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Tribološka svojstva estetskih protetskih materijala

Wear Characteristics of Esthetic Prosthetic Materials

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Sažetak

Poznavanje triboloških svojstava estetskih protetskih materijala nužno je u svakodnevnoj stomatološkoj praksi. Usavršiti novu, originalnu, metodu i konstruirati uređaj za ispitivanje triboloških svojstava gradivnih protetskih materijala, ispitati tribološka svojstva različitih estetskih protetskih materijala te ispitati međusobno ponašanje materijala tribološkog para: prirodan zub - protetski materijal. Istraživanje je rađeno na modificiranom uređaju "Taber abraser", na uzorcima šest različitih estetskih protetskih materijala. Trošenje je najmanje za uzorke glinične keramike (Creation i d.Sign), a najveće za polimer (Chromasit) te ceromer (Targis). Najmanji faktori trošenja određeni su, također, za glinične keramike. Istraživanje je rezultiralo razvojem nove metode i uređaja za ispitivanje triboloških svojstava protetskih materijala.

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Uvod

Trenje i trošenje zbivaju se na dodiru realnih površina koje su više ili manje hrapave. Pod trošenjem zuba podrazumijeva se postupni nestanak zubnog tkiva u:

- međusobnim dodirima zuba tijekom funkcijskih i parafunkcijskih kretnji čeljusti,
- abrazivnim djelovanjem raznih čestica, tvrdih predmeta neovisno o funkciji, te
- kemijskim učinkom kisele hrane, pića i regurgitiranog želučanog sadržaja.

U ustima se tijekom trošenja tvrdih zubnih tkiva događaju procesi abrazije, atricije, erozije, adhezije, korozije i umora materijala (1). Fiziološka abrazija

Introduction

Abrasion and wear are constant in the relationship between real surfaces that are more or less rough. Tooth wear implies that tooth substance is lost due to:

- contact between teeth in functional and parafunctional movements of the jaw
- abrasive wear of different hard object particles in no relation to function, and
- chemical effect of acid food, drinks and gastric reflux.

As teeth wear out, there are different processes in the mouth: abrasion, attrition, erosion, adhesion, corrosion, and material wear (1). Physiologikao prirodna pojava nastaje kao rezultat međusobnog usklađivanja genetski determiniranog oblika pojedinih dijelova stomatognatog sustava njegovoj funkcijskoj dinamici. Trošenje protetskih materijala uvjetovano je: fizikalnim faktorima (mikrotvrdoća, koeficijent trenja, umor materijala, otpornost na lom); mikrostrukturalnim faktorima (poroznost, kristali, matrica); kemijskim faktorima (kiselost i alkalnost sredine); završnom obradom površine (neglaziranost, glaziranost, poliranje). Adhezijsko trošenje javlja se npr. u ispitivanjima na uzorcima zlatne legure tip III kada čestice zlata adheriraju na površinu cakline. Umor površine javlja se kod krhkih materijala kao što je keramika tijekom ponavljanih kliznih kontakata ili zbog opterećenja. Tribokorozija ili tribokemijsko trošenje iako se ubraja u osnovne mehanizme trošenja, ipak je kombinacija kemijskih reakcija na površini triboelementa i jednog od navedenih mehanizama trošenja (1). Najvažnija preventivna tribološka mjera je pravilan izbor materijala, odnosno zaštite od trošenja. Izbor materijala mora se provesti uzimajući u obzir predviđeni stupanj opasnosti od pojedinih mehanizama trošenja u projektiranom tribosustavu, a izbor postupaka oplemenjivanja površine u svrhu smanjenja trošenja. Pritom, osnovni materijal ispunjava zahtjeve u pogledu tehnologičnosti i cjelovitosti triboelemenata, a oplemenjena površina ispunjava tribološke zahtjeve.

Velik broj u literaturi opisanih, vrlo različitih, metoda za ispitivanje trošenja materijala, od vrlo jednostavnih, nefizioloških, Wig-L-Bug metode (2) do mnogo složenijih kolčić-disk sistema koji oponašaju sile i kretnje koje se javljaju tijekom žvačnog ciklusa (3, 4) i uključuju mogućnost promjene temperature (5), izraz su stalne težnje (6, 7) za razvitkom jedinstvene metode za ispitivanje triboloških svojstava materijala. Klinička, *in vivo*, ispitivanja trošenja protetskih materijala su dugotrajna, uključuju velik broj pacijenata, što predstavlja problem kako s ekonomskog, tako i s praktičnog i etičkog stajališta. *In vitro* ispitivanja omogućuju brže dobivanje podataka jer se radi na principu ubrzanog trošenja sa simulacijom uvjeta usne šupljine ili bez nje (8). Meyer (9) tvrdi da se kod abrazije uključuje i neko treće brusno tijelo, to su osim korpuskularnih sastojaka hrane i otkinuti fragmenti cakline, čime su zapravo vlastiti zubi proizvođač brusnog tijela. Abrazija se javlja i kod prehrane mekšom i prerađenom hranom. Većina se autora slaže da važnu ulogu u nastanku abrazije imaju žvačne sile (10). Pregledom relevantne literature, keramika je najčešće opisivana kao materijal s odličnim estetskim mogućnostima, ali krhak i abrazivan

cal abrasion as a naturally occurring phenomenon is a result of fine-tuning of genetically determined shapes of different parts in the oral cavity system to its functional dynamics. Prosthetic material wear is determined by physical factors (microhardness, friction coefficient, material endurance, fracture resistance), microstructural factors (porosity, crystals, matrix); chemical factors (acidity and alkality of the environment) and surface finishing (polishing, final layering – glazing). Adhesional wear is present in experiments on gold alloys type III samples, when gold particles adhere to enamel surface. Surface wear is present in brittle materials, such as ceramic materials, due to repeated contacts or due to loading. Corrosional wear, or chemical wear, although a basic wear mechanism, is a combination of chemical reactions at the surface of the element and one of the stated wear mechanisms (1). The most important preventive measure is proper selection of a material, or protection from wear. Material selection must be performed with regard to the degree of danger of some wear mechanisms in the projected wear system. The choice of the procedures for enriching the surface must be performed with the aim of reducing the wear. The basic material must fulfill the requirements regarding technologicality and wholeness of the system, and the enriched surface must fulfill the wear requirements.

A number of different methods for wear assessment in the literature is a result of a constant wish for developing a unique method. They span from simple, non-physiological, Wig-L-Bug method (2), to sophisticated pin-on-disc systems that imitate forces and movements of masticatory cycle (3, 4), and can even include temperature changes (5-7). Clinical, *in vivo*, wear studies of prosthetic materials are of long duration and include great number of patients, which represents a problem from an economical point, as well as from practical and ethical points. *In vitro* studies can give the results faster, since they use sped-up processes with or without simulation of oral cavity conditions (8). Meyer (9) claims that abrasion includes a third object, this being fractured enamel particles; natural teeth being, therefore, the sources of wearing objects. Abrasion can be seen in situation where softer and prefabricated food is used. Majority of authors concur that masticatory forces have a great role in abrasion occurrence (10). A review of relevant literature has shown that ceramic materials are usually described as materials with excellent esthetic possibilities, but they are brittle and abrasive (11). Most ceramic

(11). Većina keramika ima veće vrijednosti mikrotvrdoće u usporedbi s protetskim legurama ili caklinom. Do nedavno se smatralo da je veća vrijednost mikrotvrdoće povezana s većom abrazivnošću keramike u kontaktu s legurama i caklinom (12, 13). Rezultati različitih ispitivanja (14) pokazuju da sama vrijednost mikrotvrdoće protetskog materijala nije dovoljna kao pouzdan pokazatelj kojim se predviđa ponašanje materijala u pogledu trošenja cakline nasuprotnih zubi. Seghi (15), Magne (16), Clelland (6) u laboratorijskim ispitivanjima su utvrdili da keramike manje tvrdoće dovode do većeg abrazijskog trošenja cakline nego keramički materijali koji imaju veće vrijednosti tvrdoće. Iznos trošenja i tvrdoće nije proporcionalno povezan kod materijala koji su krhki po prirodi. Kada keramika kliže po keramici ili caklini, ne dolazi do trošenja mehanizmom plastične deformacije kao kod legura, već pojavom loma. Razlog zbog kojeg se ne može na osnovi same vrijednosti mikrotvrdoće predvidjeti trošenje materijala je i nehomogenost građe kristala u staklenom matriksu. Kod keramike bez kristalne faze pod opterećenjem prvo dolazi do plastične deformacije i posljedičnog loma slabijeg dijela matriksa, dok kod keramika s kristalima dolazi do dislokacije kristala u staklenom matriksu. Ova činjenica donekle objašnjava slabu povezanost vrijednosti mikrotvrdoće i trošenja kod keramičkih materijala s kristalnom fazom, jer mikrotvrdoća tih keramičkih materijala varira ovisno o orijentaciji tijela koje prodire u materijal u odnosu na kristale (15). Međudjelovanje okoline, medija usne šupljine, i keramike također utječe na mehaničke karakteristike i ponašanje keramike. Staklo postaje tvrđe kada je vrijednost zeta potencijala (električni potencijal izmjeren na površini) približno nula, a mekše kada je vrijednost pozitivnija. Vlažnost medija usne šupljine može povećati pozitivan naboj stakla ili površine keramike, dolazi do ionske izmjene, gubitka iona, npr. natrija, i smanjenja tvrdoće površine. Dakle, keramički materijali se mogu ponašati različito, ovisno o međudjelovanju njihovih mikrostrukturnih komponenti i okoline (17). Hrapava površina, veliko opterećenje i velika kontaktna brzina djeluju tako da povećavaju koeficijent trenja, što dovodi do većeg trošenja (18). Nadalje, kada površine dvaju materijala imaju ionske ili polarne karakteristike međusobno slične, kao staklo i keramika, prisutnost vode ili druge polarne tekućine također povećava koeficijent trenja. Kada je jedan od materijala nepolaran, kao polimer, voda nema utjecaja ili se ponaša kao lubrikacijsko sredstvo. *In vitro* ispitivanje trošenja pokazalo je da je trošenje keramike i

materials have higher microhardness values when compared to prosthetic alloys and enamel. Until recently, these values were thought to be in correlation to higher abrasiveness of ceramic materials in contact with alloys and enamel (12, 13). The results of different studies (14) have shown that the microhardness value itself is not a reliable marker for predictions of material wear in contact with enamel of opposing teeth. Seghi (15), Magne (16) and Clelland (6) have confirmed in laboratory tests that ceramic materials with lower toughness values cause more enamel abrasion than ceramic materials with higher toughness values. Result of wear and toughness is not proportionally correlated in brittle materials. When ceramics slide on ceramics or enamel, the mechanism of wear is not plastic deformation (as in alloys), but fracture. The reason why it is not possible to determine the wear based on the microhardness is also the non-homogeneity of crystalline structure in the glass matrix. When ceramic materials without crystalline phase are loaded, there is first plastic deformation and subsequent fracture of the weaker part of the matrix, while ceramic materials with crystals exhibit crystal dislocation inside the glass matrix. This partly explains the weak correlation between microhardness value and wear of ceramic materials with crystalline phase, since microhardness of these materials varies depending on the orientation of the object that penetrates into the material, in relation to crystals (15). The relationship of oral cavity and ceramic materials also influences the mechanical characteristics and properties of the ceramic material. Glass becomes harder when zeta potential (electrical potential on the surface) is close to zero, and softer when the potential is more positive. Humidity of the oral cavity can increase the positive potential of the glass or ceramic surface; there is ion exchange, loss of, for example, sodium ions, and decrease of surface hardness. Therefore, ceramic materials can have different properties, depending on the conditions of the environment and the relationship of their microstructural components (17). Rough surface, great load and great contact surface increase the friction coefficient, thus leading to greater wear (18). Furthermore, when surfaces of two materials have similar ionic or polar characteristics, like glass and ceramics, presence of water or some other polar liquid increases the friction coefficient as well. When one of the materials is non-polar, like polymer, water has no influence, or represents a lubricating agent. *In vitro* wear study has shown that ceramics and cakline mnogo veće u jako kiseloj sredini (pH 2,28 do 2,37) nego u manje kiseloj (19). Zanimljivim se pokazalo da više poroznosti ima keramika koja se peče na nižim temperaturama, keramika malih čestica nego glinična keramika (16). Ako dođe do izlaganja subpovršinske poroznosti tijekom procesa trošenja (okrugla fraktura), oštar rub defekta uzrokuje porast trošenja zuba antagonista. Magne (16) upozorava da manji abrazijski potencijal staklokeramike može biti djelomično povezan s vrstom (tetrasilicij fluorovi kristali, kristali tinjca; $K_2Mg_5Si_8O_{20}F_4$), rasporedom, i malom veličinom kristala (5 do 7 µm). Brojne studije su rađene kako bi se pronašla optimalna tehnika završne obrade nadomjestka (20-23); od Campbella (21), Klausnera (22), Pattersona (23) koji ističu glaziranost do Scurria (24) koji tvrdi da poliranje površine daje istu ili glađu površinu nego glaziranje. Ward (25) i Kawai (26) pokazali su da je polirana površina glađa te da je manja adhezija plaka na takvu površinu nego na glaziranu do konačno Monaskya i Taylora (5) koji tvrde da je utjecaj površinske hrapavosti na trošenje ograničavajući. Rezultati nedavnih ispitivanja pokazali su jače izraženo trošenje zubi suprotne čeljusti u kontaktu s glaziranom površinom nego onom koja je polirana (27). Ovakvi rezultati mogu se povezati s većom lomnom žilavosti glazirane površine.

Svrha ovog istraživanja bila je:

1. usavršiti metodu za ispitivanje triboloških svojstava gradivnih protetskih materijala - konstruirati uređaj koji podržava razvijenu metodu
2. ispitati tribološka svojstva različitih estetskih protetskih materijala
3. ispitati međusobno ponašanje materijala tribološkog para: prirodan zub – estetski protetski materijal.

Materijali i postupci

Ovo istraživanje provedeno je na uzorcima šest različitih estetskih protetskih materijala (po 3 uzorka za svaki ispitivani materijal), oblika pločice, dimenzija 20 x 25 x 0,5 mm:

- uzorci I, glinična keramika, d.Sign (Ivoclar-Vivadent, Schaan, Liechtenstein) - izmodelirane pločice u vosku izljevene u Co-Cr leguri, na njih su napečena tri osnovna keramička sloja te glazura po uputama prizvođača.
- uzorci II, polimer, SR Chromasit (Ivoclar-Vivadent, Schaan, Liechtenstein) - uzorci su izrađeni po preporuci proizvođača, polirani gumenim polirerom, četkom od prirodne dlake i zatim kolutom od vune.

enamel wears are greater in acid environment (pH 2.28-2.37) than in less acid (19). Interestingly, it has been shown that ceramic material that needs lower temperatures is more porous, as well as that small-particle ceramics is more porous than alumina ceramics (16). If there is subsurface porosity during wear (round fracture), sharp border of the defect increases the wear of the opposing tooth. Magne (16) implies that lower abrasive potential of glass ceramic material can partially be in correlation to the type of ceramics (tetrasilicium fluoride crystals; $K_2Mg_5Si_8O_{20}F_4$), structure, and small crystal size (5 to 7 µm). Numerous studies that were performed in order to discover the optimal finishing technique for bridges and crowns (20-23); from Campbell (21), Klausner (22) and Patterson (23) that stress the glazing, to Scurria (24) who claims that polishing yields smoother surface than glazing. Ward (25) and Kawai (26) showed that polished surface is smoother, and that plaque adhesion to such surface is smaller when compared to glazed surface. Monasky and Taylor (5) claim that the influence of the surface roughness on wear is limited. The results of recent studies have indicated greater wear of opposing teeth in contact with glazed than polished ceramic surface (27). Such data can be correlated to greater fracture resistance of the glazed surface.

The aim of the study was to:

1. Perfect a method for examining wear characteristics of prosthetic materials and to construct a device that can support the developed method
2. Assess wear characteristic of esthetic prosthetic materials
3. Examine the relationship in a wear pair: natural tooth – prosthetic material

Material and methods

This study was performed on samples of six different esthetic prosthetic materials (3 samples for each tested material) in plate design 20×25×0.5 mm:

- Samples I: alumina ceramic material, d.Sign (Ivoclar Vivadent, Schaan, Liechtenstein) – plates modeled in wax, cast in Co-Cr alloy with three basic ceramic layers and glazed, according to the manufacturer's instructions.
- Samples II: polymer, SR Chromasit (Ivoclar Vivadent, Schaan, Liechtenstein) – samples manufactured according to manufacturer's instructions, polished with pumice, natural hair and cotton.

- uzorci III, glinična keramika niske temperature pečenja, Creation LF (Klema Dentalprodukte, Meiningen, Austria) – podloge u Co-Cr leguri izrađene su i obrađene na isti način kao uzorci I na njih je napečen sloj glinične keramike niske temperature pečenja prema uputama proizvođača. Završna obrada uzoraka sastojala se od mehaničkog poliranja gumicama.
- uzorci IV, vlaknima ojačan kompozit, Targis (Ivoclar-Vivadent, Schaan, Liechtenstein) – izrađene su pločice od dvije nemetalne komponente. Podloga je izrađena iz Vectris Single materijala koji se koristi pri izradi stražnjih krunica, a estetska obloga izrađena je iz Targis materijala. Poštivane su sve preporuke proizvođača za laboratorijsku izradu nadomjestka u stražnjem području zubnog niza.
- uzorci V, staklokeramika, IPS Empress 1, materijal za tehniku bojenja (Ivoclar-Vivadent, Schaan, Liechtenstein) – uzorci su izrađeni po naputcima proizvođača; te na kraju glazirani.
- uzorci VI, glinična keramika, Creation CC (Klema Dentalprodukte, Meiningen, Austria) – pločice izljevene u Co-Cr leguri napravljene su standardnim postupkom, obrađene i pjeskarene (te premazane U-bondom koji se peče u keramičkoj peći na 990°C-za Co-Cr). Slijedilo je napečenje triju osnovnih keramičkih slojeva po tvornički zadanim uputama. Završna obrada sastojala se od mehaničkog poliranja gumicama.

Istraživanje je provedeno na Zavodu za materijale, Fakulteta strojarstva i brodogradnje u Zagrebu, a korišten je modificirani uređaj "Taber abraser", tvrtke Taber, SAD (po standardu ASTM D-1044). Uređaj radi na principu "pin on disc" metode, koja je uobičajena za tribološka ispitivanja u strojarstvu, ali za ispitivanje biomaterijala modificiran je na taj način da se na mjestu pina nalazi zub, a umjesto diska ispitivani materijal.

Uzorci zuba korišteni u ispitivanju su ljudski, intaktni, treći kutnjaci izvađeni iz ortodontskih razloga; nakon vađenja bili su pohranjeni u fiziološku otopinu. Rezani su u aksijalnoj, sagitalnoj i horizontalnoj ravnini kako bi se dobile izolirane pojedine kvržice. Izolirana kvržica zuba bila je pričvršćena na pokretni dio, koji je klizao iznad dijela koji rotira, na kojem su se nalazili uzorci estetskih protetskih materijala. Uzorci su bili nepomični, pričvršćeni na dio koji rotira akrilnim ljepilom. Rotiranjem pričvršćenih uzoraka dolazi do kontakta zuba i uzorka, i klizanjem preko povšine uzorka zub ostavlja trag trošenja. Moguće je bilo primijeniti različit iznos

- Samples III: low temperature alumina ceramics, Creation LF (Klema Dentalprodukte, Meiningen, Austria) – base in Co-Cr alloy, prepared and finished in the same way as samples I; alumina ceramic was layered on the alloy, according to manufacturer's instructions. Final polishing was performed with pumice.
- Samples IV: fiber reinforced composite, Targis (Ivoclar Vivadent, Schaan, Liechtenstein) – two plates of components were fabricated. The base was manufactured from Vectris Single, used for lateral crowns, and esthetic component was manufactured from Targis. All instructions for laboratory manufacturing were observed.
- Samples V: glass ceramic material, IPS Empress 1, material for colouring technique (Ivoclar Vivadent, Schaan Liechtenstein) – samples were fabricated according to manufacturer's instructions and glazed at the finish.
- Samples VI: alumina ceramic material, Creation CC (Klema Dentalprodukte, Meiningen, Austria) – plates cast in Co-Cr alloy and fabricated by standard procedure, and sandblasted (layered with U-bond for ceramic oven at 990°C for Co-Cr), followed by three basic ceramic layers, according to manufacturer's instructions. Finally, the samples were polished with pumice.

The study was performed at The Department of Materials, School of Engineering, University of Zagreb, Croatia, by the device named "Taber abraser" (Taber, USA; according to standards ASTM D-1044). The device uses the "pin-on-disc" method that is accustomed for wear testing in engineering; it was modified for testing biomaterials so that instead of a pin we used a tooth, and instead of a disc we used the tested ceramic material.

Tooth samples used in a study were intact human third molars extracted due to orthodontic reasons, stored in saline after extraction. The teeth were cut in axial, sagittal and horizontal plane in order to obtain isolated tuberculum. Each isolated tuberculum was connected to the movable part that was sliding above the rotating part, which harbored samples of esthetic prosthetic materials. The samples were static, bonded to the rotating part by means of acrylic bond. Rotation of the bonded samples leads to establishing a contact between the samples and the tooth, and sliding over sample surface leaves a wear mark. It was possible to use different loading values to the samples, by directly changing the mass. The tuberculum slid over the sample surface in a circle with 10 mm diameter, at 60 revolutions per minute.

opterećenja na uzorke, direktnim mijenjanjem postavljene mase. Kvržica zuba klizala je preko površine ispitivanog materijala opisujući kružnicu promjera 10 mm, s učestalošću od 60 ciklusa u minuti. Ispitivanje je obavljeno bez prisutnosti trećeg medija lubrikanta, uz opterećenje od 10N, tijekom 500 ciklusa. Mjeren je gubitak mase nakon 100, 200, 300, 400, te 500 ciklusa.

U ovom istraživanju je izračunat faktor K' – konstanta materijala koja opisuje intenzitet trošenja za pojedini materijal. Ako se ta konstanta K' podijeli s tvrdoćom materijala H, dobiva se izraz za izračunavanje faktora trošenja, K (izračunati su faktori trošenja uzoraka nakon 100 okretaja): pri čemu je: K – faktor trošenja, 10^{-6} mm^3/Nm, V – istrošeni volumen; K' – konstanta materijala; F_N – normalna komponenta opterećenja; s – prijeđeni put; H – tvrdoća materijala.

$$K = \frac{V}{F_N \cdot s}$$

Rezultati

Provedeno istraživanje rezultiralo je razvojem nove metode i uređaja za ispitivanje triboloških svojstava gradivnih protetskih materijala. Metoda i uređaj ispitani su na šest različitih tribosustava koji se sastoje od tribopara, zub – estetski protetski materijal. Utvrđena je značajna razlika u gubitku mase te u dubini i širini traga trošenja ispitivanih uzoraka (Slika 1), što predstavlja osnovu za kvalitativnu i kvantitativnu usporedbu otpornosti na trošenje različitih materijala. Uzorak VI glinična keramika (Creation) pokazuje najmanje trošenje, slijede Uzorci I i IV, dok je najveće trošenje primijećeno kod uzorka II polimera (Chromasit). Prilikom ispitivanja (nakon 100 ciklusa) došlo je do loma uzoraka III glinične keramike niske temperature pečenja (Creation LF) i V staklokeramike (IPS Empress), te nije bilo moguće odrediti sve njihove parametre trošenja. Korištenim uređajem moguće je ispitivanje uzoraka materijala s niskom udarnom radnjom loma. Vrlo je jednostavno mijenjati opterećenje i brzinu okretanja diska, čime se parametri mogu prilagoditi različitim uzorcima materijala. Dobiveni rezultati omogućuju i kvantitativnu usporedbu otpornosti na abrazijsko trošenje. Matematički izrazi uvedeni u radu omogućuju kvantificiranje otpornosti materijala na abrazijsko trošenje putem faktora trošenja preuzetog iz strojarske prakse. Tijekom ispitivanja fotografirani su uzorci svih ispitivanih materijala i zuba kao tribopara, rezultati su prikazani pojedinačno, tablično i

The test was performed without lubricant, with 10 N load, during 500 cycles. Loss of mass was measured after 100, 200, 300, 400, and 500 cycles.

A factor K' was computed – constant of the material that describes wear intensity for each material. If the constant K' was divided by the material hardness (H), we can obtain a formula for computing the wear factor, K (computed wear factors after 100 revolutions), where K is the wear factor (10^{-6} mm^3/Nm), V is lost volume, K' is material's constant, F_N – normal wear component, s – trip, and H – material hardness:

$$K = \frac{V}{F_N \cdot s}$$

Results

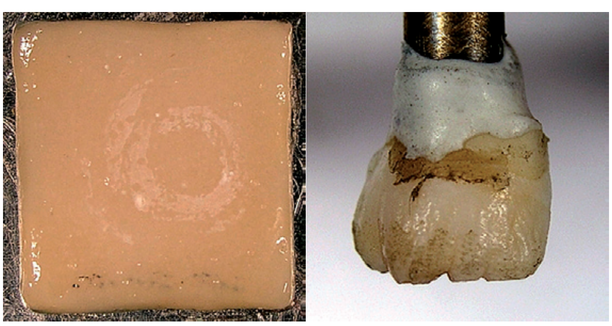
The study resulted in a novel method and device for assessing wear characteristics of prosthetic materials. The method and the device were tested with six different wear systems that consist of a wear pair – tooth and esthetic prosthetic material. A significant difference in mass loss, depth and width of wear trace in tested materials was found (Fig. 1). This fact represents the base for qualitative and quantitative comparison of wear resistance of different materials. Sample VI (alumina ceramic Creation) presented least wear, and it was followed by samples I and IV, while the greatest wear was seen in sample II (polymer Chromasit). The fracture of sample III (alumina ceramic Creation LF) and V (IPS Empress) occurred during testing (after 100 cycles), so it was not possible to determine all of their wear parameters. The used device can test samples with low fracture tendency. It is very easy to change the load and speed of disc rotation, so the parameters can be adapted to different material samples. The obtained results enable qualitative comparison of abrasive wear resistance. Mathematical formula in the study enables quantification of abrasive wear resistance by means of wear factor that was transferred from engineering. Samples of all tested materials and teeth were photographed, but in this article only mean values for samples I, II, IV and V were depicted (Fig. 2), as well as wear factors for all samples (Fig. 3).

Discussion

The wear of hard, non-shedding tooth tissue is a natural and unavoidable process. Enamel wear in contact with enamel amounts to 20 to 40 µm per grafički, ali u ovom radu (zbog opsega) prikazani su samo rezultati srednjih vrijednosti gubitka mase za uzorke I, II, IV, VI (Slika 2) te faktori trošenja svih uzoraka (Slika 3).

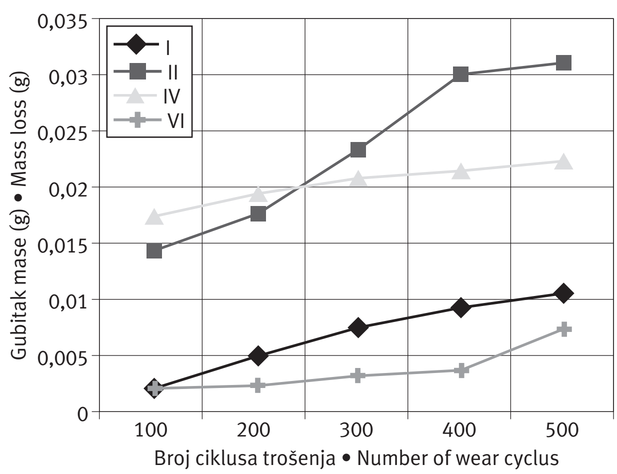
Rasprava

Trošenje tvrdih zubnih tkiva prirodan je i neizbježan proces. Trošenje cakline u kontaktu s caklinom iznosi 20 do 40 µm na godinu u području pretkutnjaka i kutnjaka (Lambrechts) (28). Količina trošenja idealnog protetskog gradivnog materijala trebala bi biti slična onoj kod cakline (15). Monasky i Taylor (5), upozoravaju da nema statistički značajne razlike u trošenju cakline i zlatne legure tip III, što objašnjavaju dvojako, apsorpcijom okluzijskih sila zbog klizanja atoma zlata, ili pak adhezijom tankog sloja tip III zlatnih čestica na površinu cakline. Moguće je da taj sloj služi kao lubrikant ili zaštitni sloj za caklinske uzorke. U kliničkim ispitivanjima ova se pojava nije promatrala, hrana i četkanje odstranili bi čestice prije nego što bi se stigla nakupiti vidljiva količina sloja (7). U mnogim ispitivanjima trošenja, zbog jednostavnosti mjerenja, primjene rezultata u kliničkoj praksi te lakše usporedbe s vertikalnom dimenzijom međučeljusnih odnosa, trošenje se određuje kao smanjenje visine uzoraka. Međutim, mjerenje gubitka volumena mnogo je preciznija mjera jer se mijenja linearno s vremenom (29). Najveća razlika u određivanju trošenja mjerenjem volumena ili visine javlja se kada su nasuprotne plohe morfološki u obliku kvržica. Ta je razlika smanjena kada se odstrani sam vrh kvržice i nasuprotna ploha izgleda ravna (16). Creation keramika (Klema Dentalprodukte, Meiningen, Austria), pokazuje i moguće dobro kliničko ponašanje s obzirom na trošenje i kroz gubitak volumena i dubinu traga trošenja (30). Na isto upućuju i rezultati dobiveni u ovom ispitivanju, najmanji gubitak mase, a time i najmanje trošenje izmjereno je za glinič-

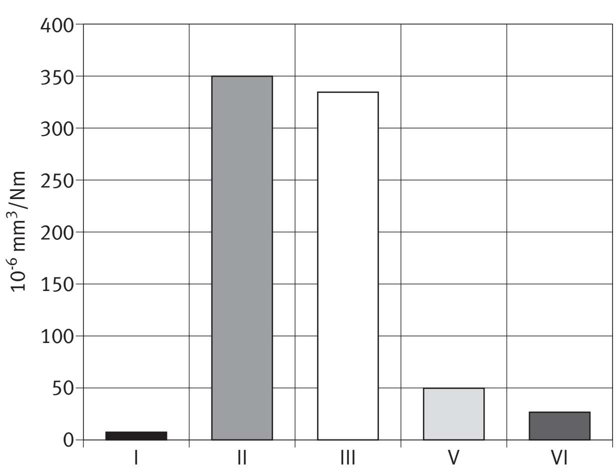


Slika 1. Uzorak I, glinična keramika, i kvržica zuba nakon 500 ciklusa trošenja
Figure 1. Sample I, alumina ceramic material, and tuberculum after 500 cycles.

year in premolars and molars (28). The amount of wear of the ideal prosthetic material should be similar to that of the enamel (15). Monasky and Taylor (5) point that there is no statistically significant difference in enamel wear and gold alloy type III wear, which is explained in two ways, by absorption of occlusal forces due to gold atom sliding, or by adhesion of a thin layer of gold particles on the enamel. It is plausible that this layer serves as a lubricant, or a protective layer for the enamel. In clinical studies this was not observed; food and toothbrush would remove gold particles before they could amount to a significant thickness (7). Many wear studies, due to the simplicity of measurement, result application and easier comparison to the vertical dimension of the intermaxillary relations, use the decrease of the height of samples as wear. However, volume loss is more precise method, since it changes with time in a linear fashion (29). The greatest difference in wear determination by volume or height can be



Slika 2. Prikaz srednje vrijednosti gubitka mase uzoraka I, II, IV i VI
Figure 2. Mean values of mass loss of samples I, II, IV and VI



Slika 3. Prikaz faktora trošenja uzoraka
Figure 3. Wear factors of samples

nu keramiku (Creation). Rezultati ispitivanja Imai i sur. (31) pokazali su najmanje trošenje za uzorke IPS Empress 1 keramike u usporedbi s drugim keramikama u testu trošenja s dva i tri tijela. Prema rezultatima ovog ispitivanja, faktor trošenja za IPS Empress 1 keramiku u kontaktu s caklinom bio je nizak kao i za glinične keramike.

Zaključci

1. Provedeno istraživanje rezultiralo je razvojem nove metode i uređaja za ispitivanje triboloških svojstava estetskih protetskih materijala.
2. Utvrđena je značajna razlika u gubitku mase te u dubini i širini traga trošenja na različitim estetskim protetskim materijalima.
3. Uzorci estetskih protetskih materijala pokazali su razlike u ponašanju pri istim uvjetima abrazivnog trošenja: uzorak VI glinična keramika (Creation) pokazuje najmanje trošenje, slično kao i uzorak I glinične keramike (d.Sign). Najveće trošenje određeno je za uzorak II polimer (Chromasit) te ceromer (Targis).
4. Faktori trošenja, određeni matematičkim izrazom preuzetim iz strojarske prakse, predstavljaju brojčani pokazatelj na temelju kojeg je moguće usporediti različite vrste materijala koji se koriste u kliničkoj praksi.

observed when the opposing surfaces are tuberculi. This difference decreases when the peak of a tuberculum is removed, and the opposing surface appears flat (16). Creation ceramic material (Klema Dentalprodukte, Meiningen, Austria) presents possibly excellent clinical properties with regards to wear, volume loss, and depth of the wear trace (30). It is implied by the results from this study – least mass loss and least wear was measured for the alumina ceramic material Creation. The results of Imai et al. (31) have shown least wear for IPS Empress 1 samples when compared to other ceramic materials in wear test with two and three parts. According to the results of this study, wear factor for IPS Empress 1 in contact with enamel was low, as was for alumina ceramic materials.

Conclusions

1. The study resulted in a novel method and device for testing wear properties of esthetic prosthetic materials.
2. Statistical difference in mass loss, depth and width of wear trace in tested materials was found.
3. Samples of esthetic prosthetic materials have shown differences in the same conditions of abrasive wear: sample VI alumina ceramic Creation showed least wear, similarly to sample I alumina ceramic d.Sign. Most wear was observed for sample II polymer Chromasit and ceromere Targis.
4. Wear factors, determined by a mathematical formula transferred from engineering, represent a numerical indicator that can be used as the base for comparison of different materials that are used in clinical practice.

Abstract
Knowledge of wear characteristics of esthetic prosthetic materials is essential in everyday dental practice. To establish a new, original, method and produce a device for examining wear characteristics of constructive prosthetic materials, to assess the wear characteristics of different esthetic prosthetic materials and to examine the relationship in a wear pair: natural tooth - prosthetic material. The study was performed on a modified device "Taber abraser" on samples of six different esthetic prosthetic materials. The wear is smallest for samples of alumina ceramics (Creation and d.Sign), and greatest for polymer (Chromasit) and ceromer material (Targis). The smallest wear factors were established for alumina ceramics as well. The study has resulted in the development of a new method and new device for examining the wear characteristics of prosthetic materials.

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References

1. Ivušić V. Tribologija. Zagreb: Hrvatsko društvo za materijale i tribologiju; 1998.
2. Jones DW, Jones PA, Wilson HJ. A simple abrasion test for composites. J Dent. 1972; 1(1): 28-34.
3. Harrison A, Lewis TT. The development of an abrasion testing machine for dental materials. J Biomed Mater Res. 1975; 9(3): 341-53.
4. Powell JM, Dickson G. *In vitro* wear testing of restorative materials. IADR. 1975; 54: 356.
5. Monasky GE, Taylor DF. Studies on the wear of porcelain, enamel, and gold. J Prosthet Dent. 1971; 25(3): 299-306.
6. Clelland NL, Agarwala V, Knobloch LA, Seghi RR. Wear of human enamel opposing low-fusing and conventional ceramic restorative materials. J Prosthodont. 2001; 10(1): 8-15.
7. Ramp MH, Suzuki S, Cox CF, Lacefield WR, Koth DL. Evaluation of wear: Enamel opposing three ceramic materials and a gold alloy. J Prosthet Dent. 1997; 77(5): 523-30.
8. DeLong R, Douglas WH. Development of an artificial oral environment for the testing of dental restoratives: bi-axial force and movement control. J Dent Res. 1983; 62(1): 32-6.
9. Meyer E, Eichner K. Klinische Untersuchungsergebnisse zu verblendeten Kronen und Brücken-Vergleich Kunststoff/Keramik. Dtsch zahnarztl Z. 1980; 35(9): 864-9.
10. Komar D, Kosovel Z. Vrednovanje opterećenja pojedinih zubi u pacijenata s patološkom abrazijom. Acta Stomatol Croat. 1986; 20 Suppl: 99-105.
11. Kelly JR, Nishimura I, Campbell SD. Ceramics in dentistry: Historical roots and current perspectives. J Prosthet Dent. 1996; 75(1): 18-32.
12. Hudson JD, Goldstein GR, Georgescu M. Enamel wear caused by three different restorative materials. J Prosthet Dent. 1995; 74(6): 647-54.
13. Fisher RM, Moore BK, Swartz ML, Dykema RW. The effects of enamel wear on the metal-porcelain interface. J Prosthet Dent. 1983; 50(5): 627-31.
14. Dahl BL, Oilo G. *In vivo* wear ranking of some restorative materials. Quintessence Int. 1994;25(8):561-5.
15. Seghi RR, Rosenstiel SF, Bauer P. Abrasion of human enamel by different dental ceramics *in vitro*. J Dent Res. 1991; 70(3): 221-5.
16. Magne P, Oh WS, Pintado MR, DeLong R. Wear of enamel and veneering ceramics after laboratory and chairside finishing procedures. J Prosthet Dent. 1999; 82(6): 669-79.
17. Yap AU, Teoh SH, Hastings GW, Lu CS. Comparative wear rankingof dental restorative materials utilizing different wear simulation modes. J Oral Rehabil. 1997; 24(8): 574-80.
18. Koran A, Craig RG, Tillitson EW. Coefficient of friction of prosthetic tooth materials. J Prosthet Dent. 1972; 27(3): 269-74.
19. al-Hiyasat AS, Saunders WP, Sharkey SW, Smith GM, Gilmour WH. The abrasive effect of glazed, unglazed, and polished porcelain on the wear of human enamel, and the influence of carbonated soft drinks on the rate of wear. Int J Prosthodont. 1997; 10(3): 269-82.
20. Grieve AR, Jeffrey IW, Sharma SJ. An evaluation of three methods of polishing porcelain by comparison of surface topography with the original glaze. Restorative Dent. 1991; 7(2): 34-6.
21. Campbell SD. Evaluation of surface roughness and polishing techniques for new ceramic materials. J Prosthet Dent. 1989; 61(5): 563-8.
22. Klausner LH, Cartwright CB, Charbeneau GT. Polished versus autoglazed porcelain surfaces. J Prosthet Dent. 1982; 47(2): 157-62.
23. Patterson CJ, McLundie AC, Stirrups DR, Taylor WG. Efficacy of a porcelain refinishing system in restoring surface finish after grinding with fine and extra-fine diamond burs. J Prosthet Dent. 1992; 68(3): 402-6.
24. Scurria MS, Powers JM. Surface roughness of two polished ceramic materials. J Prosthet Dent. 1994; 71(2): 174-7.
25. Ward MT, Tate WH, Powers JM. Surface roughness of opalescent porcelains after polishing. Oper Dent. 1995; 20(3): 106-10.
26. Kawai K, Urano M, Ebisu S. Effect of surface roughness of porcelain on adhesion of bacteria and their synthesizing glucans. J Prosthet Dent. 2000; 83(6): 664-7.
27. Jagger DC, Harrison A. An *in vitro* investigation into the wear effects of unglazed, glazed, and polished porcelain on human enamel. J Prosthet Dent. 1994; 72(3): 320-3.
28. Lambrechts P, Braem M, Vuylsteke-Wauters M, Vanherle G. Quantitative *in vivo* wear of human enamel. J Dent Res. 1989; 68(12): 1752-4.
29. Pintado MR, Anderson GC, DeLong R, Douglas WH. Variation in tooth wear in young adults over a two-year period. J Prosthet Dent. 1997; 77(3): 313-20.
30. Derand P, Vereby P. Wear of low-fusing dental porcelains. J Prosthet Dent. 1999; 81(4): 460-3.
31. Imai Y, Suzuki S, Fukushima S. Enamel wear of modified porcelains. Am J Dent. 2000; 13(6): 315-23.