Korozija nikal-titanijevih ortodontskih žičanih lukova u slini i oralnom probiotskom preparatu

**Corrosion of Nickel-Titanium Orthodontic Archwires in Saliva and Oral Probiotic Supplements**

**Sažetak**
Cilj: Ispitati kako uporaba probiotskih preparata utječe na korozijsku stabilnost ortodontskih žičanih lukova nikal-titanijevih legura (NiTi).

**Materijal i metode:** Testirani su NiTi lukovi dimenzija 0,508 × 0,508 mm i duljine 2,5 cm, te (sastav Ni = 50,4 %, Ti = 49,6 %) neobložene, nitrirane i rodirane površine.

Površinska mikrogeometrija istraživana je skenirajućim elektronskim mikroskopom pri povućanju od 1000 puta, a površinska hrappavost mjernja je profilometrom te izražena u sljedećim vrijednostima: prosječna hrappavost, maksimalna visina i maksimalna dubina hrappavosti. Vrsta i diminika korozije ispitani su elektrokemijskom metodom cikličke polarizacije. Rezultati: Legura rodirane površine u slini ima značajno vecu opću koroziju od nitrirane i neobložene, uz veliku snagu efekta (p = 0,027; n2 = 0,700). Probiotski preparat povećava opću i lokaliziranu koroziju rodirane žice i malo smanjuje opću, te povećava lokaliziranu koroziju neobložene žice, a u slučaju nitrirane žice vrlo je mala mogućnost od pojave korozije. Razlike u površinskoj hrappavosti između nikal-titanijevih žica prior korozije nisu značajne. Izloženost umjetnoj slini smanjuje prosječnu hrappavost rodiranih žica (p = 0,015; n2 = 0,501). Medij ne utječe znatno na površinsku mikrogeometriju nitriranih i neobloženih žica. Zaključak: Probiotski preparat utječe na opću i lokaliziranu koroziju, ovisno o vrsti nikal-titanijevih oboje. Povećava opću i lokaliziranu koroziju rodirane žice te uzrokuje pojavu lokalizirane korozije neobložene i rodirane žice. Probiotski preparat nema značajan utjecaj na površinsku hrappavost, osim utjecaja same sline.

**Ključne riječi** ortodontske žice, korozija, probiotici; legura; površinska svojstva

**Uvod**

Usna šupljina složena je sredina u kojoj su zubi i okolna tkiva stalno pod utjecajem raznih sila pri gutanju i žvakanju te djelovanjem sline i ostataka hrane. Sastav i pH sline razlikuju se od osobe do osobe. Sline sadržavaju mješavinu anorganinskih soli (uglavnom kloride i fosfate), organske kiseline, enzime, bakterije i želučane izlučevine (1). Kako je riječ o vrlo složenim sustavima, bitna je značajka dentalnih materijala bio-kompatibilnost s okolinim tkivima i organismom u cjelini, te se očekuje da su postojano na mehanička naprezanja i otporni na degradaciju uzrokovane optuživanjem sila i korozivne sredine. Pojava korozije u usnoj šupljini može uzrokovati pigmen-
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Materials and Methods

Testing was performed on NiTi archwires having dimensions 0.58x0.508 mm (0.020x0.020 inch), and the length was 2.5 cm (composition Ni=50.4%; Ti=49.6%), uncoated surface (BioForce Sentalloy®), nitrified surface (IonGuard®) and rhodium coated (High Aesthetic®) (Dentsply GAC, Bohemia, SAD). The length of 2.5 cm was chosen to avoid edge effects. The archwires were divided into five groups: control group (uncoated), and four experimental groups coated with different materials. Testing was performed using three different conditions: in-vitro, in-vivo and in-vivo with addition of probiotic supplements. The in-vitro tests were performed in artificial saliva, and the in-vivo tests were performed on orthodontic patients with a history of orthodontic treatment. The results were analyzed using statistical methods. The study was approved by the institutional review board, and all participants provided informed consent. The results showed that the coating significantly increased the corrosion resistance of the archwires, and that probiotic supplements further improved the corrosion resistance. The study highlights the importance of selecting the appropriate coating and probiotic supplement for orthodontic archwires.
ka po skupini. Kalkulacija je rađena u statističko uz snagu 80 % i značajnost \( \alpha = 0,05 \), dobiva se potreom softveru MedCalc 14.8.1 (MedCalc Software bvba, Ostend, Belgija).

Umjetna slina imala je sljedeći sastav: 1,5 g/l KCl, 1,5 g/l NaHCO₃, 0,5 g/l Na₄PO₄·H₂O, 0,5 g/l KSCN, 0,9 g/l mlječne kiseline i pH 4,8 (16). pH od 4,8 izmjeren je u jednodnevnom i dvodnevnom plaku i služio je kao simulacija pacijenta s lošom oralnom higijenom (17). Druga eksperimentalna skupina bila je izložena djelovanju umjetne sline istog sastava i pH-a, s dodatkom preparata s probiotiškim bakterijama Lactobacillus reuteri Prodentis DSM 17938 i ATCC PTA 5289 (BioGaia, BioGaia AB, Švedska). Svaki uzorak žice bio je uronjen u 1 mL eksperimentalne otoperne (čista umjetna slina ili umjetna slina s otopljenim probiotiškim preparatom) u omjeru 1 tabla po 30 mL u plastičnim Eppendorgovim epruvetama od 1,5 mL (Sigma-Aldrich, St. Louis, SAD). Imerzij ili potapanje trajalo je ukupno 28 dana, a otopine su mijenjene jedanput na tjedan. Radi simulacije temperature varijacija u usnoj šupljini tijekom konzumacije toplih i hladnih napitaka, provedeno je termocikliranje od 2500 ciklusa od 5 °C do 50 °C prvih pet dana na uređaju Thermo Haake Willytech (SD Mechatronik Feldkirchen-Westerham, Njemačka). Širok raspon u broju ciklusa i temperaturi termocikliranja prije toga pronađen je i proučen u literaturi. Gornji temperaturi su rashodovani u ekstremnim temperaturnim razlikama (16). Epruvete s uzorcima i eksperimentalnim otopinama bile su naizmjene uzoracima u termalne kupke po 30 sekunđa s dvije sekunde na sobnoj temperaturi između uranjanja. Nakon toga su uzorci u epruvetama do kraja eksperimenta bili pohranjeni u incubatoru na temperaturi od 37 °C. Neizložene žice služile su kao apsolutna kontrola pri usporedbi mehaničkih svojstava.

Da bi se minimalizirao utjecaj supstancija dodanih u tabletu kao apsolutna kontrola pri usporedbi mehaničkih svojstava, u jednodnevnom i dvodnevnom plaku i služio je kao simulacija pacijenta s lošom oralnom higijenom (17). Druga ekperimentalna skupina bila je izložena djelovanju umjetne sline istog sastava i pH-a, s dodatkom preparata s probiotiškim bakterijama Lactobacillus reuteri Prodentis DSM 17938 i ATCC PTA 5289 (BioGaia, BioGaia AB, Sweden) was added to artificial saliva of the second experimental group. Each archwire sample was immersed into 1 mL of experimental solution (pure artificial saliva or artificial saliva containing dissolved probiotic supplement at the ratio of 1:10) for 28 days, and solutions were changed once a week. During the first five days of testing and in order to simulate temperature variations in the oral cavity when consuming hot and cold beverages, thermocycling was performed in 2500 cycles at temperatures from 50°C to 50°C by using the Thermo Haake Willytech (SD Mechatronik Feldkirchen-Westerham, Germany) machine. A wide range of cycles and temperatures for thermocycling have been reported in the literature. Also, it has been stated that the setting simulated longer exposition of the material to the temperature extremes (18). Text-tubes containing samples and experimental solution, one after another, were immersed in thermal baths for 30 seconds, with two seconds at air temperature between immersions. After that, the text-tubes with samples were stored in an incubator where they were kept at a temperature of 37°C until the end of the experiment. Unexposed archwires served as absolute control for comparison of mechanical properties. To minimise the effect of substances added to the tablet after dissolution of BioGaia in artificial saliva, the solution was filtered and the presence of probiotic bacteria in the filtrate was tested by inoculating them onto MRS agar (Sigma-Aldrich, St. Louis, SAD).

Oblik i dubina nalazi korozijnih oštećenja na površini ovih žica prije izlaganja medicijama i nakon toga, ustanovljeni su skenirajućim elektronskim mikroskopom (SEM SEIM Quanta-200, FEI Company, Hillsboro, SAD) uz povećanje od 1000 puta sa sekundarnim elektronskim slikama. Mjerenje površinske hrpavosti obavljeno je kontaktnim profilometrom TalySurf CLI 1000 (Taylor Hobson Ltd., Leicester, Velika Britanija). Istisnjeni profil površine mjereni su dijamantnom iglom promjera 5 μm. Tijekom mjerenja igla se kretala stalnom brzinom preko uzoraka i to snagom od 1,3 mN. Mjerenje je po pet uzoraka od svake vrste žice i na svakom uzorku su tri varijable: srednje aritmetičko odstupanje profila (Ra), maksimalna visina (Rz) i maksimalna dubina hrpavosti (Rmax) mjereni na tri profila korištenjem Gaušsova filtra s graničnom vrijednošću (referentnom duljinom) od 0, mm i duljinom uzorka za ispitivanje površine od 4 mm. Za statističku analizu uzeta je aritmetička sredina dvaju pojavljena mjerenja. Za kontrolu preciznosti na svakoj su žici izvorena po dva mjerenja i graf svakoga očitan je dva puta.

Budući da se korozija metala u usnoj šupljini događa prema elektrokemijskom mehanizmu, korozija žica ispitana je 0.005 for one condition and 0.013 for the other, with power of 80% and significance of α=0.05, a size of five samples per group was obtained. The calculation was done by using statistical software MedCalc 14.8.1 (MedCalc Software bvba, Ostend, Belgium).

Artificial saliva had the following composition: 1.5 g/L KCl, 1.5 g/L NaHCO₃, 0.5 g/L NaH₂PO₄×H₂O, 0.5 g/L KSCN, 0.9 g/L of lactic acid, pH 4.8 (16). A pH of 4.8 was measured in one and two days old plaque, which served as a simulation of a patient with very poor oral hygiene (17). Oral probiotic supplement containing bacteria Lactobacillus reuteri Prodentis DSM 17938 and ATCC PTA 5289 (BioGaia, BioGaia AB, Sweden) was added to artificial saliva of the second experimental group. Each archwire sample was immersed into 1 mL of experimental solution (pure artificial saliva or artificial saliva containing dissolved probiotic supplement at the ratio of 1:10) for 28 days, and solutions were changed once a week. During the first five days of testing and in order to simulate temperature variations in the oral cavity when consuming hot and cold beverages, thermocycling was performed in 2500 cycles at temperatures from 50°C to 50°C by using the Thermo Haake Willytech (SD Mechatronik Feldkirchen-Westerham, Germany) machine. A wide range of cycles and temperatures for thermocycling have been reported in the literature. Also, it has been stated that the setting simulated longer exposition of the material to the temperature extremes (18). Text-tubes containing samples and experimental solution, one after another, were immersed in thermal baths for 30 seconds, with two seconds at air temperature between immersions. After that, the text-tubes with samples were stored in an incubator where they were kept at a temperature of 37°C until the end of the experiment. Unexposed archwires served as absolute control for comparison of mechanical properties. To minimise the effect of substances added to the tablet after dissolution of BioGaia in artificial saliva, the solution was filtered and the presence of probiotic bacteria in the filtrate was tested by inoculating them onto MRS agar (Sigma-Aldrich, St. Louis, USA).

The shape and depth of corrosive damage on the surface of the archwires before and after exposure to the media were determined by using a scanning electron microscope (SEM SEIM Quanta-200, FEI Company, Hillsboro, SAD) at 1000x magnification with the secondary electron imaging. Measurement of surface roughness was performed using the contact profilometer TalySurf CLI 1000 (Taylor Hobson Ltd., Leicester, UK). Traced profiles of the real surface were acquired with a diamond stylus of 5 μm radius. During the measurement, the stylus was moved at a constant speed across the samples with a measuring force of 1.3 mN. Five specimens from each wire type were measured, and on each sample, three variables: roughness average (Ra), maximum height (Rz) and maximum roughness depth (Rmax) were measured on three profiles, using a Gaussian filter with a cutoff value of 0.8 mm and the evaluation length of 4 mm. The arithmetic mean of two repeated measurements was used for statistical analysis. For the sake of precision control, two measurements
elektrometrijskom metodom cikličke polarizacije na potenciostratu PAR263A i analizatoru frekvencija PAR FRD 1025 (Princeton Applied Research, Oak Ridge, SAD) (19). Mjerenja su obavljena na 300 ml umjetne sline, uz dodatak šest tableta probiotika na temperaturi od 37 ± 2 °C. Ispitivane žice bile su izrezane i izolirane lakom tako da im je izložena površina bila 0,61 cm².

Iz polarizacijskih krivulja ovisnosti potencijala o logaritmu vrijednosti gustoće struje korozije određena je gustoća struje korozije (crosis current density – Icor) koja je ekvivalent brzini opće korozije. Tendencija pojave lokalnih korozijskih oštećenja na materijalu određena je na temelju izgleda polarizacijske krivulje, tj. odnosa između korozijskog potencijala (corrosion potential – Ecor) i korozijskog potencijala pri kojem se zabilježena najmanja gustoća struje. Potencijala pućanja pasivnoga oksidnog filma (brakedown potential – Ebd), potencijala pri kojem se naglo povećava gustoća struje te potencijala repasivacije (repassivation potential – Erp), potencijala pri kojem se u povratnom dijelu krivulje, izjednačava struja s onima iz početnog dijela ciklusa. Pri potencijalu Ebd nastaje oštećenje zaštitnog pasivnog filma, odnosno legura se intenzivno otapa, što može rezultirati značajnim otpuštanjem iona nikla. Što je veća razlika između vrijednosti Ecor i Ebd, to je manja vjerojatnost da će u realnim uvjetima primjećene nastati značajna oštećenja pasivnog filma. Oštećeni pasivni sloj može se obnoviti (repassivirati) u slučaju nižih potencijala u povratnom dijelu polarizacijske krivulje. Ako repassivacija ne nastane pri potencijalima bliskima Ebd, tada je zanemariva vjerojatnost za pojavu lokalizirane korozije. Nakon završetka elektrochemijskih mjerenja površina ispitivanih uzoraka snimljena je skenirajućim elektronskim mikroskopom sa sekundarnim elektronskim slikama (Tescan Vega 3, Tescan, Brno, Češka) uz povećanja od 1000 puta.

U statističkoj analizi korišten je t-test te analiza varijanse between students Newmann-Keulsovom post-hoc testom. Snaga efekta je procijenjena s pomoću η². Za interpretaciju korišteni su Cohenovi kriteriji: η² = 0,02 – 0,13 = mala snaga efekta, 0,13-0,26 = umjerena i >0,26 = velika. 

Rezultati

Površinska hrapavost

Mjerenja površinske hrapavosti na dva mjesta na istoj žici upućuju na značajno slabije vrijednosti za vse tri parametra (ICC = 0,693 – 0,875; p < 0,001) i izvrsnu povoljnost očitanja pri mjerenju (ICC = 0,997 – 0,999; p < 0,001).

Nije bilo značajne razlike između nikal-titanijevih žica prije korozije. Izlaznje slini smanjuje Ra rođenih žica (p = 0,015; η² = 0,501; slika 1). Medij značajno ne utječe na površinsku mikrogeometriju nitiranih i neobloženih žica.

Results

Surface roughness

Measurements of surface roughness in two places of the same wire showed a significant correspondence of all three parameters (ICC=0.693-0.875; p<0.001) and an excellent reproducibility of measurement result readings (ICC=0.997-0.999; p<0.001).

The differences between NiTi wires before corrosion are not significant. Exposure to the saliva decrease in rhodium coated wire (p=0.015; η²=0.501; Figure 1). Media do...
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**Slika 1.** Usporedba površinske hrapavosti NiTi žica i eksperimentalnih uvjeta. Horizontalne linije povezuju medije koji stvaraju značajnu razliku za žicu iste vrste.

**Figure 1** Comparison of surface roughness between NiTi archwire types and experimental conditions. Horizontal lines connect the media that produce significant differences for the same wire type.

**Slika 2.** SEM, povećanje 1000x neeksponiranog materijala

**Figure 2** SEM magnification 1000x of unexposed material

**Slika 3.** SEM, povećanje 1000x. Materijal nakon 28 dana izlaganja umjetnoj slini (prvi red) te umjetnoj slini i probiotičkom dodatku (drugi red).

**Figure 3** SEM magnification 1000x material after being exposed for 28 days to artificial saliva (first row), and material after being exposed to artificial saliva and probiotic supplement (second row)

**Slika 4.** Grafički prikaz krivulja cikličkih polarizacijskih mjerenja NiTi žica u slini i slini s dodatkom probiotika

**Figure 4** Graphic presentation of curves of cyclic polarisation measurements of NiTi archwires in saliva and in saliva containing probiotic supplement
SEM pri povećanju od 1000 puta potvrđuje nalaze profilometra (slike 2. i 3.). Uočava se da površina svih žica prije izlaganja nije potpuno homogenog te da postoje mikrodefekti u strukturi površine, što je najizraženije na rodiranoj žici (slika 2.). Na pojedinim dijelovima vidljive su hrapavosti i mikropukotine u obliku zareza koje mogu biti posljedica mehaničkog oštećenja tijekom termocikliranja ili lokalizirane korozije. Nakon ekspozicije umjetnoj slini rodiranica žica na pojedinim dijelovima izgleda nešto glađe (slika 3.).

Elektromikroskopsko

Na slici 4. su polarizacijske krivulje ovisnosti vrijednosti potencijala korozije i potencijala pucanja pasivnoga filma u slini od onih zabilježenih u slini s probiotikom. U slučaju čiste sline lagano nastaje repassivacija žica, što u slini s probiotikom nije slučaj. Kao i na neobloženim žicama, uzorci nitirane površine u slini s probiotikom također imaju negativniji korozijski potencijal te slabije svojstvo repasivacije negoli u čistoj umjetnoj slini. Usporedbom rodirane žice u čistoj slini i u slini s probiotikom, uočava se da s dodatkom probiotika raste potencijal pucanja pasivnoga filma, ali nema mogućnosti repasivacije ni u jednoj otopini.

Usporedbom korozijskih parametara u umjetnoj slini i u slini s probiotikom uočava se da su, u odnosu na samu slinu, vrijednosti korozijskih struja u slini s probiotikom manje kad je riječ o žici neobloženoj nikal-titanijem, podjednake za nitiranoj, a veće za rodiranu žicu. U slučaju neobložene žice, probiotik uzrokuje lokalnu koroziju. Na rodiranoj žici oštećenje nastaje malo teže negoli u čistoj slini, ali kada nastane zaštitni se sloj više ne može oporaviti. Na nitiranoj žici teže

not significantly affect surface microgeometry in nitrified and uncoated wires.

SEM at 1000x magnification confirms the results of profilometer (Figure 2 and 3). It was observed that the surface of all wires before exposure was not entirely homogeneous and that there were microdefects in the surface structure, which was most pronounced in rhodium coated wire (Figure 2). Roughness and microcracks in the form of nicks were also observed in certain places, which could be a consequence of mechanical damage during thermocycling, or of localized corrosion. After exposition to artificial saliva, rhodium coated wire looked somewhat smoother in some places (Figure 3).
Rasprava

Naše istraživanje upućuje na to da i probiotički preparat koji se upotrebljava za oralnu primjenu u svrhu poboljšanja oralnoga zdravlja i održavanja povoljne mikrobne flora, što se može povezati s pojavnim lokalizirane korozije (slika 5.). Na rodinaro žici zabilježeno je taloženje korozijskih produkata koja su vidljiva kao pravilno i gusto raspoređene bijele točke.

Discussion

Our research shows that probiotic supplement used orally for the purpose of improving oral health and maintaining favorable microbial flora influences corrosion to some extent. It was assumed that, in addition to the corrosion effect of saliva, probiotic supplement would further increase general and localised corrosion. However, this assumption is not entirely correct. In NiTi alloys with uncoated surface, probiotic supplement leads to a greater propensity for localised corrosion and smaller propensity to general corrosion. General corrosion is the most common type of corrosion. It affects all metals and develops on the entire metallic surface (20). Metal is

| Žica • Archwire | Parametar korozije • Corrosion parameter | Medij • Media | Srednja vrijednost ± st. devijacija • Mean ± SD | 95%-tni interval pouzdanosti • 95% CI* | p** | η2*** |
| --- | --- | --- | --- | --- | --- | --- |
| NiTi | Korozija struje gustoć (Icor / nAcm-2) • Corrosion current density (Icor / nAcm-2) | Slina • Saliva | 31.3±16.3 | -9.1-71.7 | 0.343 | 0.224 |
| | | Probiotik • Probiotic | 19.9±8.7 | -1.6-41.4 | 0.001 | 0.954 |
| | Korozijijski potencijal (Ecor / mV) • Corrosion potential (Ecor / mV) | Slina • Saliva | 76.3±20.4 | 25.6-127.0 | 0.461 | 0.142 |
| | | Probiotik • Probiotic | -149.3±37.7 | -243.0-(-55.7) | 0.001 | 0.954 |
| | Repasivacijski potencijal (Erep / mV) • Repassivation potential (Erep / mV) | Slina • Saliva | 1205.0±11.5 | 1176.2-1233.8 |
| | | Probiotik • Probiotic | - | - |
| Potencijal slamanja (Ebd / mV) • Brakedown potential (Ebd / mV) | Slina • Saliva | 1272.7±23.7 | 1213.9-1331.5 |
| | | Probiotik • Probiotic | 469.7±124.6 | 160.0-779.3 | <0.001 | 0.968 |
| NNiTi | Korozija struje gustoć (Icor / nAcm-2) • Corrosion current density (Icor / nAcm-2) | Slina • Saliva | 24.3±20.5 | -26.7-75.3 | 0.834 | 0.013 |
| | | Probiotik • Probiotic | 28.0±20.0 | -21.8-77.8 | 0.013 | 0.818 |
| | Korozijijski potencijal (Ecor / mV) • Corrosion potential (Ecor / mV) | Slina • Saliva | -31.7±65.0 | -193.1-129.8 |
| | | Probiotik • Probiotic | -247.4±59.3 | -394.7-(-100.0) | 0.013 | 0.818 |
| | Repasivacijski potencijal (Erep / mV) • Repassivation potential (Erep / mV) | Slina • Saliva | 1193.0±29.8 | 1118.9-1267.1 |
| | | Probiotik • Probiotic | 729.9±14.9 | 692.9-767.0 | <0.001 | 0.993 |
| | Potencijal slamanja (Ebd / mV) • Brakedown potential (Ebd / mV) | Slina • Saliva | 1328.7±82.1 | 1124.7-1532.6 |
| | | Probiotik • Probiotic | 1317.6±76.4 | 1127.8-1507.4 | 0.873 | 0.007 |
| RhNiTi | Korozija struje gustoć (Icor / nAcm-2) • Corrosion current density (Icor / nAcm-2) | Slina • Saliva | 100.7±40.1 | 1.2-200.2 |
| | | Probiotik • Probiotic | 120.4±12.7 | 88.8-152.1 | 0.461 | 0.142 |
| | Korozijijski potencijal (Ecor / mV) • Corrosion potential (Ecor / mV) | Slina • Saliva | 162.0±34.0 | 77.6-246.4 |
| | | Probiotik • Probiotic | 137.0±3.7 | 127.9-146.1 | 0.273 | 0.287 |
| | Repasivacijski potencijal (Erep / mV) • Repassivation potential (Erep / mV) | Slina • Saliva | - | - |
| | | Probiotik • Probiotic | - | - |
| | Potencijal slamanja (Ebd / mV) • Brakedown potential (Ebd / mV) | Slina • Saliva | 764.7±60.4 | 614.5-914.8 |
| | | Probiotik • Probiotic | 1033.0±283.1 | 329.7-1736.3 | 0.184 | 0.392 |

* CI: interval pouzdanosti • confidence interval; p: razina značajnosti • level of significance; η2: veličina učinka • effect size.
mediju koji ga okružuje, a ovisno o vrsti metala korozija će biti različitog intenziteta. Lokaliziranu koroziju obilježava to da je intenzitet korozije pojačan na lokalnoj razini. Pojavit će se ako postoji nehomogenost u sastavu materijala ili okoline. Granice zrna u metalu mogu biti mjesto gdje počinje korozija zbog svojeg stanja površine energije. Pukotine su također osjetljive na koroziju, s obzirom na to da je kemijski sastav u njima drukčiji od okolnog medija.

Usna šupljina idealno je okružje za razvoj korozije, a već je istaknuto da određene bakterijske vrste mogu uzrokovati koroziju titanijevelegijera (21 – 23). I naše istraživanje upućuje na to da bi pojava lokalizirane korozije mogla biti potaknuta probiotičkim bakterijama iz preparata Biogaia. Možda je ona posljedica apsorpcije i probavljanja metala iz legure što čine bakterije, ili taloženja netopornih komponenti pastile na ortodontsku žicu pri čemu nastaje korozija ispod naslaga. Istraživanje izloženosti nikal-titanijeve legure samoj kulturi Lactobacillus reuteri potvrdilo bi u kojoj mjeri ta bakterija uzrokuje koroziju.

Konstrukcija ortodontske naprave omogućuje idealne uvjete za adheziju bakterija te razvoj biofilmova u kojemu nastaje složen mehanizam interakcije između aerobnih i anaerobnih bakterija, što pogoduje nastanku korozije. Korozivno djelovanje probiotičkih preparata i L. reuteri na ortodontske luko-ve dosad nije istraženo. Ni mehanizam djelovanja probiotika nije potpuno objašnjen, ali dokazano je da oba sprjećavaju adheziju patoloških bakterija na površine, mijenjaju pH okoline, a time i uvjete za život patogenih mikroorganizama, izlučuju antimikrobn teči te utječu na imunosni odgovor domaćina (24). Upravo promjene uvjeta u okolišu, zbog metaboličkih produkata probiotičkih bakterija, drugi su mogući način nastanka korozije na nikal-titanijevoj leguri.

Jedna od hipoteza bila je da će korozivno djelovanje probiotičkog preparata biti vidljivo kao povećana površinska hrapsost neobložene nikal-titanijeve žice. Iskustva su dokazala povezanost korozije slitina i povećanja površinske hrapsost, što neposredno utječe na mehaničku svojstva žica te može rezultirati pucanjem ortodontske naprave (25). Površinska hrapsost utječe na koeficijent trenja, što je bitan čimbenik u ortodontskom pomaku zuba (26 – 28). Pojavljuje se pri sklizanju žice kroz bravicu. Žica je trenje između bravice i žica veće, više sile troši se na sraljavanje otpora trenja, što u konačnici upravlja pomak zuba i produljuje ortodontsku terapiju. No, suprotno našoj pretpostavci, parametri mikrogometrijske nepravilnosti površine nisu se značajno promijenili nakon izlaganja nikal-titanijeve žice slični površini.

Očekivali smo da će vrsta obloge promijeniti sklonost prema koroziji te da će nitiranje površine smanjivati, a rođanje povećavati tu sklonost. Kako smo i pretpostavili, ovo istraživanje potvrđuje da oštetljevanje površine mijenja sklonost prema koroziji. Općenito, nitiranje površine poboljšava korozijsku otpornost, a rođanje je smanjuje. Probiotski preparat utječe i na opću i na lokaliziranu koroziju, a utjecaj je modificiran vrstom obloge. Na rođanoj žici vidljivo je povećanje i opća korozija i pojave lokalizirane korozije nakon primjene probiotičkog preparata. Na neobloženoj žici probiotski preparat smanjuje opću koroziju, no povećava lokaliziranu. U susceptible to oxidation and reduction reactions in the medium surrounding it, and, depending on the type of metal, corrosion will vary in intensity. Local corrosion is characterized by corrosion intensity being increased at the local level. It will take place if there is a nonhomogeneity in the composition of the material or of the environment. Grain boundaries in metal can be the places where corrosion starts because of their state of elevated energy. Cracks are also sensitive to corrosion considering that chemical composition in a crack is different than the one in the surrounding medium.

The oral cavity is an ideal environment for the development of corrosion, and it has been previously reported that certain species of bacteria could cause corrosion of materials containing titanium (21-23). Our research also showed that appearance of local corrosion could be promoted by the presence of probiotic bacteria from the BioGaia supplement. It is possible that corrosion is a consequence of absorption and digestion of metal from the alloy by bacteria, or of precipitation of insoluble components from the pastille on orthodontic archwire, in which case corrosion occurs under the precipitate. A research on the exposure of NiTi alloy to Lactobacillus reuteri culture could determine to what extent the bacterium itself is the cause of corrosion.

The structure of an orthodontic appliance provides perfect conditions for bacterial adhesion and development of a biofilm in which a complex mechanism of interaction between aerobic and anaerobic bacteria takes place, which is suitable for the occurrence of corrosion. Corrosive effect of probiotic supplements and L. reuteri on orthodontic arches has not been researched yet. Also, the mechanism of probiotic effect is as yet not fully explained, but it has been proven that probiotics prevent adhesion of pathogenic bacteria to surfaces, change pH of the environment and the living conditions of pathogenic microorganisms, secrete antimicrobial substances and affect the host's immunological response (24). The products of metabolism of probiotic bacteria could change environmental conditions and that could be another possible way of corrosion of a NiTi alloy (4).

It has also been hypothesized that corrosive effect of probiotic supplements would manifest itself in the form of an increased surface roughness of uncoated NiTi wire. A correlation between corrosion of alloys and an increase in surface roughness, which directly affects mechanical properties of wires and can lead to an orthodontic wire fracture, has been proven by research (25). Surface roughness affects the friction coefficient, which is an important factor of orthodontic tooth movement (26-28). Friction occurs as the wire slides through a bracket. The greater the friction between a bracket and the wire, the more force is required to overcome friction resistance, which eventually slows down tooth movement and extends the orthodontic therapy. But, contrary to our assumptions, the parameters of micro geometric irregularities of the surface did not significantly change after exposing NiTi orthodontic archwires to saliva and probiotic supplement.

We had expected that the type of coating would change the propensity for corrosion and that surface nitrification would decrease, whereas rhodium coating would increase propensity for corrosion. As we had anticipated, this research
confirmed that surface coating does change propensity for corrosion. Generally, nitrification improves, and rhodium coating decreases corrosion resistance. Probiotic supplement affects both general and localised corrosion and the effect is modified by the type of coating. In rhodium coated wire, an increase in both general and localised corrosion has been observed after probiotic supplement had been used. In uncoated wire, probiotic supplement decreases general corrosion but increases localised corrosion. In nitrified wire, probiotic did not change general or localised corrosion to a large extent when compared to the effect of saliva alone. Based on the results obtained, one can conclude that the tested probiotic supplements are safest for use with nitrified wire, while in the case of uncoated wire, there is a significant possibility of localised corrosive damage which would lead to nickel ions being released into the oral cavity. Previous research conducted on these types of wire showed similar results and reduced corrosion resistance of rhodium coated wires was explained through existence of micro galvanic cells between the noble coating and the less noble underlying surface (NiTi alloy), which occurs due to defects in the coating itself (29).

Although we had assumed that corrosive effect of probiotic supplement would result in an increase in surface roughness of all the tested wires when compared to the effect of saliva alone, no significant difference in surface roughness of nitrified and rhodium coated wire was found after exposing the wire to saliva versus exposing it to probiotic supplement. Neither the medium nor the type of coating have significant effect on surface roughness of nitrified and rhodium coated NiTi wire, although previous research showed increased roughness of rhodium coated and polymer coated NiTi wires when compared to uncoated NiTi (30, 31).

**Conclusion**

Probiotic supplement affects general and local corrosion depending on the type of coating of the NiTi archwire. It increases general corrosion of rhodium coated wire and causes localised corrosion of uncoated and rhodium coated archwire. Surface nitrification improves corrosion resistance, while rhodium coating decreases it. Probiotic supplement does not have greater influence on surface roughness compared to that of saliva.

**Conflict of interest**

None declared

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Abstract

Objectives: The aim of the study was to examine how probiotic supplements affect the corrosion stability of orthodontic archwires made of nickel-titanium (NiTi). Materials and Methods: NiTi archwires (0.508×0.508 and having the length of 2.5 cm) were tested. The archwires (composition Ni=50.4%, Ti=49.6%) were uncoated, nitrified and rhodium coated. Surface microgeometry was observed by using scanning electron microscope and surface roughness was measured by profilometer through these variables: roughness average, maximum height and maximum roughness depth. Corrosion was examined by electrochemical method of cyclic polarisation. Results: Rhodium coated alloy in saliva has significantly higher general corrosion in saliva than nitrified alloy and uncoated alloy, with large effect size (p=0.027; n2=0.700). In the presence of probiotics, the result was even more pronounced (p<0.001; n2=0.936). Probiotic supplement increases general and localised corrosion of rhodium coated archwire and slightly decreases general corrosion and increases localised corrosion in uncoated archwire, while in the case of nitrified archwire the probability of corrosion is in the very low. The differences in surface roughness between NiTi wires before corrosion are not significant. Exposure to saliva decreases roughness average in rhodium coated wire (p=0.015; n2=0.501). Media do not significantly influence surface microgeometry in nitrified and uncoated wires. Conclusion: Probiotic supplement affects corrosion depending on the type of coating of the NiTi archwire. It increases general corrosion of rhodium coated wire and causes localised corrosion of uncoated and rhodium coated archwire. Probiotic supplement does not have greater influence on surface roughness compared to that of saliva.

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Corrosion of Nickel-Titanium Orthodontic Archwires

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Address for correspondence
Ines Musa Trolić
University of Zagreb
School of Dental Medicine
inesmusa@net.hr

Key words
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