Resonance Frequency Analysis, Insertion Torque, and Bone to Implant Contact of 4 Implant Surfaces: Comparison and Correlation Study in Sheep

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Introduction: *Primary stability is evaluated using resonance frequency analysis (RFA) and insertion torque (IT). Although there is a strong correlation between RFA and IT, studies failed to find a correlation between RFA and bone to implant contact (BIC) or IT and BIC.*

Objective: *To compare RFA, IT, and BIC of SLA, SLActive, Euroteknika, and TiUnite implant surfaces and evaluate the correlation between them.*

Materials and Methods: *Thirty-two implants were placed in 8 sheep. RFA and IT were recorded. Animals were killed at 1 and 2 months.*

Results: *A significant difference was found in RFA between the 4 surfaces. No significant difference was found for IT. Mean BIC was different between all 4 surfaces. A significant positive correlation was found between RFA and IT with SLA. No significant correlation was found between RFA and BIC and between IT and BIC at 1 and 2 months.*

Conclusions: *Implants with 4 different surfaces have similar IT values but different RFA and BIC. Additionally irrespective of the implant surface, there is no correlation between IT and BIC and between RFA and BIC. (Implant Dent 2014;0:1–7)*

Key Words: primary stability, resonance frequency analysis, insertion torque, bone to implant contact

Oral implantology is now a predictable technique for the rehabilitation of edentulous spaces. Attainment of this goal, however, is predicated on the ability of the implant to achieve osseointegration with its bony environment.[1,2] This process passes through a primary stage characterized by mechanical stabilization of the implant (primary stability) and a secondary stage of biological anchorage (secondary stability), that is the osseointegration process.

Primary stability is an essential factor that also plays an important role in the long-term success of dental implants.[3–5] Different methods of evaluating primary stability have been used,[6] including the resonance frequency analysis (RFA)[7] and implant insertion torque (IT) values.[8] Meredith et al[9] first introduced RFA as a noninvasive diagnostic method to evaluate implant stability. The most recent version of implant stability meters is the Osstell ISQ (Osstell AB, Sävedalen, Sweden), which is a wireless device, where a metal rod, a peg, is connected to the implant by means of a screw connection. The peg has a small magnet attached to its top and is excited by magnetic pulses, and the resonance frequency is expressed electromagnetically as an implant stability quotient (ISQ) with units ranging from 1 to 100.[10,11]

Originally described by Johansson and Strid,[12] and later developed by Friberg et al,[13] IT can be measured with appropriate drilling units or with mechanical or digital torque measuring instruments. High implant IT values are recommended when immediate or early implant loading is applied,[14] and thus determining IT during implant placement may be of great clinical value. It is considered to be a precise and established method to evaluate the bone quality and primary stability.[15] However, some controversy issues were raised recently. In fact, Sennerby and Meredith[16] suggested that RFA and IT represent 2 different features of primary

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stability, with the first indicating the resistance to bending load and the later indicating the resistance to shear forces, whereas Turkyilmaz[17] and Alsaadi et al[18] showed a strong correlation between RFA and IT values of implants at the time of implant placement. In a human cadaver study of RFA in orthodontic implants, Gedrange et al[19] found that longer implants provided greater fixation, assuming that more bone contact with the implant surface was necessary for more primary stability and that there is a relationship between resonance frequency and bone to implant contact (BIC). But when Ito et al[20] compared RFA with BIC of the implants placed in the tibia of miniature pigs, they found no correlation between RFA and BIC. Interestingly, they also showed that the correlation coefficient increased when BIC was measured at the neck of the implant, thus demonstrating that a connection between the implant and bone at the neck region of the implant affected RFA most effectively. Degidi et al[21] found no statistically significant correlation between the IT values and BIC in human-retrieved implants. They assumed that this absence of correlation between IT and BIC could be because of a lack of relationship between bone structure and IT or of the fact that primary stability may be influenced by the thickness and density of the cortical layer.

Different implant surfaces have emerged since the first commercially pure titanium implants were used. They underwent a change in the surface roughness among other changes.[22] The aim of the surface modifications was first to augment the BIC as it was the case with SLA[23] and TiUnite implant surfaces[24] and second to augment the rate of bone apposition as it was done with the SLActive implant surface.[25] A similar shift in implant surface was applied in Euroteknika implant that moved from a turned surface to a standard medium rough surface,[26] the Aesthetica implant.

The purpose of our study was first to compare the RFA, IT, and BIC values of 4 different implant surfaces in a sheep model and second to evaluate the correlation between RFA, IT, and BIC values.

MATERIALS AND METHODS

The study was approved by the Ethics Commission at Saint Joseph's University, Beirut, Lebanon.

Animals were housed and operated in the Laboratory of Surgical Sciences at Saint Joseph's University. Eight adult male sheep (3–4 years of age), 45 kg in mean weight, were included in the study.

Surgical Protocol

All surgical procedures were performed under intravenous sedation and local anesthesia. The animals were first sedated using ketamine hydrochloride 3 mL/kg (Rotexmedica GMBH, Trittau, Germany) and xylazine (Rompun; Bayer AG, Leverkusen, Germany), and 0.2 mg/kg local anesthesia consisting of lidocaine 1:100,000 was administered in the surgical area, extra- and intra-orally. The surgical area was shaved, washed, and disinfected with povidone-iodine (Betadine). The inferior edge of the mandible was exposed by a single long incision followed by a separate elevation of the skin and the facial layers. Osteotomies were performed perpendicularly to the inferior edge of the mandible and according to the manufacturer's guidelines of each implant type used. Four different implants were inserted per mandible, 2 implants on each side. For ease of identification, Aesthetica implants with a Euroteknika surface (Euroteknika, Sallanches, France) and NobelActive implants with TiUnite surface (Nobel Biocare, Göteborg, Sweden) were placed in the left side, whereas the 2 Straumann SP implants, with SLA (Straumann, Basel, Switzerland) and SLActive surface (Straumann), were placed in the right side. The Straumann SP and Aesthetica implants were standard tissue level implants, whereas the NobelActive was a bone level type implant. All implants were inserted according to the manufacturer recommendations. The Straumann SP implants and the Aesthetica implants were inserted to the rough and smooth surface junction, whereas the NobelActive implants were inserted at the level of the crest. The surgical site was sutured in a layering approach to avoid flap rupture, using resorbable polyglactin 910 sutures (Vicryl 5/0; Ethicon, Sommerville, NJ). The flaps intentionally covered all implants, including tissue level implants because the authors were highly concerned about any implant removal or accidental implant loss by the animals. A single dose of antibiotic (Alamycin 20 mg/kg; Norbrook, Northamptonshire, United Kingdom) was administered postoperatively. The sutures were removed at the first week. Animals were fed with a soft diet throughout the first 2 weeks and then a standard diet afterward.

Table 1. Distribution of Implants by Sheep (n = 8)

	Right Mandible		Left Mandible			
Sheep	SLA	SLActive	Euroteknika	TiUnite	Total	Sacrified at
1	4.1 × 12SP RN	4.1 × 12SP RN	4.1/4.8 × 12	4.3 × 11.5RP	4	1 mo
2	4.1 × 12SP RN	4.1 × 12SP RN	4.1/4.8 × 12	4.3 × 11.5RP	4	1 mo
3	4.1 × 12SP RN	4.1 × 12SP RN	4.1/4.8 × 12	4.3 × 11.5RP	4	1 mo
4	4.1 × 12SP RN	4.1 × 12SP RN	4.1/4.8 × 12	4.3 × 11.5RP	4	1 mo
5	4.1 × 12SP RN	4.1 × 12SP RN	4.1/4.8 × 12	4.3 × 11.5RP	4	2 mo
6	4.1 × 12SP RN	4.1 × 12SP RN	4.1/4.8 × 12	4.3 × 11.5RP	4	2 mo
7	4.1 × 12SP RN	4.1 × 12SP RN	4.1/4.8 × 12	4.3 × 11.5RP	4	2 mo
8	4.1 × 12SP RN	4.1 × 12SP RN	4.1/4.8 × 12	4.3 × 11.5RP	4	2 mo
Total	8	8	8	8	32	

Implants were inserted in the right and left mandible according to their surface type. A total of 32 implants were used.

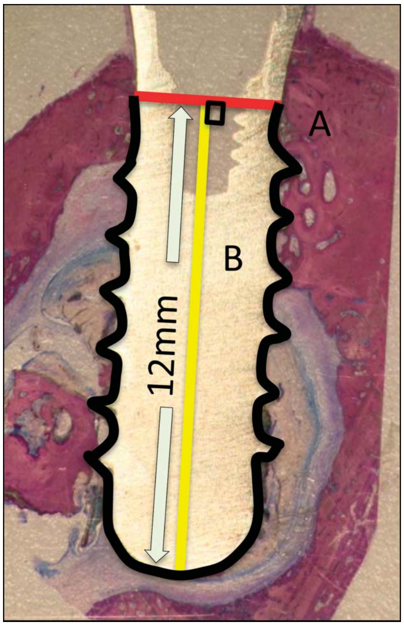

Fig. 1. The black line represents the implant surface available (ISA). It starts and ends at the intersection between the outer surface of the implant and a perpendicular line (red line A) to a 12 mm line (yellow line B) drawn in the center of the implant, starting at the tip of the implant. The 12-mm being the rough surface available on a 12-mm Straumann Standard Plus implant. The same was applied with Aesthetica implant. With NobelActive implant, ISA starts and ends at the implant shoulder.

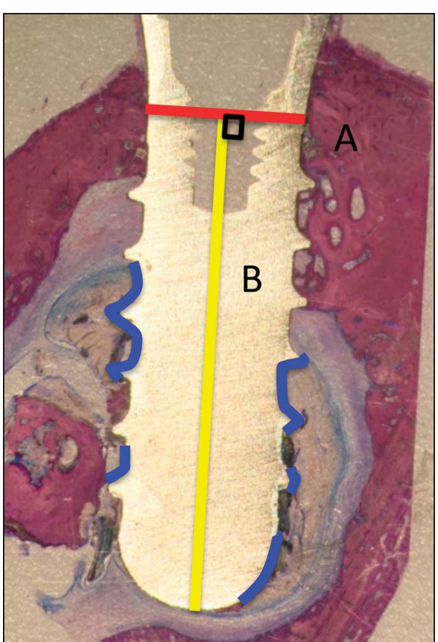

Fig. 2. The blue line represents the implant surface in contact with bone (ISB). Bone to implant contact was marked all along the length of the implant, in the predetermined ISA.

A total of 32 implants were placed. Implant length, diameter, and distribution are detailed in Table 1.

Implant Surfaces

The TiUnite implant surface has an anodized surface, with a surface oxide thickness of some 10,000 nm. The surface is now considered to be more hydrophobic than previously with the first TiUnite.[27]

The SLA surface is produced by a large grit sandblasting process with corundum particles that leads to a macroroughness on the titanium surface. This is followed by a strong acid etching bath with a mixture of HCL/H_2SO_4 at elevated temperature for several minutes. This produces 2- to 4-μm micropits superimposed on the rough-blasted surface.

In 2006, SLActive surface was introduced. It shifted from the hydrophobic surface to a hydrophilic surface.

Euroteknika implant surface has a sandblasted surface with 100- to 150-μm Ti-O2 granules. Implants are first soaked in different bathing agents of nitric acid and then acid etched using fluoridic acid. In this article, Euroteknika refers to the surface.

IT and RFA Measurements

IT values of the placed implants were recorded using a computer-assisted device (Precision Electronic Torsion-Meter; DTA by Studio AIP, Oggiona S. Stefano (VA), Italy). Recorded values consisted of a series of continuous numbers, related to a chart from the beginning till the end of the implant insertion. The final seating value was considered. Then the implant stability was measured using RFA with the Osstell ISQ (Osstell AB). Three measurements were taken per implant, and the average was recorded as final.

Histologic and Histomorphometric Analysis

Four sheep were killed at 4 weeks after implantation and the other 4 were killed at 8 weeks using an overdose of sodium thiopental.

After they were killed and the mandibles were dissected, the biopsies were thoroughly rinsed and immediately immersed in freshly prepared 10% neutral buffered formalin for fixation.

Table 2. RFA Measurements as Recorded for the 4 Different Implants

Measurements	RFA		
Implant	Mean	SD	N
SLA	73.5	4.43	8
SLActive	73.54	3.09	8
TiUnite	78.28	1.94	8
Euroteknika	75.46	3.78	8
Total			32

Undecalcified histological sections were obtained according to the method described by Donath and Breuner[28] for mineralized tissues. After fixation, the specimens were dehydrated, embedded in glycolmethacrylate (Technovit 7200VLC; Kulzer and Co Gmbh, Wehrheim, Germany), and then polymerized for 8 hours (Light Polymerization Unit; Exakt-Apparatebau GmbH & Co. KG, Norderstedt, Germany). Sections of approximately 200 μm were obtained using a diamond saw with coolant (Cutting Machine; Exakt-Apparatebau GmbH & Co. KG), then reduced to a final thickness of 50 μm using the abrasion machine (Exakt-Apparatebau GmbH & Co. KG), and subsequently stained with Giemsa-Paragon. Histomorphometric measurements were done using a light microscope (Olympus BX 60; Olympus Corporation, Tokyo, Japan) connected to a digital camera (E330; Olympus Corporation). After calibration, BIC was quantified using Image Tool 3.0 software (UTHSCSA, San Antonio, TX). From each specimen, 4 sections were analyzed and measured.

Measurements were done as described by Arisan et al.[29] The linear surface of the implant in direct contact with bone (ISB) and the total implant surface available (ISA) were measured. The percentage of BIC was thus

Table 3. IT Values As Recorded for the 4 Different Implant Surfaces

Measurements	IT		
Implant	Mean	SD	N
SLA	74.86	25.32	8
SLActive	57.35	43.53	8
TiUnite	77.73	28.56	8
Euroteknika	84.41	31.89	8
Total			32

Table 4. BIC Values As Recorded for the 4 Different Implant Surfaces

BIC	Sacrificed at	Mean	SD	N
SLA	1 mo	18.24	7.74	4
	2 mo	40.49	13.79	4
SLActive	1 mo	30.56	11.04	4
	2 mo	27.6	8.35	4
TiUnite	1 mo	24.59	3.85	4
	2 mo	51.31	15.19	4
Euroteknika	1 mo	32.66	13.69	4
	2 mo	46.44	29.48	4
Total				32

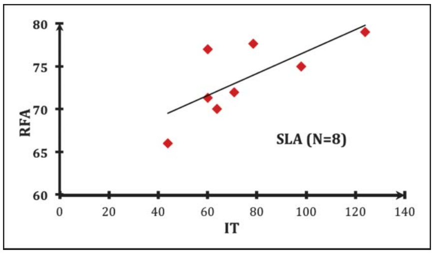

Fig. 3. Correlation between RFA and IT in SLA implant (r = 0.734; $P = 0.038$; n = 8).

calculated as follows: %BIC = (ISB × 100)/ISA as seen in Figures 1 and 2.

Statistical Analysis

The statistical analysis was performed using SPSS for Windows version 17.0. The alpha error was set at 0.05. Shapiro–Wilk tests were used to test the normality of the distribution. ANOVA followed by Tukey *post hoc* test or Kruskal–Wallis followed by Mann–Whitney tests were used to explore significant difference between mean values. Pearson or Spearman correlation coefficient was used to explore a significant association between two continuous variables.

RESULTS

Healing was uneventful for all implants placed, with no wound dehiscence, infection, or implant loss. All implants were clinically stable on the day they were killed.

Resonance Frequency Analysis

RFA measurements were made at implant insertion. All implants scored a high ISQ of more than 65. RFA values at implant placement were significantly higher with TiUnite (78.28 ± 1.94) followed by Euroteknika (75.4 ± 3.78). No significant difference was found between SLA and SLActive implants ($P = 1.000$) (Table 2).

Insertion Torque

IT values were recorded for all implants. Recorded values varied considerably. No significant difference was found between the 4 implant surfaces ($P = 0.422$). The highest IT value recorded was 84.41 ± 31.89 with the Euroteknika implant, whereas the lowest IT value measured was 57.35 ± 43.53 with the SLActive implant. The rest were intermediate values, as shown in Table 3.

Table 5. Correlation Between IT and BIC for Each Implant System at 1 and 2 Months

Sacrifice			1 Month	2 Months
Implant			BIC	
SLA	IT	Correlation coefficient	0.226	−0.931
		P	0.774	0.069
		N	4	4
SLActive	IT	Correlation coefficient	0.472	−0.603
		P	0.528	0.397
		N	4	4
TiUnite	IT	Correlation coefficient	−0.004	0.701
		P	0.996	0.299
		N	4	4
Euroteknika	IT	Correlation coefficient	0.592	0.834
		P	0.408	0.166
		N	4	4

Bone to Implant Contact

Histomorphometric measurements were made to calculate mean BIC for all implants, at 1 and 2 months. With SLA, and TiUnite, the mean BIC has significantly increased between 1 and 2 months. With SLA, recorded BIC at 1 month was 18.24 ± 7.74 and it increased to 40.49 ± 13.79 at 2 months ($P = 0.031$), and with TiUnite, BIC shifted from 24.59 ± 3.85 at 1 month to 51.31 ± 15.19 at 2 months ($P = 0.014$). Although BIC increased between 1 and 2 months with Euroteknika implants (32.66 ± 13.69 at 1 month; 46.44 ± 29.48, at 2 months) the increase was not statistically significant ($P = 0.429$). With SLActive implants, no significant difference was found in measured BIC between 1 and 2 months ($P = 0.680$) (30.56 ± 11.04 at 1 month; 27.60 ± 8.35 at 2 months) (Table 4).

Correlation

Correlation was studied between RFA and IT and RFA and BIC at 1 and 2 months and IT and BIC at 1 and 2 months.

A significant high positive correlation was found between IT and RFA in the SLA group (r = 0.734; $P = 0.038$; n = 8) (Fig. 3). This correlation was not significant for the other implant systems.

No significant correlation was found between RFA and BIC, for each implant system at 1 month ($P > 0.05$) and 2 months ($P > 0.05$) (Table 4).

No significant correlation was found between IT and BIC, for each implant system at 1 month ($P > 0.05$) and 2 months ($P > 0.05$) (Table 5).

DISCUSSION

The aim of this study was to compare RFA, IT, and BIC values of 4 different implant surfaces and to evaluate any correlation existing between these criteria.

1. Comparison Between the Implant Systems

We have compared the implant stability of the 4 different implants using

Osstell ISQ. RFA measurements were significantly different between the 4 implants (*P* = 0.032).

They were significantly higher with NobelActive implants with a TiUnite surface (78.28 ± 1.94), followed by Aesthetica implants with a Euroteknika surface (75.46 ± 3.78).

Environmental factors can cause high variations in implant stability values even when implants are located next to each other. Among other factors are bone quality at the implant site, thickness of the cortical layers, anatomical location of the implant site,[30] and operator-related factors, such as transducer positioning.[31] The effects of those factors were reduced in our experimental study because the bone at the implant sites was clinically the same. As the implants were placed next to each other (2 implants per side of the mandible), the thickness of the cortical layers could not differ significantly. An effort was also made to identically place the transducer for recording procedure.

The shape of the implant[32] and its surface properties may play a role in the outcome of stability assessment. In our study, the implants differed by their shape, by their surface, or even by both. The NobelActive implant that statistically scored the highest RFA values has a tip and a thread design that slices through bone and condenses bone as it is inserted, with a TiUnite surface that is proven to accelerate osseointegration over machined surface implants.

The SLA and SLActive implants that scored statistically the lowest RFA values have been sandblasted with high diameter particle (large grit). The macroporosity of the surface is higher. The positive effect of the roughness surface made by bigger particle has a negative effect on the geometry of the implant. With bigger particles, the edges of the threads are round. The result is that the implant requires high torque for insertion because of the fact that it is not cutting the bone.

The variation, although statistically significant between NobelActive and Aesthetica versus the Straumann SP implants, could also be due to a drilling protocol sequencing that could lead to a different implant IT values as 1 implant would be inserted more rigidly than the other. Noteworthy is the fact that all ISQ values were within the acceptable range of more than 65 and that the difference in ISQ was not worrisome because all implants reached osseointegration and none was lost. Thus, it would be interesting to study the ISQ values of those same implants over time as suggested by Lachman et al[33] who does not recommend the use of Periotest and Osstell devices for a comparison of the stability of 2 individual implants.

When comparing the IT values of the 4 different implants used, no significant difference was found between the 4 implants. IT values ranged between 53.75 N·cm for SLActive implants and 84.41 for Euroteknika implants. Those results were not surprising for SLActive implants given the nonengaging macrogeometry of Straumann SP implants. Trisi et al[34] correlated the IT to bone density and to micromotion, and later suggested that an increase in peak IT would reduce the extent of micromotion.[35] In our study, IT values were high for all 4 implants. Thus, it could be assumed that all 4 implants reached a reduced level of micromotion, below the 50 to 100 μm acceptable threshold, above which micromotion would induce bone resorption at the interface and a fibrosis around endosseous implants.[36–38] We should note that standard deviations were all elevated and a bigger sample would be more appropriate to confirm the results. A high value of IT reduces micromotion at the interface and is of interest in immediate loading cases where failure of osseointegration has been imputed to micromotion because of immediate loading.[39]

BIC was measured histomorphometrically for all 4 implants, at 1 and 2 months. Not all implants followed the same trend of bone deposition over the implant surface, as the calculated BIC shows over time. In general, one would expect more BIC with a rough surface implant as demonstrated by Ivanoff et al,[24] Wennerberg et al,[40] and Novaes et al,[41] when compared with smooth surfaces. Mean BIC of SLA implants significantly increased between 1 and 2 months, whereas it did not with SLActive implants. It is well accepted now that the main factor that influences bone apposition to an implant is the surface characteristics.[42] This has been clearly demonstrated by Buser et al[23] who showed a positive correlation between the percentage of BIC and roughness values of 5 different titanium surfaces tested. Cochran et al[43] also demonstrated that more BIC at 0 and 12 weeks was obtained with SLA implants when compared with titanium plasma sprayed (TPS) implants in a canine model. Moreover, it has been recognized that surface chemistry is another factor influencing BIC. Increasing both surface energy and wettability have an influence on bone apposition.[44–46] When Buser et al[25] compared bone apposition between SLA and SLActive implants, BIC was greater with SLActive after 2 and 4 weeks, but both surfaces showed similar results at 8 weeks. This difference in bone apposition pattern between SLA and SLActive could, in part, explain the results obtained in this study. In fact, according to the study by Buser et al,[25] we could expect the almost complete apposition to have been achieved at 4 weeks on the SLActive surface, whereas it continues on the SLA surface. In a recent human study, Lang et al[47] also showed that BIC was statistically significantly greater for SLActive at 28 days than for SLA. In our study, BIC with the NobelActive implant significantly increased between 1 and 2 months. This is in accordance with the study by Gottlow et al[48] who obtained higher BIC for SLActive implants after 10 days and then higher BIC values for TiUnite implants after 6 weeks. This meant that bone apposition was still active at 6 weeks for the TiUnite implant.

Mean BIC with Aesthetica implant has increased between 1 and 2 months. However, the difference was not statistically significant (*P* = 0.429). This could be in part because of the surface properties of the Euroteknika implant and to the fact that a high BIC was already reached at 1 month.

2. Correlation

RFA and IT. A significant high positive correlation was found between RFA and IT in SLA group (r = 0.734; *P* =

0.038; n = 8). This is in accordance with Trisi el al.,[35] who showed that IT increased primary stability and with Turkyilmaz[17] and Al Saadi et al.[18] However, other studies reported no correlation between IT and RFA.[16,17] Moreover, Al Nawas et al[15] showed that IT values for failed and successful implants were not statistically different. Interestingly, no significant correlation was found for the other implant groups. Those results need to be carefully interpreted, given the small sample studied. This clearly calls for more studies and higher numbers of studied samples.

RFA and BIC. No significant correlation was found between RFA and BIC, for each implant system at 1 month ($P > 0.05$) and 2 months ($P > 0.05$). Yet, all implants in this study were clinically stable at both 1 and 2 months. This is in accordance with Rodrigo et al[49] who considered RFA measure of primary stability as not valuable in predicting implant outcome. Moreover, according to Trisi et al,[50] micromotion is the only direct measurement of primary stability, and Osstell ISQ, which does not measure micromotion, must be considered only as being capable of approximate measurement.

IT and BIC. When studied separately, no significant correlation was found between IT and BIC, for all implant systems at 1 month ($P > 0.05$) and 2 months ($P > 0.05$). The absence of a significant positive correlation between IT and BIC, in different implant systems, is in agreement with Vercaigne et al[51] who compared TPS and HA-coated implants, in an experimental study in goats, and failed to find a correlation between IT and BIC. The lack of correlation between IT and BIC with the studied implants could be related to the small samples studied. In fact, when Degidi et al[21] found no statistically significant correlation between IT and BIC values, on human-retrieved implants, they likewise related this lack of correlation between IT and BIC values to a small sample size and a difference in implant types and geometries.

Conclusions

This study showed that although implants with 4 different surfaces can have comparable IT values, RFA and BIC could be different. Moreover, there is no correlation between IT and BIC and between RFA and BIC, regardless of the implant surface.

Disclosure

The authors claim to have no financial interest, either directly or indirectly, in the products or information listed in the article.

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