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The Influence of Blood from Patients with Different Chronic Conditions on the Wettability of Dental Implant Surfaces

Utjecaj krvi pacijenata s različitim kroničnim stanjima na vlaženje površine dentalnih implantata

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Abstract

Introduction: Conditions such as diabetes and hyperlipidemia, as well as unhealthy habits such as smoking, are known to impair wound healing. Recent studies found that greater surface wettability accelerates osseointegration and increases the bone-to-implant contact ratio. In light of this, the aim of this study was to investigate the potential correlation between impaired healing status and changes in implant surface wettability. **Materials and Methods:** This study included 18 dental implants from various systems. Blood samples were collected from 40 voluntary participants divided into four groups. **Results:** When comparing the blood of smokers and healthy people, the biggest difference was shown by Avinent, BTI UniCa, and Nobel TiUltra, where more blood was absorbed by the implants immersed in the smoker's blood. Also, some implants have shown reverse results, but the difference was smaller. When testing the blood of diabetics, there were many different results; some implants showed that they absorbed more blood when immersed in the blood of diabetics, and some in the blood of healthy people. When testing the blood of hyperlipidemic patients, it is interesting that all tested implants absorbed more blood from hyperlipidemics than blood from healthy people, except for Nobel TiUltra, where the result was reverse, but the difference was very small. **Conclusions:** Our findings demonstrate that blood from these patient groups can significantly alter the hydrophilicity of implant surfaces compared to blood from healthy individuals. *In vivo* research is needed to determine the clinical significance of this finding.

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Introduction

Osseointegration, defined as a direct and long-lasting structural and functional connection between the surface of a dental implant and the surrounding bone, remains the cornerstone for successful implant-prosthetic therapy. Its success is dependent on numerous local and systemic factors, including diseases such as diabetes and hyperlipidemia, and harmful habits such as smoking (1, 2).

According to recent studies, greater surface wettability accelerates osseointegration and increases the bone-to-im-

Uvod

Oseointegracija, definirana kao izravna i dugotrajna strukturna i funkcionalna povezanost između površine dentalnoga implantata i okolne kosti, ostaje temelj uspješne implantoprotetičke terapije. Njezin uspjeh ovisi o mnogobrojnim lokalnim i sistemskim čimbenicima, uključujući bolesti poput dijabetesa i hiperlipidemije te štetne navike kao što je pušenje (1, 2).

Prema recentnim istraživanjima, veće površinsko vlaženje ubrzava oseointegraciju i povećava omjer kontakta kosti plant contact ratio (3). Hydrophilicity—also referred to as wettability—refers to a material's affinity for water. It is determined by the interaction between a liquid and the tested solid surface. Hydrophilicity is most commonly measured using the contact angle method, where a droplet of liquid is placed on a surface and the internal angle between the surface and the droplet is measured (4).

The wettability of a dental implant surface is largely dependent on its surface treatment, which can render it rough or smooth. Surface roughness can enhance the rate of osseointegration by six to ten times. Techniques used to modify implant surfaces include ablative methods, such as sandblasting, acid etching, anodization, shot peening, and laser treatment, as well as additive techniques, among which plasma spraying is the most frequently employed (5–7).

Today, both titanium and ceramic implants are widely available on the market, with both premium and low-cost options designed for specific clinical situations. Some studies report that ceramic implants offer superior esthetic and clinical outcomes, along with comparable long-term success (8). However, other investigations suggest similar osseointegration outcomes between titanium and ceramic implants (9), and the literature still lacks robust long-term data on the success rates of ceramic implant therapy.

Several studies have identified impaired wound healing in patients suffering from diabetes or hyperlipidemia, and in people who smoke. In diabetes, wound healing is hampered by various intrinsic and extrinsic factors. Intrinsic factors include reduced macrophage function, decreased growth factor production, and a diminished number of epidermal nerve endings, whereas extrinsic factors involve traumas and mechanical injuries of the skin, which is often unresponsive due to macrovascular and microvascular ischemia (10). According to Bogachkov et al., hypercholesterolemia and consequent hyperlipidemia impair wound healing by inhibiting endothelial proliferation and angiogenesis (11). Smoking also weakens the immune system and delays wound healing, significantly increasing the risk of postoperative infection. Even smoking a single cigarette can reduce the body's ability to deliver the nutrients necessary for tissue repair. Importantly, individuals who cease smoking at least four weeks before surgery experience fewer complications and improved six-month postoperative outcomes (12).

The wettability of implant surfaces has recently become a major focus for implant manufacturers, given its pivotal role in initial clot formation and osseointegration. However, less is known about how the biological quality of a patient's blood—altered by conditions such as diabetes, hyperlipidemia, or smoking—may affect the interaction between the blood and the implant surface. It has been hypothesized that systemic diseases and smoking could influence fibrin clot formation and early protein adsorption onto implant surfaces, ultimately affecting the success of osseointegration (13, 14).

Therefore, the objective of this study was to compare the wettability of dental implants wetted with blood samples from healthy individuals, diabetic patients, hyperlipidemic patients, and smokers. Furthermore, titanium and ceramic implant surfaces were compared to explore the potential dif-

i implantata (3). Hidrofilnost – koja se također naziva vlaženje ili močivost – odnosi se na afinitet materijala prema vodi. Ona se određuje interakcijom između tekućine i ispitivane čvrste površine. Najčešće se mjeri metodom kontaktnoga kuta, pri čemu se kap tekućine stavlja na površinu, a zatim se mjeri unutarnji kut između površine i kapljice (4).

Vlaženje površine dentalnoga implantata u velikoj mjeri ovisi o njegovoj površinskoj obradi koja ga može učiniti grubim ili glatkim. Hrapavost površine može povećati brzinu oseointegracije od šest do deset puta. Tehnike koje se primjenjuju za modifikaciju površine implantata jesu ablativne metode, poput pjeskarenja, kiselinskog jetkanja, anodizacije, sačmarenja i laserske obrade, te aditivne tehnike među kojima se najčešće koristi sprejanje plazmom (5 – 7).

Danas su na tržištu dostupni kako titanijevi tako i keramički implantati, s opcijama visokoga i nižega troška, dizajnirani za specifične kliničke situacije. Autori nekih istraživanja navode da keramički implantati omogućuju postizanje superiornih estetskih i kliničkih rezultata uz usporediv dugoročni uspjeh (8). U drugim se istraživanjima pak sugeriraju slični rezultati oseointegracije između titanijevih i keramičkih implantata (9), a literatura još uvijek ne daje čvrste dugoročne podatke o stopama uspješnosti terapije keramičkim implantatima.

U nekoliko studija identificirano je narušeno cijeljenje rana kod pacijenata sa šećernom bolešću ili hiperlipidemijom te kod pušača. Kod dijabetesa cijeljenje rana otežano je različitim intrinzičnim i ekstrinzičnim čimbenicima. Intrinzični čimbenici uključuju smanjenu funkciju makrofaga, smanjenu produkciju faktora rasta i manji broj epidermalnih živčanih završetaka, a ekstrinzični obuhvaćaju traume i mehaničke ozljede kože koja često ne reagira zbog makrovaskularne i mikrovaskularne ishemije (10). Prema Bogachkovu i suradnicima, hiperkolesterolemija i posljedična hiperlipidemija narušavaju cijeljenje rana inhibiranjem proliferacije endotelnih stanica i angiogeneze (11). Pušenje također slabi imunosni sustav i usporava cijeljenje rana te značajno povećava rizik od postoperativne infekcije. Čak i jedna popušena cigareta može smanjiti sposobnost organizma da opskrbi tkivo hranjivim tvarima potrebnim za regeneraciju. Važno je napomenuti da osobe koje prestanu pušiti barem četiri tjedna prije kirurškoga zahvata imaju manje komplikacija i bolje ishode šest mjeseci poslije operacije (12).

Hidrofilnost površine implantata u posljednje je vrijeme postala jedan od glavnih fokusa proizvođača implantata, s obzirom na njezinu ključnu ulogu u inicijalnom stvaranju ugruška i oseointegraciji. No manje je poznato da biološka kvaliteta krvi pacijenta, promijenjena stanjima poput dijabetesa, hiperlipidemije ili pušenja, može utjecati na interakciju između krvi i površine implantata. Pretpostavlja se da sistemske bolesti i pušenje mogu utjecati na formiranje fibrinskoga ugruška i ranu adsorpciju proteina na površinu implantata, što u konačnici može utjecati na uspjeh oseointegracije (13, 14).

Stoga je cilj ove studije bio usporediti vlaženje dentalnih implantata natopljenih uzorcima krvi zdravih osoba, dijabetičara, bolesnika s hiperlipidemijom i pušača. Nadalje, uspoređene su titanijeve i keramičke površine implantata kako bi ferences between them.

The null hypothesis of this study was that there would be no statistically significant difference in the wettability of implant surfaces wetted with blood from different patient groups compared to healthy controls. The alternative hypothesis was that the wettability would be reduced when using blood from diabetic patients, hyperlipidemic patients, and smokers compared to blood from healthy individuals.

Materials and Methods

This study was conducted at the Department of Oral Surgery and Institute for Metabolic Diseases at the Clinical Hospital Center Zagreb, Croatia and at the School of Dental Medicine University of Zagreb, Croatia. It was approved by the Ethics Committee of the School of Dental Medicine, University of Zagreb (No. 05-PA-30-22-11/2023, dated 23 October 2023), and the Ethics Committee of the Clinical Hospital Center Zagreb (Class: 8.1-23/275-2, No. 02/013 AG, dated 30 October 2023).

This study included 18 sterile dental implants from original boxes—16 titanium and 2 zirconia—from various systems and with different surfaces, as shown in Table 1. This table has been adapted from our previous study (15) on the hydrophilicity of dental implants surfaces and expanded to include three additional implants.

In this study, we aimed to investigate how different implants - made from various materials and exhibiting diverse surface characteristics in terms of mechanical and chemical properties as well as surface energy, interact with blood from different patient groups. Instead of referring to hydrophilicity, which primarily refers to the interaction between a surface and water, we measured the wettability of implant surfaces with blood. Due to viscosity and density of blood, dispensing a 1 µL droplet using a micropipette was not feasible, and the limited dimensions of the dental implants prevented the use of larger measurement surfaces. Therefore, unlike in our previous study (15) where we used contact angle measurements, we employed a method based on measuring the mass of blood retained on the implant after immersion. Therefore, an alternative method was used, which involved evaluating potential differences in the wettability of implant surfaces by measuring the amount of blood retained on the surface after immersion, as in the study conducted by Anitua (16).

Prior to the measurements, blood samples (4 mL each) were collected from 40 voluntary participants divided into four groups. All participants were informed about the purpose of the study, provided written informed consent, and they voluntarily agreed to participate. The groups comprised 10 healthy individuals without systemic diseases; 10 diabetic patients who had received treatment for at least two years without other diseases; 10 hyperlipidemic patients who had received treatment for at least two years without other diseases; and 10 patients without systemic diseases who reported smoking at least 10 cigarettes a day. Both the healthy individuals and the smokers were recruited from the Clinic of Dental Medicine, while the diabetic and hyperlipidemic patients were recruited from the Institute for Metabolic Dis-

se istražile moguće razlike među njima.

Nulta hipoteza ove studije bila je da neće biti statistički značajne razlike u vlaženju površina implantata natopljenih krvlju različitih skupina pacijenata u usporedbi sa zdravim kontrolama. Alternativna hipoteza bila je da će hidrofilnost površina implantata biti manja kada se koristi krv dijabetičara, bolesnika s hiperlipidemijom i pušača u usporedbi s krvlju zdravih osoba.

Materijali i metode

Ova studija provedena je u Zavodu za oralnu kirurgiju i Zavodu za bolesti metabolizma Kliničkoga bolničkoga centra Zagreb (Hrvatska) te na Stomatološkom fakultetu Sveučilišta u Zagrebu (Hrvatska). Odobrilo ju je Etičko povjerenstvo Stomatološkog fakulteta Sveučilišta u Zagrebu (br. 05-PA-30-22-11/2023, od 23. listopada 2023.) i Etičko povjerenstvo Kliničkoga bolničkoga centra Zagreb (klasa: 8.1-23/275-2, br. 02/013 AG, od 30. listopada 2023.).

U ovoj studiji obuhvaćeno je 18 sterilnih dentalnih implantata iz originalnih pakiranja – 16 titanijevih i 2 cirkonijska – iz različitih sustava i s različitim površinama, kako je prikazano u tablici 1. Ova tablica preuzeta je i prilagođena iz naše prethodne studije (15) o hidrofilnosti površina dentalnih implantata i proširena je uključivanjem još triju dodatnih implantata.

U ovoj studiji svrha nam je bila istražiti kako različiti implantati – izrađeni od različitih materijala i s različitim karakteristikama površine kad je riječ o mehaničkim i kemijskim svojstvima te o površinskoj energiji – interagiraju s krvlju iz različitih skupina pacijenata. Umjesto da se pozivamo na hidrofilnost koja se uglavnom odnosi na interakciju površine s vodom, mjerili smo vlaženje površina implantata s krvlju. Zbog viskoznosti i gustoće krvi doziranje kapljice od 1 µL mikropipetom nije bilo izvedivo, a ograničene dimenzije dentalnih implantata spriječile su korištenje većih površina za mjerenje. Zato, za razliku od naše prethodne studije (15) u kojoj smo se koristili mjerenjem kontaktnoga kuta, primijenili smo metodu temeljenu na mjerenju mase krvi koja ostaje na implantatu nakon uranjanja. Drugim riječima, upotrijebili smo alternativnu metodu koja je uključivala procjenu potencijalnih razlika u vlaženju površine implantata mjerenjem količine krvi koja ostaje na površini nakon uranjanja, slično kao u studiji koju je proveo Anitua (16).

Prije mjerenja prikupljeni su uzorci krvi (po 4 mL) od ukupno 40 dobrovoljnih sudionika raspoređenih u četiri skupine. Nakon što su informirani o ciljevima istraživanja, svi su potpisali informirani pristanak i pristali dobrovoljno sudjelovati. Skupine su uključivale deset zdravih osoba bez sistemskih bolesti, deset bolesnika s dijabetesom koji su bili pod terapijom najmanje dvije godine, deset bolesnika s hiperlipidemijom, također pod terapijom najmanje dvije godine te deset osoba bez sistemskih bolesti koje su prijavile konzumaciju najmanje deset cigareta na dan. Iz studije su isključene osobe s komorbiditetima, ili ako su u terapiji dijabetesa ili hiperlipidemije bili kraće od dvije godine. Zdravi ispitanici i pušači regrutirani su u Klinici za dentalnu medicinu, a dijabetičari i osobe s hiperlipidemijom uključeni su u istraživa-

Table 1 Dental implants included in this study
Tablica 1. Dentalni implantati uključeni u studiju

Dental Implant • Dentalni implantat	Material • Materijal	Surface Treatment • Obrada površine	Manufacturer • Proizvođač	Dimensions (Diameter × Length) • Dimenzije (promjer × duljina)
Alpha Bio MultiNeO	Titanium • titanij	Sandblasted and acid-etched, TiO_2 protective layer • pjeskareno i jetkano kiselinom, TiO_2 zaštitini sloj	Alpha Bio Tec Ltd., Modi'in, Israel	5 × 13 mm
Ankylos®	Titanium • titanij	Grit-blasted and high-temperature-etched • pjeskareno krupnim česticama i jetkano na visokoj temperaturi	Dentsply Implants Manufacturing GmbH, Hanau, Germany	7 × 14 mm
Astra Tech OsseoSpeed™ TX	Titanium • titanij	Grit-blasted (TiO blast) and acid-etched • pjeskareno (TiO) i jetkano kiselinom	Dentsply Implants Manufacturing GmbH, Hanau, Germany	5 × 17 mm
Avinent	Titanium • titanij	Surface containing calcium and phosphorus (detailed information unavailable) • površina s kalcijem i fosforom (detaljnije informacije nedostupne)	Avinent Implant System S.L., Santpedor-Barcelona, Spain	5 × 13 mm
Bioactive Ti+Mg composites implant	Titanium • titanij	**	**	3.5 x 10 mm
Bioactive Ti+Mg composites implant (+5' f.o.) *	Titanium • titanij	**	**	3.5 x 10 mm
BTI UniCa	Titanium • titanij	Titanium surface modified with calcium ions (detailed information unavailable) • površina modificirana kalcijevim ionima (detaljnije informacije nedostupne)	B.T.I. Biotechnology Institute S.L., Minano-Alava, Spain	5.5 × 11.5 mm
BTI Optima	Titanium • titanij	Without calcium ions (detailed information) • bez kalcijevih iona (detaljnije informacije nedostupne)	B.T.I. Biotechnology Institute S.L., Minano-Alava, Spain	5.5 × 13 mm
Bredent blueSKY	Titanium • titanij	Sandblasted and acid-etched • pjeskareno i jetkano kiselinom	Bredent medical GmbH & Co.KG, Senden, Germany	4.5 × 14 mm
Bredent whiteSKY	Zirconia • cirkonij	Sandblasted • pjeskareno	Bredent medical GmbH & Co.KG, Senden, Germany	4.5 × 14 mm
Champions® R(E)volution	Titanium • titanij	Sandblasted and etched • pjeskareno i jetkano	Champions-implants GmbH, Flonheim, Germany	3.5 x 12 mm
Dentium Implantatium	Titanium • titanij	Sandblasted with large grits and acid-etched • pjeskareno krupnim česticama i jetkano kiselinom	Dentium Co., Suwon, Republic of Korea	5 × 14 mm
GC Implant Aadva® Standard	Titanium • titanij	Sandblasted with high-purity alumina particles and acid etching • pjeskareno aluminijevim česticama visoke čistoće i jetkano kiselinom	GCTech.Europe GmbH, Breckerfeld, Germany	5 × 12 mm
ICX-Active Liquid Implant	Titanium • titanij	(Detailed information unavailable) • (detaljnije informacije nedostupne)	Medemtis Medical GmbH, Bad Neuenahr-Ahrweiler, Germany	4.8 × 15 mm
Nobel Parallel™ CC TiUltra™	Titanium • titanij	Anodized and preserved with a protective layer • anodizirano i zaštićeno zaštitnim slojem	Nobel Biocare AB, Göteborg, Sweden	5.5 × 15 mm
Nobel Pearl™ Tapered WP	Zirconia • cirkonij	ZARAFIL™ surface-modified with sandblasting and acid etching • ZARAFIL™ površina, pjeskareno i jetkano kiselinom	Nobel Biocare AB, Göteborg, Sweden	5.5 × 12 mm
PRAMARF Sweden&Martina	Titanium • titanij	Sandblasted with zirconia and acid-etched with mineral acids • pjeskareno cirkonijem i jetkano mineralnim kiselinama	Sweden & Martina S.p.A. Due Carrare—Padova, Italy	5 x 15 mm
Straumann Roxolide® SLActive®	Titanium • titanij	Large-grit sandblasted and acid-etched • pjeskareno krupnim česticama i jetkano kiselinom	Institute Straumann AG, Basel, Switzerland	4.8 × 12 mm

* Five-minute immersion in saline to dissolve superficial magnesium layer. ** Research-phase implants not yet approved for clinical use. • * Petominutna imerzija u fiziološku otopinu provedena je sa svrhom otapanja površinskog sloja magnezija. ** Implantati su u fazi istraživanja te još nisu odobreni za kliničku primjenu.

eases at the Clinical Hospital Center Zagreb. Given that we had 18 different implants and 40 study participants, a total of 720 measurements were taken.

Blood was collected using a sterile venipuncture needle dimensions 21G × ¾" × 7", 0.8 mm × 19 mm × 178 mm (Vacuumed-Blood Collection Needles, Zhejiang Kindly Medical Devices Co., Ltd., China) into a 4 mL EDTA (K2E) tube (BD Vacutainer®, Plymouth, United Kingdom). Samples were immediately transported to the Institute of Physics, Zagreb, in a portable cooler (Powerbox Plus, Application des Gaz, France) and analyzed within 12 h.

Wettability was assessed by measuring the mass of blood retained on the implant surface according to the following protocol: the blood sample was placed in a tube holder positioned on a digital microbalance (Digital Mini Scales 50 g/0.001 g; Anhui Uni Electronic Technology Co., Ltd., China) and tared to zero (Figure 1).

The implants were held either by their fixture mount or by the cervical area using sterile tweezers and immersed in the blood sample for 30 s. We decided to keep the implants submerged for 30 seconds because in another study comparing the surface hydrophilicity of different implant systems, we measured the contact angle after 5, 15, and 30 seconds of contact between a drop of saline solution and the implant surface (Figure 2).

After 30 s of immersion, the implant was carefully removed from the blood sample, and the weight displayed on the microbalance was recorded, representing the mass of blood absorbed by the implant surface. An example of an implant after 30 s of immersion is shown in Figure 3.

As 1 mg equals approximately 1.06 µL of blood, calculating the average blood density, the measurements were con-

nje posredovanjem Zavoda za metaboličke bolesti Kliničkoga bolničkog centra Zagreb. Budući da je u ispitivanje bilo uključeno 18 različitih implantata i 40 ispitanika, ukupno je provedeno 720 mjerenja.

Uzorci krvi prikupljeni su sterilnom iglom za venepunkciju dimenzija 21G × ¾" × 7", 0,8 mm × 19 mm × 178 mm (Vacuumed-Blood Collection Needles, Zhejiang Kindly Medical Devices Co., Ltd., Kina) i spremani u epruvete od 4 mL s dodatkom antikoagulansa EDTA (K2E) (BD Vacutainer®, Plymouth, Ujedinjeno Kraljevstvo). Odmah poslije prikupljanja prevezeni su u prijenosnom hladnjaku (Powerbox Plus, Application des Gaz, Francuska) na Stomatološki fakultet u Zagrebu gdje su analizirani unutar 12 sati od uzorkovanja.

Vlažnost, odnosno vlaženje površine implantata procjenjivana je mjerenjem mase krvi zadržane na površini implantata prema sljedećem protokolu: uzorak krvi postavljen je u držač epruvete smješten na digitalnu mikrovagu (Digital Mini Scales 50 g/0,001 g; Anhui Uni Electronic Technology Co., Ltd., Kina), a vaga se podešavala na nultu vrijednost prije svakog mjerenja (slika 1.).

Implantati su tijekom mjerenja bili pričvršćeni sterilnim pincetama za nosač implantata ili za cervikalni dio implantata te uronjeni u uzorak krvi 30 sekunda. To vrijeme uranjanja odabrano je na temelju prethodnog istraživanja u kojemu je ispitivana hidrofilnost površine različitih sustava dentalnih implantata, pri čemu su mjereni kontaktni kutovi poslije 5, 15 i 30 sekunda kontakta kapljice fiziološke otopine s površinom implantata (slika 2.).

Nakon 30-sekundnog uranjanja, implantat je pažljivo izvađen iz uzorka krvi, a vrijednost prikazana na digitalnoj mikrovagi zabilježena je kao masa krvi zadržane na površini

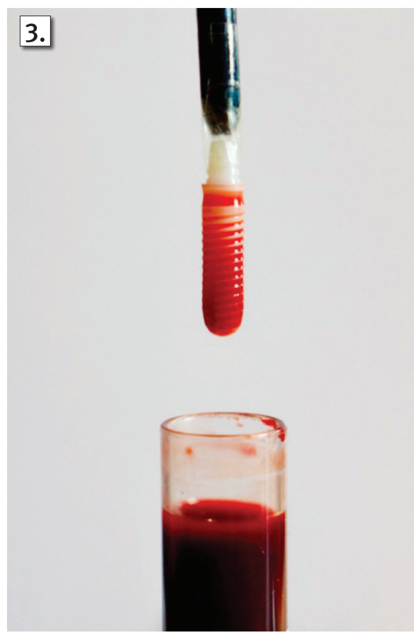

Figure 1 Straumann Roxolid® SLActive® implant prior to immersion in blood.
Slika 1. Implantat Straumann Roxolid® SLActive® prije uranjanja u krv
Figure 2 Bredent whiteSKY implant submerged in blood.
Slika 2. Implantat Bredent whiteSKY uronjen u krv
Figure 3 Bredent whiteSKY dental implant after removal from blood.
Slika 3. Implantat Bredent whiteSKY dentalni nakon vađenja iz epruvete s krvlju

verted accordingly. A total of 720 measurements were collected. For each implant type, four identical implants were available, and one implant was assigned to each patient group, allowing 10 measurements to be obtained for each implant. Between measurements, the implants were rinsed with saline and dried using a Cleaning Air Blowing Ball (Nedis, The Netherlands), ensuring that no contact was made with the implant surface. A drying period of approximately one minute was implemented prior to the next measurement cycle.

Two implant types, Straumann Roxolid® SLActive® and ICX-Active Liquid, were delivered in sterile containers immersed in 0.9% NaCl to preserve their surface characteristics prior to clinical use and because of that a new implant was always used for each measurement.

Statistical Analysis

To detect differences between continuous variables with a medium effect size (f = 0.25), at a significance level of α = 0.05 and a statistical power of 80%, the minimum sample size was calculated to be 579 measurements (approximately 9 participants per group). Categorical data were presented as absolute and relative frequencies. The normality of distribution of continuous variables was assessed using the Shapiro–Wilk test. Numerical data were described using the median and interquartile range due to non-normal distribution. Differences in continuous variables between two independent groups were tested using the Mann–Whitney U test, with the Hodges–Lehmann median difference and the corresponding 95% confidence interval (CI) reported. All *P* values were two-tailed. The level of statistical significance was set at alpha = 0.05. Data analysis was performed using MedCalc® Statistical Software version 23.2.1 (MedCalc Software Ltd, Ostend).

Results

Lower wettability was observed in healthy individuals compared to smokers for the following implants: Astra, Avinent, Nobel TiUltra (Mann–Whitney U test, p = 0.04), Bredent whiteSKY (Mann–Whitney U test, p = 0.02), Bioactive Ti+Mg (5′ f.o.) (Mann–Whitney U test, p = 0.03), and Champions (Mann–Whitney U test, p = 0.005). No significant differences were found for the other implants (Table 2).

Lower wettability was also observed in healthy individuals compared to patients with diabetes for the following implants: Alpha Bio MultiNeO (Mann–Whitney U test, p = 0.006), Astra, Bioactive Ti+Mg (Mann–Whitney U test, p = 0.003), Avinent (Mann–Whitney U test, p = 0.001), Bioactive Ti+Mg (5′ f.o.) (Mann–Whitney U test, p = 0.02), Bredent whiteSKY, PRAMARF (Mann–Whitney U test, p = 0.04), and GC Aadva (Mann–Whitney U test, p = 0.002), as well as ICX Active L. and Straumann implants (Mann–

implantata. Na taj način određena je količina krvi koju je površina implantata apsorbirala. Primjer kako izgleda implantat poslije 30 sekunda imerzije vidi na slici 3.

Jedan miligram krvi odgovara približno 1,06 µL, što je određeno na temelju prosječne gustoće krvi pa su mjerenja odgovarajuće konvertirana. Ukupno je prikupljeno 720 pojedinačnih mjerenja. Za svaki tip implantata bila su dostupna četiri identična primjerka, pri čemu je jedan implantat dodijeljen svakoj od četiriju skupina ispitanika, što je omogućilo obavljanje deset mjerenja po implantatu. Između pojedinačnih mjerenja implantati su ispirani fiziološkom otopinom i osušeni s pomoću loptice za ispuhivanje zraka (Cleaning Air Blowing Ball, Nedis, Nizozemska), pazeći pritom da se površina implantata ne dodiruje. Prije sljedećeg ciklusa mjerenja implantati su ostavljeni da se samostalno osuše još otprilike jednu minutu.

Dva tipa implantata, Straumann Roxolid® SLActive® i ICX-Active Liquid, pakirani su u tekućem mediju, 0,9-postotnome NaCl-u, radi očuvanja njihovih površinskih svojstava prije kliničke upotrebe, zbog čega je za svako mjerenje korišten novi implantat.

Statistička analiza

Da bi se otkrile razlike između kontinuiranih varijabli srednje veličine učinka (f = 0,25), na razini značajnosti α = 0,05 i uz statističku snagu od 80 %, minimalna veličina uzorka izračunata je na 579 mjerenja (otprilike 9 sudionika po skupini). Kategorijski podatci prikazani su kao apsolutne i relativne frekvencije. Normalnost distribucije kontinuiranih varijabli procijenjena je Shapiro-Wilkovim testom. Numerički podatci opisani su medijanom i interkvartilnim rasponom zbog nenormalne distribucije. Razlike u kontinuiranim varijablama između dviju nezavisnih skupina ispitane su Mann-Whitneyjevim U testom, a prikazana je Hodges-Lehmannova razlika medijana s odgovarajućim 95-postotnim intervalom pouzdanosti (CI). Sve P vrijednosti bile su dvosmjerne. Razina statističke značajnosti postavljena je na α = 0,05. Analiza podataka obavljena je u programu MedCalc® Statistical Software verzija 23.2.1 (MedCalc Software Ltd, Ostend).

Rezultati

Kod zdravih ispitanika uočeno je manje vlaženje površine u usporedbi s pušačima za sljedeće implantate: Astra, Avinent, Nobel TiUltra (Mann-Whitney U test, p = 0,04), Bredent whiteSKY (Mann-Whitney U test, p = 0,02), Bioactive Ti+Mg (5′ f.o.) (Mann-Whitney U test, p = 0,03) i Champions (Mann-Whitney U test, p = 0,005). Za ostale nisu pronađene značajne razlike (tablica 2.).

Manje vlaženje površine također je uočeno kod zdravih ispitanika u usporedbi s osobama s dijabetesom za sljedeće implantate: Alpha Bio MultiNeO (Mann-Whitney U test, p = 0,006), Astra, Bioactive Ti+Mg (Mann-Whitney U test, p = 0,003), Avinent (Mann-Whitney U test, p = 0,001), Bioactive Ti+Mg (5′ f.o.) (Mann-Whitney U test, p = 0,02), Bredent whiteSKY, PRAMARF (Mann-Whitney U test, p = 0,04) i GC Aadva (Mann-Whitney U test, p = 0,002), kao i kod ICX Active L. i Straumann implantata (Mann-Whitney

Table 2 Differences between healthy individuals and smokers.
Tablica 2. Razlika između zdravih ispitanika i pušača

	Median (Interquartile Interval) • Medijan (Interkvartalni raspon)		Difference • Razlika	95% CI	p *
	Control (µl) • Zdravi ispitanici (µl)	Smokers (µl) • Pušači (µl)			
Alpha Bio MultiNeO	32.18 (31.24–36.91)	31.24 (28.4–32.18)	−0.94	−5.7 to 1.9	0.44
Ankylos	32.18 (26.5–36.97)	29.82 (24.61–35.02)	−1.42	−7.57 to 4.73	0.59
Astra	14.67 (14.2–17.98)	19.88 (17.98–20.82)	1.74	0 to 6.62	0.04
Avinent	18.93 (17.04–26.5)	26.5 (23.66–29.34)	7.1	0 to 10.41	0.04
Bioactive Ti+Mg	16.09 (14.2–17.04)	16.57 (14.2–17.98)	0.95	−1.89 to 2.84	0.40
Bioactive Ti+Mg (5′ f.o.)	14.67 (1.36–16.09)	17.01 (17.04–17.98)	2.84	0.95 to 6.63	0.03
Bredent blueSKY	24.14 (20.82–26.5)	25.09 (21.77–28.4)	1.42	−2.84 to 6.62	0.50
Bredent whiteSKY	20.82 (20.82–2.72)	24.61 (2.72–26.5)	3.78	0.95 to 6.63	0.02
BTI Optima	28.87 (27.45–31.24)	32.19 (30.29–35.97)	2.84	0 to 6.63	0.05
BTI UniCa	28.87 (25.56–32.18)	35.97 (31.24–40.07)	6.16	0.95 to 1.67	0.05
Champions	22.72 (20.82–24.61)	29.35 (23.66–30.29)	6.16	2.84 to 10.41	0.005
Dentium	35.97 (35.02–37.86)	26.03 (2.72–35.02)	−8.51	−13.25 to 0	0.02
GC Aadva	25.56 (19.88–27.45)	27.93 (20.82–31.24)	2.37	−3.79 to 7.57	0.32
ICX Active L.	25.56 (16.09–28.4)	32.18 (24.61–34.07)	6.15	−0.95 to 12.31	0.09
Nobel Pearl	21.77 (19.88–23.66)	17.04 (17.04–17.98)	−3.75	−5.68 to −1.9	0.01
Nobel TiUltra	30.29 (26.5–37.86)	37.86 (35.97–40.07)	6.94	0 to 1.36	0.04
PRAMARF	21.77 (16.09–26.5)	21.77 (18.93–29.34)	1.89	−6.63 to 9.47	0.57
Straumann	20.82 (17.98–20.82)	23.19 (17.98–24.61)	2.84	−1.89 to 4.74	0.21

* Mann–Whitney U test (Hodges–Lehmann median difference). * Mann–Whitney U test (Hodges–Lehmannova medijalna razlika

Whitney U test, $p < 0.001$), whereas no significant differences were observed for the remaining implants (Table 3).

Lower wettability was further observed in healthy individuals compared to hyperlipidemic individuals for the following implants: Alpha Bio MultiNeO, Astra, Bredent blueSKY (Mann–Whitney U test, $p = 0.04$), Avinent (Mann–Whitney U test, $p = 0.002$), Bioactive Ti+Mg (Mann–Whitney U test, $p = 0.003$), Bredent whiteSKY (Mann–Whitney U test, $p = 0.001$), BTI UniCa (Mann–Whitney U test, $p = 0.03$), Champions, Nobel Pearl (Mann–Whitney U test, $p < 0.001$), Dentium (Mann–Whitney U test, $p = 0.006$), ICX Active L. (Mann–Whitney U test, $p = 0.007$), and Straumann implants (Mann–Whitney U test, $p = 0.008$). No significant differences were found between healthy individuals and hyperlipidemic individuals for the other implants (Table 4).

U test, p < 0,001). Za preostale implantate nisu zabilježene značajne razlike (tablica 3.).

Nadalje, manje vlaženje površine uočeno je kod zdravih ispitanika u usporedbi s hiperlipidemijskim ispitanicima za sljedeće implantate: Alpha Bio MultiNeO, Astra, Bredent blueSKY (Mann-Whitney U test, p = 0,04), Avinent (Mann-Whitney U test, p = 0,002), Bioactive Ti+Mg (Mann-Whitney U test, p = 0,003), Bredent whiteSKY (Mann-Whitney U test, p = 0,001), BTI UniCa (Mann-Whitney U test, p = 0,03), Champions, Nobel Pearl (Mann.Whitney U test, p < 0,001), Dentium (Mann-Whitney U test, p = 0,006), ICX Active L. (Mann-Whitney U test, p = 0,007) i Straumann implantate (Mann-Whitney U test, p = 0,008). Nisu pronađene značajne razlike između zdravih i hiperlipidemijskih ispitanika za ostale implantate (tablica 4.).

Table 3 Differences between healthy individuals and those with diabetes.
Tablica 3. Razlike između zdravih ispitanika i osoba s dijabetesom

	Median (Interquartile Interval) • Medijan (Interkvartalni raspon)		Difference • Razlika	95% CI	p *
	Control (µl) • Zdravi ispitanici (µl)	Diabetics (µl) • Dijabetičari (µl)			
Alpha Bio MultiNeO	32.18 (31.24–36.91)	37.67 (35.97–41.65)	5.15	2.79 to 10.32	0.006
Ankylos	32.18 (26.5–36.97)	27.0 (21.35–35.45)	-3.78	-10.9 to 3.84	0.42
Astra	14.67 (14.2–17.98)	20.82 (19.55–2.43)	5.35	1.9 to 7.3	0.003
Avinent	18.93 (17.04–26.5)	35.97 (28.5–36.91)	16.1	8.1 to 19.89	0.001
Bioactive Ti+Mg	16.09 (14.2–17.04)	19.88 (17.98–20.82)	3.79	1.89 to 5.68	0.003
Bioactive Ti+Mg (5′ f.o.)	14.67 (1.36–16.09)	17.98 (16.37–19.88)	3.79	0.94 to 6.62	0.02
Bredent blueSKY	24.14 (20.82–26.5)	22.53 (20.82–23.66)	-1.14	-4.74 to 2.84	0.49
Bredent whiteSKY	20.82 (20.82–2.72)	24.47 (21.6–25.45)	3.51	0 to 6.62	0.04
BTI Optima	28.87 (27.45–31.24)	30.89 (30.29–32.29)	1.89	-0.95 to 3.89	0.12
BTI UniCa	28.87 (25.56–32.18)	33.35 (27.77–39.75)	5.58	-1.57 to 1.36	0.23
Champions	22.72 (20.82–24.61)	17.98 (17.98–20.55)	-3.79	-6.63 to -1.22	0.005
Dentium	35.97 (35.02–37.86)	33.82 (29.48–38.45)	-2.36	-7.57 to 3.43	0.49
GC Aadva	25.56 (19.88–27.45)	32.29 (28.4–3.98)	7.57	2.84 to 10.87	0.002
ICX Active L.	25.56 (16.09–28.4)	38.71 (35.46–41.65)	13.99	8.27 to 20.83	<0.001
Nobel Pearl	21.77 (19.88–23.66)	20.31 (18.5–28.4)	-0.09	-3.79 to 7.58	0.94
Nobel TiUltra	30.29 (26.5–37.86)	26.5 (24.61–27.45)	-4.1	-12.41 to 0	0.04
PRAMARF	21.77 (16.09–26.5)	28.92 (25.45–31.24)	7.7	1.05 to 14.15	0.04
Straumann	20.82 (17.98–20.82)	26.5 (25.56–27.45)	5.73	4.73 to 8.52	<0.001

* Mann–Whitney U test (Hodges–Lehmann median difference). • * Mann–Whitney U test (Hodges–Lehmannova medijalna razlika)

Discussion

To our knowledge, no previous study has compared the wettability of dental implant surfaces exposed to blood from patients with diabetes, hyperlipidemia, or a smoking habit versus healthy, non-smoking individuals. We also compared these four groups regarding titanium and ceramic implants. Considering that conditions such as diabetes, hyperlipidemia, and smoking are known to impair wound healing (1,17–19), we aimed to investigate the possibility of a correlation between impaired healing status and changes in implant surface wettability. In our study, implant surfaces showed statistically significant differences in blood absorption (as a surrogate for hydrophilicity) when exposed to blood from individuals with diabetes or hyperlipidemia, or the blood of smokers, compared to healthy controls, with several implant

Rasprava

Koliko nam je poznato, ni u jednoj dosadašnjoj studiji nije uspoređeno vlaženje površina dentalnih implantata izloženih krvi pacijenata s dijabetesom, hiperlipidemijom ili pušačkom navikom u usporedbi sa zdravim osobama nepušačima. Također smo usporedili te četiri skupine u kontekstu titanijevih i keramičkih implantata. S obzirom na to da su stanja poput dijabetesa, hiperlipidemije i pušenja poznata po tome da otežavaju cijeljenje rana (1,17 – 19), cilj nam je bio istražiti moguću povezanost između krvi navedenih ispitanika i promjena u hidfilnosti površine implantata. U našem istraživanju površine implantata pokazale su statistički značajne razlike u apsorpciji krvi, kao pokazatelj hidrofilnosti, kada su bile izložene krvi osoba s dijabetesom ili hiperlipidemijom te krvi pušača, u usporedbi s kontrolnim skupinama. Viša ili

Table 4 Differences between healthy individuals and hyperlipidemic individuals.
Tablica 4. Razlike između zdravih ispitanika i osoba s hiperlipidemijom

	Median (Interquartile Range) • Medijan (Interkvartalni raspon)		Difference • Razlika	95% CI	p *
	Control (µl) • Zdravi ispitanici (µl)	Hyperlipidemic (µl) • Hiperlipidemičari (µl)			
Alpha Bio MultiNeO	32.18 (31.24–36.91)	35.49 (3.13–42.59)	4.73	0 to 10.4	0.04
Ankylos	32.18 (26.5–36.97)	36.44 (28.4–37.86)	2.84	-3.78 to 9.47	0.24
Astra	14.67 (14.2–17.98)	19.88 (16.37–24.61)	4.26	0 to 9.47	0.04
Avinent	18.93 (17.04–26.5)	27.45 (23.66–29.34)	7.1	3.78 to 12.3	0.002
Bioactive Ti+Mg	16.09 (14.2–17.04)	20.35 (17.98–20.82)	4.73	1.89 to 6.63	0.003
Bioactive Ti+Mg (5′ f.o.)	14.67 (1.36–16.09)	16.37 (15.14–17.98)	2.84	−0.95 to 5.01	0.10
Bredent blueSKY	24.14 (20.82–26.5)	27.93 (26.5–32.18)	3.79	0 to 8.52	0.04
Bredent whiteSKY	20.82 (20.82–2.72)	28.4 (23.66–29.34)	6.62	1.9 to 9.46	0.001
BTI Optima	28.87 (27.45–31.24)	32.19 (28.4–35.02)	1.89	−0.95 to 5.68	0.17
BTI UniCa	28.87 (25.56–32.18)	33.6 (32.18–37.86)	5.67	0 to 12.3	0.03
Champions	22.72 (20.82–24.61)	28.4 (26.5–29.34)	5.68	2.84 to 7.58	<0.001
Dentium	35.97 (35.02–37.86)	40.7 (37.86–41.65)	3.79	-1.89 to 6.63	0.006
GC Aadva	25.56 (19.88–27.45)	27.93 (25.56–30.29)	3.32	0 to 8.52	0.05
ICX Active L.	25.56 (16.09–28.4)	34.08 (27.45–35.97)	8.99	1.89 to 15.15	0.007
Nobel Pearl	21.77 (19.88–23.66)	26.98 (25.56–27.45)	4.74	2.84 to 7.57	<0.001
Nobel TiUltra	30.29 (26.5–37.86)	28.4 (23.66–32.18)	−4.26	-1.36 to 2.84	0.18
PRAMARF	21.77 (16.09–26.5)	27.92 (2.72–30.29)	4.26	−0.95 to 12.3	0.07
Straumann	20.82 (17.98–20.82)	23.66 (2.72–26.5)	3.78	1.89 to 6.63	0.008

* Mann–Whitney U test (Hodges–Lehmann median difference). • * Mann–Whitney U test (Hodges–Lehmannova medijalna razlika)

systems demonstrating higher or lower wettability depending on the group analyzed.

Previous studies have confirmed that systemic factors such as diabetes mellitus can lead to impaired angiogenesis, reduced macrophage activity, and defective granulation tissue formation, which collectively delay wound healing (10, 19). Additionally, hyperlipidemia has been proven to negatively impact endothelial proliferation and angiogenesis, which are critical for implant osseointegration (11). Smoking, through vasoconstriction and decreased oxygen tension in tissues, further impairs both the inflammatory and reparative phases of healing (12, 18). Recent studies have also highlighted that hyperglycemia- and hyperlipidemia-induced oxidative stress lead to persistent inflammatory signaling, disrupting normal wound matrix remodeling (20). Chronic systemic inflammation could, therefore, modify

niža hidrofilnost zabilježena je ovisno o analiziranoj skupini i korištenom sustavu implantata.

Autori dosadašnjih studija potvrdili su da sistemski čimbenici poput *diabetesa mellitusa* mogu potaknuti slabiju angiogenezu, smanjenu aktivnost makrofaga i slabije formacije granulacijskoga tkiva, što sve usporava cijeljenje rana (10, 19). Nadalje, pokazano je da hiperlipidemija negativno utječe na proliferaciju endotela i angiogenezu, što je ključno za oseointegraciju implantata (11). Pušenje, zbog vazokonstrikcije i smanjenoga napona kisika u tkivima, dodatno ometa i upalne i reparativne faze cijeljenja (12, 18). U nedavnim istraživanjima također je istaknuto da oksidacijski stres izazvan hiperglikemijom i hiperlipidemijom uzrokuje trajne upalne signale i ometa normalno remodeliranje rane (20). Kronična sistemska upala može time modificirati dinamiku zgrušavanja krvi i njezinu interakciju s površinom implantata, utječu-blood clot dynamics and blood's interaction with implant surfaces by affecting the blood's biochemical properties, including its viscosity, fibrinogen levels, platelet function, and clot formation (21–23). This could partially explain our findings that different blood sources interacted differently with implant surfaces.

Interestingly, in our study, the Astra, Avinent, Nobel TiUltra, and Bredent whiteSKY implants, among others, demonstrated significantly greater wettability when exposed to smokers' blood compared to controls. This could be associated with the altered surface tension properties of smokers' blood, which may be linked to increased fibrinogen levels and modified plasma protein profiles in smokers (24). It has also been observed that smoking induces hypercoagulable states by increasing circulating thrombin and fibrinogen, potentially affecting blood viscosity and early clot formation on biomaterials (25). These changes may enhance or modify the spread of blood on implant surfaces depending on surface energy and chemistry.

Similar trends were observed in the diabetic and hyperlipidemic groups, especially for implants such as Avinent, ICX Active Liquid, and Straumann, for which the wettability was significantly greater when exposed to these two groups compared to controls.

Implant surface properties, particularly roughness and chemistry, are essential to early healing (26). Surfaces such as SLA (sandblasted, large-grit, acid-etched) and hydrophilic modifications like SLActive® were developed to optimize early blood interaction and fibrin network formation (27). In our study, the Straumann Roxolid® SLActive® implant, which features this hydrophilic surface modification, exhibited increased blood retention in diabetic and hyperlipidemic patients compared to healthy controls. This suggests that while such surface designs promote early blood interaction, systemic patient factors can modulate this effect, potentially altering the expected advantages of these advanced implant surfaces.

Current trends in implant design emphasize creating superhydrophilic surfaces to accelerate fibrin matrix adhesion and early osteoblast recruitment (28). The balance between surface topography and chemistry remains crucial for tailoring favorable blood interactions for predictable healing. Therefore, any biological or systemic factor that alters blood–implant surface interactions could influence initial healing and, possibly, long-term outcomes, which we investigated in this study.

Of course, surface hydrophilicity is an important factor for osseointegration; however, for successful and long-term implant-prosthetic therapy, it is also necessary to investigate and improve other parameters. For instance, Bandela's (29) study highlighted the significant influence of the implant angulation on stress distribution, demonstrating that an increased inclination angle leads to higher stress levels within the crown, the implant body, and the surrounding bone, while simultaneously increasing the magnitude of forces in both the vertical and anteroposterior directions.

In recent years, the production and clinical application of short and ultra-short dental implants have become

ći na biokemijska svojstva krvi, uključujući viskoznost, razinu fibrinogena, funkciju trombocita i stvaranje ugruška (21 – 23). To bi djelomično moglo objasniti naše nalaze da različiti izvori krvi različito djeluju na površine implantata.

Zanimljivo je da su u našem istraživanju implantati Astra, Avinent, Nobel TiUltra i Bredent whiteSKY pokazali značajno veće svojstvo vlaženja kad su bili izloženi krvi pušača u u usporedbi s kontrolama. To bi se moglo povezati s promjenama u površinskoj napetosti krvi pušača, vjerojatno prouzročenima povišenim razinama fibrinogena i izmijenjenim proteinima plazme (24). Također je uočeno da pušenje inducira hiperkoagulabilna stanja povećanjem razine trombina i fibrinogena, što može utjecati na viskoznost krvi i stvaranje početnog ugruška na biomaterijalima (25). Te promjene mogu pojačati ili promijeniti širenje krvi na površini implantata, ovisno o površinskoj energiji i kemiji.

Slični trendovi zabilježeni su u skupinama s dijabetesom i hiperlipidemijom, posebno pri uporabi implantata Avinent, ICX Active Liquid i Straumann, kod kojih je hidrofilnost bila znatno veća u tim skupinama nego kod zdravih ispitanika.

Svojstva površine implantata, osobito hrapavost i kemijski sastav, ključna su za rano cijeljenje (26). Površine poput SLA-e, pjeskarene velikim granulama i jetkane kiselinom, te hidrofilne modifikacije poput SLActive® razvijene su kako bi optimizirale ranu interakciju s krvlju i formaciju fibrinske mreže (27). U našem je istraživanju implantat Straumann Roxolid® SLActive®, s hidrofilnom površinskom obradom, pokazao veću apsorpciju krvi kod pacijenata s dijabetesom i hiperlipidemijom u usporedbi sa zdravim osobama. To sugerira da, iako dizajn takvih površina potiče ranu interakciju s krvlju, sistemski čimbenici mogu modulirati taj učinak i potencijalno mijenjati očekivane prednosti naprednih površina implantata.

Trenutačni trendovi u dizajnu implantata pokazuju stvaranje superhidrofilnih površina radi ubrzanja prianjanja fibrinske mreže i ranoga regrutiranja osteoblasta (28). Ravnoteža između topografije i kemije površine ostaje ključna za prilagodbu krvnih interakcija koje omogućuju predvidivo cijeljenje. Stoga, svaki biološki ili sistemski čimbenik koji mijenja interakciju krvi i površine implantata može utjecati na početno cijeljenje i potencijalno na dugoročne rezultate, što je upravo ono što smo istraživali u ovoj studiji.

Naravno, hidrofilnost površine važan je čimbenik za osteointegraciju; međutim, za uspješnu i dugotrajnu implantoprotetičku terapiju potrebno je istražiti te poboljšati i druge parametre. Primjerice, Bandel je u svojoj studiji (29) istakno značajan utjecaj angulacije implantata na raspodjelu naprezanja i pokazao da povećanje kuta nagiba rezultira višim razinama naprezanja unutar krune, tijela implantata i okolne kosti, istodobno povećavajući veličinu sila u vertikalnom i anteroposteriornom smjeru.

Posljednjih godina proizvodnja i klinička primjena kratkih i ultrakratkih dentalnih implantata postaju sve češće, sa svrhom izbjegavanja kirurških zahvata s neizvjesnom prognozom, poput augmentacije alveolarnoga grebena u slučaju smanjene vertikalne dimenzije. Posljedično, sve je više literature u kojoj se uspoređuju standardni, kratki i ultrakratki implantati. Carelli i suradnici (30) pokazali su da se primjeincreasingly common, aiming to avoid surgical procedures with uncertain prognosis, such as alveolar ridge augmentation in cases of reduced vertical dimension. Consequently, there has been a growing body of literature comparing standard, short, and ultra-short implants. Carelli et al. (30) demonstrated that the use of short implants in transcrestal sinus floor elevation procedures can achieve outcomes comparable to those of standard-length implants after five years of follow-up. Similarly, Schiegnitz et al. (31) reported that a three-year follow-up of patients with short implants placed in the resorbed alveolar ridge of the posterior maxilla yielded results comparable to those obtained with standard implants combined with lateral sinus floor elevation. Furthermore, the study by Karci and Oncu (32) found that implant length does not significantly influence bone loss, peri-implant osteoimmunological and microbiological marker levels, or implant survival rates. Although these studies have demonstrated comparable results after several years of monitoring dental implants of different lengths, when planning the placement of short and ultra-short implants in patients treated for diabetes, hyperlipidemia, or who are smokers, it would be advisable to consider using implants that showed statistically better results in our research. The goal is to promote faster osseointegration to potentially compensate for the inability to use longer implants by greater surface wettability. To confirm these considerations and assess their clinical relevance, further *in vivo* studies are needed.

Furthermore, we observed notable differences between titanium and ceramic implants in our study. Ceramic implants, particularly those based on zirconia, are gaining popularity due to their esthetic properties and favorable soft tissue integration (8, 9). Zirconia implants also demonstrate lower bacterial adhesion compared to titanium, which is particularly advantageous in patients at higher risk of peri-implantitis, such as smokers or individuals with metabolic syndromes (33). However, their hydrophilicity and blood protein interactions are inherently different compared to those of titanium, which could affect early healing, especially under compromised systemic conditions (34).

Our findings suggest that systemic health status might subtly modulate implant surface wettability during the critical early phases of healing, depending on the type of implant material and surface modification involved. This may have clinical implications, particularly in patient groups known to have impaired healing responses. However, it must be emphasized that *in vitro* measurements of wettability, while informative, may not fully translate into clinical outcomes without considering the complexity of the healing environment, including immune responses, vascularization, and cellular interactions.

The limitations of our study include the *in vitro* nature of the blood–implant interaction measurement, and the lack of longitudinal clinical outcome data. Future studies should explore the correlation between *in vitro* hydrophilicity measurements and clinical parameters such as marginal bone loss and implant survival rates in these specific patient populations. Our study highlights that systemic diseases and lifestyle factors can influence the interaction between blood

nom kratkih implantata u transkrestalnim postupcima podizanja dna sinusa mogu postići rezultati usporedivi s onima standardnih implantata nakon pet godina praćenja. Slično tomu, Schiegnitz i suradnici (31) izvijestili su da je trogodišnje praćenje pacijenata s kratkim implantatima postavljenim u resorbirani alveolarni greben stražnje maksile dalo rezultate usporedive s onima dobivenima primjenom standardnih implantata u kombinaciji s lateralnim podizanjem dna sinusa. Nadalje, u istraživanju Karcija i Oncua (32) utvrđeno je da duljina implantata nema značajan utjecaj na gubitak kosti, razine periimplantnih osteoimunosnih i mikrobioloških markera, ni na stopu preživljavanja implantata. Iako su ova istraživanja pokazala usporedive rezultate poslije nekoliko godina praćenja dentalnih implantata različitih duljina, pri planiranju postavljanja kratkih i ultrakratkih implantata pacijentima s dijabetesom, hiperlipidemijom ili kod pušača, preporučuje se razmotriti primjenu implantata koji su u našem istraživanju pokazali statistički bolje rezultate. Cilj je potaknuti bržu oseointegraciju kako bi se nadoknadila nemogućnost korištenja duljih implantata s većom hidrofilnošću površine.

Također smo uočili značajne razlike između titanijevih i keramičkih implantata. Keramički implantati, osobito oni od cirkonija, postaju sve popularniji zbog estetskih svojstava i povoljne integracije s mekim tkivima (8, 9). Cirkonijski implantati također pokazuju manju adheziju bakterija u usporedbi s titanijevima, što je osobito korisno za pacijente s povećanim rizikom od periimplantitisa, poput pušača ili osoba s metaboličkim sindromom (33). No njihova hidrofilnost i interakcija s krvnim proteinima inherentno se razlikuju u odnosu prema titaniju, što može utjecati na rano cijeljenje, osobito u slučaju kompromitiranih sistemskih stanja (34).

Naši rezultati sugeriraju da sistemsko zdravstveno stanje pacijenata može suptilno modulirati vlaženje površine implantata tijekom kritičnih ranih faza cijeljenja, ovisno o vrsti materijala i korištenoj površinskoj obradi. To može imati kliničke implikacije, osobito ako je riječ o pacijentima za koje se zna da im je usporen odgovor na cijeljenje. No važno je istaknuti da se mjerenjima hidrofilnosti *in vitro*, iako su korisna, možda ne mogu u cijelosti predvidjeti klinički ishodi bez uzimanja u obzir složenosti stvarnoga biološkog okruženja, uključujući imunosne reakcije, vaskularizaciju i stanične interakcije.

Ograničenja naše studije uključuju prirodu mjerenja interakcije krvi *in vitro* i implantata te nedostatak longitudinalnih kliničkih podataka. U budućim studijama autori bi trebali istražiti korelaciju između mjerenja hidrofilnosti *in vitro* i kliničkih parametara poput marginalnoga gubitka kosti i stope preživljenja implantata u ovim specifičnim populacijama pacijenata. U našem istraživanju ističe se da sistemske bolesti i životne navike mogu utjecati na interakciju krvi i površine implantata, što bi teoretski moglo utjecati na rano cijeljenje rana i oseointegraciju. Potrebna su dodatna klinička istraživanja kako bi se ove povezanosti istražile *in vivo*.

Razumijevanje ovih složenih interakcija omogućit će kliničarima bolje prilagođavanje pri odabiru implantata i planiranju liječenja u skladu s individualnim profilima rizika svakog pacijenata. Sistemska zdravstvena stanja i lijekovi koje and implant surfaces, which could, theoretically, impact early wound healing and osseointegration. Further clinical research is warranted to explore these associations *in vivo*.

Understanding complex interactions will enable clinicians to better tailor implant selection and treatment planning according to individual patient risk profiles. Systemic health conditions and the medications taken by patients receiving dental implants not only affect biological healing processes, but may also affect fundamental physicochemical interactions at the implant surface level, thus highlighting the importance of personalized implant dentistry.

Conclusions

This study provides novel insights into the interaction between the blood from individuals with diabetes, hyperlipidemia, and smoking habits, and the wettability of various dental implant surfaces. Our findings demonstrate that blood from these patient groups can significantly alter the wettability of implant surfaces compared to blood from healthy individuals, particularly in several titanium and ceramic implant systems. Given the critical role of early blood–implant interactions in the osseointegration process, these results may have important implications for clinical outcomes, especially in patients with impaired healing potential. While implant material and surface modifications are designed to optimize early healing, systemic factors might modulate their effectiveness by influencing blood adhesion and fibrin clot formation on the implant surface. Future clinical studies are needed to correlate these *in vitro* findings with long-term implant survival and peri-implant health in systemically compromised populations.

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pacijenti uzimaju ne utječu samo na biološke procese cijeljenja, nego mogu utjecati i na temeljne fizikalno-kemijske interakcije na razini površine implantata, što dodatno ističe važnost personalizirane dentalne implantologije.

Zaključak

Ova studija pruža nove spoznaje o interakciji između krvi osoba sa šećernom bolešću, hiperlipidemijom i pušačkih navika te vlaženja različitih površina dentalnih implantata. Naši nalazi pokazuju da krv tih skupina bolesnika može značajno promijeniti vlaženje površina implantata u usporedbi s krvlju zdravih osoba, osobito kod nekoliko sustava titanijevih i keramičkih implantata. S obzirom na ključnu ulogu ranih interakcija krvi i implantata u procesu oseointegracije, ovi rezultati mogu imati važne implikacije za kliničke ishode, osobito kod pacijenata s narušenim potencijalom cijeljenja. Iako su materijali implantata i modifikacije površine dizajnirani za optimizaciju ranog cijeljenja, sistemski čimbenici mogu modulirati njihovu učinkovitost i utjecati na adheziju krvi i formiranje fibrinskoga ugruška na površini implantata. Buduće kliničke studije potrebne su kako bi se ovi nalazi *in vitro* povezali s dugoročnim preživljavanjem implantata i zdravljem periimplantnoga tkiva kod sistemski kompromitiranih populacija.

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Uporaba umjetne inteligencije za pomoć pri pisanju: Autori izjavljuju da u izradi ovoga članka nisu korištene tehnologije temeljene na umjetnoj inteligenciji (AI), poput velikih jezičnih modela (LLM-ova), chatbotova ili alata za generiranje slika.

Doprinos autora: T. Č., D. G., I. M., V. K. – konceptualizacija; **T. Č., T. B., B. Š.** – metodologija; **T. Č., T. B., D. G.** – validacija; **T. Č., I. M., B. Š.** – istraživanje; **B.Š., V.K.,R.B.** – resursi; **I.M.,R.B.** – obrada podataka; **T. Č., T. B., D. G.** – pisanje izvornoga teksta; **T. Č., T. B., R. B., D. G.** – pisanje, pregled i uređivanje; **T. B., V. K., D. G.** – nadzor; **T. Č., I. M., V. K.** – administriranje podataka; **T. Č, T.B., B. Š., R. B., D. G.** – pribavljanje sredstava.

Sažetak

Uvod: Stanja poput šećerne bolesti i hiperlipidemije te nezdrave navike kao što je pušenje, poznata su zato što narušavaju proces cijeljenja rana. Autori nedavnih istraživanja pokazali su da povećano površinsko vlaženje ubrzava oseointegraciju i povećava omjer kontakta između kosti i implantata. U skladu s tim, svrha ovog istraživanja bila je ispitati moguću povezanost između narušenoga statusa cijeljenja i promjena u površinskom vlaženju implantata. **Materijali i metode:** U ovo istraživanje bilo je uključeno 18 dentalnih implantata različitih sustava. Uzorci krvi prikupljeni su od 40 dobrovoljnih sudionika podijeljenih u četiri skupine. **Rezultati:** U usporedbi krvi pušača i zdravih osoba najveću razliku pokazali su implantati Avinent, BTI UniCa i Nobel TiUltra, pri čemu su oni uronjeni u krv pušača apsorbirali više krvi. Neki implantati pokazali su suprotan rezultat, no razlika je bila manja. Pri ispitivanju krvi dijabetičara dobiveni su različiti rezultati – pojedini implantati apsorbirali su više krvi kada su bili uronjeni u krv dijabetičara, a drugi su pokazali veću apsorpciju u krvi zdravih osoba. Pri ispitivanju krvi bolesnika s hiperlipidemijom zanimljivo je da su svi testirani implantati, osim Nobel TiUltre, apsorbirali više krvi iz uzoraka hiperlipidemijskih bolesnika nego iz krvi zdravih osoba, pri čemu je kod Nobel TiUltre rezultat bio obrnut, ali razlika je bila vrlo mala. **Zaključak:** Naši nalazi pokazuju da krv tih skupina bolesnika može značajno promijeniti hidrofilnost površine implantata u usporedbi s krvlju zdravih osoba. Potrebna su istraživanja *in vivo* kako bi se utvrdila klinička važnost ovog nalaza.

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