Comparative analysis of elemental composition between dental implants with different microgeometry using an energy-dispersive X-ray spectroscope

Abstract

Background
The microgeometry of dental implants has undergone a great evolution to enhance the osseointegration, thereby the survival of implants. The present study was done to compare the surface chemistry of sandblasted acid-etched and anodized titanium dental implants.

Materials and Methods
SLA (n=3), SLActive (n=3) and TiUnite (n=3) were evaluated for chemical composition in terms of atomic percentage (at.%) and weight percentage (wt.%) of the elements using energy-dispersive X-ray spectroscope (EDX). Atomic and weight percentages were compared between the three implants by ANOVA and pairwise comparison by Tukey's HSD post hoc test.

Results
A statistically significant difference in at.% and wt.% of Titanium (Ti), Oxygen (O), Carbon (C), Sodium (Na), Chlorine (Cl) and Phosphorus (P) between the three implants with the p value of 0.000. Also, there was a statistically significant difference between SLA and SLActive for Ti, O, C, Na, Cl (p=0.000), between SLA and TiUnite for Ti, O, C, P (p=0.000), between SLActive and TiUnite for all the elements (p=0.000) in terms of at.% and wt.%

Conclusion
Chemical composition of anodized dental implants differs from sandblasted acid-etched implants due to the electrochemical oxidation process.

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Dental implant, Microgeometry, Surface modifications, Surface treatments

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INTRODUCTION

For patients who are either completely or partially dentulous, dental implants offer a significant course of treatment. These prosthetic teeth are supported by biocompatible metal anchors called implants, which are surgically placed in the jawbone to replace missing teeth. Dental implants have a long history dating back to 600 A.D., when the Mayan people replaced missing teeth with fragments of shell(1). In the 1930s, the first endosteal implants made up of Vitallium were used in dentistry(2). A spiral stainless-steel implant was created in the 1940s to promote bone growth onto metal, and it subsequently developed into a double-helical spiral implant. Surprisingly, the first stable dental implant documented was a threaded titanium root-form implant, which Dr. Per-Ingvar Branemark first used on patients in 1965(3). In order to consistently increase implant success, implants have undergone significant shape, size, and surface evolution since that time.

There are numerous methods of modifying the surface of dental implants which include acid treatments, sandblasting or various oxidization mechanisms(4). The process of sandblasting with large grit and then using a combination of sulfuric and hydrochloric acids for acid etching results in the rough surface of sandblasted-acid etched (SLA) implants. However, the osseointegration process may be hampered by blasting material embedded in the surface as a result of sandblasting. Additionally, the hydrophobic surface may prevent cells from adhering to implants(5). In an effort to get around these restrictions, researchers have been working to alter the characteristics of implant surfaces by enhancing surface wettability and maximizing surface chemistry.

A modification over SLA surface is SLActive surface. The same processes are used to create SLActive surfaces - sandblasting and acid etching, but they are not stored dry; instead, the SLActive implants are rinsed under nitrogen protection to keep them from coming into contact with the air and are then kept in a sealed glass tube filled with isotonic NaCl solution. The SLActive implant has a higher surface energy and is more hydrophilic than the SLA implant because of this contamination-reducing storage technique. Important surface properties that support a stronger cell response and bone tissue response in the early stages of bone healing are higher surface energy and hydrophilicity(6). TiUnite implant surface is made by treating implants in a galvanic cell with an electrolyte of phosphoric acid through an oxidation process. A thick layer of TiO_2 enriched with highly crystalline calcium phosphate characterizes a TiUnite surface, which may encourage the deposition of apatite around implants(7).

The various surface treatments performed on the dental implants could significantly affect the chemical composition which in turn could potentially influences the osseointegration(8,9). In this context, the present study was done to compare the surface chemistry of sandblasted acid-etched (SLA, SLActive) and anodized (TiUnite) titanium dental implants.

MATERIALS AND METHODS

The study included three implants namely SLA (n=3; SLA®, Straumann, Basel, Switzerland), SLActive (n=3; SLActive®, Straumann, Basel, Switzerland) and TiUnite (n=3; Nobel Biocare®, Gothenburg, Sweden). Three implants of each type were subjected to chemical analysis.

The surface chemistry of the selected implant surfaces was measured with a built-in energy-dispersive X-ray spectroscope (EDX detector, X-PLORE-30/C-SWIFT, Oxford Instruments, Wiesbaden, Germany) using point scanning. The implants (three of each type) were meticulously positioned horizontally on the sample holder, and the standardised area (thread flanks) of each implant was identified and assessed. For data analysis, Aztec software (Aztec Software Associates, Springfield, New Jersey, United States) was employed. The software was configured to automatically identify the elements, and provide data in terms of atomic and weight percentages.

The software was set to detect the elements automatically, with obtained data representing the atomic percent and weight percent. The mapping area was between 50-100 μm at a magnification of x250 - x500, with the setting of UHD = 20 kV and WD = 10 mm.

Mean atomic percent and weight percent values were compared between the three implants by ANOVA using the Statistical Package for Social Sciences (SPSS Software, Version 23.0; IBM Corp., Armonk, NY, USA). For pairwise comparison, Tukey's HSD post hoc test was performed. p value of < 0.05 was considered to be statistically significant.

RESULTS

Chemical composition and differences between SLA, SLActive and TiUnite in terms of atomic percentage (at.%) (Figure 1, Figure 2, Figure 3) and weight percentage (wt.%) (Figure 4, Figure 5, Figure 6) are summarized in Table 1 and Table 2 respectively. There was a statistically significant difference in at.% and wt.% of Titanium (Ti), Oxygen (O), Carbon (C), Sodium (Na), Chlorine (Cl) and Phosphorus (P) between the three implants with the p value of 0.000. On pairwise comparison, there was a statistically significant difference between SLA and SLActive for Ti, O, C, Na, Cl (p=0.000), between SLA and TiUnite for Ti, O, C, P (p=0.000), between SLActive and TiUnite for all the

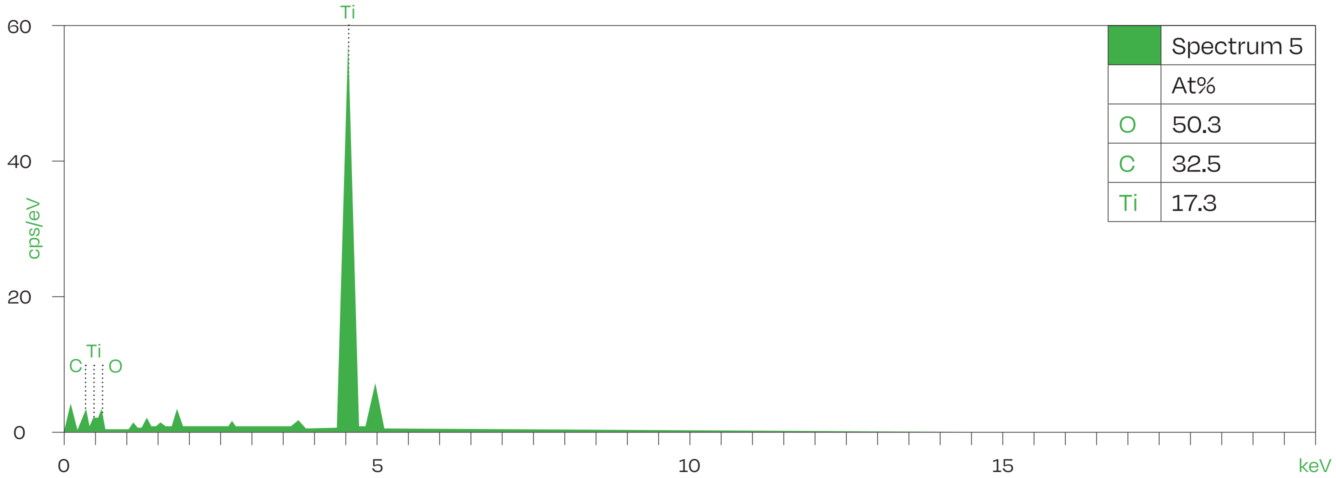

Fig. 1 Atomic percentages of elements in SLA implant determined using EDX

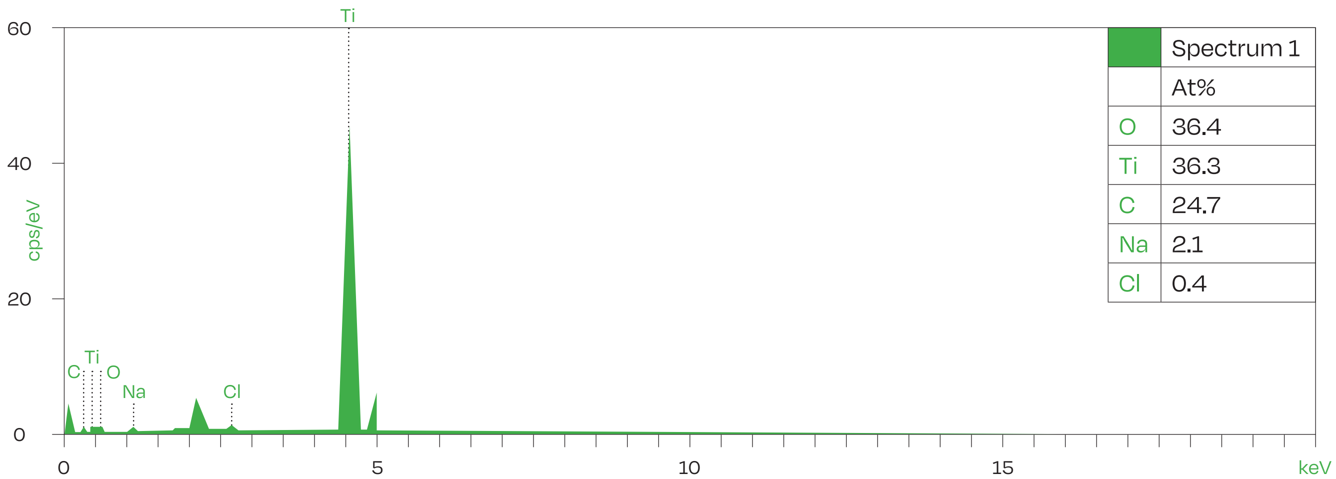

Fig. 2 Atomic percentages of elements in SLActive implant determined using EDX

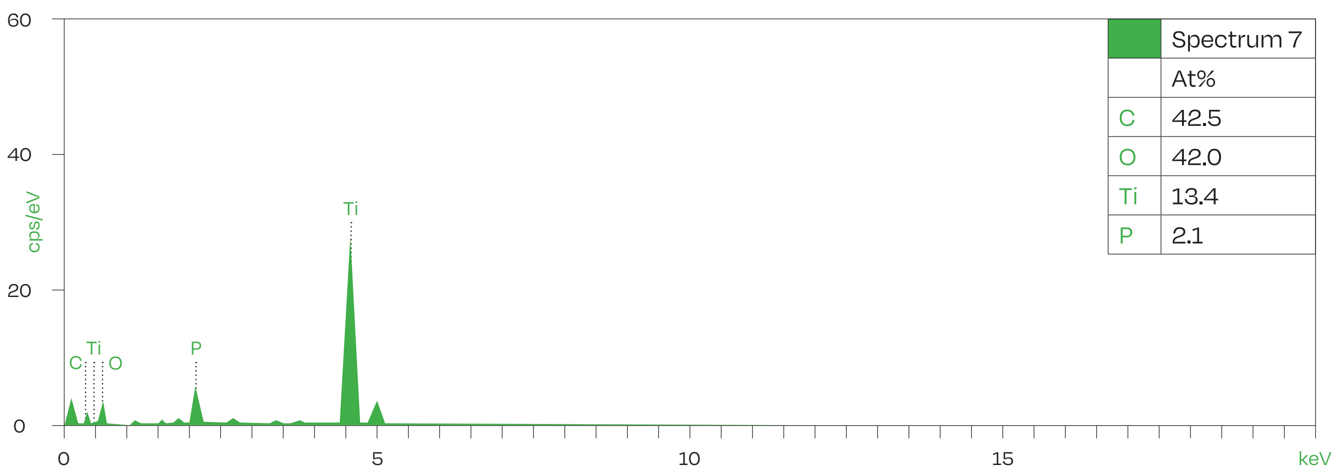

Fig. 3 Atomic percentages of elements in TiUnite implant determined using EDX

Implant Systems	Atomic Percentage (Mean±SD)					
	Ti	O	C	Na	Cl	P
SLA	17.7±0.4	51.9±1.6	32.8±0.4	0	0	0
SLActive	37.3±1.0	36.7±0.3	22.6±1.8	2.3±0.2	0.5±0.1	0
TiUnite	13.6±0.3	43.0±1.0	43.4±0.8	0	0	2.2±0.1
ANOVA Test	p = 0.000*	p = 0.000*	p = 0.000*	p = 0.000*	p = 0.000*	p = 0.000*
Tukey's HSD post hoc test						
SLA vs SLActive	Mean Difference: -19.533 p = 0.000*	Mean Difference: 15.233 p = 0.000*	Mean Difference: 10.166 p = 0.000*	Mean Difference: -2.30 p = 0.000*	Mean Difference: -0.500 p = 0.000*	Mean Difference: 0 p = 1.000
SLA vs TiUnite	Mean Difference: 4.066 p = 0.001*	Mean Difference: 8.933 p = 0.000*	Mean Difference: -10.633 p = 0.000*	Mean Difference: 0 p = 1.000	Mean Difference: 0 p = 1.000	Mean Difference: -2.20 p = 0.000*
SLActive vs TiUnite	Mean Difference: 23.60 p = 0.000*	Mean Difference: -6.30 p = 0.001*	Mean Difference: -20.80 p = 0.000*	Mean Difference: 2.30 p = 0.000*	Mean Difference: 0.500 p = 0.000*	Mean Difference: -2.20 p = 0.000*
*Statistically significant						

Tab. 1 Comparison of atomic percentage (at.%) of elements between three types of implants

Implant Systems	Atomic Percentage (Mean±SD)					
	Ti	O	C	Na	Cl	P
SLA	41.4±0.7	41.4±1.7	19.6±0.4	0	0	0
SLActive	65.6±1.0	22.2±0.6	10.3±0.7	1.9±0.1	0.7±0.1	0
TiUnite	34.5±0.5	36.5±1.1	28.3±1.2	0	0	3.6±0.1
ANOVA Test	p = 0.000*	p = 0.000*	p = 0.000*	p = 0.000*	p = 0.000*	p = 0.000*
Tukey's HSD post hoc test						
SLA vs SLActive	Mean Difference: -24.20 p = 0.000*	Mean Difference: 19.20 p = 0.000*	Mean Difference: 9.333 p = 0.000*	Mean Difference: -1.90 p = 0.000*	Mean Difference: -0.70 p = 0.000*	Mean Difference: 0 p = 1.000
SLA vs TiUnite	Mean Difference: 6.90 p = 0.000*	Mean Difference: 4.866 p = 0.006*	Mean Difference: -8.70 p = 0.003*	Mean Difference: 0 p = 1.000	Mean Difference: 0 p = 1.000	Mean Difference: -3.60 p = 0.000*
SLActive vs TiUnite	Mean Difference: 31.10 p = 0.000*	Mean Difference: -14.333 p = 0.000*	Mean Difference: -18.033 p = 0.000*	Mean Difference: 1.900 p = 0.000*	Mean Difference: 0.700 p = 0.000*	Mean Difference: -3.60 p = 0.000*
*Statistically significant						

Tab. 2 Comparison of weight percentage (wt.%) of elements between three types of implants

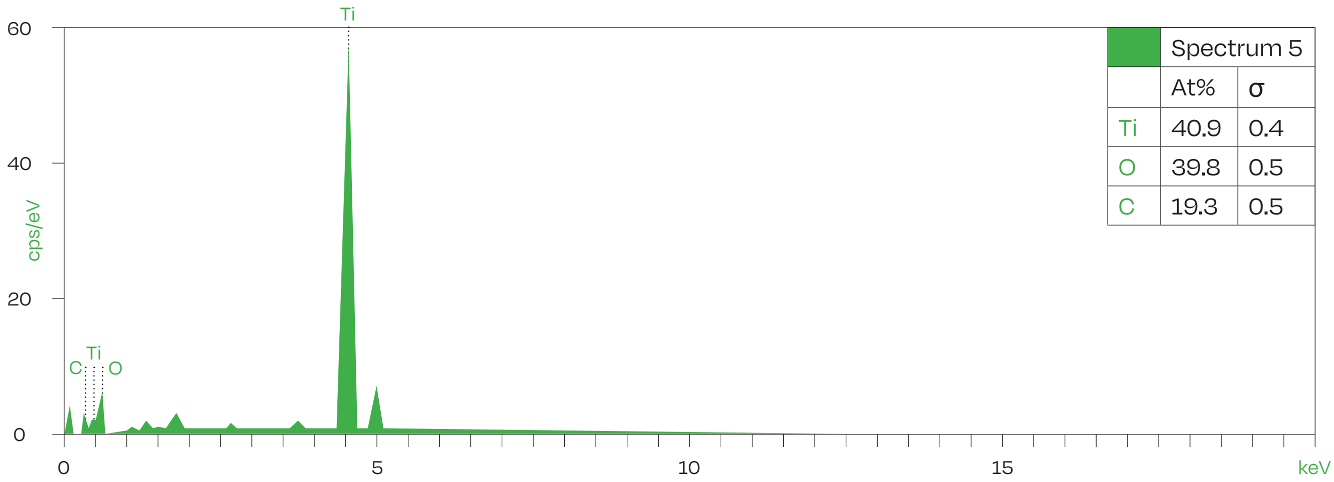

Fig. 4 Weight percentages of elements in TiUnite implant determined using EDX

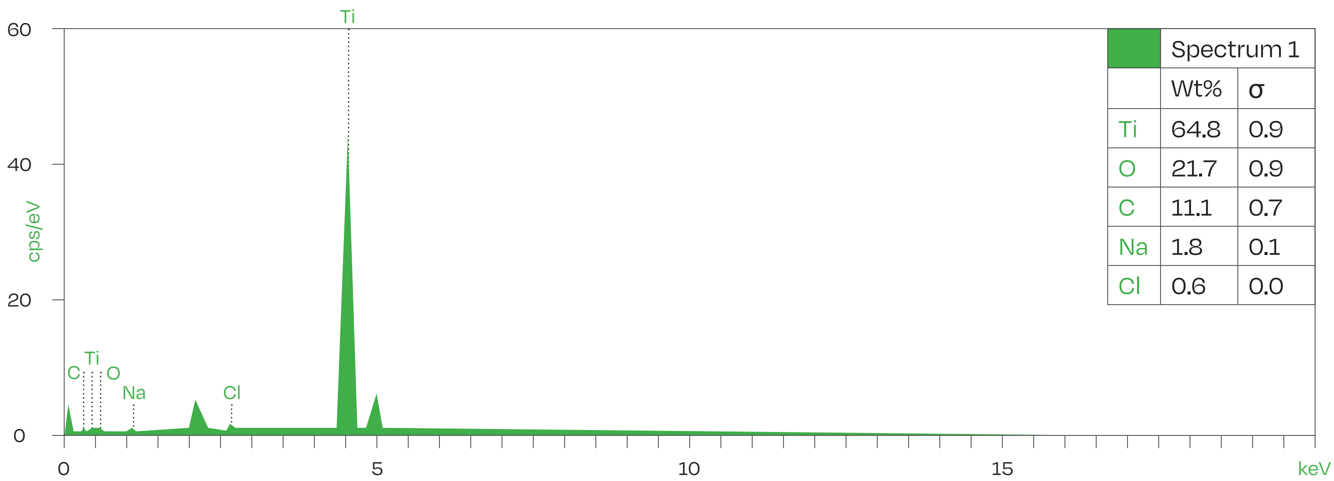

Fig. 5 Weight percentages of elements in TiUnite implant determined using EDX

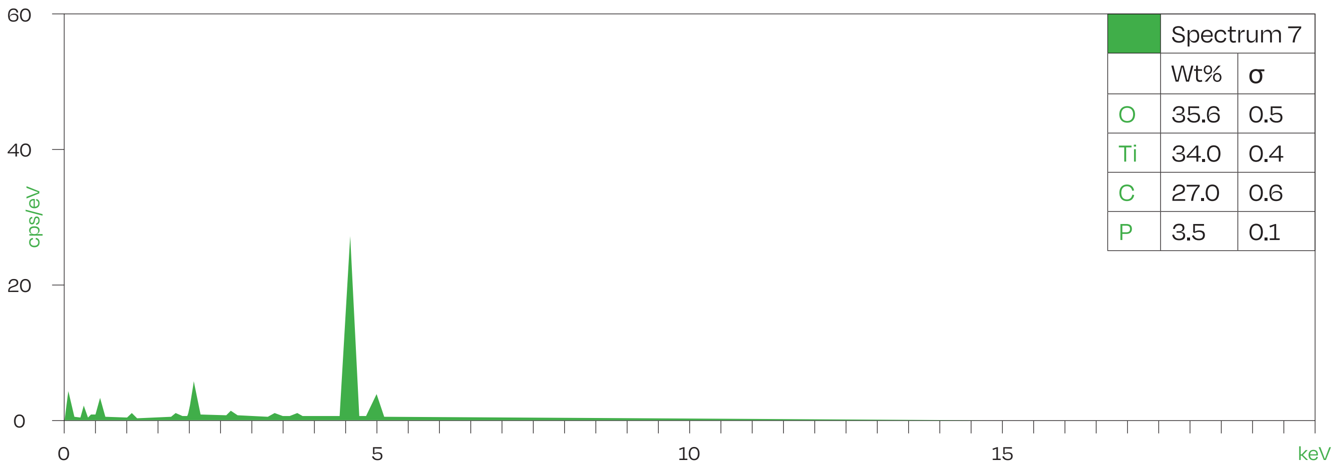

Fig. 6 Weight percentages of elements in TiUnite implant determined using EDX

elements (p=0.000) in terms of at.% and wt.%

DISCUSSION

The physico-chemical behaviour and microstructural characteristics of the implant can be altered by various surface treatments for titanium, which can then have an impact on the processes involved in bone formation. Sandblasting in conjunction with acid etching and electrochemical oxidation processes are the most often used treatments.10 Biomolecular adsorption, cell adhesion, and osteoblast cell maturation may be significantly influenced by surface characteristics(11,12). Furthermore, the surface characteristics of dental implants have indeed gained increasing attention in recent years due to their significant impact on the incidence and progression of peri-implant diseases. The long-term effects and predictive variables of implant success were assessed by Romandini M et al.(13). The authors evaluated the impact of smoking, gender, patient age, periodontal status, implant diameter, length, brand, type, and surface characteristics, as well as their location, on the success of dental implants and revealed that implant surface characteristics was the most reliable indicator of implant loss. Recent analyses also documented the longitudinal effects of the implant surface decontamination protocols, highlighting the importance of surface characteristics in preventing biofilm formation and promoting osseointegration(14,15). Therefore, the surface characteristics of dental implants are crucial in determining their long-term success and the health of surrounding tissues. Advances in surface engineering aim to strike a balance between promoting osseointegration and minimizing the risk of bacterial colonization, thereby reducing the incidence of peri-implant diseases. Continuous research and development in this field are essential to improving implant outcomes and patient care. In view of this, the current study analyzed the elemental composition of the three most commonly used dental implants.

The chemical makeup of the dental implants examined in this study revealed a variation in element composition, which may have resulted from residual elements produced by the surface modification process(16) or organic contamination from the dental implant packaging(17). In the present study, Ti, O and C was observed as major elements in all the three implants, in accordance with the previous studies(18,19). On the other hand, Na and Cl was observed only on the SLActive implants, as they are stored in NaCl solution. As a result, a NaCl aggregate forms across the whole surface when the solution dries quickly(20). Phosphorus (P) was observed only in TiUnite implants, due to the incorporation of anions of the used electrolyte during anodization process(21).

The composition of Carbon (C) dominated in the TiUnite implant followed by SLA and SLActive implants. The most common contaminant on commercial implants is carbon. Carbon contamination in commercially available titanium implants was reported by Morra M et al., irrespective of the surface alteration process employed by the manufacturers(22). A larger amount of carbon contributed to more unfavourable osteoblast attachment and differentiation on titanium discs, according to concentration-dependent phenomena described by Hayashi R et al., even though the precise minimum dose of carbon required to cause an unfavourable response is still unclear(23). Our research clearly shows that the TiUnite implants had a higher carbon concentration than other implants.

SLActive implants demonstrated comparatively less amount of Carbon. This could be because of the fact that SLActive implants are hydroxylated, rinsed under nitrogen protection, and kept in an isotonic saline solution until its usage to reduce the absorption of carbonates and hydrocarbons and to promote hydrophilicity(24). In addition, the chemical alterations in SLActive implants alter their structure at the nanoscale and produce a hydrophilic surface with high surface energy, which increases the amount of oxygen absorbed and decreases the amount of carbon(25). To ensure the mechanical stability of the dental implant, high osseointegration levels are necessary. In this research, the elemental make-up of three implant systems has been compared and significant differences were observed. When choosing dental implants, clinicians should consider these factors. To evaluate the impact of these elemental variations on osseointegration and peri-implant new bone formation, further studies are warranted.

CONCLUSION

Chemical composition of anodized dental implants differ from sandblasted acid-etched implants due to the electrochemical oxidation process.

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