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Comparative Analysis of the Hydrophilic Characteristics of Two Zirconia Dental Implants

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Abstract

Objective: To compare the surface hydrophilicity property of two zirconia implants using confocal laser microscopy and a goniometer.

Materials and Methods: Two groups of zirconia implants were analyzed. Group 1: Straumann PURE Ceramic n=5. Group 2: Tree-Oss CERAMIC n=5. Contact angles were determined using Confocal Laser Microscopy and a Goniometer.

Confocal Laser Microscopy: The implants were positioned and a drop of 0.05 ml of ultrafiltered water was placed with a calibrated pipette, and photographs were taken at 10× for 5 minutes. The height profile was extracted, and the contact angle was manually determined from the secant to the curve of the drop at the point of contact with the surface. Goniometer: the implants were positioned perpendicular to the axis between the light source and the camera. The video recording process was documented when the water drop was deposited on the implant surface 10 seconds after deposition. SpanishDub video editor and ImageJ image-processing software were used with the Drop analysis-LB-ADSA plugin. The parameters drop height, inclination, position, and volume were manually adjusted. The values were analyzed using the t-test for independent samples. The tests were carried out in the LAMARX Laboratory.

Results: Using Confocal Laser Microscopy, the contact angle in Group 1 was 86.97° ± 1.39 and in Group 2 was 76.67° ± 8.32, with significant differences between groups ($p = 0.0039$). Using the Goniometer, the contact angle values were 120.9° ± 12.29 for Group 1 and 94.3° ± 12.16 for Group 2, with statistically significant differences for both implants ($p = 0.0001$).

Conclusions: The analysis of the contact angles revealed a statistically significant difference between the evaluated implants. Tree-Oss CERAMIC implants obtained a zirconia surface with a higher hydrophilicity profile compared to Straumann

PURE Ceramic implants.

Keywords: Dental Implants, Zirconia, Hydrophilicity, Roughness, Chemical Composition

Introduction

Osseointegration is a dynamic biological process described as the direct contact of bone tissue with the implant surface and depends on factors related to the implant, the surgical site, the type of bone, and the patient's conditions [1]. Due to their excellent biocompatibility and mechanical properties, titanium and zirconia are commonly used as materials for dental implants [2]. Since the effectiveness of osseointegration is closely related to the surface of the implants, numerous modifications have been published to improve the surface topography of the biomaterial, as well as chemical modifications [3,4].

It has been shown that modifications and surface treatments that improve the hydrophilicity of dental implants promote bone differentiation, indicating that hydrophilic surfaces may play an important role in enhancing osseointegration [5]. Modifications of implant surface properties such as roughness, wettability, and topography influence hydrophilicity phenomena [6]. These changes transform the surfaces of zirconia implants into bioactive and multifunctional surfaces that favor the biological and mechanical responses of peri-implant tissue. They induce osteogenic stimulation, fibroblast adhesion, and an antibacterial effect. They improve and accelerate bone healing response and clinically reduce healing time [7].

Surface wettability influences the behavior of adhesion proteins, the interactions between hard and soft tissue cells with conditioned surfaces, bacterial adhesion, biofilm formation, and the rate of osseointegration [8]. Likewise, it plays an important role in the healing and regeneration of tissues that surround the implant surface [9].

Surface modification of topography or physicochemistry increases surface wettability, resulting in superhydrophilicity. X-ray photoelectron spectroscopy revealed that the decrease in carbon content and the introduction of hydroxyl groups was responsible for superhydrophilicity [10]. Increased surface roughness improves wettability, while changes in chemical composition may increase or decrease it depending on the treatment applied. Moderately rough surfaces (between 0.2 and 2 μm) achieve a balance between promoting osseointegration and minimizing bacterial adhesion [11,12].

Surface wettability is indicated by its contact angle with water: angles between 0° and 90° indicate hydrophilic surfaces, while angles greater than 90° indicate hydrophobic surfaces. Hydrophilic surfaces preserve the conformation and function of proteins, while hydrophobic textures may cause protein denaturation due to conformational changes. Protein adsorption significantly influences the ability of cells to adhere to implant surfaces and migrate across them; hydrophilic surfaces show a greater affinity for proteins compared to hydrophobic ones. Furthermore, a higher degree of hydrophilicity is associated with greater differentiation and maturation of osteoblasts, which may accelerate the osseointegration process [13,14], and facilitate the initial interactions between the surface and the wetting fluid, which is relevant for wound healing and osseointegration [15].

The nanoscale surface topography of dental implants plays a crucial role in cell–surface interaction, promoting adhesion, proliferation, and differentiation. A high-energy surface and a hydrophilic implant are important for the absorption of water molecules from the bloodstream and subsequently for cell adhesion to the implant-binding protein [16]. Surface nanotopography may be an important factor for adding hydrophilicity to implants, but it is also influenced by surface purity and physicochemical properties [17].

Given the need to evaluate the hydrophilic conditions of zirconia surfaces, this study aims to compare the surface hydrophilicity of two zirconia implants using confocal laser microscopy and a goniometer.

Materials and Methods

Two groups of zirconia implants from the following commercial brands were formed. Group 1: Straumann PURE Ceramic (Basel, Switzerland) n=5. Group 2: Tree-Oss CERAMIC (Buenos Aires, Argentina) n=5. Contact angles were determined to allow evaluation of surface wettability using Confocal Laser Microscopy and a Goniometer.

Confocal Laser Microscopy

The implants were placed on an implant holder, and both were positioned on the sample holder with their axis perpendicular to it. This procedure was carried out using the mid-axis of the microscope as a reference. Thus, the implant to be measured was positioned vertically, with its lower part facing upward, and the measurement was taken in all cases in the apical portion. Finally, the axis of the sample was aligned parallel to the laser so that the surface was aligned with the light beam.

Subsequently, a drop of 0.05 ml of ultrafiltered water was placed with a calibrated pipette. All implants were measured at a temperature of (23±2) °C and ambient humidity. Measurements were performed in less than 5 minutes to minimize drop evaporation. In all samples studied, measurements were taken with a 10× objective lens. Once the equipment recorded the three-dimensional image of the water drop on the metal surface, the height profile was extracted, and the contact angle was manually determined from the secant to the curve of the drop at the point of contact with the surface. An Olympus Lext 3D Confocal Laser Microscope was used. (Figure 1 a and b).

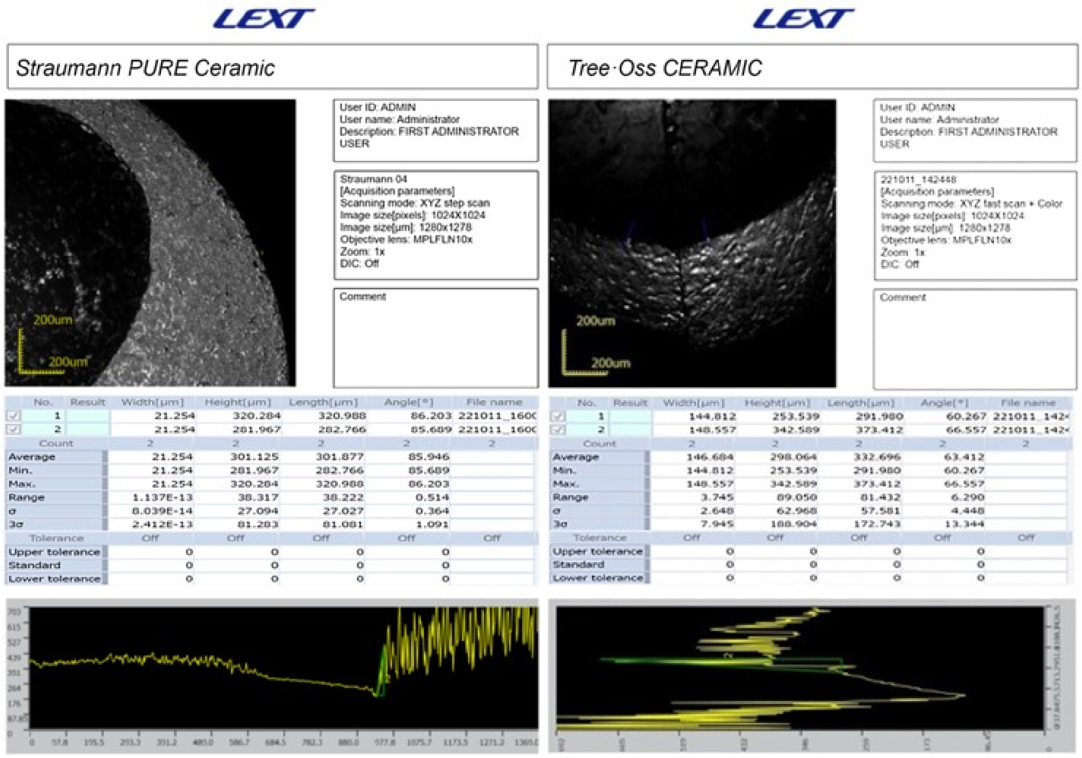

Figure 1: a – Confocal Laser Microscope report for implant sample group 1, Straumann PURE Ceramic. b – Confocal Laser Microscope report for implant sample group 2, Tree-Oss CERAMIC.

In the upper left part of this figure, an image of the drop on the rough metal surface is shown. In the lower part, the reconstruction of the height profile along a segment that crosses the edge of the drop is displayed. In this profile, the contact angle is calculated by determining the angle of the tangent to the drop surface at the point of contact with the implant surface with respect to the line of the implant surface.

Goniometer

The implants were placed on the goniometer sample holder with the implant axes tilted so that the surface to be measured was in a horizontal position. The axis of the sample was aligned perpendicular to the axis between the light source and the camera, adjusting the height so that the deposited drop was fully captured, ensuring the implants were at the height of the light focus striking them.

Subsequently, the specimens were centered with respect to the needle, and the needle tip position was adjusted to a height of 2 mm above the surfaces. Once video recording began, the water drop was deposited on the implant surface right in the middle of the valley between peaks, and at least 10 seconds were allowed to pass after deposition to ensure system equilibrium.

After the recording was finished, it was analyzed using the SpanishDub video editor, and the first frame without changes compared to the next—indicating equilibrium—was selected. This frame was used to determine the contact angle in the "ImageJ" image-processing software, using the Drop analysis-LB-ADSA plugin developed at the Swiss Federal Institute of Technology Lausanne. The model parameters (drop height, inclination, position, and volume) were manually adjusted to achieve precise correlation between the experimental shape of the drop from the obtained image and the theoretical contour produced by the model. Once optimized correlation was achieved, the program provided the corresponding contact angle (Figure 2).

Both tests were carried out in the Laboratory of Electron Microscopy and X-Ray Analysis (LAMARX, Córdoba, Argentina), Faculty of Mathematics, Astronomy, Physics, and Computer Science (FAMAF), National University of Córdoba (UNC). The obtained values were analyzed with the t-test for independent samples.

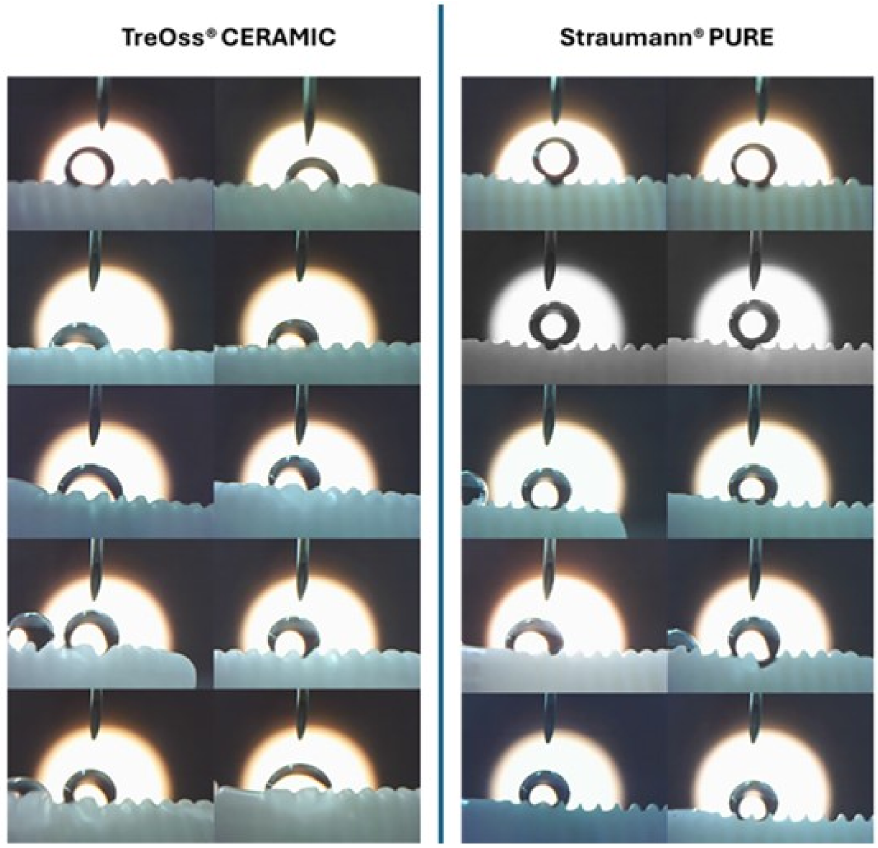

Figure 2: Images of water drops in contact with the surface of Tree-Oss CERAMIC and Straumann PURE implants measured with a goniometer.

Results

Contact Angle Measured by Confocal Laser Microscopy (OLYMPUS Lext 3D Microscope)

Using Confocal Laser Microscopy, the contact angle was calculated by determining the angle of the tangent to the drop surface at the point of contact with the implant surface relative to the implant surface line. Analyzing these results, an average of 86.97° was obtained for Straumann PURE Ceramic implants and an average of 76.67° for Tree-Oss CERAMIC implants, with a standard deviation for Straumann PURE of 1.39 and for Tree-Oss CERAMIC of 8.32.

Results of contact angle (°) measurements of samples taken with Confocal Laser Microscopy. Differences between means and statistical contrast between groups (t-test; p-value) are also shown in table 1.

Table 1: Average: 87.0 (Group 1) – 76.7 (Group 2) **Standard deviation:** 1.4 (Group 1) – 8.3 (Group 2) Final expression: 87.0 ± 1.4 (Group 1) – 77.7 ± 8.3 (Group 2)

Implant (n)	Repetition	Group 1 – Straumann PURE Ceramic	Group 2 – Tree-Oss CERAMIC
1	A	86.1	60.3
	B	87.2	66.6
2	A	87.8	85.8
	B	87.4	85.9
3	A	86.2	80.2
	B	85.7	83.2
4	A	88.1	73.1
	B	89.1	80.5
5	A	87.8	74.8
	B	84.3	76.3

Difference between means: 10.3, 95% CI (4.3 – 16.3) **t:** 3.86 **p:** 0.0039

This allowed us to express the results as (87±1)° for Group 1 and (77±8)° for Group 2. This form of expression indicated that **68.2%** of the contact angles measured with this technique for the implants of each brand were in the ranges of **86–88°** for Straumann PURE Ceramic and **69–85°** for Tree-Oss CERAMIC (Figure 3).

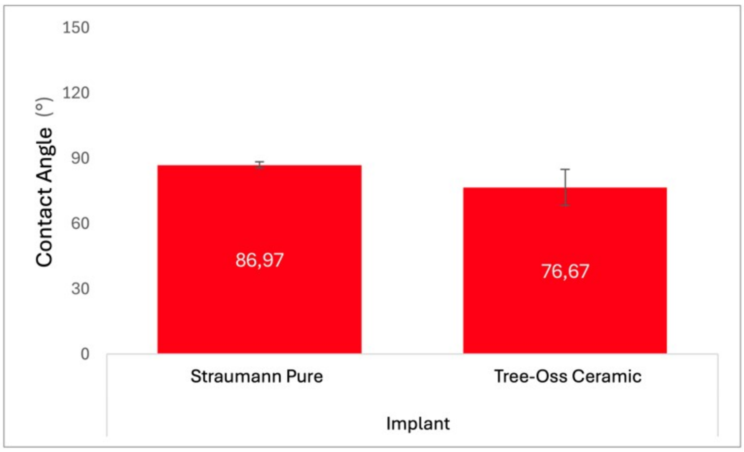

Figure 3: Mean and standard deviation obtained for the contact angle of the implant surface measured by Confocal Laser Microscopy.

The results of the t-test established a confidence level of 95%, with significant differences between groups (p = 0.0039).

Contact Angle Measured by Goniometer

Results of contact angle measurements of samples taken with a Goniometer. Differences between means and statistical contrast between groups (t-test; p-value) are also shown in table 2.

Table 2: Average: 120.9 (Group 1) – 94.3 (Group 2) **Standard deviation:** 12.3 (Group 1) – 12.2 (Group 2) **Final expression:** 120.9 ± 12.3 – 94.3 ± 12.2

Implant (n)	Repetition	Group 1 – Straumann PURE Ceramic	Group 2 – Tree-Oss CERAMIC
1	A	126	108
	B	134	80
2	A	128	93
	B	125	87
3	A	110	106
	B	140	89
4	A	100	103
	B	118	105
5	A	120	72
	B	108	100

Difference between means: 26.6, 95% CI (15.1 – 38.1) **t:** 4.86 **p:** 0.0001

An average of 120.9° was obtained for Group 1 and 94.3° for Group 2, with similar standard deviations in both cases (12.29 and 12.16, respectively). This allowed us to express the results as (120±10)° and (90±10)° for Straumann PURE Ceramic and Tree-Oss CERAMIC implants, respectively. This expression indicated that **68.2%** of the contact angles measured with this technique for the implants of each brand were in the ranges of **110–130°** for Straumann PURE Ceramic and **80–100°** for Tree-Oss CERAMIC. The average for each implant, as well as the specified ranges, are included in Figure 4.

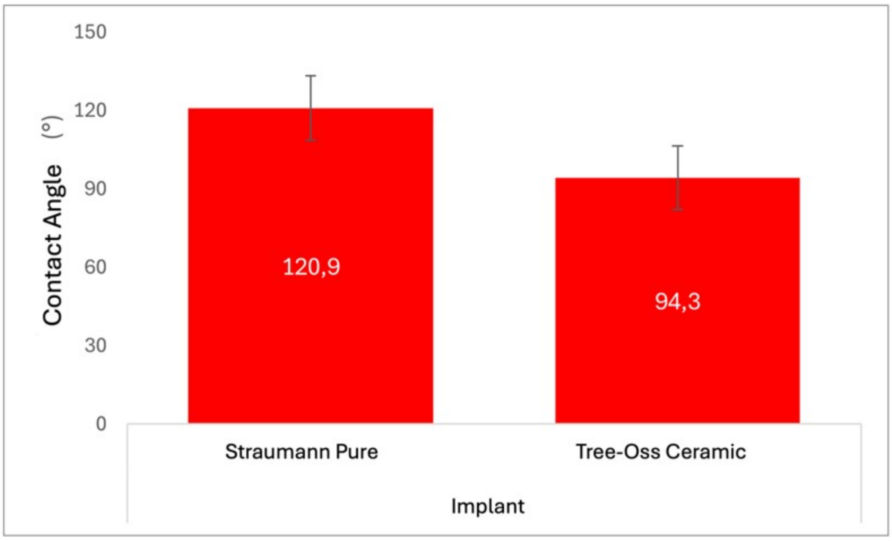

Figure 4: Mean and standard deviation obtained for the contact angle of the implant surface measured by Goniometer.

The t-test determined statistically significant differences between the contact angles obtained for both brands. The p-value (0.0001) indicated that an even higher level of significance could have been achieved, since according to this value a 99.99% significance level could have been reached (Table 2).

With the aim of strengthening the analytical section and providing greater methodological rigor, the effect size was calculated using **Cohen's d coefficient** in order to quantify the magnitude of the differences observed between the evaluated implant surfaces. The value of *d* was obtained as the difference between the group means divided by the pooled standard deviation. For the confocal microscopy analysis, a large effect size was observed ($d = 1.20$), indicating a substantial difference between the TREE OSS and STRAUMANN surfaces. In the measurements performed with the goniometer, the effect size was even greater ($d = 1.54$), reflecting a very large magnitude of difference between the groups. According to conventional interpretation criteria (small ≈ 0.2; medium ≈ 0.5; large ≥ 0.8), both results demonstrate considerable practical relevance.

Discussion

In the present study, the values obtained in the contact angle tests using Confocal Laser Microscopy were 86.97º for Straumann PURE implants and 76.67º for Tree-Oss CERAMIC implants. Using the goniometer tests, values of 120.9º were reached for Group 1 and 94.3º for Group 2.

Measuring the contact angle with a goniometer provides a rapid and direct characterization of the droplet profile (angle, area, volume) in 2D, making it ideal for standard wettability studies. On the other hand, confocal laser microscopy offers detailed 3D and topographic visualization, allowing for a much more precise heterogeneous surfaces. Furthermore, the goniometer measurements were taken at the apex of the implant, while those taken with a confocal microscope were taken in the implant body in the valley between two thread peaks.

For this reason, both studies are complementary to each other and serve to confirm the information obtained.

Zirconia implants present high biocompatibility, with a success rate of 97% after one year and 93% thereafter in a follow-up of 2 to 3 years, demonstrating to be a viable alternative to titanium implants. Other advantages include the absence of adverse reactions, such as hypersensitivity, and a coloration similar to natural teeth [18,19].

The hydrophilicity of a surface is commonly measured using the contact angle method, also known as the wetting angle. When placing a drop of liquid on the surface of a material, the attractive forces between the liquid molecules create surface tension, causing the droplets to adopt a dome shape. The contact angle is defined as the internal angle between the tangent to the surface of the liquid and the material surface at the point of tangency.

The measurement of the contact angle is generally performed by depositing a drop of liquid on the surface of a material. The material must remain fixed when using this method, and the internal angle between the drop and the surface is measured after the drop comes into contact with the flat surface. When the measured contact angle is less than 90°, the surface is hydrophilic. If the contact angle is less than 10°, the surface is superhydrophilic. Conversely, if the contact angle exceeds 90°, the surface is hydrophobic, and an angle greater than 150° indicates a superhydrophobic surface [8,20].

Results from wettability testing in which contact angles on various surfaces were measured have been published. A 0.5 μL drop of ultrapure water was placed on each sample, and averages of 86.9°, 80.5°, 91.5°, 61.6°, and 98.5°, respectively, were obtained. Zirconia and zirconia/titanium surfaces showed slight hydrophilicity, while zirconia/aluminum and zirconia/zinc showed slight hydrophobicity. The contact angle on the zirconia/silicon surface was significantly lower than that of the other samples [21].

Various studies in the scientific literature highlight the importance of surface hydrophilicity in improving the osseointegration potential of dental implants. Ultrahydrophilic surfaces contribute significantly to early bone–implant contact and primary stability, especially in critical clinical situations such as low bone density, immediate loading protocols, or changes in implant surface chemistry [22-24].

The interaction between the implant surface and the biological environment greatly influences osseointegration; hydrophilic surfaces enhance this interaction by facilitating rapid protein adsorption and promoting osteoblastic activity [25]. Titanium implants with ultrahydrophilic surfaces analyzed demonstrated superior wettability. They report achieving hydrophilic properties less favorable in zirconia and in some titanium implants, highlighting the need for continued innovation in surface treatments to optimize performance. The results underline the advantages of advanced surface engineering and storage in a humid medium to maintain optimal implant properties [26].

Conversely, it has been published that zirconia used in implants presents higher contact angles than other dental restorative materials, suggesting lower hydrophilicity. This characteristic may influence the initial interactions between the implant surface and biological fluids, potentially affecting osseointegration [27].

It has been reported, in a study on the influence of ultraviolet photofunctionalization on the surface characteristics of zirconia-based dental implant materials, that treatment with ultraviolet light significantly modified the hydrophilic state of zirconia, changing it from hydrophobic to hydrophilic. The average contact angles ranged from 56.4° to 69° before treatment and from 2.5° to 14.1° after treatment [28].

Extensive research is being conducted on surface treatments to inhibit bacterial adhesion and improve osseointegration and soft tissue adhesion, making it difficult to evaluate the properties of materials without surface treatment. Titanium osseointegration is superior to zirconia without surface treatment; after treatment, both materials exhibit comparable osseointegration. Surface morphology is more important for osseointegration than surface composition. To inhibit bacterial adhesion, zirconia is superior to titanium and therefore more suitable for abutments. Both materials present similar soft tissue adhesion capability [29].

The development of surface modification techniques in bio-ceramics to improve cellular response in implants is still under investigation, but it is promising. Over time, surface modification will become the key to improving implant reliability [30].

In a review where the mechanical, aesthetic, and biocompatible properties of zirconia for oral implants were analyzed, they mainly highlight sufficient durability and biocompatibility. Regarding zirconia biocompatibility, sandblasting and acid etching proved effective for bone formation, with a synergistic effect of micro- and nanotopography. Superhydrophilic treatment, particularly cold plasma, improved initial adhesion of osteoblastic cells and oral keratinocytes [31].

Numerous studies state that zirconia implants have shown higher cell proliferation and viability, as well as improved biocompatibility compared to titanium. Another advantage of zirconia is its high corrosion resistance, low infection rate, and low plaque formation. Increased success and survival rates, together with high biocompatibility, make zirconia an ideal material for dental implants [32,33]. However, there is no conclusive evidence indicating that titanium is superior to other implant materials. Clinical evidence suggests little difference between various implant materials in terms of peri-implant bone stability [34].

It has been shown that morphology, chemical composition, and roughness are the main factors affecting the quality and quantity of formed tissue. Surface modifications in zirconia implants change interfacial topographic characteristics and may improve biological performance, directly impacting the osseointegration process [35]. Surface treatment of zirconia generates roughness that accelerates osseointegration phenomena and achieves greater mechanical adhesion with the environment. Techniques to modify surfaces are divided into additive and ablative. Additive techniques may involve the addition of particles, with plasma thermal spraying being a widely used technique. Ablative techniques remove material from the implant surface, such as sand-blasting, etching, anodizing, milling, and laser treatments. Additionally, other treatments such as UV photofunctionalization modify surface hydrophilicity. Both techniques aim to obtain a porous surface and significantly influence contact angle results [36-38].

The findings presented in this research support that surface modifications of zirconia implants to achieve a lower contact angle are a critical factor in improving biological performance. Measurement of a reduced contact angle correlates directly with a significant increase in surface hydrophilicity or wettability of the implant.

Conclusions

The analysis of the contact angles revealed a statistically significant difference between the evaluated implants. Tree-Oss CERAMIC implants showed a zirconia surface with a better hydrophilicity profile compare to Straumann PURE implants. Strict control of the surface contact angle is not only a physical parameter but probably also a direct predictor of the clinical effectiveness of the implant.

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