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Impact of Poorly Controlled Type 2 Diabetes Mellitus on the Wettability of Different Dental Implant Surfaces: *In Vitro* Study

Kötü Kontrollü Tip 2 Diabetes Mellitus'un Farklı Dental İmplant Yüzeylerinin Islatılabilirliği Üzerindeki Etkisi: *İn Vitro* Çalışma

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ABSTRACT Objective: The wettability of the implant surfaces is crucial for successful osseointegration. The spreading of the blood on the titanium has become more critical in recent years. This study evaluated the wettability of the different types of titanium surfaces with hyperglycemia and whole blood. **Material and Methods:** Three surface groups were formed according to the surface texture and composition, machine (turned) titanium, anodized titanium, and sand blasted acid etched titanium alloy with 15% zirconia. Blood samples were obtained from healthy and Type 2 diabetes mellitus individuals and dropped to the disc surfaces. Contact angles were measured between the blood samples and disc surfaces by the sessile drop technique. **Results:** Regardless of the disc types, diabetic blood samples showed the highest contact angle. The surfaces of titanium alloy with 15% zirconia samples had the lowest wettability capacity, whether control or diabetic blood was dropped on them, whereas the anodized titanium disc surfaces showed the maximum wettability. **Conclusion:** Our results indicated that anodized titanium surfaces might have superiority in terms of wettability. Moreover, the wetting characteristics of blood may change in patients with poorly managed Type 2 diabetes, which may reduce the titanium dental implants' surface wettability and result in the failure of dental implant treatment.

Keywords: Hydrophilicity; diabetes mellitus; glycated hemoglobin; titanium; surface properties

ÖZET Amaç: İmplant yüzeylerinin ıslanabilirliği, osseointegrasyonun başarılı olması için gereken önemli kriterlerin başında gelmektedir. Bu nedenle kanın titanyum üzerinde yayılması, son yıllarda daha da önemli hâle gelmiştir. Bu çalışma, farklı tipte titanyum yüzeylerin hiperglisemik ve sağlıklı kan ile ıslanabilirliğini değerlendirmektedir. **Gereç ve Yöntemler:** Tornalanmış makine, anodik oksidayon ve kumlanmış-asitlenmiş yüzey özelliği ve yapısına sahip üç çalışma grubu oluşturuldu. Kan örnekleri sağlıklı ve Tip 2 diyabete sahip bireylerden alınarak ve disk yüzeylerine damlatıldı. Kan örnekleri ile disk yüzeyleri arasındaki temas açıları damla yayılımı yöntemi kullanılarak ölçüldü. **Bulgular:** Diyabetik kan örneklerinin damlatıldığı tüm yüzeylerde en yüksek temas açısı gözlemlendi. Kontrol ve diyabetik grup kanları damlatıldığında, %15 zirkonya içeren kumlanmış asitlenmiş yüzeye sahip örneklerin en düşük ıslanabilirlik kapasitesine sahip olduğu, buna karşın anodik okside titanyum disk yüzeylerin ise maksimum ıslanabilirliğe sahip olduğu belirlendi. **Sonuç:** Sonuçlarımız, anotlanmış titanyum yüzeylerin ıslanabilirlik açısından üstünlüğe sahip olabileceğini göstermektedir. Ayrıca kontrol altında olmayan Tip 2 diyabetli hastalarda kanın ıslatma özellikleri değişebilmekte, bu da titanyum diş implantlarının yüzey ıslanabilirliğinin azalmasına ve başarısız tedavi sonuçlarına yol açabilir.

Anahtar Kelimeler: Hidrofilite; diabetes mellitus; glikolize hemoglobin; titanyum; yüzey özellikleri

Dental implants are considered the most superior option for replacing lost teeth in contemporary dentistry. Their success relies on osseointegration, which is the structural and functional bond between native bone and implant surfaces.[1] Better osseointegration has been seen in dental implants made from

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titanium alloys like titanium-6-aluminum-4-vanadium and titanium-zirconium. The surface characteristics of titanium alloys, including both macro- and micro-surface structures, play a crucial role in the osseointegration process, despite the material's inherent benefits.[2] Therefore, altering implant surfaces is a key method to achieve successful osseointegration for a favorable treatment result, and commercial dental implant firms commonly employ processes such as surface coating, acid etching, blasting, anodizing, and laser therapy to change implant surfaces. It is obvious that the goal of these surface treatments is to create a textured surface that increases the implant's surface area and improves bone-implant interaction. This can speed up osseointegration without affecting the formation of a uniform implant-bone bond. However, the implant surface needs to be wet with enough blood to initiate the osseointegration process.[3,4] Ensuring a quick and even distribution of blood leads to the precipitation of plasma proteins including vitronectin, fibronectin, and fibrinogen on titanium, facilitating the bonding of osteoprogenitor cells.[5] Therefore, treating the implant surfaces does more than just increase the surface area and make the bone-implant interface better. It also makes it easier for blood to flow over the implant's surface by changing the titanium's surface structure to make it more hydrophilic.[6]

The viscosity of blood is another crucial component that influences the wettability of the implant surface.[7] Various physical and physiological factors such as temperature, pressure, humidity, flow velocity, and hematocrit level might impact the viscosity of whole blood. Substantial changes in these factors, including a significant shift in hematocrit levels, could lead to differences in blood flow characteristics.[8] Many other medical disorders such as viral illnesses, anemia, diabetes mellitus, and hyperlipidemia have an influence on the alteration of blood viscosity.[9] The correlation between elevated blood viscosity and diabetes mellitus has been clearly established. While one reason for the increased whole blood viscosity in diabetic patients is the increased red blood cell aggregation and fibrinogen levels, the other one is diabetic dyslipidemia, which is an increase in blood lipid levels and free fatty acids due to microvascular changes.[10-13]

The simplest and most common approach for determining the wettability of solid materials is the sessile drop technique. This involves placing a drop on the sample's surface and measuring the contact angle, which is the angle formed between the tangent to the drop passing through the intersection of the three phases (solid/liquid/gas) and the solid surface's horizontal line. Surfaces with contact angle values beyond 90 degrees are classified as hydrophobic, whereas those with values below 90 degrees are deemed hydrophilic. Surfaces with contact angle values below 5 degrees are categorized as super hydrophilic.[14,15]

Since inadequate blood spreading on implant surfaces may lead to a lack of osseointegration due to an insufficient fibrin network, much research has focused on the surface characteristics in order to assess the wettability of the implants.[4,7,16] However, the role of systemic factors, specifically the increased blood viscosity related to poorly controlled Type 2 diabetes mellitus, on the wettability of implant surfaces is still not clear. Based on these considerations, it was hypothesized that the presence of poorly controlled Type 2 diabetes mellitus would significantly increase the whole blood contact angle, consequently reducing the wettability of all tested titanium surfaces when compared to blood from healthy individuals. Furthermore, we also hypothesized that the distinct implant surface characteristics (Machined, Anodized, and SLA-Zr [Sand-blasted, Large-grit, Acid-etched, Titanium-zirconia alloy]) would inherently yield a statistically significant difference in whole blood wettability, independent of the patient's systemic diabetic status. Therefore, in this study, we aim to investigate the wetting capabilities of diabetic blood samples on different titanium surfaces by measuring the contact angle.

MATERIAL AND METHODS

The present study was carried out in accordance with the principles outlined in the Helsinki Declaration, and the researchers obtained ethical permission from the Near East University Health Sciences Ethics Committee under the reference number YDU/2022/100-1498 (date: May 21, 2022). All volunteers have read and signed the "informed consent form" which includes all the details regarding the study.

STUDY GROUPS

The study groups included volunteers who were hospital personnel, faculty members, and patients referred to the periodontology clinics at the Near East University Faculty of Dentistry. A total of 60 volunteers, consisting of 28 males and 32 females, were categorized into 2 groups: Diabetic patient and healthy. The patient group consisted of 30 non-smoking Type II diabetic patients with no other systemic disorders such as cardiovascular problems, hypercholestrolemia, or complications related to diabetes, whereas 30 non-smoking and systemically healthy subjects served as their control. All the diabetic patients were poor glycemic control individuals whose glycated hemoglobin (HbA1c) levels were >7% or >53 mmol/mol.[17] None of the subjects underwent any kind of medical treatment and did not take prescribed or non-prescribed medications such as antibiotics, anticoagulant agents, and painkillers in the last 6 months prior to the commencement of this study.

EXPERIMENT PROTOCOLS

Blood Samples

A volume of 9 milliliters of whole blood was drawn from each participant using blood collection tubes containing EDTA (Vacuette® Tube 9 mL K2E K2EDTA, #455045, Greiner Bio-One GmbH, Kremsmünster, Austria). This blood sample was utilized to determine the blood cell count, assess the cholesterol level, and measure the contact angle. The blood samples from individuals with diabetes were designated as blood samples of the diabetes patients (BD), while the blood samples of the healthy subjects were labeled as Blood samples of the control group (BC).

Disc Surfaces

Three different disc types, a total of 60 sterilized discs, each measuring 5 mm in diameter and 2 mm in thickness, were used to replicate the surface properties of dental implants already in use in the market and dentistry. The disc types were as follows: 1) Machined surface (M) (CP Ti grade 4) (ICX dental implant, Aydın Dental, İstanbul, Türkiye); 2) Anodically oxidized surface (T) (CP Ti grade 4) (TiUnite, Nobel Biocare, EOT Dental, İstanbul, Türkiye); 3) (R) large AlO2 particle blasted, acid etched (HCl/H2SO4) (Ti 85%, Zr 15% alloy) (Roxolid SLA, Straumann Group, İstanbul, Türkiye).

Contact Angle Measurements

We used a simple sessile drop approach to measure the contact angle between the disc surface and the blood drop, following the method previously reported by our research team.[15] Briefly, 30 µL of blood was promptly drawn into an automatic pipettor, and 10 µL was dispensed onto each of the 3 different types of the disc surfaces from a height of a few millimeters. The samples were allowed to sit undisturbed for 15 minutes at room temperature to achieve an intact sphere-shaped blood clot formation on the disc surfaces. Samples failing this type of clot were eliminated from the analysis. Subsequently, photographs were captured from a consistent angle. The images were subsequently added to the database of the Contact Angle Goniometer (OCA15EC model, Data Physics Instruments GmbH, Filderstadt, Germany). Contact angles were measured using the "sessile" approach using the SCA 20 program (Figure 1).

STATISTICAL ANALYSIS

One-way analysis of variance was applied to compare the contact angle degrees on the 3 different disk types. The contact angle differences between the diabetic and control blood samples were evaluated by the independent t-test. The sample size determination was performed using a "post hoc" power analysis based on the primary outcome measure: The difference in mean contact angle between the Poorly Controlled Type II Diabetic (BD) and Control (BC) groups. Using the observed mean differences, standard deviations, and an alpha level (a) of 0.05, the calculation (performed with G*Power software [3.1.9.6 macos version, Heinrich-Heine-Universitat Düsseldorf; Düsseldorf, Germany]) indicated that a total sample size of n=30 per group was sufficient to detect the observed large effect size (d=0.75) with a statistical power exceeding 85%. This finding confirms that the study had adequate power to reject the null hypothesis for the primary comparison. Additionally, to investigate the mechanical link between the severity of diabetes and the main outcome, a Pearson's correlation analysis was performed between the

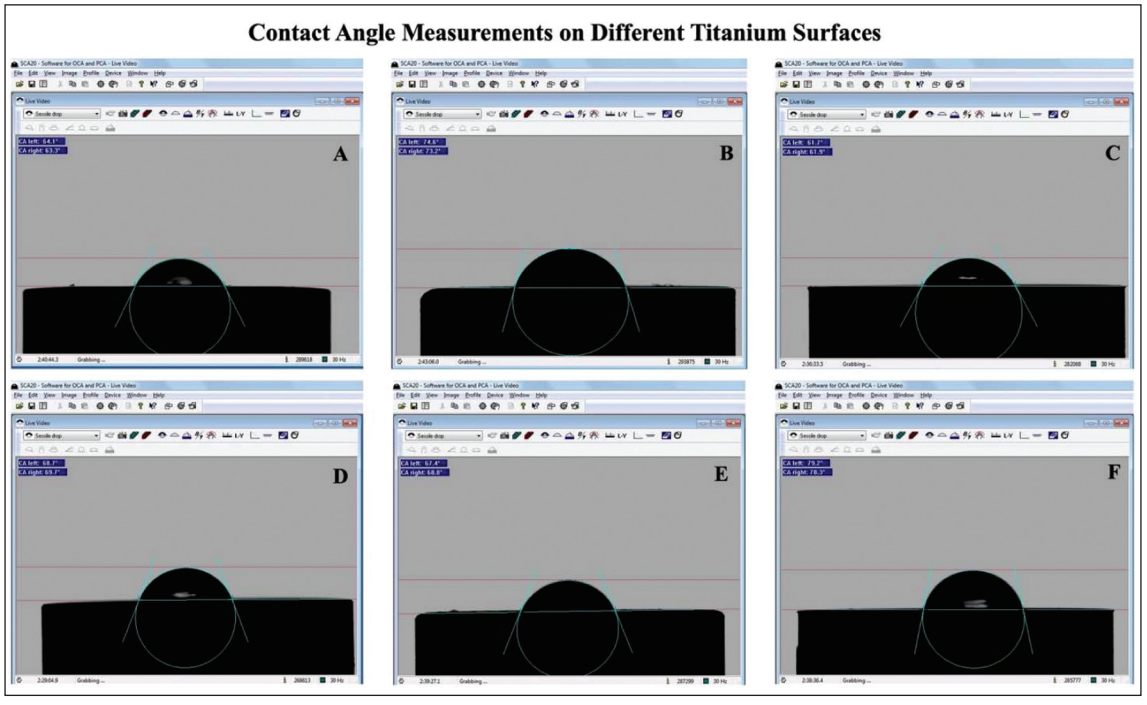


FIGURE 1: Representative contact angle measurements on different surface types in control and diabetic conditions. This panel illustrates the variation in blood wettability across different surface treatments and health conditions. A positive correlation was observed between HbA1c levels and contact angle values, indicating that higher HbA1c levels are associated with reduced wettability of blood. This suggests that diabetic conditions may impair surface interactions due to altered blood properties. [A) Contact angle measurements of Machined surface with control blood sample (left: 64.1°/right: 63.3°); B) Contact angle measurements of Machined surface with DM Type II blood (left: 74,6°/right: 73,2°); C) Contact angle measurements of Anodized surface with control blood sample (left: 61,7°/right: 61,9°); D) Contact angle measurements of Anodized surface with DM Type II blood sample (left: 68,7°/right: 69,7°); E) Contact angle measurements of SLA-Zr surface with control blood sample [left: 67,4°/right: 68,8°); F) Contact angle measurements of SLA-Zr surface with DM Type II blood sample (left: 79,2°/right: 78,3°)]
HbA1c: Glycated hemoglobin; DM: Diabetes mellitus; SLA-Zr: Sand-blasted, Large-grit, Acid-etched, Titanium-zirconia alloy

HbA1c levels of the diabetic patient group and the mean contact angle calculated across the 3 different titanium surfaces for each patient. The correlation coefficient (r) and the associated p value were reported to determine the linearity and significance of this relationship. All statistical analyses were performed using statistical software (IBM SPSS Statistics 26.0, IBM Inc., Armonk, NY, USA), and p values less than 0.05 were considered statistically significant."

RESULTS

According to our findings, when the blood samples were dripped onto the disc surfaces, the contact angle of the diabetic blood samples was significantly higher compared to the blood samples of the control group, regardless of the disc type (The p values for the BD vs. BC in the M, R, and T groups are $p<0.024$, $p<0.044$, and $p<0.041$, respectively) (Figure 2).

Additionally, the disc types M, T, and R were individually compared to each other to determine the contact angle formed with each of the blood samples, BD and BC. Upon dripping the blood samples taken from the BD group onto the disc surfaces, the R surface exhibited the maximum contact angle degree, while the T group discs displayed the lowest contact angle ($p<0.01$ for R vs. T; $p=0.019$ for R vs. M; $p=0,028$ for M vs. T). Similarly, when the blood samples collected from the BC group were placed on the surfaces of the discs, the R surface showed the highest degree of contact angle, whilst the T group discs had the lowest contact angle ($p<0.01$ for R vs. T; $p<0.021$ for R vs. M; $p<0.024$ for M vs. T) (Figure 3).

Furthermore, the Pearson's correlation analysis revealed a strong, highly significant positive correlation between the HbA1c levels and the mean whole blood contact angle (across all tested surfaces) in the

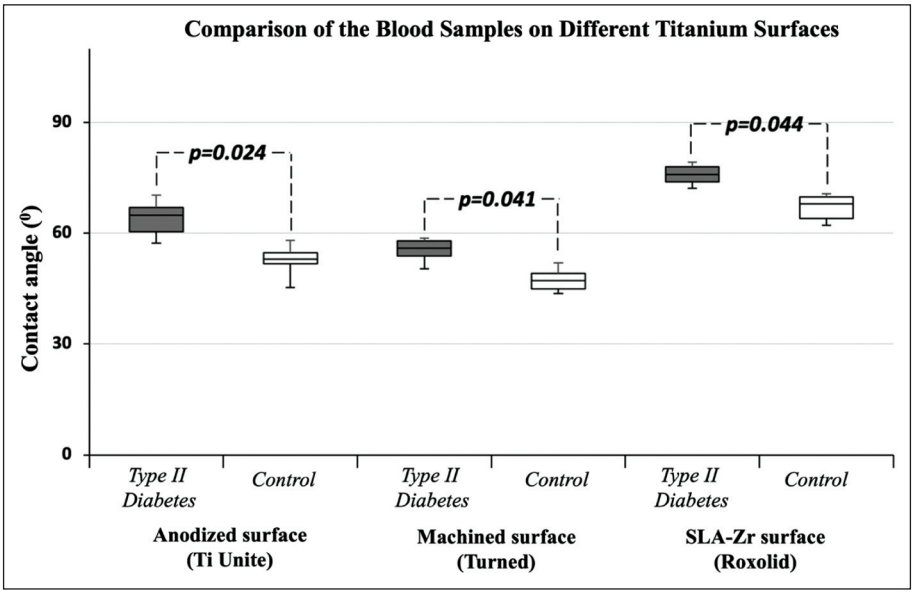


FIGURE 2: The blood samples from individuals with poorly controlled Type 2 diabetes mellitus shown substantially reduced wetting potential on the surfaces of all disc groups compared to the controls.
SLA-Zr: Sand-blasted, Large-grit, Acid-etched, Titanium-zirconia alloy

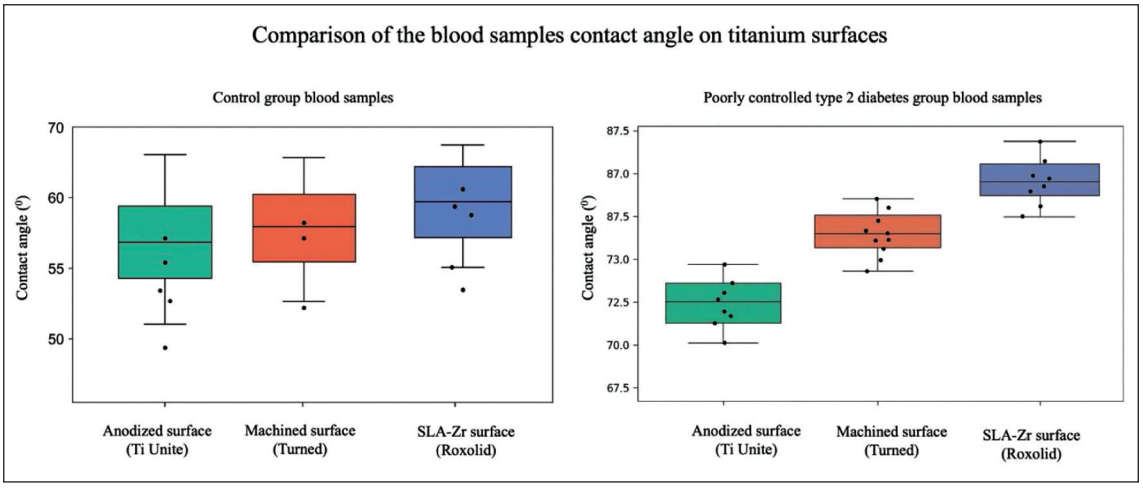


FIGURE 3: The contact angle of the anodized surfaces (Ti-Unite) was determined to be the lowest, regardless of whether the blood sample was from patients with poorly controlled Type 2 diabetes mellitus or the control group. In contrast, SLA-Zr (Roxolid) demonstrated the highest measurement value (the p values for the poorly controlled Type 2 diabetes group were as follows: Anodized vs. Machined p=0.028; Anodized vs. SLA-Zr p<0.01; Machined vs. SLA-Zr p=0.019, and the p values for the control group were as follows: Anodized vs. Machined p=0.024; Anodized vs. SLA-Zr p<0.01; Machined vs. SLA-Zr p=0.021). SLA-Zr: Sand-blasted, Large-grit, Acid-etched, Titanium-zirconia alloy

diabetic group (r=0.85, p<0.001). This finding is visually represented in Figure 4.

Demographic information, body mass index, red blood cell counts, and cholesterol levels did not show any statistically significant differences between the BD and BC groups. However, there were differences in platelet counts, hematocrit percentage, HbA1C, and blood glucose levels (p=0.043, p=0.041, p=0.035, and p=0.023, respectively) (Table 1).

DISCUSSION

The phenomenon of blood contact and the subsequent stabilization of blood clots on the surface of implants has been extensively investigated and its significance

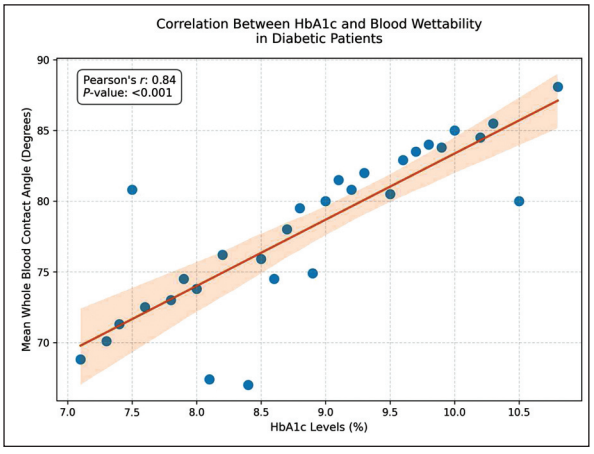


FIGURE 4: Scatter plot with regression line showing the correlation between HbA1c levels and mean whole blood contact angle in diabetic patients. A statistically significant positive correlation was observed (Pearson's r=0.84, p<0.001), suggesting reduced blood wettability with increasing HbA1c.
HbA1c: Glycated hemoglobin

TABLE 1: Demographic data, blood cell count, and cholesterol levels of diabetic patients and healthy individuals

		Blood samples of	Blood samples of	p value
Age (years)		38.3±2.8	40.1±1.9	*p=0.698*
Gender	Male (n)	15	14	*p=0.946*
	Female (n)	15	16	*p=0.946*
Blood test components		**Blood samples of diabetic individuals (BD)**	**Blood samples of healthy individuals (BC)**	**p value**
RBC (10^6/mm^3)		4.91±1.1	4.18±1.3	*p=0.856*
WBC (10^3/mm^3)		9.6±0.3	9.48±1.4	*p=0.798*
Platelet (10^3/mm^3)		279.1±5.2	258.3±1.4	***p=0.043***
Hemoglobin (g/dL)		13.7±2.2	14.8±2.1	*p=0.820*
Hematocrit (%)		48.8±3.3	40.2±2.1	***p=0.041***
LDL (mg/dL)		119.8±12.4	116.6±9.8	*p=0.741*
HDL (mg/dL)		58.7±20.8	50.8±11.3	*p=0.139*
Triglyceride (mg/dL)		151±11.2	141.4±9.6	*p=0.351*
Total cholesterol (mg/dL)		198.3±20.4	172.7±12.8	*p=0.069*
HbA1c (%)		7.8±0.6	5.6±0.2	***p=0.035***
Glucose (mg/dL)		148±25.6	80.2±5.4	***p=0.023***
BMI (kg/m^2)		24.3±1.6	22.2±1.7	p=0.456

Platelet, hematocrit, HbA1C and preprandial glucose levels of the BD group were determined to be statistically higher than those of the BC group (*p=0.043, p=0.041, p=0.035, and p=0.023*, respectively). BD: Blood samples of the diabetes patients; BC: Blood samples of the control group; RBC: Red blood cell count; WBC: White blood cell count; LDL: Low-density lipoproteins; HDL: High-density lipoproteins; HbA1c: Glycated hemoglobin; BMI: Body mass index

has been elucidated. Thus far, there has been a scarcity of scientific studies examining the potential influence of blood density on the wetting surface of implants as a factor in the formation of contact angles. The objective of this study was to evaluate the influence of blood glucose levels on the wetting behavior of the implant surface when exposed to blood. In order to accomplish this, we performed measurements of the contact angles between the surface of a titanium disc (3 different types) and the blood samples collected from individuals with different blood glucose levels, ranging from elevated to reduced. This study shows preliminary findings indicating that diabetes blood exhibits a significantly higher contact angle on the titanium surface, irrespective of any modifications made to the surface. Furthermore, our research has demonstrated that titanium surfaces subjected to anodic oxidation exhibit the greatest propensity for blood wetting.

Numerous studies have documented the significance of surface wettability in relation to the adherence of fibrin and cells on titanium surfaces.[5,18-20] Consequently, multiple commercial enterprises have been trying to identify the most effective technique for treating titanium surfaces. In this study, we tested the surface features of wettability using titanium discs from 2 common dental implants, Ti-Unite (anodized) and Roxolid SLA (sandblasted, acid-etched). For these groups, we also used a machined surface (turned), as a control group. The results of our study suggest that the anodized titanium exhibited the greatest wettability when compared to sandblasted, acid-etched and machine (turned) groups. Studies in the literature support our finding.[5,21,22] Upon doing a comparative analysis of the T and M surfaces, it was noticed that the T group had a notable advantage over the M group in relation to wettability. Takebe et al. conducted a study using Hank's balanced salt solution, distilled water, and bovine serum albumin to assess the wettability of anodized titanium surfaces and machine (turned) titanium surfaces. The researchers observed that anodized titanium surfaces exhibited a notable increase in wettability across all 3 liquids, in comparison to machine (turned) titanium surfaces. Additionally, they suggested that anodized titanium surfaces may have possessed superfilic properties, which aligns with our findings.[21] Another potential explanation for our finding could be Li et al. research, which has identified a correlation between the pro-

cesses occurring during anodic oxidation and the alterations in surface morphology, roughness, and hydrophilicity. According to the results of their research, a prolonged period of anodization results in an augmentation of titanium's surface energy, consequently leading to an enhancement in its wettability.[22]

Another intriguing finding from our research is that the R group had the highest hydrophobicity of the 2 other test groups, T and M. The study conducted by Sista et al. revealed that there were no variations in water contact angles or surface energy between a titanium-zirconia alloy with a 50% zirconia surface and a titanium surface.[23] However, Tan et al. demonstrated a notable decrease in contact angle formation on a titanium-zirconia alloy with a 50% zirconia surface compared to a commercially available titanium-zirconia alloy with 16% zirconia and a turned-machine titanium surface.[24] These discrepancies between the existing publications and the outcome of our research could be explained as follows: topography, roughness, and composition of the material surface.[25]

The application of anodizing method for the generation of nanotubules is an effective procedure for enhancing wettability and microroughness on the surface of titanium-zirconia alloys, as well as on the surfaces of commercially available titanium.[5,26] In our test groups, it was seen that group T exhibited an anodized surface, while group R displayed a SLA surface. The variation in the surface treatments could be an additional factor contributing to our observed outcomes. However, a study performed by Abaricia et al. in 2021 has provided additional proof to our own findings, demonstrating that anodized titanium surfaces exhibit a greater capability for wettability in comparison to titanium-zirconia surfaces.[27]

Most researchers have concentrated on either altering the surface texture through various treatment methods or creating titanium alloys by augmenting numerous elements, such as zirconia and niobium, in different percentages.[23,25,28] In addition, the current literature extensively relies on a range of liquids, such as distilled water, Hank's salt solution, saline water, and physiological fluids derived from humans or animals (e.g., saliva, blood, blood clots, and serum), to assess the wettability of dental implants or dental titanium surfaces.[5,6,15,21,23,25,29,30] Besides that, in order to attain optimal wettability on the dental implant surface, it is necessary to consider the features and wetting properties of the blood that can be influenced by changes in its viscosity.[31]

Systemic conditions (e.g., diabetes, hyperlipidemia, etc.), diet, and age may all affect blood viscosity.[32] However, to our knowledge, the current literature lacks research on these, and our investigation might have brought novelty by assessing the wettability of titanium surfaces via blood under consideration of diabetes as a systemic factor that affects the viscosity of blood. Our results revealed elevated hematocrit and platelet levels in the blood samples of the BD group. In line with our results, the review study of Li et al. demonstrated that patients with HbA1c levels beyond 8% exhibited a mean platelet count that was 10% greater compared to individuals without diabetes.[33] In our point of view, these factors, elevated hematocrit and platelet levels, might have contributed to an upsurge in blood viscosity, possibly resulting in a decrease in wettability in the BD group compared to the BC group, irrespective of the kind of surface. The research by Sun et al. may help explain our outcome. They found that higher HbA1c levels cause higher hematocrit levels and lower plasma due to diuretic osmosis. This, in turn, makes individuals with Type 2 diabetes have denser blood.[13]

The methodology of our investigation is primarily limited by the use of EDTA-anticoagulated whole blood. While logistics required EDTA to stabilize samples and prevent spontaneous clotting during the inter-institutional transfer for contact angle measurements, we acknowledge that any anticoagulant restricts the technique. EDTA, a strong calcium chelator, completely stops the normal coagulation cascade; therefore, our results solely reflect the liquid and cellular components' physicochemical properties, not the dynamic *in vivo* clotting behavior that affects wettability. Studies indicates that anticoagulants such as EDTA may elevate blood surface tension, thus affecting wettability assessments; yet, it could be regarded as an acceptable method.[34,35] Thus, the

observed quantitative variations should be understood as representing diabetic biochemical alterations (protein glycation and plasma composition) rather than a full model of *in vivo* hemocompatibility.

Another significant drawback is the lack of comprehensive patient history on diabetes duration and long-term treatment (oral versus insulin therapy). The chronicity of hyperglycemia and the type of pharmacological management can independently affect blood rheology; hence, these issues must be considered as potential unexplained confounding variables contributing to the heterogeneity in diabetic blood parameters. Furthermore, the observed elevation in blood cholesterol levels in the BD group (although not statistically significant) suggests the potential impact of hyperlipidemia on blood viscosity and wetting qualities.[15,36] To capture the whole physiological response and mitigate these constraints, future studies should emphasize the acquisition of these critical patient history characteristics and employ non-anticoagulated or alternative anticoagulants like heparin or citrate, ideally collected promptly.

Our data indicate that diabetic blood samples exhibit diminished wettability on all titanium surfaces, and the correlation analysis demonstrates that chronic glycemic dysregulation adversely affects blood-surface interaction, evidenced by the robust positive correlation between elevated HbA1c levels and increased contact angles. According to the results of this research, we might suggest that glycemic control directly influences implant failure, rather than merely the presence of a diabetes diagnosis.

CONCLUSION

In conclusion, this study demonstrates 2 critical findings with direct practical implications for implant dentistry. Firstly, poorly controlled Type 2 Diabetes Mellitus significantly compromises whole blood wettability on all tested titanium surfaces, highlighting that systemic disease is a dominant factor overriding surface modifications. The practical implication is that clinicians must prioritize and verify the patient's HbA1c level as a key criterion before surgical placement, recognizing that poor glycemic control likely increases early implant risk due to deficient initial blood-surface interaction. Secondly, our results confirm that anodically oxidized (Ti-Unite) surfaces provide superior wettability across both healthy and diabetic blood samples, suggesting they may offer a more resilient and biologically advantageous option, particularly in systemically compromised patients. Moving forward, clinical protocols should focus on optimizing the patient's metabolic health to improve blood properties, while material science continues to develop surfaces, like the anodized type, that ensure optimal blood spreading regardless of physiological variability.

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Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

Idea/Concept: *Gökhan Kasnak, Revan Birke Koca Ünsal;* ***Design:*** *Gökhan Kasnak, Revan Birke Koca Ünsal, Onur Güven;* ***Control/Supervision:*** *Gökhan Kasnak, Revan Birke Koca Ünsal, Onur Güven, Erhan Fıratlı;* ***Data Collection and/or Processing:*** *Gökhan Kasnak, Onur Güven;* ***Analysis and/or Interpretation:*** *Gökhan Kasnak, Revan Birke Koca Ünsal, Onur Güven, Erhan Fıratlı;* ***Literature Review:*** *Gökhan Kasnak, Revan Birke Koca Ünsal;* ***Writing the Article:*** *Gökhan Kasnak, Revan Birke Koca Ünsal, Onur Güven, Erhan Fıratlı;* ***Critical Review:*** *Gökhan Kasnak, Erhan Fıratlı;* ***References and Fundings:*** *Gökhan Kasnak, Revan Birke Koca Ünsal, Onur Güven;* ***Materials:*** *Gökhan Kasnak, Revan Birke Koca Ünsal, Onur Güven.*

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