and the other paste contains disalicylate. The setting reaction occurs between the calcium hydroxide and disalicylate, forming calcium disalicylate. Two-paste calcium hydroxide system may also contain other components, such as zinc oxide (a reactant, but not a principle reactant), zinc stearate (accelerator), radiopacifier (cement tungstate, or barium sulfate etc.), pigments, plasticizer and/or oil (to make a paste form), and/or an antibacterial agent. The setting time for a two-paste calcium hydroxide system is normally 2–6 min. The physical strengths, such as compressive strength, tensile strength, and modulus of elasticity, are usually low. Although two-paste calcium hydroxide systems have setting characteristics, they are still soluble and could dissolve over time. Two-paste calcium hydroxide systems have been shown to be more toxic than the non-setting one-paste calcium hydroxide systems, possibly due to the added toxicity of the additional components such as disalicylate, accelerator, and/or plasticizer. For example, in a 3-day MTT assay test with odontoblasts cells, two-paste calcium hydroxide (Dycal) demonstrated the lower cell vitality rate than other types of direct pulp capping materials, such as one-paste calcium hydroxide and MTA. Dycal also showed significantly greater toxicity to human dental pulp cells than resin composites. It was reported that the toxicity of the two-paste calcium hydroxide system was not able to be altered by six different growth factors (bone morphogenic peptide-2 and 7, fibroblast growth factor-2, epidermal growth factor, transforming growth factor-β, and insulin-like growth factor-I) which have been shown to alter pulp cell growth or differentiation. In contrast, some of the specific growth factors can make pulp cells resistant to the toxicity of composite materials. The success rate for Dycal in direct pulp capping was reported to be 73% (15 cases) after 6-month follow-up. The success rates for another two-paste calcium hydroxide (Life, Kerr) after 3-year direct pulp capping were reported as 92.2% with mechanical exposure and 33.3% with carious exposure. In another clinical study, the success rate for Life in 132 pulp caps was 37% (18% questionable and 45% failure) in the 5-year group and 13% (80% failing and 7% questionable) in the 10-year group.

Light-curable resin-modified calcium hydroxide materials, such as Prisma VLC Dycal (Dentsply Tulsa Dental), Calcimol LC (Voco), and Ultra-Blend Plus (Ultradent Products) (Table 1) have been used for direct pulp-capping. Compared to the conventional one-paste or two-paste calcium hydroxide systems, the resin-modified version has several advantages, including light-polymerization, superior physical properties, minimally affected by phosphoric acid, and low water solubility/does not dissolve over time. It is known that un-polymerized resins/monomers are toxic to pulp cells. For example, it was reported that Calcimol LC presented the higher cytotoxicity to MDPC-23 cells than the resin-free non-setting calcium hydroxide paste Calciure, but it showed similar or lower cytotoxicity than two-paste self-setting calcium hydroxide Dycal (vitality with MTT test after 72 h: Calciure 21%, Calcimol LC 15%, Dycal 9%; number of vital cells with Alamar blue tests after 72 h: Calciure 262000, Calcimol LC 330000, Dycal 300000). However, the composite resin presented mild to no toxic effects to the odontoblast-like MDPC-23 cells, as long as it was polymerized. A study showed resin-modified calcium hydroxide VLC Dycal was not more cytotoxic than the control calcium hydroxide. When VLC Dycal was cured sufficiently with a longer curing time, the cytotoxicity of the resin in VLC Dycal disappeared. At the same time, OH− was released and started to cause cytotoxicity. An in vitro study indicated that Ultra-Blend Plus had no increase of adult human dermal fibroblast cytotoxicity levels, compared to negative control. It is worth to note that a typical 70% of polymerization degree of conversion of dimethacrylate monomers does not mean 30% of free monomers. It means 30% of methacrylate groups are still available for polymerization, but among those 30%, most of them are already in the polymer matrix. Approximately, only 9% of monomers are free monomers (i.e., both methacrylate groups in one monomer are uncured), and most of that 9% free monomers are located inside the polymer matrix (would not leach out).

**CALCICUR:**

**CALCIUM SILICATES AND RESIN-MODIFIED CALCIUM SILICATES**

Mineral trioxide aggregates (MTA), such as ProRoot MTA (Dentsply Tulsa Dental) has been widely used as a direct pulp capping material (Table 1). MTA is a mixture of tricalcium silicate, dicalcium silicate, and tricalcium aluminate. Bismuth oxide (roughly 20%) is also included in MTA for radiopacity. Because of the success of MTA, new versions of calcium silicate-based materials (such as Biodentine (Septodont, Saint-Maurdes-Fosses, France)) have also been developed (Table 1). The mechanism of action of MTA/calcium silicat is similar to that of calcium hydroxides. Calcium hydroxide is the by-product of the primary reaction (hydration) of MTA/calcium silicates with water. The hydration slowly results in a gel which solidifies after several hours. MTA/calcium silicates are believed to have better sealing ability, biocompatibility and higher physical strength than calcium hydroxides. For instance, the compressive strength of Biodentine (calcium silicates) was reported to be 49 MPa after 7 days, while Dycal (two-paste self-setting calcium hydroxide) was only 16 MPa. Compared to calcium hydroxide, MTA/calcium silicates produce more uniform and thicker dentin bridge formations with less inflammatory response and less necrosis of pulp tissue, possibly due to its ability to increase bone...
morphogenetic protein (BMP-2 protein) production\textsuperscript{24} and induce reparative dentinogenesis\textsuperscript{25}.

Many studies have demonstrated that MTA/calcium silicates were less toxic than calcium hydroxides. In one study, MTA exhibited no cytotoxicity to rat dental pulp cells after 72 h, whereas the two-paste calcium hydroxide (Dycal) killed almost all cells\textsuperscript{26}. Another study also suggested that calcium silicates (ProRoot MTA, MTA-Angelus (Angelus, Londrina, PR, Brazil), Biodentine) were less cytotoxic to odontoblasts cells than two-paste calcium hydroxide (Dycal) and one-paste calcium hydroxide (Calicur)\textsuperscript{20}. An in vitro adult human dermal fibroblast cytotoxicity study showed that MTA materials (MTA-Angelus, Brasseler Endosquence Root Repair Putty) and resin-modified Ca(OH)\textsubscript{2} (Ultra-Blend Plus) had cytotoxicity levels statistically similar to the negative control, which was statistically less cytotoxic than the two-paste calcium hydroxide (Dycal)\textsuperscript{20}. MTA also showed less toxic to human tooth germ stem cells than Dycal\textsuperscript{20}. An in vivo study (60 days) with dogs showed that none or mild inflammatory response occurred beneath the pulpal wound capped with calcium hydroxide saline paste or Pro-Root MTA. MTA and calcium hydroxide presented no statistical difference in terms of the pulpal response, but the teeth capped with calcium hydroxide had greater healthy pulp loss\textsuperscript{27}.

One study compared MTA (ProRoot) with two-paste calcium hydroxide system (Dycal) when used as pulp-capping materials in 11 pairs of human teeth. After 1 week, 2, 3, 4, and 6 months, MTA groups presented less inflammation, less hyperaemia, less necrosis, more frequent odontoblastic layer formation, and thicker dentinal bridging (0.19–0.43 mm for ProRoot, and 0.02–0.15 mm for Dycal from 3–6 months) than the calcium hydroxide group\textsuperscript{20}. Another in vivo study also demonstrated that MTA caused less inflammation, less necrosis, and faster dentin bridge formation, than calcium hydroxide Dycal\textsuperscript{20}. An in vitro study from the same paper demonstrated that calcium hydroxide (29.4% decrease of cell metabolic activity) caused higher cytotoxic effects to the MDPC-23 cells than MTA (9.9% decrease)\textsuperscript{27}. The success rate of MTA (ProRoot) for direct pulp capping was reported to be 80.3% (195 cases) after 2 year-recall, which was higher than that of calcium hydroxide (Life, Kerr) (68.5%, 181 cases)\textsuperscript{20}.

Another clinical trial showed the overall success rate of MTA (ProRoot) was 80.5% (170 teeth total), with 33 failed teeth (19.5%) in 10 years\textsuperscript{10}. The success rate was higher than that of calcium hydroxide (59%). The failure included subsequent root canal treatment (25 teeth), pulp necrosis (2 teeth), asymptomatic apical periodontitis (4 teeth), and extraction (2 teeth)\textsuperscript{10}. In another paper, 98% of teeth (49 teeth total) capped with MTA received favorable outcomes on the basis of radiographic appearance, subjective symptoms, and cold testing, over an observation period of nine years\textsuperscript{9}.

Similar to resin-modified calcium hydroxides, light-cureable resin-modified calcium-silicate based materials (such as TheraCal LC, Bisco, Schaumburg, IL, USA) have been developed and used for direct pulp capping. Compared to conventional calcium silicates/MTA materials, the resin-modified version has several advantages, including immediate light-polymerization, preventing wash out of material, and superior physical properties\textsuperscript{30}. One study showed that TheraCal LC presented higher calcium release than MTA (ProRoot) and calcium hydroxide (Dycal) throughout a 28-day test period, while its solubility was significantly lower\textsuperscript{31}. The pH profile of the medium conditioned by TheraCal LC was similar as that of ProRoot MTA (from 11 to 8) during the 28-day test\textsuperscript{31}. Similar to other types of calcium hydroxides or calcium silicates materials (Dycal, Calcitur, Calcimol LC, MTA Angelus, and Biodentine), TheraCal LC exhibited valuable antibacterial activity\textsuperscript{32}.

It was reported that TheraCal LC stimulated apatite formation after 24 h immersion in Dulbecco’s Phosphate Buffered Saline (DPBS) solution\textsuperscript{33}. It is worth noting that there is a major difference between TheraCal LC and resin-modified calcium hydroxide (such as Calcimol LC, VLC Dycal, and Ultra-Blend Plus). TheraCal LC contains a hydrophilic monomer/polymer matrix, while Calcimol LC, VLC Dycal, and Ultra-Blend Plus contain a hydrophobic monomer/polymer matrix. The hydrophilic matrix allows higher calcium and hydroxide release, which are very important in protecting pulp cell’s ability to stimulate dentin formation and provide antibacterial action (high alkalinity), respectively\textsuperscript{33,34,35}.

Both TheraCal LC and resin-modified calcium hydroxide were shown to be more cytotoxic to murine odontoblasts cells and human dental pulp stem cells than resin-free calcium silicates, such as Biodentine, MTA Angelus, and ProRoot MTA, but they showed similar or lower cytotoxicity than Dycal (vitality with MTT test after 72 h: resin-modified materials: 14–15%, resin-free MTA 28–35%, Dycal 9%; number of vital cells with Alamar blue tests after 72 h: resin-modified materials: 33000–35000, resin-free MTA 333000–533000, Dycal 30000)\textsuperscript{30}. However, this cytotoxicity might be due to the uncured monomers in the oxygen inhibition layer on the surface of TheraCal LC test samples during sample preparation in the laboratory (exposure to air/oxygen). Research studies suggested that uncured monomers/resins were toxic to pulp cells, while cured resins presented no toxic effects\textsuperscript{7,10}. However, it is worth noting that an oxygen inhibition layer is not clinically relevant, since the pulp capping materials are placed inside teeth with no oxygen present. It would be more clinically relevant to remove the oxygen inhibition layer prior to cytotoxicity tests. Covering the materials with a Mylar strip may reduce the oxygen inhibition layer, but it does not completely remove it. A rinse of the surface with ethanol or acetone may remove the oxygen inhibition layer. A 14-day in vivo study with rats indicated that the tissue responses and temporospatial localization of dentin matrix protein 1 and osteopontin in pulps capped with TheraCal LC were similar to those capped with calcium hydroxide or ProRoot MTA\textsuperscript{30}. Compared to the resin-containing calcium hydroxide (Ultra-Blend Plus) and resin-modified Glass Ionomer (Vitrebond, 3M, ESPE), the resin-containing calcium silicates (TheraCal...
LC) presented lower cytopathic effects to cultured pulp cells\(^{36}\). In a 4-week in vivo study on primate pulp capped with 4 different materials, both the Portland cement and TheraCal LC groups presented more frequent and thicker hard tissue bridge formation than the GIC and VLC Dycal groups\(^{37}\). A 2-year in vivo study demonstrated that TheraCal LC had higher success rate (93.3\%) for direct pulp capping than antibacterial adhesive system (Protect Bond, Kuraray) (83.3\%) and Glass Ionomer cement (Fuji IX, GC) (66.6\%)\(^{38}\). Another clinical study indicated that the success rate for TheraCal LC was not significantly different from that for Dycal (~70\% in 15 cases) in direct pulp capping after 6-month follow-up\(^{14}\). The success rate went up to 100\% with a pre-treatment of laser irradiation to the exposed pulp\(^{14}\).

Calcium silicates/MTA-based materials and Portland cements contain trace amount of heavy metals, such as lead (Pb), arsenic (As), cadmium (Cd), nickel (Ni), iron (Fe), copper (Cu), manganese (Mn), and zinc (Zn)\(^{39}\). It was reported that the MTA/Portland cements materials, such as CPM (Egeo, Buenos Aires, Argentina), CPM Sealer (Egeo), Gray MTA-Angelus (Angelus), ProRoot-MTA (Dentsply Tulsa Dental), and Gray Portland cement (Votorantim Cimentos, Cubatão, SP, Brazil) contained arsenic levels higher than the ISO-recommended limit for water-based cements of 2 mg arsenic/kg material (ISO 9917-1 standard). Only White Portland cement (Cimento Rio Branco, Rio de Janeiro, RJ, Brazil), MTA-Obtura (Angelus) and White MTA-Angelus (Angelus) presented arsenic levels below the limit set in the ISO standard\(^{40}\). Other studies demonstrated that MTA-based materials, such as ProRoot, MTA-Angelus, and/or Biodentine, contained low level of arsenic\(^{41-43}\), aluminium\(^{44}\), beryllium\(^{45}\), cadmium\(^{46}\), chromium\(^{46,47}\), iron\(^{48}\), and lead\(^{42,49}\). During the long setting periods of MTA/calcium silicates, toxic chemicals could leach out, causing cytotoxicity. It was reported that a calcium phosphate silicate-based sealer (EndoSequence BC Sealer, Brasseler, Savannah, GA, USA) required 168 h to reach the final set, and it exhibited severe cytotoxicity at 24 h, which gradually decreased to moderate cytotoxicity over the 6-week period\(^{40}\). Other evidence was shown that low levels of heavy metals like chromium, arsenic and lead leached out from the solid MTA-based materials, such as ProRoot and MTA-Angelus in water and simulated body fluid\(^{41,48}\). It is important to note that “the dose makes the poison”. In the other words, all substances could be poisonous, depending upon dosage\(^{50}\). The low levels of concentration were believed to be safe for use in clinical practice\(^{41,43}\). An in vivo study using rats compared the release of heavy metal (aluminium) from three different type of calcium silicate-based materials: MTA Angelus, MTA Fillapex (containing MTA, salicylate resin, natural resin, bismuth oxide, and silica), and resin-containing TheraCal LC. After 6, 30, and 60 days of restorations with these materials, the levels of aluminium (Al) in the plasma in which MTA Angelus (322–529 ppb) and MTA Fillapex (299–468 ppb) were implanted, were around twice as high as Theracal LC (143–226 ppb) and the control (102–155 ppb) groups\(^{49}\). It is likely that Theracal LC released less Al because of its lower solubility\(^{50}\) and shorter setting time (immediately light-cured) which reduces the chance of Al-release prior to the setting of the material\(^{50}\).

### OTHER MATERIALS FOR PULP-CAPPING

Several other types of materials have been reported as direct pulp-capping materials, including zinc oxide eugenol (ZOE), glass ionomer/resin-modified glass ionomer (GI/RMGI), and adhesive systems. Similar to calcium hydroxide and calcium silicates, ZOE has bactericidal effects. However, ZOE releases sufficient amounts of eugenol to be highly cytotoxic. A study showed ZOE causes chronic inflammation, with no pulp healing and no dentin bridge formation after 12-weeks direct pulp-capping, while calcium hydroxide showed pulpal healing\(^{51}\). ZOE is not recommended for direct pulp capping.

GI/RMGIs are less cytotoxic than ZOE. In addition, they are able to chemically bond to teeth. However, unlike calcium hydroxide/calcium silicates, GI/RMGIs are acidic and lack anti-bacterial effects. This initial acidity of GI/RMGI with a prolonged period at low pH, in addition to cytotoxicity of other components, may cause damaging effects on the pulp\(^{46}\). It was reported that direct pulp-capping with RMGI showed chronic inflammation and no dentin bridge formation after 10 months of restoration, while calcium hydroxide showed significantly better pulpal healing\(^{52}\). GI/RMGIs should not be used for direct pulp capping.

Due to their excellent bonding ability, resin adhesive systems were suggested for pulp capping 20 years ago. However, similar to GI/RMGI, adhesives are acidic and have no bactericidal effects. Dental adhesives exhibited poor pulp healing, chronic inflammation, and lack of dentin bridge formation, while the control calcium hydroxide demonstrated good pulpal healing, dentin bridge formation and no or slight inflammation\(^{53,54}\). It is interesting to note that pulp capped directly with non-acidic bonding resin or resin composite showed a trend towards better pulp response than the ones capped with acidic primers or adhesives\(^{53}\). Dental adhesive should be avoided for direct pulp capping.

### CONCLUSIONS

Based on this review, the following can be concluded regarding direct pulp capping:

1. Resin adhesive systems, zinc oxide eugenols, and glass ionomers/resin-modified glass ionomers have been shown to have cytotoxic effects on pulp cells. When used for direct pulp capping, they exhibited chronic inflammation, poor pulpal healing, and lack of dentin bridge formation, and should be avoided for direct pulp capping.

2. Calcium hydroxide-base products include one-paste non-setting calcium hydroxide systems, two-paste self-setting calcium hydroxide systems,
and light-curable resin-modified calcium hydroxides. They all demonstrate antibacterial properties and the ability to stimulate dentin bridge formation. Calcium hydroxide has the longest track record of clinical success and is still considered the gold standard for direct pulp capping. Two-paste calcium hydroxide systems contain toxic components other than calcium hydroxide, resulting in the higher cytotoxicity than one-paste calcium hydroxide system.

3. Compared to calcium hydroxide, MTA/calcium silicate materials have been shown to have less cytotoxicity and better or comparable clinical outcomes for direct pulp capping.

4. In vitro testing showed that light-curable resin-modified calcium hydroxides or calcium silicates did exhibit the higher cytotoxic effects than resin-free version possibly because oxygen inhibition layers were not first removed which may not be clinically relevant since the tooth interface which these materials come into contact with is oxygen free. Light-curable resin-modified products have the advantages of precise placement, command set, superior physical strength, less solubility, and reduced heavy metal release. Light-curable products with hydrophilic polymer matrix allowed the high release of calcium and hydroxide ions. They are promising materials for dental treatment of direct pulp capping.

REFERENCES