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NOVITETI U MATERIJALIMA ZA PREKRIVANJE PULPE

NOVELTIES IN PULP CAPPING MATERIALS

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Sažetak

Uvod: *Terapijski pristupi koji naglašavaju očuvanje pulpe od suštinskog su značaja za održavanje vitalnosti zuba sa izloženom pulpom i dubokim kavitacijama. Iako se indirektne i direktne metode prekrivanja pulpe koriste već više od jednog veka, ove vitalne terapije pulpe (VPT) ne predstavljaju novinu. Vitalnost zubne pulpe značajno utiče na dugovečnost stalnih zuba. Budući da je dokazano da inflamirana pulpa ima sposobnost regeneracije, terapija vitalne pulpe u poslednjim godinama privlači sve veću pažnju. Koncept izložene pulpe, nekada smatran beznadežnim stanjem, doživeo je značajnu transformaciju – od percepcije „osuđenosti" ka mogućnosti izlečenja. Ova promena shvatanja potpomognuta je razvojem savremenih materijala za prekrivanje pulpe, čime je označen početak nove ere u terapiji očuvanja vitalne pulpe.*
Cilj: *Cilj ovog rada bio je da pruži pregled i diskusiju o savremenim materijalima koji se koriste za prekrivanje pulpe i zaštitu kompleksa dentin–pulpa.*
Zaključak: *Kada se patološke promene pulpe tačno dijagnostikuju, očuvanje zuba moguće je primenom adekvatne terapije i odgovarajućih dentalnih materijala. Efikasnost prekrivanja pulpe i vitalne terapije pulpe zavisi od stručnosti kliničara, pravilnog izbora materijala i adekvatne selekcije slučajeva. Napredak u očuvanju vitalnosti pulpe donosi značajne koristi i pacijentima i stomatolozima zahvaljujući boljem razumevanju bioloških procesa karijesa, tehnološkim inovacijama i savremenim restaurativnim materijalima.*

Ključne reči: *biokompatibilnost, dentinski most, prekrivanje pulpe, materijal za prekrivanje pulpe*

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Abstract

Introduction: *Therapeutic approaches that emphasize preserving pulp are essential for maintaining vital teeth with exposed pulp and deep cavities. However, indirect and direct pulp capping methods reportedly have been used for more than a century, so these vital pulp therapies (VPTs) are not new. The vitality of the dental pulp greatly influences the longevity of permanent teeth. Since it has been demonstrated that the inflamed pulp can heal, vital pulp therapy, or VPT, has received a lot of interest in recent years. The concept of an exposed pulp organ, once considered a dire situation, has undergone a remarkable transformation. It has transitioned from being perceived as 'doomed' to one of hope and healing. This shift in perception has been facilitated by the development of various pulp capping materials, marking a new era in vital pulp treatment.*
Aim: *This paper aimed to provide an overview and discussion of the various, more recent pulp capping materials utilized to protect the dentin-pulp complex.*
Conclusion: *When pulpal pathosis is accurately diagnosed, teeth can be preserved with appropriate treatment using suitable dental materials. Effective pulp capping and vital pulp therapy rely on the clinician's ability, material selection, and proper case selection. The advancement of pulp preservation has proven beneficial for patients and clinicians due to an increased understanding of technological developments, the biology of dental caries, and better restorative materials.*

Key words: *biocompatible, dentin bridge, pulp capping, pulp capping agent*

Introduction

The main challenge of today's restorative dentistry methodology is the induction of remineralization in hypomineralized carious dentine, hence protecting and preserving the vital pulp. Historically, pulp exposure and subsequent root canal therapy were common outcomes of deep caries management. It has been recommended to promote biologically-based treatment techniques for partial caries removal in order to prevent exposure to carious pulp. Complete or nonselective carious removal is currently regarded as overtreatment, according to recent consensus studies[1]. When it comes to managing the cariously exposed pulp, management approaches are also changing by preventing procedures like pulpectomy and instead emphasize the benefits of vital pulp therapy (VPT) methods, including pulp capping and partial and complete pulpotomy[2].

Pulp preservation methods and vital pulp treatment (VPT) are experiencing somewhat of a resurgence. As gold was applied to injured pulp as early as the 18th century, VPT is not a novel treatment approach; rather, it is an old one that incorporates a variety of methods with an emphasis on minimal intervention and preserving pulp tissue health[3,4].

Rebel claimed in 1922 that the "exposed pulp was a doomed organ," an idea that people still hold today. Even though pulp was deemed "doomed" in 1922, systematic, rigorous research on pulp healing and the reaction to direct pulp capping was not conducted until the 1940s and 1950s. This research not only highlighted the unpredictable nature of the results of direct pulp capping but also made significant contributions to understanding how the pulp reacts to the injury and subsequent repair[4,5]. These findings may have contributed to the scepticism around VPT as a substitute for more established treatments, like root canal therapy (RCT), in which success rates were reported at the time to be between 60% and 70% for direct pulp capping and 80% to 90% for RCT[5].

In the past, calcium hydroxide (CH) was the preferred material used as a GOLD standard for DPC[6]. When CH is first applied to exposed pulp, superficial necrosis develops as a result[7]. When there is firm necrosis, the pulp is prompted to protect and repair itself. Cellular differentiation, extracellular matrix secretion, and mineralization finally result in the production of a reparative dentin bridge. This irritates the pulp slightly. Tunnel defects were detected in 89% of the dentin bridge built below CH[8]. These tunnel defects in the heterogeneous dentin barrier not only fail to form a suitable and long-lasting barrier against pathogenic microorganisms, but they also fail to establish an efficient long-term seal. One of the limitations of CH is dissolution[9]. These days, newer materials that produce more consistent clinical results—calcium silicate materials, or CSMs—are replacing calcium hydroxide.

The introduction of bioactive hydraulic calcium silicate cements (HCSCs)[10,11], advances in our biological understanding of pulp reparative processes[12], and scientific and biological advancements in wound lavage and tissue handling[2,13] have all significantly altered our perspectives and revitalized the VPT field.

It's interesting to note that the term VPT was formerly only used to refer to direct pulp capping. However, the latest definitions of the term have simplified and expanded its meaning to encompass all "strategies aimed at maintaining the vitality of the pulp"[14]. This naturally includes direct pulp capping, pulpotomy procedures, one- and two-step selective caries removal techniques, and indirect pulp capping to prevent pulp exposure.

The ideal characteristics of the pulp capping material should include:

- Reparative dentin formation
- Maintaining the vitality of the tooth
- Release fluoride
- Bactericidal or bacteriostatic
- Adhere to dentin and restorative material
- Resist forces during restoration placement and its life in the oral cavity
- Sterile and radiopaque
- Provide a seal against bacteria[15]

Mineral Trioxide Aggregate

In the 1990s, MTA was first described in the literature as an experimental substance based on calcium silicate[16]. According to Tanomaru et al., MTA is a material that is commonly used to seal pulpal cavities and external root surface communications. MTA has the ability to keep pulp viable and has been shown to cause mineralization in exposed pulp.

MTA can be used in many other clinical applications, such as direct[17] and indirect pulp capping, root perforation repairs or in furcations[18], and apexification treatment It has been used recently as a preferable replacement

for Ca(OH)2. MTA is made up of bismuth oxide, a radiopacifier, and Portland cement, which is mostly made up of tri- and dicalcium silicate[19].

ProRoot MTA has been on the market for 20 years, during which time it has undergone thorough testing and been shown to be biocompatible. To address these issues, new MTA-based material types have been developed in response to the lengthy setting time and high cost. In addition to meeting the benefits of ProRoot MTA, the substitute materials need to be easier to get, less costly, and able to set faster. Alternatively, MTA Angelus was created, which has the benefit of having a final setting time that is lowered from 228–261 minutes specific for ProRoot MTA to 24–83 minutes[20]. Retro MTA is one of the recently introduced fast-setting calcium silicate cements that takes approximately 12 minutes to set completely[20]. The predominant calcium ion released from the material combines with phosphates in tissue fluid to generate hydroxyapatite, which is the basis for the biocompatibility and sealing ability of MTA[21].

MTA was first formulated in a gray color, but a distinct chemical structure was introduced in response to reports of tooth discolouration[22]. White MTA lacks the chemical component of iron, but discolouration is still noticeable and is one of the material's key drawbacks[23]. When calcium silicate and dicalcium silicate are combined with water, they react to form calcium hydroxide and calcium silicate hydrate. Despite MTA cement's many beneficial effects, there were certain drawbacks that kept clinicians from utilizing it regularly. The main drawbacks are that the powder contains heavy metals, has a long setting time (up to 284 min)[24], is difficult to handle, and discolours the remaining tooth structure[25].

Confirmatory evidence for MTA's higher efficacy as a DPC agent was found when it was compared with Ca(OH)2 in a randomized clinical trial[26].

Furthermore, MTA is less irritating to the pulp than Ca(OH)2, less toxic, and easier to use during pulp capping methods[27]. A histological investigation verified that the administration of MTA directly impacts the dental pulp's capacity for regeneration and is related to a rise in TGF-β1 production from pulp cells[28]. This component influences the quality of the induced hard barrier by directing the progenitor cells' migration to the material–pulp contact and stimulating their dif-ferentiation into odontoblastic cells secreting reparative dentin.

Therefore, it can be said that normal dentine did not regenerate. Additionally, pulp-capping material (RetroMTA) has limited bioactive potential, indicating that it cannot be used in regenerative dentistry. Furthermore, mineral trioxide aggregate (White-ProRoot®MTA, Dentsply Sirona, York, PA, USA) promotes the same desired cellular response. It exhibits positive metabolic activity in contrast to calcium hydroxide, leading to a decreased incidence of tunnel defects and a higher clinical success rate[29]. When compared to the Biodentine group, the MTA group exhibits a more regular, homogenous reparative dentin layer with consistent thickness in terms of dentin bridge creation, as determined by the micro-CT imaging technique.

For direct pulp capping, MTA is the preferred material[29]. The ability of the bioactive materials to seal the tooth structure, the bond strength between the pulp capping material, and restorative qualities are further essential components for successful pulp capping treatments.

Novel Mineral Trioxide Aggregate Restorative Cements

New generation MTA-based cements, such as Neo MTA Plus (Avalon Biomed Inc., Houston, TX, USA) and the iRoot (Innovative BioCeramix Inc., Vancouver, BC, Canada) product family, have recently been developed as a result of alterations in material features.

Because bismuth oxide is eliminated, Neo MTA Plus was created to be used in pulpotomies without the possibility of discolouration. Tantalum oxide, which has a radiopacity value of 3.76 ± 0.13 mm Al and has no effect on hydration, was utilized in place of the radiopacifying agent[30].

Neo MTA Plus was shown to have a final setting time that was up to 315 ± 5 minute[30]. Additionally, NeoMTA Plus showed greater apatite formation, higher crystallinity, and higher Ca/P in comparison to MTA Angelus. However, it also displayed a lower CO3/PO4 ratio, which may have led to increased bioactivity. Additional *in vivo* and *in vitro* research is needed to support such claims.

Resin-based MTA

TheraCal LC

A few modified resin-based MTAs were developed in order to address the original MTA's drawbacks. Most of these MTAs are designed to reduce the setting time via modifying the particle size or composition of the powder[31].

TheraCal LC is a substance based on calcium silicate resin that can be used in conjunction with restorative materials as a protective liner and as a pulp capping agent. This substance is classified as a fourth-generation calcium silicate material and is a light-curable MTA-cement.

According to Gandolfi et al., TheraCal LC has shown its ability to release calcium ions, which is essential for the material's ability to stimulate human dental pulp cells to proliferate and differentiate, as well as for the formation of new mineralized hard tissues[32]. The concentration of calcium ions generated by TheraCal LC fell within the range that can stimulate the dental pulp and odontoblasts.

TheraCal LC's clinical success rate in comparison to other materials over a shorter time span has been studied[33]. Over six months, the effects of TheraCal LC, Biodentine, and MTA on carious pulp exposure in ninety permanent important teeth were assessed. TheraCal, Biodentine, and MTA did not show a statistically significant difference in overall success rate when compared to one another. As a result, using TheraCal LC as a DPC material was advised.

Super MTA Paste

Super MTA Paste,a resin-based MTA material, has recently been introduced. Portland cement is combined with tributylborane (TBB) as a polymerization initiator in Super MTA Paste, a resin-modified MTA that doesn't need light curing.

In addition to its great biocompatibility, Super MTA Paste may promote the formation of a homogeneous dentin bridge by acting as a pulp capping material. TheraCal LC's therapeutic efficacy is comparable to that of Super MTA Paste's tissue reactivity in exposed pulp.

To substantiate its efficacy in both short- and long-term therapeutic outcomes, clinical trials are required.

Biodentine

A newly developed material by Septodont is called Biodentine (BD; Septodont, Saint-Maur-des-Fosses, France). It is a Portland cement made of calcium silicate. BD comes in capsule form and is made up of powder that includes calcium carbonate, iron oxide, zirconium oxide, tricalcium silicate, and dicalcium silicate.

The manufacturer claims that the setting should take nine to twelve minutes; however, it took forty-five minutes to set completely. One of the material's disadvantages is that, even with zirconium oxide present, radiopacity is much lower than MTA Angelus[34]. Additionally, radiopacity generally diminishes over time, making long-term radiographic examinations challenging.

By stimulating tertiary dentin formation and remineralization, BD's interactions with hard and soft tissues in both the direct and indirect capping procedures result in marginal sealing and protect the underlying pulp. Tricalcium silicate materials such as BD, may be better for IPC based on the release of hydroxide (OH^-) and calcium (Ca^{2+}) ions from the material. It's a biocompatible and bioactive substance.

Improvements in BD properties, such as mechanical properties, initial cohesiveness, and setting time, compared to MTA, have led to a wider variety of uses, such as endodontic repair and vital pulp therapy. It has been demonstrated that Biodentine is readily tolerated by the pulp tissue when it is in proximity (in situations of direct pulp capping), producing reparative dentine. Biodentine has a beneficial effect on vital pulp cells and promotes tertiary dentine formation[35].

Nowicka et al. found that placing MTA required more time and technically more difficulty than placing Biodentine in a study evaluating the pulpal response to various pulp capping materials (MTA and Biodentine). Additionally, they found that Biodentine exhibited similar efficacy in clinical settings, suggesting its potential as an alternative to MTA.

According to a recent study, which assessed the effectiveness of Biodentine in fifteen cases with follow-up periods ranging from 12 to 24 months, all 15 cases showed no symptoms during the follow-up period. This suggests that Biodentine should be used as a vital pulp therapy material[36].

Mtya1-ca

Calcium hydroxide-containing resinous direct pulp capping agent was created by Atsuko Niinuma. The mixture of liquid (67.5% triethyleneglycol dimethacrylate, 30.0% glyceryl methacrylate, 1.0% o-methacryloyl tyrosine amide, 1.0% dimethylaminoethylmethacrylate, and 0.5% camphorquinone) and powder (89.0% microfiller, 10.0% calcium hydroxide, and 1.0% benzoyl peroxide) was combined.

MTYA1-Ca was shown to have good physical properties, dentine bridge formation without the development of a necrotic layer and was histopathologically comparable to Dycal. Niinuma et al. believe that MTYA1-Ca, a recently produced material, has the potential to be used as an effective direct pulp capping material[37].

BioAggregate

When compared to MTA, BioAggregate, a bioinductive tricalcium cement, can induce mineralization with greater efficacy. The main components of this material include tantalum oxide, which is used as a radiopacifier, tricalcium silicate, dicalcium silicate, monobasic calcium phosphate, and amorphous silicon dioxide[38].

According to Kim et al., BioAggregate exhibits improved sealing performance and biocompatibility compared to MTA[38]. BioAggregate is significantly more effective than MTA at stimulating odontoblastic development and mineralization in pulp capping[39].

Tantalum oxide makes up the majority of BioAggregate's composition, with the absence of aluminium and a little amount of bismuth oxide and calcium phosphate[40]. Its lack of aluminum in its chemical composition may account for its less harmful effects on the inflammatory cell response[38].

According to recent research, the MTA greatly outperformed the BioAggregate in terms of thicker hard tissue formation. However, a thick and uniform hard tissue barrier formation was also seen in the BioAggregate group[38].

Castor Oil Bean Cement

The COB is believed to be a naturally occurring polyol made up of 81–96% triglyceride of ricinoleic acid and three hydroxyl radicals. RCP (Ricinus Communis Polyurethane) or COB was first developed biomaterial to regenerate and heal bone in the event of a localized bone injury. These benefits make the material a great option for pulp capping[41].

Emdogain (EMD)

An enamel matrix derivative called EMD is released from Hertwig's epithelial root sheath during the formation of porcine teeth. It is an essential regulator of enamel mineralization and plays a significant role in the development of periodontal tissue. EMD contains both BMP-expressing cells and BMP-like substances. EMD stimulates the growth of odontoblasts and the production of reparative dentin, just like BMP molecules do.

Recent research has revealed that EMD, which has components resembling TGF-β, inhibits immune cells' production of inflammatory cytokines.

Nakamura Y et al. reported that teeth treated with EMD produced more than twice as much hard tissue as teeth treated with calcium hydroxide. Al-Hezaimi K evaluated ProRoot White MTA, calcium hydroxide, and white Portland cement following the application of EMD to the exposed pulp. The quality of the reparative hard tissue response was higher when EMD was used in addition to MTA than when calcium hydroxide was used alone[42].

Calcium Aluminate-Based Materials (EndoBinder)

A novel calcium aluminate-based endodontic cement called EndoBinder (Binderware, So Carlos, SP, Brazil) was developed to maintain the beneficial properties and therapeutic applications of MTA while eliminating its drawbacks.

In contrast to MTA, EndoBinder lacks ferric oxide, which causes tooth discolouration, and magnesium and calcium oxides, which contribute to the material's undesirable expansion.

Due to reduced release of calcium hydroxide, EndoBinder demonstrated superior osteoblastic differential as compared to MTA, which is another characteristic that makes it a good bioactive material[43]. Based on the research data that is currently available, it could be a valuable addition to VPT operations. However, physicians may be hesitant to utilize it due to a lack of studies elucidating and substantiating its biological and physiochemical characteristics.

Calcium Enriched Mixture

Calcium-enriched mixture (CEM) cement was introduced as an endodontic filling material in dentistry. In contrast to Portland cement (PC) and mineral trioxide aggregate (MTA), the composition of cement powder is calcium oxide (CaO), sulfur trioxide (SO3), phosphorous pentoxide (P2O5), and silicon dioxide (SiO2)[44,45].

Three-dimensional seal, appropriate antibacterial characteristics, and biocompatibility are important for the effectiveness of VPT[46]. Comparable to MTA[44], CEM's sealing ability is enhanced by storing in phosphate-buffered saline solution[47]. According to Soheilipour et al., CEM has smaller particles than MTA; this could be the reason for its better sealing qualities[48]. It can stimulate the creation of hydroxyapatite in saline solution[45]. It may also stimulate the differentiation process in stem cells and cause cementogenesis, the induction of hard tissue[49].

CEM's antibacterial properties are comparable to those of CH[44]. According to a comparison of CEM and MTA's antifungal qualities on *Candida albicans*, they both cause the fungal cells to die completely after 24 hours[50].

The alkaline pH of ~11 of CEM is essential for this biomaterial's antibacterial characteristics. According to a number of animal studies[44], the induction of dentin bridge formation in CEM under various VPT treatments was superior to that in CH and comparable with that of MTA. Full pulpotomy treatment studies employing CEM, MTA, and CH have demonstrated that samples in the CEM group showed superior pulp vitality status, better quality/thickness of calcified bridge, and morphology of odontoblast cells in comparison to CH. Nonetheless, Tabarsi et al. found no significant differences when compared to MTA[51].

In comparison to the white/gray MTA groups, the CEM group had considerably lower levels of inflammation after 60 days. Partirokh et al. reported that the biomaterials' ability to induce osteogenesis was indicated by the dystrophic calcification[52].

Pre-Mixed Bioceramics

The iRoot products address the challenges faced during MTA handling and come in a variety of consistencies, which may provide the benefit of choosing the appropriate one for each clinical application. The novel premixed bioceramics are composed of "calcium silicates, zirconium oxide, tantalum oxide, calcium phosphate monobasic, and fillers".

Their mechanical and biological qualities are superior to other materials. Their outstanding handling properties make them ready-to-use materials. Because premixed bioceramics are hydrophilic, they require moisture from the surrounding tissues to solidify. These are categorized according to consistency

1. Syringe form
2. Putty form
3. Fast-set putty form.

There are three premixed bioceramics currently available to date:

• iRoot BP (Innovative Bioceramics, Vancouver, Canada)

• EndoSequence root repair (Brasseler USA, Savannah, GA)

• TotalFill (FKG Dentaire SA, Switzerland)

iRoot BP is a recently discovered calcium silicate-based bioactive ceramic that mainly consists of tri-calcium silicate, bi-calcium silicate, and calcium phosphate[53]. The use of iRoot BP Plus and Ca(OH)2 as pulpotomy materials in cases of complex crown fractures in permanent incisors and found that most dentin bridges with iRoot BP Plus had no tunnel defects and were able to produce reparative dentin within 6 weeks[54].

No inflammation or multinucleated giant cells were observed surrounding the material in the histological analysis. Results after three months revealed more than 75% of the bridge formation showing irregular tubules[53].

Microcomputed tomography study of tertiary dentin revealed that iRoot BP had no defects, while some ProRoot MTA samples exhibited small defects and a lack of continuity[55]. iRoot BP Plus can be used as a pulp capping material in vital pulp therapy as it has been shown to have good biocompatibility and can induce the formation of a reparative dentine bridge[56].

Another novel material developed for pulp capping is Endosequence Root Repair Material (ERRM; Brasseler USA, Savannah, GA). This bio-ceramic material has a high pH, is hydrophilic, radiopaque, and has no aluminium. According to Silva et al., the investigations revealed that ERRM had an identical antibacterial effect on *Enterococcus faecalis* as MTA[57]. Hirschman WR et al. tested four pulp capping materials for cytotoxicity on adult human skin fibroblasts. They concluded that, in terms of cell viability, ERRM outperformed MTA, Dycal, and Ultra-blend

Plus (a calcium hydroxide liner based on resin). When compared to CH, the antibacterial characteristics of endo sequence root repair material against the primary cariogenic bacteria, salivary *Streptococcus mutans* (SM) and *Lactobacilli*, were comparable to those of MTA[58]. The authors concluded that ERRM was a good substitute for other pulp capping materials. According to Damas et al., it contains calcium silicates, zirconium oxide, tantalum oxide, thickening agents, and proprietary fillers[59]. The cytotoxicity of Brasseler Endosequence Root Repair Putty (ERRP), Ultra-blend Plus (UBP)-(light curable Ca(OH)), Dycal, and MTA-Angelus was assessed by Hirschman et al. They discovered that ERRP and UBP have lower cytotoxicity.

Conclusion

Recent advancements in pulp capping materials have significantly enhanced the predictability and success rates of vital pulp therapy. Innovations such as bioactive materials, including calcium silicate-based cements, have demonstrated superior biocompatibility, promoting dental pulp healing and regeneration. Additionally, the development of modern resin-based materials and improved adhesion properties has facilitated better sealing capabilities, reducing the risk of contamination. Understanding the biology of caries, conviction about better restorative materials, and having clarity about technological advancements have led to the initiation of pulp preservation, which is beneficial to both the patient and the physician. When pulpal pathosis is accurately diagnosed, teeth can be preserved with appropriate treatment using suitable dental materials. Effective pulp capping and vital pulp therapy rely on the clinician's ability, material selection, and proper case selection.

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