The Effect of Altered pH on Push-Out Bond Strength of Biodentin, Glass Ionomer Cement, Mineral Trioxide Aggregate and Theracal

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SUMMARY

Introduction Throughout the history of dentistry, a wide variety of materials such as gold-foil, silver posts, amalgam, zinc oxide eugenol, glass ionomer cements, mineral trioxide aggregate have been used as retrograde fillings. Altered pH in periapical lesions can affect push-out bond strength of these materials. The aim of this study was to evaluate the effect of altered pH on push-out bond strength of Biodentin, Glass ionomer cement (GIC), Mineral trioxide aggregate (MTA) and Theracal.

Material and Methods Forty-eight dentin slices of extracted single–rooted human teeth were sectioned and their canal portion instrumented to achieve a diameter of 1.4 mm. The specimens were then assigned into the four groups (one group for each material) with 12 samples in each group. All groups were further divided into 3 subgroups (with 4 specimens in each subgroup): acidic (butyric acid buffered at pH 6.4), neutral (phosphate buffer saline solution at pH 7.4) and alkaline (buffered potassium hydroxide at pH 8.4). Samples were incubated for 4 days at 37°C in acidic, neutral or alkaline medium. Push-out bond strength was measured using a Universal Testing Machine. The slices were examined under a stereomicroscope to determine the nature of bond failure.

Results GIC showed the highest bond strength (33.33MPa) in neutral and acidic medium (26.75MPa) compared to other materials. Biodentin showed the best result in alkaline medium.

Conclusion Altered pH level affected push-out bond strength of root end materials. GIC demonstrated good push-out bond strength that increased with decrease of pH whereas newer materials Biodentin and Theracal showed satisfying results in altered pH.

Keywords: push-out bond strength; altered pH; root end filling materials

INTRODUCTION

Infected or inflamed tissue may have a normal pH of 7.4 or an acidic pH as low as 5.0. Acidic pH may inhibit setting reaction, affect adhesion, or increase solubility of materials. If infection or inflammation persists, erosion of filling materials can occur in acidic environment generated by bacteria or inflammation [1]. Also, exposure of root end filling material to an alkaline environment after pretreatment with calcium hydroxide might affect its properties [2]. Therefore, sealing ability of material may be directly or indirectly affected by environmental conditions and pH of medium [1]. Over the years various root end filling materials such as gold-foil, silver posts, amalgam (with and without bonding agent), zinc oxide eugenol, glass ionomer cements, mineral trioxide aggregate have been used as retrograde fillings [3].

Glass ionomer cements (GICs) are widely used for a variety of purposes such as intermediate restorations, permanent restoration of micro-cavities, fissure sealing of erupting molars and root end filling material [4]. GICs are formed by the reaction between calcium–aluminosilicate glass particles and aqueous solutions of polyacrylic acid. The main advantages of GICs are their strong chemical bond with dentin and their ability to release fluoride ions. Due to this chemical bonding to dentin, GICs have shown higher bond strength even when used as root end filling material. It has been reported that these cements are easy to handle and they do not cause any adverse histological reaction in the periapical tissue [3]. However, push-out bond strength of GICs under altered pH has not been studied yet.

In the recent decades, mineral trioxide aggregate (MTA) has shown promising results when used as repair material of lateral root walls or furcation perforations, root-end filling, apical plug, and root canal filling [5, 6]. It consists of a fine powder of tricalcium silicate, dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite, and bismuth oxide. During clinical application as root-end and perforation filling material or as an apical plug in necrotic teeth with open apices, MTA may be exposed to an acidic environment because of the presence of periradicular inflammation [7, 8]. pH change of host tissues because of the presence of pre-existing disease may affect physical and chemical properties of material [9, 10]. It has been reported that hardness [11], diametric tensile strength
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As MTA has been shown to be suitable material, other calcium silicate–based materials have been developed recently to improve MTA drawbacks such as prolonged setting time, difficult handling, high cost, and potential tooth discoloration.

Recently, a new calcium silicate–based material Biodentin (Septodont, Saint-Maur-des-Fossés, France) has been introduced to the market. Biodentin is composed of tricalcium silicate, calcium carbonate, zirconium oxide, and a water-based liquid containing calcium chloride used as setting accelerator and water-reducing agent [13]. Biodentin is a fast-setting calcium silicate–based material that can be used as dentin restorative material as well as endodontic material with characteristics comparable to MTA [14].

Theracal (Bisco Inc, Schaumburg, IL, USA) is a new light-cured resin-modified calcium silicate–filled base/liner material designed for direct and indirect pulp capping. It contains approximately 45% wt mineral material (type III Portland cement), 10% wt radiopaque component, 5% wt hydrophilic thickening agent (fumed silica) and approximately 45% resin [15]. It also shows physiochemical bonding to dentin, good sealing abilities and it is well tolerated by immortalized odontoblast cells [16, 17].

The aim of periradicular surgery is to remove the cause of disease and provide favourable environment for surgical wound healing. Placement of a root-end filling is one of the key steps in managing root end [18]. However, periapical lesions affect pH with consequent alteration of bond strength of root end filling materials.

The aim of the current study was to evaluate the effect of altered pH on push-out bond strength of Biodentin, Glass ionomer cement, Mineral trioxide aggregates and Theracal.

MATERIAL AND METHODS

Forty-eight single-rooted human anterior teeth with straight canals, extracted for periodontal and orthodontic reasons, were collected and stored in phosphate-buffered saline solution until used. Midroot dentin was sectioned horizontally into slices 1 mm thick. A diamond disc was used to obtain 48 root dentin slices (Figure 1). The canal portions of root dentin slices were instrumented to achieve a standardized diameter of 1.4 mm using round carbide bur (Figure 2). All used materials were mixed according to their manufacturers’ instructions and introduced incrementally with no pressure into the lumens of the root-dentin slices. The specimens were then divided into the four groups (n=12), i.e. Biodentin, Glass ionomer cement, MTA (Mineral trioxide aggregates) and Theracal. These groups were further divided into 3 subgroups (n = 4), i.e. acidic (butyric acid buffered at pH 6.4), neutral (phosphate buffer saline solution at pH 7.4) and alkaline (buffered potassium hydroxide at pH 8.4). They were then incubated for 4 days at 37°C.

Push-out bond strength was measured using a universal testing machine (Figure 3). The samples were placed...
on a metal slab with a central hole to allow free motion of the plunger. Compressive load was applied by exerting downward pressure on the surface of materials using 1 mm diameter cylindrical jig at a speed of 1 mm/min. The jig had a clearance of approximately 0.2 mm from the margin of dentinal wall to insure contact with material only. Maximum load applied to material at the time of dislodgement was recorded in newton's.

In order to express bond strength in MPa, recorded value was divided by the adhesion area of root canal filling calculated by the following formula: \(2\pi r \times h\), where \(r\) is the root canal radius and \(h\) is the thickness of the root-dentin slice in millimeters. The slices were then examined under a stereomicroscope to determine the nature of bond failure. Each sample was categorized into one of three failure modes: adhesive failure at the material and dentin interface, cohesive failure within materials, or mixed failure. The data were analyzed using one-way analysis of variance followed by the Tukey’s Post Hoc Test.

**RESULTS**

Results showed a statistically significant difference among groups (\(p<0.001\)) after 4 days, where GIC had the highest bond strength in acidic and neutral environment while Biodentin showed the highest bond strength in alkaline environment. MTA showed the lowest push-out bond strength in all mediums compared to other root end filling materials. Statistical analysis also showed that the type of cement and storage solution significantly affected micro-push-out bond strength. Three modes of bond failure were found: adhesive failure at the material and dentin interface, cohesive failure within material, or mixed failure (Figure 4a-c; Graph 1; Table 1).

**DISCUSSION**

Russian biologist Metchnikoff reported first evidence of acidic pH inside phagocytes in 1893. Later, Jensen and Bainton (1973) demonstrated that pH of a phagosome was reduced to approximately 6.5 within 3–4 min after initiation of phagocytosis. Also pH of pus aspirated from periapical tissues has been confirmed as acidic (6.68±0.324) [9]. Under certain clinical applications calcium silicate–based materials are used for the repair of root and furcation perforations, root-end fillings, and apical plugs. They
are often placed in an environment where inflammation may be present and surface of unset material exposed to low pH. This altered pH may affect its physical and chemical properties [18, 19].

Normal tissue pH is 7.4 but it can be affected by certain clinical conditions. Tronstad et al. [20] showed pH in the range of 6.4–7 in the pulp, dentin, cementum, and periodontal ligament of vital or necrotic pulp teeth. As calcium hydroxide is preferred intracanal medicament, after its placement pH values of the most inner part of circum-pulpal dentin change to pH range 11.1–12.2. It might be beneficial to provide pretreatment with calcium hydrox-ide in necrotic open apices or root perforations before application of biomaterials [21, 22]. There are conflicting results regarding the effect of calcium hydroxide dressing on sealing ability of various biomaterials [23, 24]. It has been suggested that residual calcium hydroxide might interfere with material adaptation to the root canal walls or chemically interact with them.

In the present study, push-out bond strength of Biodentin, Glass ionomer cement, MTA and Theracal was evaluated and compared after exposure to acidic, neutral and alkaline pH. For acidic environment, butyric acid, a byproduct of anaerobic bacteria metabolism, buffered at pH 6.4 was used. For alkaline environment buffered potassium hydroxide at pH 8.4 was used while for neutral environment phosphate buffer saline solution at pH 7.4 was used.

The results of present study indicate that push-out bond strength of GIC (26.75 MPa) in acidic medium was significantly higher while MTA had the lowest (2.78 MPa) push-out bond strength compared to other materials. In alkaline medium, the highest push-out bond strength was shown by Biodentin (28.89 MPa) and the lowest by MTA (8.03 MPa). In neutral medium, the highest push-out bond strength was shown by GIC (33.22 MPa) and the lowest by MTA (8.92 MPa). MTA showed inferior bond strength in all environmental conditions, which is in agreement with Shokouhinejad et al. [10]. It is possible that pH inhibits setting reaction, affects adhesion, or increases solubility of calcium silicate–based materials eventually affecting mechanical properties of material including surface microhardness.

In the current study, Biodentin showed greater bond strength in both acidic and alkaline medium than MTA. Bond strength of MTA was most likely affected by the alkaline pH of dentin [12]. Biodentin also showed superior bond strength in alkaline medium than in neutral conditions. GIC demonstrated the highest bond strength compared to other root end filling materials in acidic and neutral pH. This result is probably related to its strong chemical bonding to dentin.

Theracal is pulp-capping material but due to its good sealing ability we used it as root end filling material. It showed higher bond strength than MTA (8.03), almost comparable to GIC (13.78) in alkaline environment and higher than Biodentin in acidic environment. Further in vivo and in vitro research should be done in order to assess Theracal as root end filling material.

**CONCLUSION**

Altered pH levels affect the properties of root end materials. MTA showed inferior push-out bond strength that was affected by pH of surrounding environment. GIC has good bond strength that increased with decrease in pH opposite to other materials. Further research is needed for Biodentin and Theracal as root end filling materials.

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Uticaj vrednosti pH na otpornost na smicanje biodentina, glasjonomer-cementa, mineralnog trioksidnog agregata i terakala

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KRATAK SADRŽAJ
Uvod Gledamo kroz istoriju stomatologije, širok spektar materijala kao što su zlatne folije, srebrni kočići, amalagam, cink-okсид eugenol, glasjonomer-cement i mineralni trioksidni agregat korisniji su za retrogradno punjenje kanala korena zuba. Pokazano je da pH u predelu periapikalne lezije utiče na otpornost na smicanje ovih materijala. Cilj ovog istraživanja bio je da se utvrdi uticaj izmjenjene vrednosti pH na otpornost na smicanje biodentina, glasjonomer-cementa (GJC), mineralnog trioksidnog agregata (MTA) i terakala.

Materijal i metode rada Četdeset osam jednokorenih zuba je horizontalno presečeno na dve različite visine da bi se dobilo 48 cilindričnih uzoraka. Njihov lumen je obrađen kako bi se postigao prečnik od 1,4 mm. Uzorci su zatim svrstani u četiri grupe (jedna grupa za svaki materijal) od po 12 uzoraka. Svaka grupa je dodatno podeljena na tri podgrupe sa po četiri uzorka: kisel pH (puferizovan butanskom kiselinom na pH od 4,6), neutralni pH (puferizovan fosfatnim puferom fiziološkog rastvora na pH od 7,4) i bazni pH (puferizovan kalijum-hidroksidom na pH od 8,4). Uzorci su inkubirani tokom četiri dana na 37°C u kiseloj, neutralnoj ili baznoj sredini. Otpornost na smicanje je merena pomoću univerzalne mašine za testiranje (Univerzal Testing Machine). Uzorci su takođe posmatrani pod stereomikroskopom, kako bi se utvrdila priroda prekida vezica s materijala sa dentinom.

Rezultati Najveću otpornost na smicanje pokazao je GJC (33,33 MPa) u neutralnoj sredini (26,75 MPa) u porastu sa drugim materijalima. Biodentin je pokazao najniži rezultat u neutralnoj sredini.

Zaključak Izmjenjena vrednost pH utiče na otpornost na smicanje materijala za punjenje apeksa kanala korena zuba. GJC je pokazao dobru otpornost na smicanje koja se poboljšava sa smanjenjem vrednosti pH. Noviji materijali, biodentin, biodentin i terakal, pokazali su zadovoljavajuće rezultate u izmjenjenom pH sredini. MTA je pokazao najbolju otpornost na smicanje.

Ključne reči: otpornost na smicanje; promena vrednosti pH; materijal za punjenje apeksa kanala korena zuba

UVOD
Inficirana i upaljena tkiva mogu imati normalnu vrednost pH od 7,4, ali i kisel pH od oko 5,0. Kiseli pH može sprečiti uspostavljanje reakcije, uticati na prianje ili povećati rastvorljivost materijala. Ako infekcija ili upala tražu dugo, to može dovesti i do erozije materijala [1]. S druge strane, i izloženost baznoj sredini nastaloj nakon medikacije kanala kalijum-hidroksidom može uticati na svojstva materijala za punjenje apeksa korena zuba [2]. Na taj način sposobnost opturacije materijala može biti direktno ili indirektno poremećena [1]. Kroz istoriju stomatologije različiti materijali su korisniji za retrogradno punjenje kanala korena zuba, kao što su zlatne folije, srebrni kočići, amalagam (sa adhezivom i bez njega), cink-oksidni eugenol, glasjonomer-cement, mineralni trioksidni agregat i dr. [3].

Glasjonomer-cement (GJC) se koristi u različite svrhe, kao što su privremeni ispun, stalni ispun malih kaviteta, zalivanje fisura i punjenje apeksa korena [4]. GJC se formira reakcijom čestica kalijum-aluminosilikatnog stakla i vodenog rastvora poliakrilne kiseline. Glavna prednost ovog cementa je jaka hemijska veza sa dentinom i sposobnost oslabljanja jona fluorida. Zahvaljujući dobroj hemijskoj vezi sa dentinom, GJC pokazuje dobru vezu kada se koristi kao materijal za punjenje apeksa korena. Ovaj cement je jednostavan za upotrebu i ne dovodi do loših reakcija na histološkom nivou u periapikalnom tkivu [3]. Dosada nije objavljena nijedna studija koja meri otpornost na smicanje GJC u uslovima izmjenjene vrednosti pH.

U posljednjih nekoliko decenija mineralni trioksidni agregat (MTA) se pokazao vrlo uspješnim kada se koristi kao materijal za zatvaranje perforacija (bočnih zidova ili furkaacija), kao apikalni čep i kao materijal za punjenje kanala korena [5, 6]. Sastoji se od finog praha trikalijum-silikata, dikalijum-silikata, trikalijum-aluminata, tetraoksid-aluminofera i bimuk-sida. S obzirom na njegov klinički upotrebu, MTA može biti izložen kiseloj sredini zbog postojanja periapikalnog zapaljenja [7, 8]. Promena vrednosti pH zbog već postojećeg stanja može uticati na fizičke i hemijske osobine materijala [9, 10]. Tako je pokazano da se tvrdoća [11], dužinska zatezna čvrstoća [8], otpornost na smicanje [10] i sposobnost zaptivanja MTA [12] smanjuju nakon postavljanja materijala u kiseloj sredini. Novi materijali na bazi kalijum-silikata uvedeni su da bi se prevazišli nedostaci MTA poput dužeg vremena vezivanja, teškog rukovanja, visoke cene i potencijalnog preobrazivanja.

Najnoviji na tržištu je kalijum-silikatni materijal biodentin (Septodont, Saint-Maur-des-Fossés, Francuska), koji se sastoji od trikalijum-silikata, kalijum-karbonata, cirkonijum-okside i tečnosti na bazi vode koja sadrži kalijum-hlorid kao akcelerator i agens za oduzimanje vode [13]. Biodentin je brzo vezujući kalijum-silikatni materijal koji se može koristiti kao restorativni materijal za dentin, ali i kao endodontski materijal sa osobinama sličnim MTA [14].

Terakal (Bisco Inc, Schamburg, IL, SAD) je novi svetlosno-polimerizujući kalijum-silikatni cement modificovan smolom (baza/lajner) dizajniran za direktno i indirektno prekrivanje pulp. On sadrži oko 45% mineralnih materijala po težini (tip III Portland cementa), 10% rendgenkontrastne komponente, 5% hidrofilnog agens za zgušnjavanje (fumed silika) i oko 45% smole [15]. Pokazuje dobru fiziokemisku vezu za dentin, dobro zaptivanje i dobru toleranciju od strane odontoblasta [16, 17].

Cilj periapikalne hirurgije je da ukloni uzrok bolesti i omogući povoljno okruženje za zarastanje. Apikalno punjenje je jedno od ključnih koraka [18]. Međutim, postojanje periapikalne lezije utiče na promenu vrednosti pH, što dovodi do smanjenja kvaliteta veze s materijalom za punjenje apeksa kanala korena.

Cilj ovog rada je bio da se proceni efekat izmjenjene vrednosti pH na otpornost na smicanje biodentina, GJC, MTA i terakala.

MATERIJAL I METODE RADA
U studiju je bilo uključeno 48 jednokorenih zuba s pravim kanalima koji su bili ekstrahovani iz parodontoloških ili ortodont-
ski razloga. Pre eksperimenta zubi su čuvani u puferizovanim fiziološkom rastvoru. Svaki koren zuba je presećen horizontalno dijamantskim diskom, da bi se dobili dentinski diskovi debljine 1 mm – ukupno 48 disкова (Slika 1). Deo kanala svakog diska je obrađen okruglim karbidnim svrdlom, da bi se dobio prečnik od 1,4 mm (Slika 2). Testirani materijali su zamašeni prema uputstvu proizvođača i u inkrementima uneseni u lumen kanala svakog dentinskog diska. Uzorci su zatim svrstani u četiri grupe od po 12 uzoraka: biodentin, GJC, MTA i terakal. Potom je sva grupa podeljena na tri podgrupe od po četiri uzorka: kiselja sredina (butirična kiselina puferovana na vrednosti pH od 6,4), neutralna sredina (fiziološki rastvor puferizovan fosfatnim puferom na pH 7,4) i bazna sredina (puferizovana kalijum-hidroksidom na pH 8,4). Svi uzorci su inkubirani četiri dana na 37°C.

Otpornost na smicanje (tzv. *push-out* čvrstoća) svakog materijala merena je pomoću univerzalne mašine za merenje (Slika 3). Uzorci su postavljeni na metalnu ploču s otvorom u centru, da bi se klip mogao slobodno kretati. Pritisk opterećenje je aplikovano pritisnom nadole na površinu materijala pomoću cilindra prečnika 1 mm brzinom od 1 mm u minuti. Pritisni cilindar je bio bar 0,2 mm daleko od dentinskog zida, kako bi se osigurao kontakt samo s materijalom. Maksimalno opterećenje koje je podneo materijal u trenutku izbacivanja izražen je u njutnama (N).

Kako bi izrazili čvrstoću u MPa, zabeležena vrednost je pođeljena površinom materijala u kanalu korena prema sledećoj formuli: 2πrh; gdje je r prečnik kanala, a h debljina dentinskog diska izražena u mm. Svaki dentinski disk je potom ispitan pomoću stereomikroskopa, da bi se utvrdila priroda preknika kontakt-a između materijala i dentina, i to kao: narušavanje adhezivne veze između materijala i dentina, narušavanje kohezivne veze unutar materijala ili mešoviti prekid kontakta. Prikupljeni podaci su analizirani pomoću jednosmerne analize varijanse i *post hoc* Takjevim (Tukey) testom.

**REZULTATI**

Rezultati su pokazali statistički značajnu razliku između posmatranih grupa uzoraka nakon četiri dana (p<0,001), s tim da je GJC izrazito veću čvrstoću u kiseloj i neutralnoj sredini, a biodentin u baznoj sredini. MTA je pokazao najmanju otpornost na smicanje u svim medijima u poravnuću sa drugim materijalima. Statistička analiza je takođe pokazala da je vlastita cementa i sredina značajno utiču na mikro-*push-out* čvrstoću. Takođe su otkrivena sva tri načina kidanja veze između materijala i dentina, i to: adhezivni, kohezivni i mešoviti (Slika 4a-c; Grafikon 1; Tabela 1).

**DISKUISIJA**

Ruski biolog Mečnikov potvrdio je prvi put kiseli pH unutar fagocita 1893. godine. Kasnije su Jensen i Bejton, 1973. pokazali da pH u fagocitu dostiže oko 6,5 u roku od tri-četiri minute nakon početka fagocitoze. Takođe je pokazano da je pH gnoja aspiriranog iz peripapikalnih apscesa kiseo (6,68±0,324) [9]. Pod određenim kliničkim uslovima materijali na bazi kalciijum-silikata se koriste za optučenje perforacije korena, apekse kanala ili kao apikalni čepovi. Oni se često unose u sredinu u kojoj postoji upalni proces, tako da površina materijala može biti izložena niskoj vrednosti pH. Promenjena vrednost pH može uticati na fizička i hemijska svojstva materijala [18, 19].

Normalna vrednost pH zdravih tkiva je oko 7,4 i na nje- ga mogu uticati različita klinička stanja. Bronštad i saradnici [20] su pokazali da je pH pulpe, dentina, cementa i parodontalnog ligamenta vitalnih ili nekrotičnih zuba u ra- sponu od 6,4 do 7. Kako se kalciijum-hidroksid veoma često koristi kao intrakanalni medikament, nakon njegove upotrebe pH vrednost cirkumpulpalnog dentina dostiže vrednosti 11,1–12,2. Interesantna primena kalciijum-hidroksida je značajna u terapiji nekrotične pulpe kod otvorenih apeksa ili perfokacija. Osim toga, u literaturi postoje opšti rezultati koji se odnose na uticaj kalciijum-hidroksida na zaptivanje raznih biomaterijala. Zastoji kalciijum-hidroksid bi mogao fizički ometati adaptaciju materijala uz zidoove korenova ili hemijski reagovati s njima.

U ovom studiji otpornost na smicanje biobiotina, GJC, MTA i terakala je procenjivana nakon izlaganja materijala kiselim, neutralnom i baznom pH. Za postizanje kiseline upotrebljena je butirična kiselina puferovana na vrednost pH od 6,4. Bazna sredina je postignuta rastvorom kalijum-hidroksida puferovanim na pH 8,4, dok je za neutralnu sredinu korisni neutralni fosfatni pufer na pH 7,4. Rezultati ovog istraživanja su pokazali da je otpornost na smicanje GJC u kiseloj sredini bila najveća (26,75 MPa), a MTA najniža (2,78 MPa). U baznoj sredini najveću otpornost na smicanje pokazao je biodentin (28,89 MPa), a najnižu MTA (8,03 MPa). U neutralnoj sredini najveću otpornost na smicanje opet je pokazao GJC (33,22 MPa), a najnižu MTA (8,92 MPa). MTA je pokazao slabiju čvrstoću u odnosu na druge materijale pri svim pH vrednostima, što je u skladu s nalazima Shokuhinežada (Shokuhinežad) i saradnika [10]. Moguće je da pH blokira reakciju stvrdnjavanja, utiče na adheziju ili povećava rastvorivost materijala na bazi kalciijum-silikata, što takođe utiče na mehanička svojstva materijala, uključujući i mikrotvrđvoću.

U našoj studiji biobiotin je pokazao veću čvrstoću i u kiseloj i u baznoj sredini nego MTA. Na jačinu vrednosti veze MTA i dentina najverovatnije je uticao bazni pH dentina [12]. Biodentin je pokazao bolju čvrstoću u baznoj sredini nego u neutralnoj. GJC je pokazao najbolju čvrstoću od svih materijala u kiselim i neutralnom pH. Ovaj rezultat je verovatno posledica snažne hemijske veze sa dentinom.

Terakal je materijal za pokrivanje pulpe, a zbog svog dobrog rubnog zaptivanja izabran je za ovu studiju. On je pokazao veću čvrstoću nego MTA (8,03), gotovo uporedivu sa GJC (13,78), u baznoj sredini i veću nego biodentin u kiseloj sredini. Ipak, potrebna su dodatna istraživanja in vivio i *in vitro* da bi se tera- kal uspešno primenio kao materijal za punjenje apeksa kanala korena zuba.

**ZAKLJUČAK**

Promene vrednosti pH sredine utiču na svojstva materijala za punjenje apeksa korena. MTA je pokazao slabiju otpornost na smicanje, na koju je uticala promena pH sredine. GJC je pokazao dobru čvrstoću, koja se poboljšavala sa smanjenjem vrednosti pH sredine, što je bilo u suprotnosti sa drugim materijalima. Potrebna su dodatna istraživanja za procenu biodentina i terakala kao materijala za punjenje apeksa kanala korena.