



ISSN Print: 2394-7489

ISSN Online: 2394-7497

IJADS 2022; 8(1): 01-05

© 2022 IJADS

www.oraljournal.com

Received: 15-10-2021

Accepted: 03-12-2021

Heriberto Cardenas Dominguez
Master's in Sciences Student,
Universidad Autonoma de Nuevo
Leon, Facultad de Odontologia,
Monterrey, Nuevo Leon, 64460 ZIP,
Mexico

Fanny Lopez Martinez
Professor, Universidad Autonoma de
Nuevo Leon, Facultad de
Odontologia, Monterrey, Nuevo Leon,
64460 ZIP, Mexico

Idalia Rodriguez Delgado
Professor, Universidad Autonoma de
Nuevo Leon, Facultad de
Odontologia, Monterrey, Nuevo Leon,
64460 ZIP, Mexico

Luis Martin Vargas Zuñiga
Professor, Universidad Autónoma de
Guerrero, Facultad de Odontología.
Acapulco de Juárez de Guerrero,
México

Juan Manuel Luna Gomez
Professor, Universidad Autónoma de
Guerrero, Facultad de Odontología.
Acapulco de Juárez de Guerrero,
México

**Maria Argelia Akemi Nakagoshi
Cepeda**
Professor, Universidad Autonoma de
Nuevo Leon, Facultad de
Odontologia, Monterrey, Nuevo Leon,
64460 ZIP, Mexico

Angela Benitez Santos
Dentistry Student, Universidad
Autonoma de Nuevo Leon, Facultad
de Odontologia, Monterrey, Nuevo
Leon, 64460 ZIP, Mexico

Juan Manuel Solis Soto
Professor, Universidad Autonoma de
Nuevo Leon, Facultad de
Odontologia, Monterrey, Nuevo Leon,
64460 ZIP, Mexico

Corresponding Author:
Juan Manuel Solis Soto
Professor, Universidad Autonoma de
Nuevo Leon, Facultad de
Odontologia, Monterrey, Nuevo Leon,
64460 ZIP, Mexico

TheraCal as the material of choice for direct pulp treatment compared to two other materials: MTA and biodentine

Heriberto Cardenas Dominguez, Fanny Lopez Martinez, Idalia Rodriguez Delgado, Luis Martin Vargas Zuñiga, Juan Manuel Luna Gomez, Maria Argelia Akemi Nakagoshi Cepeda, Angela Benitez Santos and Juan Manuel Solis Soto

DOI: <https://doi.org/10.22271/oral.2022.v8.i1a.1393>

Abstract

Introduction: Direct pulp treatment is a procedure in which the exposed vital pulp is treated with a therapeutic material, it is sought to promote healing, maintain pulp vitality and protect the pulp.

Objective: To prove that TheraCal is the material of choice as a coating for direct pulp treatment in terms of biocompatibility and cytotoxicity, solubility and clinical management, effects on the pulp, clinical and radiographic success in comparison with current materials used; MTA and Biodentine.

Methodology: An electronic search was performed during September 2021 in the PubMed-MEDLINE database. Human or *In vitro* comparative studies evaluating biocompatibility, clinical and radiographic success were included. No restriction was applied to the date of publication. Case series and expert opinions were excluded. Keywords such as "Theracal", "direct pulp capping", "Biodentine", "MTA" and "vital pulp treatment" were used.

Results: Only one article was found that discussed the toxic effects of TheraCal. TheraCal has very favorable effects on the pulp, as it could be observed to induce dentin formation, these effects are to some extent limited. The solubility of TheraCal is one of its strongest characteristics, and it is very useful in indirect pulp capping, but not very useful in direct pulp capping. In comparison with other materials, Theracal shows good results that are considerably successful, however, the MTA and Biodentine variants present better percentages and higher probabilities of success.

Conclusion: Theracal cannot be considered as a first-choice material when performing direct pulp treatment.

Keywords: Vital pulp therapy, direct pulp capping, MTA, biodentine, TheraCal

1. Introduction

Direct pulp treatment is a procedure in which the exposed vital pulp is treated with a therapeutic material to promote healing, maintain pulp vitality, and protect the pulp ^[1]. There are a variety of non-invasive, micro-invasive and minimally invasive treatments for primary and permanent teeth. The management of deep caries, with exposed pulp, should be treated using direct pulp treatment ^[2]. Vital pulp therapy is designed to preserve and maintain pulp health in teeth that have been exposed to trauma, caries, restorative procedures or anatomical abnormalities ^[3].

Mineral Trioxide Aggregate (MTA) has been used in direct pulp treatment, with excellent clinical results reported, compared to the results of conventional use of calcium hydroxide ^[4]. Biodentine exhibits rapid results, no discoloration and similar results are obtained compared to MTA, so it is considered an appropriate veneering material to replace MTA ^[5]. Calcium silicate-based cements have achieved remarkable results as predictable, safe and successful therapies ^[6]. TheraCal LC is a calcium silicate-based material that is designed as a direct/indirect pulp capping material. It is resin-based and does not require any dentin surface conditions ^[1]. It has been reported to enhance the formation of apatite and secondary dentin. Due to its high physical properties and low solubility, it is applied as the main barrier and

Direct pulp treatment is a procedure in which the exposed vital pulp is treated with a therapeutic material to promote healing, maintain pulp vitality, and protect the pulp^[1]. There are a variety of non-invasive, micro-invasive and minimally invasive treatments for primary and permanent teeth. The management of deep caries, with exposed pulp, should be treated using direct pulp treatment^[2]. Vital pulp therapy is designed to preserve and maintain pulp health in teeth that have been exposed to trauma, caries, restorative procedures or anatomical abnormalities^[3].

Mineral Trioxide Aggregate (MTA) has been used in direct pulp treatment, with excellent clinical results reported, compared to the results of conventional use of calcium hydroxide^[4]. Biodentine exhibits rapid results, no discoloration and similar results are obtained compared to MTA, so it is considered an appropriate veneering material to replace MTA^[5]. Calcium silicate-based cements have achieved remarkable results as predictable, safe and successful therapies^[6]. TheraCal LC is a calcium silicate-based material that is designed as a direct/indirect pulp capping material. It is resin-based and does not require any dentin surface conditions^[1]. It has been reported to enhance the formation of apatite and secondary dentin. Due to its high physical properties and low solubility, it is applied as the main barrier and protection of the dental pulp complex^[7]. It is evident that in the dental area there has been a constant evolution in the different treatments, consequently, new procedures and new materials are emerging, or even materials that already existed, but are being adapted to the new existing needs. TheraCal is a relatively recent material that is being widely used.

Therefore, the objective of this review is to prove that TheraCal is the material of choice as a coating for direct pulp treatment in terms of biocompatibility and cytotoxicity, effects on the pulp, solubility and clinical manipulation, clinical and radiographic success in comparison with the current materials used; MTA and Biodentine.

2. Materials and methods

Articles on the subject published through the PubMed, SCOPUS and Google Scholar databases were analyzed, with emphasis on the last 5 years. The quality of the articles was evaluated using PRISMA guidelines, i.e., identification, review, choice and inclusion. The quality of the reviews was assessed using the measurement tool for evaluating systematic reviews (AMSTAR-2). The search was performed using Boolean logical operators AND, OR and NOT. It was realized with the words "TheraCal", "MTA", "Biodentine", "Biocompatibility", "Clinical success". The keywords were used individually, as well as each of them related to each other.

3. Results & Discussion

3.1 Biocompatibility and Cytotoxicity

3.1.1 TheraCal

The result revealed that the bioactive cements and CPP-ACP had bioactivity capability for one week^[8]. TheraCal LC and Activa exhibited a low degree of conversion, low calcium ion release, acceptable biocompatibility and moderate antibacterial activity^[9].

3.1.2 MTA

Calcium silicate cement containing synthesized gypsum showed minimal cytotoxicity and did not inhibit in human

dental pulp stem cells (hDPSC) proliferation^[10]. The highest cell viability was demonstrated by Biodentine, MTA and Repair HP, in descending order. Bio-C Repair and Bio-C Repair Íon+ showed moderate cytotoxicity, similar to MTA Repair HP in the 7-day analysis^[11].

3.1.3 Biodentine

Biodentine tends to promote the formation of dentin bridges and this may result in a combination of biocompatibility, alkalinity and sealing ability^[12]. Using the CBCT system, it was found that Biodentine can induce this reparative dentin formation in a direct pulp capping^[13].

3.1.4 Comparison of Materials

The biocompatibility of TheraCal was first evaluated after exhibiting slow cell migration at 2-4 days. Alkaline phosphatase enzyme activity was highest with Biodentine at days 10 and 14, with TheraCal having the lowest activity. Human dental pulp stem cells cultured in ProRoot MTA and TheraCal LC eluates showed a significant increase in mineralized nodule formation on day 21 compared to Biodentine. These results indicate that MTA, Biodentine and TheraCal exhibit good biocompatibility^[14]. Theracal LC and MTA were tolerated in experimental use in rats in connective tissue. Histologically, no problems were demonstrated by direct contact of Theracal and MTA when mixed with 25% bioactive G3 glass with connective tissue^[15]. After one and three months, TheraCal LC demonstrated a higher inflammatory response and frequency of radiolucent distribution followed by Biodentine and MTA, respectively. Meanwhile, the highest cell migration was observed in the presence of calcium-enriched mixture (CEM) and Biodentine ($P < 0.05$). The biological compatibility associated with CEM and Biodentine indicates promising applications in the field of vital pulp therapy. The biomaterials of MTA, CEM and Biodentine at different dilutions had no cytotoxic effects on hDPSCs at different times; however, the undiluted extract of TheraCal showed toxic effects after 24, 48 and 72 h^[16]. A comparison made *In vitro* for cytotoxicity and genotoxicity on these three materials revealed that none proved to have either of these two characteristics. Therefore, TheraCal LC, Biodentine and ProRoot MTA can be used for vital pulp capping^[17]. *In vitro* biocompatibility and bioactive properties of MTA and Biodentine in HDPS suggest their superior regenerative potential compared to Dycal and TheraCal^[18]. Theracal LC had a heterogeneous structure with large non-hydrated particles because there was insufficient moisture to allow hydration to continue. The composition of Biodentine was shown to be optimized and environmental conditions did not affect the microstructure of the material^[19]. Of all the study groups, MTA demonstrated biocompatibility at a level close to that of the control groups. Inflammation was observed to be more severe in resin-containing materials^[20]. Several pulp capping materials, except Dycal, exhibited biological properties favorable to hDPSC viability. ProRoot MTA and TheraCal LC promoted higher Runx2 expression than Biodentine^[21]. The recently introduced TheraCal PT offers improved *In vitro* mineralization and cytocompatibility potential in hDPSC compared to its predecessor, TheraCal LC, and biological properties comparable to Biodentine^[22]. Only one article was found that discussed toxic effects of TheraCal, however, all others discussed positive biocompatibility.

3.2 Effect on Pulp

3.2.1 TheraCal

The degree of monomer conversion and fluoride release of both F1 and F2 were significantly lower than those of VB. F1 showed biaxial flexural strength comparable to VB, but higher strength than TC [23]. TheraCal LC showed the lowest temperature rise in the pulp chamber [24].

3.2.2 MTA

MTA induces a pulp healing process; activation of cell proliferation occurred within 1 week, followed by odontoblast differentiation within 2 weeks [25]. One study revealed that MTA can synergize with osteostatin and showed that more mineralized dentin bridge was formed [26]. MTA-based products show discrete antimicrobial activity compared to calcium hydroxide-based materials, which show higher antimicrobial activity [27]. One study showed that the application of PRGF-rich and PRGF-poor fraction as pulp capping material, stimulated dentin formation more strongly than MTA and untreated negative control [28]. A study compared MTA and HA / β -TCP / C local action, being similar to that of MTA, when used as a vital pulp treatment agent in terms of absence of inflammation and maintenance of pulp vitality, although there are significant differences between the two materials in terms of dentin bridging [29].

3.2.3 Biodentine

In an animal study it was demonstrated that Biodentine allowed the synthesis at the lesion site of a mineralized bridge formed from mineralized tissue secreted by cells exhibiting odontoblastic characteristics [30]. It was concluded that, on clinical and histological evaluation, Biodentine performed better as a direct pulp capping treatment agent. Subsequently, Biodentine is more reliable for long-term protection of dental pulp than Dycal [31].

3.2.4 Comparison of Materials

A gene ontology functional enrichment analysis revealed results for TheraCal of ($P < 0.001$) and inflammatory response ($P < 0.01$) compared to MTA. TheraCal showed enriched positive regulation of cell migration at 72 h ($P < 0.001$). Thus, differentially expressed genes in TheraCal may be involved in pathways associated with osteoclastogenesis and osteoclast differentiation [32]. The adhesion of THP-1 cells to endothelial cells and their activation were reduced by Biodentine and TheraCal. In the same article, Biodentine is shown to have the highest anti-inflammatory and pulp-healing potential compared to resin-containing materials [33]. Mild or no inflammatory responses were observed in all groups. Initial MTF was observed except for DY. No inflammation with complete MTF, including the presence of odontoblast-like cells, was observed in the MTAPPL, NX and TH groups on day 70 [34].

TheraCal has very favorable effects on the pulp, since, if it could be observed that it induced dentin formation, which is one of the main outcomes sought in indirect and direct pulp capping, however, these effects are to some extent limited.

3.3 Solubility and Clinical Handling

3.3.1 TheraCal

Gandolfi *et al.* (2014). Reported that the material showed lower solubility and higher calcium ion release. Unlike Biodentine, TheraCal LC is unable to alternate MTA in furcation perforation repair due to its poor biocompatibility and poor marginal adaptation.

3.3.2 MTA

MTA Plus showed enhanced reactivity and prolonged ability to release calcium. These pronounced ion releasing properties are related to its remarkable porosity, water absorption and solubility and to the formation of calcium and phosphorus minerals [35]. The radiopacity of the three new MTAs was considerably lower than that of PR [36].

3.3.3 Biodentine

Experimental materials were used in an investigation that showed higher viscosity and microhardness, but similar dentin shear bond strength compared to commercial resin-modified glass ionomer cements. All direct pulp capping materials showed low solubility; the pH of the materials tested ranged from 10 to 12 and showed a non-significant increase/decrease after 24 hours [4].

3.3.4 Comparison of Materials

A correlation of *In vitro* and *in vivo* data revealed that, currently, the most validated material for pulp capping procedures remains MTA, despite the superiority of Biodentine in relatively easier handling, competitive pricing and predictable clinical outcomes [37]. TheraCal LC demonstrated the highest frequency of gap distribution followed by MTA and Biodentine respectively. The least soluble material after one week was TheraCal LC, followed by MTA and Biodentine. TheraCal had a depth of cure of 1.7 mm. The solubility of TheraCal ($\Delta-1.58\%$) was low and significantly lower than that of Dycal ($\Delta-4.58\%$) and ProRoot MTA ($\Delta-18.34\%$) [38]. Calcium silicate materials showed high porosity values: the capped Tech Biosealer, MTA Plus gel and MTA Angelus showed the highest values of porosity, water absorption and solubility, while TheraCal the lowest. The solubility of the water-containing materials was higher and correlated with the ratio of liquid to powder [39].

It is easy to conclude that the solubility of TheraCal is one of its strongest characteristics and very useful in indirect pulp coatings, but not very useful in direct ones.

3.4 Clinical and Radiographic Success

3.4.1 TheraCal

TheraCal LC has a low bond strength to dentin, and stability may be affected when restorative material is placed and condensed on it. Its bond to dentin could be significantly improved by using dentin adhesives or resin cements. TheraCal LC bonded significantly more strongly than MTA Angelous (AMTA) regardless of the bonding agents tested. Resin-modified calcium silicate showed higher bond strength than AMTA in terms of composite bonding to these materials with different bonding systems [40].

3.4.2 MTA

The combination of diode laser and MTA yielded better clinical and radiographic success rates over pulpotomy procedures performed with the aid of MTA alone [41]. The 12 articles reviewed reported favorable results of vital pulp therapy performed with hydraulic calcium silicate cements on permanent mature posterior teeth with symptomatic irreversible pulpitis, with radiographic success in the range of 81 to 90% [42].

3.4.3 Biodentine

In a Class II restoration the largest gaps appeared for Geristore (first) and Biodentine (not significantly lower), while the gaps of the composite controls were smaller, the

lowest being the two-step self-etch system relative to the three-step etch-and-bond system, but without statistical significance [43]. The most clinically acceptable bond strength between Biodentine and the overlay composite restoration is 14 days after maturation of Biodentine [44]. One clinical case in which Biodentine was used, at 2-year follow-up, the teeth were asymptomatic. Radiographs showed healing of the periapical lesion and periodontal ligament. Biodentine TM complete pulpotomy of mature permanent teeth with irreversible pulpitis and apical periodontitis may be an alternative option to root canal therapy [45].

3.4.4 Comparison of Materials

In a comparison of radiographic and clinical first molars, it was revealed that TheraCal exhibited comparable results to MTA in direct pulp treatment after 12 months. The overall success rates of MTA and TheraCal were 94.5% and 91.8%, respectively [46]. Another study revealed high success rates for MTA (86.3%-85.4%), Biodentine (79.4%-80.1%), and TheraCal (72.1%-73.6%). Therefore, it was concluded that both MTA and Biodentine were suitable direct pulp capping materials for permanent teeth. And TheraCal-LC facilitates the use of calcium silicates, but there is a lower success rate [47]. ProRoot MTA and Biodentine were shown to be biocompatible and possess antibiofilm properties. Their clinical application in vital pulp therapy provided successful results after 2 years of follow-up. TheraCal causes moderate discoloration, greater than that caused by Biodentine and TotalFill [48].

Compared to other materials, Theracal CL shows good results that are considerably successful, however, the MTA variants and Biodentine show better percentages and higher probabilities of success.

4. Conclusion

TheraCal LC is a material whose properties are quite useful for indirect pulp capping. However, despite its good biocompatibility and achieving certain effects on the pulp, it cannot be considered as a first-choice material for direct pulp treatment, as it does not have a sufficient success rate due to its low solubility, which consequently does not have sufficient effects on the pulp.

5. References

1. Arandi NZ, Rabi T, Thera Cal LC. From Biochemical and Bioactive Properties to Clinical Applications. *Int J Dent* 2018;2018:3484653.
2. Poggio C, Beltrami R, Colombo M, Ceci M, Dagna A, Chiesa M. *In vitro* antibacterial activity of different pulp capping materials. *J Clin Exp Dent* 2015;7(5):e584-8.
3. Gasperi TL, Silveira JACD, Schmidt TF, Teixeira CDS, Garcia LD, Bortoluzzi EA. Physical-Mechanical Properties of a Resin-Modified Calcium Silicate Material for Pulp Capping. *Braz Dent J* 2020;31(3):252-256.
4. Thepveera W, Potiprapanpong W, Toneluck A, Channasanon S, Khamsuk C, Monmaturapoj N *et al.* Rheological Properties, Surface Microhardness, and Dentin Shear Bond Strength of Resin-Modified Glass Ionomer Cements Containing Methacrylate-Functionalized Polyacids and Spherical Pre-Reacted Glass Fillers. *J Funct Biomater* 2021;12(3):42.
5. Kermanshah H, Ranjbar Omrani L, Ghabraei S, Fekrazad R, Daneshparvar N, Bagheri P. Direct Pulp Capping With ProRoot MTA Alone and in Combination With Er: YAG Laser Irradiation: A Clinical Trial. *J Lasers Med Sci* 2020;11(1):S60-S66.
6. Bossù M, Mancini P, Bruni E, Uccelletti D, Preziosi A, Rulli M, *et al.* Biocompatibility and Antibiofilm Properties of Calcium Silicate-Based Cements: An *In vitro* Evaluation and Report of Two Clinical Cases. *Biology (Basel)* 2021;10(6):470.
7. Alazrag MA, Abu-Seida AM, El-Batouty KM, El Ashry SH. Marginal adaptation, solubility and biocompatibility of TheraCal LC compared with MTA-angelus and biodentine as a furcation perforation repair material. *BMC Oral Health* 2020;20(1):298.
8. Daneshpoor N, Pishevar L. Comparative evaluation of bioactive cements on biomimetic remineralization of dentin. *J Clin Exp Dent* 2020;12(3):e291-e299.
9. Koutroulou A, Kuehne SA, Cooper PR, Camilleri J. The role of calcium ion release on biocompatibility and antimicrobial properties of hydraulic cements. *Sci Rep* 2019;9(1):19019.
10. Hayashi Y, Kawaki H, Hori M, Shintani K, Hasegawa T, Tanaka M *et al.* Evaluation of the mechanical properties and biocompatibility of gypsum-containing calcium silicate cements. *Dent Mater J* 2021;40(4):863-869.
11. Klein-Junior CA, Zimmer R, Dobler T, Oliveira V, Marinowic DR, Özkomür A, *et al.* Cytotoxicity assessment of Bio-C Repair Íon+: A new calcium silicate-based cement. *J Dent Res Dent Clin Dent Prospects* 2021;15(3):152-156.
12. Arandi NZ, Thabet M. Minimal Intervention in Dentistry: A Literature Review on Biodentine as a Bioactive Pulp Capping Material. *Biomed Res Int.* 2021, 5569313.
13. Bui AH, Pham KV. Evaluation of Reparative Dentine Bridge Formation after Direct Pulp Capping with Biodentine. *J Int Soc Prev Community Dent* 2021;11(1):77-82.
14. Kim Y, Lee D, Song D, Kim HM, Kim SY. Biocompatibility and Bioactivity of Set Direct Pulp Capping Materials on Human Dental Pulp Stem Cells. *Materials (Basel)* 2020;13(18):3925.
15. Mena-Álvarez J, Rico-Romano C, Gutiérrez-Ortega C, Arias-Sanz P, Castro-Urdá J. A Comparative Study of Biocompatibility in Rat Connective Tissue of a New Mineral Trioxide Compound (Theracal) versus MTA and a Bioactive G3 Glass. *J Clin Med* 2021;10(12):2536.
16. Omidi S, Bagheri M, Fazli M, Ahmadiankia N. The effect of different pulp-capping materials on proliferation, migration and cytokine secretion of human dental pulp stem cells. *Iran J Basic Med Sci* 2020;23(6):768-775.
17. Zakerzadeh A, Esnaashari E, Dadfar S. *In vitro* Comparison of Cytotoxicity and Genotoxicity of Three Vital Pulp Capping Materials. *Iran Endod J* 2017;12(4):419-425.
18. Manaspon C, Jongwannasiri C, Chumprasert S, Sa-Ard-Iam N, Mahanonda R, Pavasant P, *et al.* Human dental pulp stem cell responses to different dental pulp capping materials. *BMC Oral Health* 2021;21(1):209.
19. Camilleri J, Laurent P, About I. Hydration of Biodentine, Theracal LC, and a prototype tricalcium silicate-based dentin replacement material after pulp capping in entire tooth cultures. *J Endod* 2014;40(11):1846-54.
20. Bakir EP, Yildirim ZS, Bakir S, Ketani A. Are resin-containing pulp capping materials as reliable as traditional ones in terms of local and systemic biological effects? *Dent Mater J*, 2021.
21. Kim Y, Lee D, Kim HM, Kye M, Kim SY. Biological

- Characteristics and Odontogenic Differentiation Effects of Calcium Silicate-Based Pulp Capping Materials. *Materials* (Basel) 2021;14(16):4661.
22. Sanz JL, Soler-Doria A, López-García S, García-Bernal D, Rodríguez-Lozano FJ, Lozano A, *et al.* Comparative Biological Properties and Mineralization Potential of 3 Endodontic Materials for Vital Pulp Therapy: Theracal PT, Theracal LC, and Biodentine on Human Dental Pulp Stem Cells. *J Endod* 2021;S0099-2399(21)00563-X.
23. Potiprapanpong W, Thepveera W, Khamsuk C, Channasanon S, Tanodekaew S, Patntirapong S, *et al.* Monomer Conversion, Dimensional Stability, Biaxial Flexural Strength, Ion Release, and Cytotoxicity of Resin-Modified Glass Ionomer Cements Containing Methacrylate-Functionalized Polyacids and Spherical Pre-Reacted Glass Fillers. *Polymers* (Basel). 2021;13(16):2742.
24. Lakhani J, Agrawal V, Mahant R, Kapoor S, Vaghanshi D, Shah A. Pulpal Temperature Rise: Evaluation after Light Activation of Newer Pulp-Capping Materials and Resin Composite. *Contemp Clin Dent*. 2018;9(4):644-648.
25. Xu D, Mutoh N, Ohshima H, Tani-Ishii N. The effect of mineral trioxide aggregate on dental pulp healing in the infected pulp by direct pulp capping. *Dent Mater* J. 2021.
26. Yoon JH, Choi SH, Koh JT, Lee BN, Chang HS, Hwang IN *et al.* Hard tissue formation after direct pulp capping with osteostatin and MTA *in vivo*. *Restor Dent Endod*. 2021;46(2):e17.
27. Poggio C, Lombardini M, Colombo M, Beltrami R, Rindi S. Solubility and pH of direct pulp capping materials: a comparative study. *J Appl Biomater Funct Mater*. 2015;13(2):e181-5.
28. Gaviño-Orduña JF, Caviedes-Bucheli J, Manzanares-Céspedes MC, Román-Richon S, Martín-Biedma B, Segura-Egea JJ, *et al.* Dentin Growth after Direct Pulp Capping with the Different Fractions of Plasma Rich in Growth Factors (PRGF) vs. MTA: Experimental Study in Animal Model. *J Clin Med*. 2021;10(15):3432.
29. Guerrero-Gironés J, Alcaina-Lorente A, Ortiz-Ruiz C, Ortiz-Ruiz E, Pecci-Lloret MP, Ortiz-Ruiz AJ, *et al.* Biocompatibility of a HA/β-TCP/C Scaffold as a Pulp-Capping Agent for Vital Pulp Treatment: An *In Vivo* Study in Rat Molars. *Int J Environ Res Public Health*. 2021;18(8):3936.
30. Minic S, Florimond M, Sadoine J, Valot-Salengro A, Chaussain C, Renard E, *et al.* Evaluation of Pulp Repair after Biodentine™ Full Pulpotomy in a Rat Molar Model of Pulpitis. *Biomedicines*. 2021;9(7):784.
31. Abdul MSM, Murali N, Rai P, Mirza MB, Salim S, Aparna M, *et al.* Clinico-Histological Evaluation of Dentino-Pulpal Complex of Direct Pulp Capping Agents: A Clinical Study. *J Pharm Bioallied Sci*. 2021;13(1):S194-S198.
32. Nam OH, Kim JH, Choi SC, Kim Y. Time-Dependent Response of Human Deciduous Tooth-Derived Dental Pulp Cells Treated with TheraCal LC: Functional Analysis of Gene Interactions Compared to MTA. *J Clin Med*. 2020;9(2):531.
33. Giraud T, Jeanneau C, Bergmann M, Laurent P, About I. Tricalcium Silicate Capping Materials Modulate Pulp Healing and Inflammatory Activity *In vitro*. *J Endod*. 2018;44(11):1686-1691.
34. Toida Y, Kawano S, Islam R, Jiale F, Chowdhury AA, Hoshika S, *et al.* Pulpal response to mineral trioxide aggregate containing phosphorylated pullulan-based capping material. *Dent Mater J*. 2021.
35. Gandolfi MG, Siboni F, Primus CM, Prati C. Ion release, porosity, solubility, and bioactivity of MTA Plus tricalcium silicate. *J Endod*. 2014;40(10):1632-7.
36. Kang TY, Choi JW, Seo KJ, Kim KM, Kwon JS. Physical, Chemical, Mechanical, and Biological Properties of Four Different Commercial Root-End Filling Materials: A Comparative Study. *Materials* (Basel) 2021;14(7):1693.
37. Kunert M, Lukomska-Szymanska M. Bio-Inductive Materials in Direct and Indirect Pulp Capping-A Review Article. *Materials* (Basel) 2020;13(5):1204.
38. Gandolfi MG, Siboni F, Prati C. Chemical-physical properties of TheraCal, a novel light-curable MTA-like material for pulp capping. *Int Endod J* 2012;45(6):571-9.
39. Gandolfi MG, Siboni F, Botero T, Bossù M, Riccitiello F, Prati C. Calcium silicate and calcium hydroxide materials for pulp capping: biointeractivity, porosity, solubility and bioactivity of current formulations. *J Appl Biomater Funct Mater* 2015;13(1):43-60.
40. Karadas M, Cantekin K, Gumus H, Ateş SM, Duymuş ZY. Evaluation of the bond strength of different adhesive agents to a resin-modified calcium silicate material (TheraCal LC). *Scanning* 2016;38(5):403-411.
41. Satyarth S, Alkhamis AM, Almunahi HF, Abdulaziz Alsuhyami MO, Vadde HB, Senapathi SN, *et al.* Comparative Evaluation of Mineral Trioxide Aggregate Pulpotomy and Laser-Assisted Mineral Trioxide Aggregate Pulpotomy: An Original Research Article. *J Microsc Ultrastruct* 2021;9(1):7-11.
42. Santos JM, Pereira JF, Marques A, Sequeira DB, Friedman S. Vital Pulp Therapy in Permanent Mature Posterior Teeth with Symptomatic Irreversible Pulpitis: A Systematic Review of Treatment Outcomes. *Medicina (Kaunas)* 2021;57(6):573.
43. Salerno M, Vizza F, Amaroli A, Signore A, Itri A. 3D optical profilometer analysis of the marginal gap of Class II restorations made with different materials for vital pulp therapy procedures. *Dent Mater* J 2021;40(2):407-415.
44. Mustafa RM, Al-Nasrawi SJ, Aljdaimi AI. The Effect of Biodentine Maturation Time on Resin Bond Strength When Aged in Artificial Saliva. *Int J Dent*. 2020;2020:8831813.
45. Tran XV, Ngo LTQ, Boukpessi T. Biodentine™ Full Pulpotomy in Mature Permanent Teeth with Irreversible Pulpitis and Apical Periodontitis. *Healthcare* (Basel) 2021;9(6):720.
46. Erfanparast L, Iranparvar P, Vafaei A. Direct pulp capping in primary molars using a resin-modified Portland cement-based material (TheraCal) compared to MTA with 12-month follow-up: a randomised clinical trial. *Eur Arch Paediatr Dent* 2018;19(3):197-203.
47. Peskersoy C, Lukarcin J, Turkun M. Efficacy of different calcium silicate materials as pulp-capping agents: Randomized clinical trial. *J Dent Sci*. 2021;16(2):723-731.
48. Al-Hiyasat AS, Ahmad DM, Khader YS. The effect of different calcium silicate-based pulp capping materials on tooth discoloration: an *In vitro* study. *BMC Oral Health*. 2021;21(1):330.