Relationship Between Insertion Torque and Resonance Frequency Measurements, Performed by Resonance Frequency Analysis, in Micromobility of Dental Implants: An *In Vitro* Study

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Purpose: *To evaluate the micromobility of dental implants under occlusal loading in relation to stability measurements of resonance frequency analysis and insertion torque.*

Materials and Methods: *The sample comprised of 24 implants inserted in 12 fresh cow ribs. Insertion torque and Osstell implant stability quotient (ISQ) measurements were recorded. An* "ad hoc" *acrylic premolar was made on a temporary abutment and screwed to each implant, and a force of 100 N was subsequently applied at an angle of 6 degrees. Implant micromotion was measured using a Questar microscope with a resolution of 2 μm and an image analysis program.*

Results: *Data show a statistically significant inverse correlation between the ISQ values and implant micromotion under a load of 100 N ($R^2 = 0.86$, P < 0.0001). The same relationship is found between insertion torque and implant micromotion, although the relationship is linear up to 34 N·cm and becomes exponential for higher values ($R^2 = 0.78$, P $<$ 0.0001). A direct correlation is established between insertion torque and ISQ values.*

Conclusion: *There is an inverse relationship between both ISQ and insertion torque values and implant micromotion under a load of 100 N.*

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Key Words: implant stability quotient, dental implant micromotion, implant stability

During surgical insertion of a dental implant into the maxillary bone, various factors may adversely affect the initial osseointegration. Some are related to the surgical technique (excessive heat and torque) and others to a lack of primary stability and/or initial overload. In a way similar to a broken bone, which needs to be fixed so that all biological phenomena that lead to bone healing can occur,[1] dental implants also require an absence of clinical mobility, so that a fibrous bone-implant interface does not developed and osseointegration takes place instead. Implant micromotions in a range between 50 and 150 μm are well tolerated and not detrimental to the achievement and maintenance of osseointegration[2–4]; however, if above these values, a predominance of the fibrous interface could be expected.

To achieve the required primary stability, a certain insertion torque of the implant is needed. Torque cannot be excessive so as not to increase the periimplant bone stress, leading to increased bone resorption, lack of osseointegration, and implant failure. Although each implant manufacturer recommends a certain maximum insertion torque, usually in a range between 35 and 70 N·cm, several authors argue that torques below 25 N·cm do not cause failure of osseointegration, even

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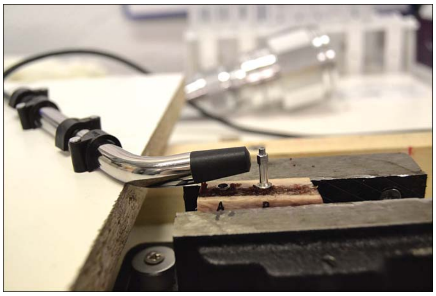

Fig. 1. Detail of the measurement of parallel ISQ (to the longitudinal axis of the implant) of one of the implants of the sample.

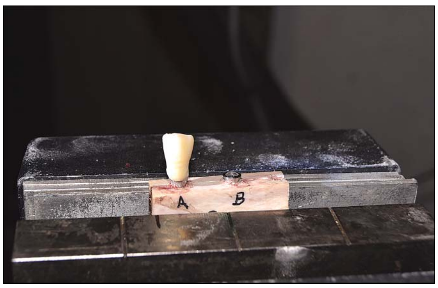

Fig. 2. Crown screwed down, and the rib located on the clamp of the load creep-testing machine.

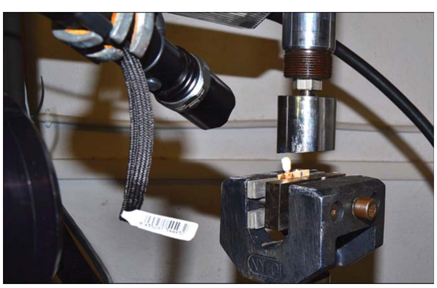

Fig. 3. Crown on the clamp and the upper arm of the load creep-testing machine. The Questar microscope is visible in the upper left corner of the image.

Table 1. Mean and Range of the Different Variables

Parameters	N	Mean	Range
Peak insertion torque (N·cm)	19	32.7 (20.9)	10–73
RFA perpendicular ISQ	19	68.2 (6.9)	56–79
RFA parallel ISQ	19	72 (6.5)	59–83
Micromotion (μm)	19	68.2 (44.3)	14.6–164

SD given in parentheses.

in immediate loading protocols.[5] Then, if primary stability is achieved for a known insertion torque, quantifying the implant micromotion at this early stage will allow forecasting of implant failure and even assessment of the influence of torque values on implant stability.

Among the various methods proposed to assess implant stability, resonance frequency analysis (RFA) by the Osstell implant stability quotient (ISQ) (Osstell AB, Goteborg, Sweden) is commonly used.[6–8] This method is based on measuring the oscillation frequency of the implant in the bone, transforming their values from Hertz to ISQ; it has been shown *in vitro* that ISQ values increase with increasing stiffness of the bone-implant interface,[7] and animal bone models show inverse correlation between ISQ values and lateral implant displacement values under load, measured with a micrometer.[8,9]

In this context, the evaluation of relationship between insertion torque, ISQ values, and implant micromotion under load remains unfinished and requires extended clarification. Therefore, our hypothesis states that there is an inverse correlation of implant micromotion under functional loading with ISQ and insertion torque values. The aim of this study was to evaluate measurements of implant micromotion under occlusal loading and relate them to ISQ and insertion torque values. Another objective was to show the relationship of ISQ and insertion torque with implant stability.

MATERIALS AND METHODS

Specimens and Implants

The sample consisted of 12 fragments of fresh cow ribs without periosteum (size = 50 × 18 × 15 mm), simulating a bone of quality type 1 and 2 from Lekholm and Zarb classification,[10] which were stored for 5 days in a 50% ethanol and saline solution at room temperature, according to the method described by Tricio et al.[11] Two Klockner Essential Cone implants (Soadco S.L., Escaldes Engordany, Andorra), 10 mm in length and 4 mm in diameter and with an internal connection and polished neck (1.5 mm), were randomly placed 20 mm apart in each rib. The bed of each implant was introduced by drilling, using a surgical kit box and following the protocol established by the manufacturer: ∅ 1.8-mm initial drill, ∅ 2.8-mm pilot drill, ∅ 4.5-mm countersink drill, and ∅ 3.6-mm final drill.

Measurement Procedures and Data Recording

Each implant was screwed onto a rib using a calibrated BTG90CN (Tohnichi, Tokyo, Japan) analog dynamometer that records insertion torque in newton centimeters. In all cases, the polished neck of the implant was outside the bone. The initial ISQ values were then recorded with an ISQ Osstell machine (Osstell AB) using a Smartpeg (Osstell AB) screwed to the implant with torque of 4 to 6 N·cm, as recommended by the manufacturer. Measurements were made parallel (parallel ISQ) and perpendicular (perpendicular ISQ) to the longitudinal axis of the bone, changing the transducer every 10 measurements (Fig. 1). For the loading tests, an *ad hoc* lower premolar was prepared by heat-curing acrylic on a temporary abutment, which was screwed to each implant of the sample with a torque of 10 N·cm, which was unscrewed and screwed into another implant once each test was concluded (Fig. 2). For the loading simulation, a previously calibrated servohydraulic testing machine, MTS BIONIX 358 (MTS Sensor Technologie GmbH & Co. KG, Lüdenscheid, Germany), was used, equipped with a load cell of 2.5 kN and TestStar II software (MTS Sensor Technologie GmbH & Co. KG, Lüdenscheid, Germany). To conduct the tests, an upper mechanical clamp was prepared to apply stresses at an angle of incidence of 6 degree of inclination to the premolar occlusal plane, at a rate of 10 N/s for a maximum load of 100 N.[12] Before and after each load test, images were taken at a constant distance of 30 cm with a Questar QM 100 microscope (long distance traveling microscope) with a resolution of 2 μm (Seven Astro-Optics Division, Laurel, MD)

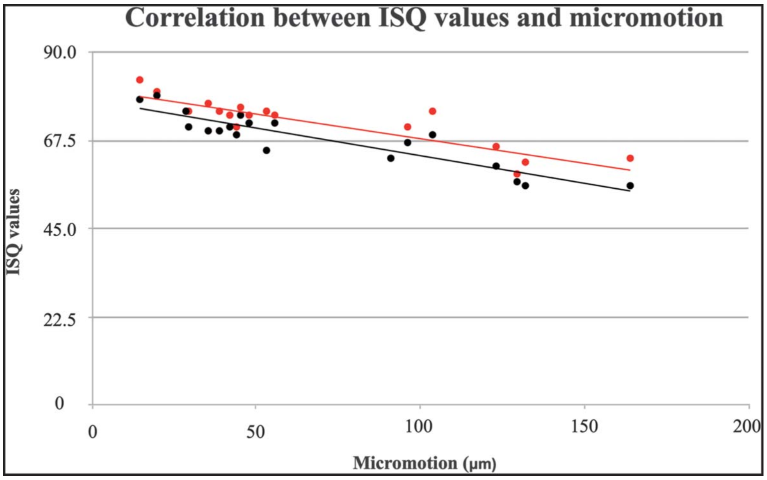

Fig. 4. Correlation between parallel ISQ and micromotion (in red color) ($R^2 = 0.74$, $P \leq 0.0001$) and between perpendicular ISQ and micromotion (in black color) ($R^2 = 0.82$, $P \leq 0.0001$).

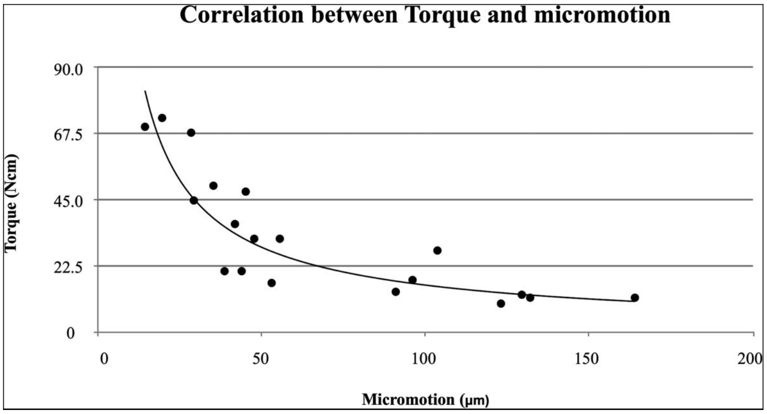

Fig. 5. Correlation graph between insertion torque and micromotion. ($R^2 = 0.78$).

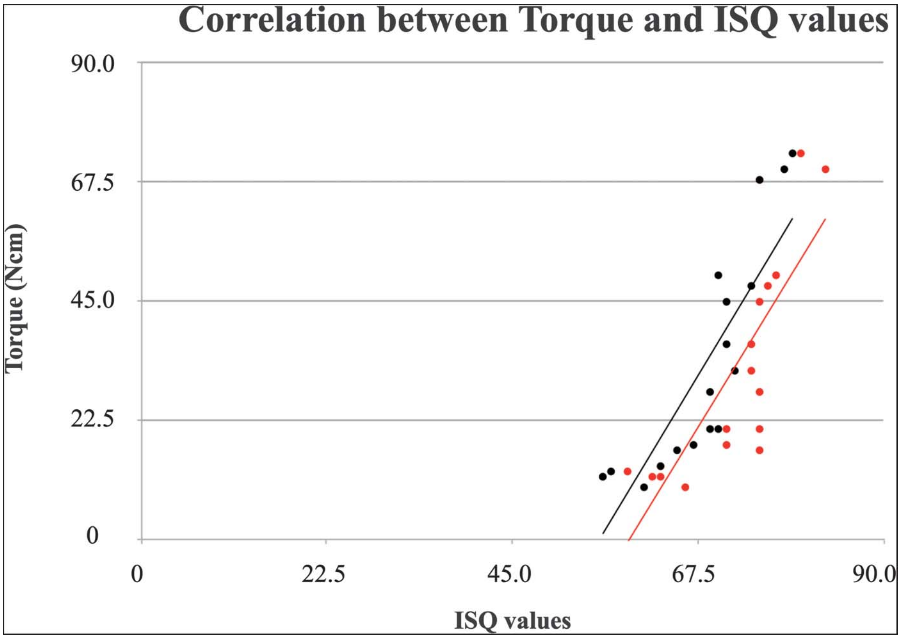

Fig. 6. Correlation between torque and parallel ISQ (in red color) ($R^2 = 0.62$, $P \leq 0.0001$) and between torque and perpendicular ISQ (in black color) ($R^2 = 0.73$, $P \leq 0.0001$).

(Fig. 3). These captured images were processed using IMAGE-J version 1.47 image analysis software (National Institutes of Health, Bethesda, MD), evaluating implant micromotion by controlling displacement of a minimum of 5 points per component and determining the 2-dimensional unit displacement of the sample on the *x* and *y* axes, respectively, under 2 loading levels, 0 and 100 N, respectively.

Statistical Analysis

The Pearson correlation coefficient was used to calculate possible relationships between the different variables studied (ISQ, micromotion, and insertion torque). If $P < 0.05$, the hypothesis of independence is rejected, and the variables are considered to be related.

RESULTS

The final sample was composed of 19 implants in 10 ribs because 5 implants were excluded from the study as their insertion torques were less than 10 N·cm or greater than 90 N·cm, which are the minimum and maximum measurement limits of the torque meter, respectively.

Table 1 shows the statistics of the study variables and their statistical significance. Figure. 4 shows the relationship between implant micromotion and parallel and perpendicular ISQ values. For both, an inverse linear relationship is established with Pearson correlation coefficients of 0.86 and 0.91, respectively, such that with increasing ISQ, implant micromotion decreases. A similar tendency is observed for the insertion torque by implant micromotion ratio; however, in this case, the plot is an exponential curve, such that below a torque of 30 N·cm, micromotion increases considerably, and above this threshold value, a gently progressive reduction of micromotion is observed with increasing insertion torque. It was calculated that each torque increase of 1 N·cm above 34 N·cm corresponded to approximately less than 1 μm decrease in implant micromotion (Fig. 5). However, Fig. 6 shows a direct relationship between insertion torque and perpendicular and parallel ISQ values, with Pearson correlation coefficients of 0.86 and 0.79, respectively.

DISCUSSION

This study shows an inverse and statistically significant correlation, with strong association, between ISQ values and implant micromotion under a load of 100 N slightly inclined with respect to the implant (6 degrees). This finding indicates that the larger the implant ISQ value is, measured in either direction, the lower its micromotion will be, under a given load. These results are consistent with the results reported by other authors applying similar designs, although there is difference in the strength and inclination of the load.[8,9] The clinical relevance of this finding is that it is likely the relevant tendency because, excluding other limitations of the study, the experimental conditions were similar to the biomechanical atmosphere of a premolar inside the mouth.[12] Additionally, the ISQ value of 57 obtained from the data corresponds to an implant micromotion of 150 μm, regarded as the upper threshold that should not be exceeded to achieve and maintain osseointegration.[13] This finding agrees with the results of the clinical study by Sjöström et al,[14] which reports an association between primary ISQ values below 56.4 and increased implant failure.

Nonetheless, our data also establish that there is an inverse relationship between insertion torque and likely implant micromotion under load, represented by a curve in which significant torque increases from a certain value (34 N·cm) do not result in a large decrease in micromotion. In contrast, for values below 22.5 N·cm, a small decrease in torque results in a large increase in micromotion. According to this finding, there would not be clinical justification to use a high insertion torque, as indicated by Khayat et al,[15] given that large differences in the stability of the implant would not be obtained, whereas a high torque could cause plastic deformation of the bone during implant insertion and could even fracture the threaded bone bed, as reported in a former study by Ueda et al,[16] with torques of 50 and 70 N·cm. Additionally, our results show that an insertion torque of only 11.57 N·cm is needed for implant micromotion under loads of 100 N to be less than 150 μm. This finding is in agreement with clinical studies and studies in human cadaver, showing no significant differences in osseointegration when implants were inserted with torques below 25 to 20 N·cm,[5,17] and also explains the results of another study in an animal model reporting less bone apposition and reduced removal torque for control implants, inserted with an average torque of 10 N·cm.[18]

Although insertion torque and RFA, measured as ISQ, are 2 indicators of the stability of the implant, they do not measure or reflect exactly the same mechanical conditions. Insertion torque measures the mechanical frictional resistance of the bone bed to apical implant advance, rotating about its longitudinal axis, whereas ISQ is based on the rigidity of implant contact with its bed and therefore its resistance to lateral displacement. Even with these differences, this study reports a directly proportional and significant relationship between insertion torque and ISQ values measured in 2 directions under a load of 100 N. The result stating that increasing the insertion torque increases ISQ by a certain ratio—and therefore applying more torque would increase ISQ and provide greater primary stability—is controversial because there are studies that show a significant relationship between the 2 variables,[17,19] whereas others do not reach the same conclusions.[20–22] This lack of agreement regarding insertion torque and ISQ can be explained in certain clinical circumstances and must be taken into account. For example, in the study of Akkocaoglu et al[23] in immediate postextraction implants placed in a human cadaver, the existence of an apical implant fixation in the cortical bone leads to a high implant insertion torque, but for a coronal gap with alveolar bone greater than 1 mm, ISQ values are relatively low.

CONCLUSION

Considering the limitations of previous studies and according to this study's results, our conclusions are the following:

1. Insertion torque and ISQ values relate inversely with implant micromotion under an occlusal loading of 100 N. Therefore, the initial hypothesis is supported.
2. The relationship between ISQ and implant micromotion is linear and exponential with insertion torque, with a progressive increase in micromotion with decreasing insertion torque and ISQ values.
3. An ISQ value of 57 and an insertion torque of 11.57 N·cm correspond to 150 μm of micromotion.
4. A directly proportional relationship is established between ISQ and insertion torque values.

DISCLOSURE

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

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