Original Article

Resonance Frequency Analysis Mapping During Implant Healing Using a Nanostructured Hydroxyapatite Surface

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ABSTRACT

Aim: Stability measured by resonance frequency analysis (RFA) is an important factor to be considered in the success of dental implant treatments, which can be evaluated from the implant stability quotient (ISQ). The aim of the present case series was to map the RFA during healing of implants with nanostructured hydroxyapatite surface to describe the behavior of ISQ values related to individual factors. **Materials and Methods:** Twenty-three implants were placed in eight patients by conventional surgical protocol, and ISQ values were monitored from the day of implant placement until week 20. To obtain the ISQ values, an Osstell device was used and the placed implants were grouped in proportional amounts to describe the ISQ behavior considering the length (≤10 or >10 mm), the diameter (3.5 or 4.3 mm), the insertion torque (<40 N-cm or ≥40 N-cm), and the placement area (maxilla or mandible). **Results:** All the implants assessed decreased their values in the first 3 weeks after placement. Subsequently, the ISQ values increased by amounts similar to those obtained at the time of the placement and even more. Implants with length >10 mm, diameter 4.3 mm, and insertion torque ≥40 N-cm showed the highest ISQ values. **Conclusions:** A decrease in the ISQ values of dental implants with nanostructured hydroxyapatite surface was evidenced between weeks 2 and 3 considering length, diameter, insertion torque, and maxillary or mandibular placement site.

Keywords: *Dental implants, nanostructured hydroxyapatite, osseointegration, resonance frequency analysis, wound healing*

Introduction

Nanotechnology refers to technology related to small structures or small-sized materials. Its application in dentistry is extensive, including oral implantology, with various nanostructures being incorporated into the implant surface to improve its osseointegration.[1,2]

The use of dental implants is an increasingly widespread treatment option that achieves good esthetic and functional results in the rehabilitation of patients requiring single, partial, or complete dental prostheses.[3,4] In the last 20 years, this type of oral rehabilitation has proposed more attractive alternatives for patients, reducing treatment time and improving comfort and satisfaction with predictable results.[5]

One of the great advances in oral implantology is the better knowledge of implant stability, defined as the absence of clinical mobility, which is considered an essential factor for treatment success.[6] Initially, the stability of the implant is produced mechanically by

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means of macro retentions that penetrate the bone walls of the surgical site, a stage known as primary stability. A few days later, bone resorption occurs during early healing of the implant, resulting in the loss of mechanical retention, and the primary stability is replaced by a biological union, a stage called secondary stability or osseointegration, which causes a temporary decrease in the stability.[7-9]

In recent years, various implant surface technologies have been introduced to improve osseointegration and reduce treatment time, allowing immediate or early functional loading in patients with reduced bone density.[10] One of the novel technologies is the incorporation of bioactive surfaces such as nanostructured hydroxyapatite. This technique uses the coating of nano-sized crystalline hydroxyapatite on the implant surface, demonstrating positive effects on the bond strength between titanium and bone.[11]

Considering that implant stability is an important factor for osseointegration, many clinicians use this concept to monitor the success of the treatment. In this sense, several techniques have been suggested to determine it, being the resonance frequency analysis (RFA) one of the most used. The RFA uses the Osstell device to quantitatively assess implant stability by providing information on the stiffness of the bone-implant junction and recording it in an index called implant stability quotient (ISQ) ranging from 1 to 100, with 100 being the highest stability.[12,13]

Recently, Huang *et al.*[14] described several factors that may influence ISQ measurements such as implant location, diameter and length, insertion torque, macro and micro design, bone type, number of implants, and surgical technique among others. However, in the current literature, these factors have been analyzed considering implant surfaces treated mainly with mechanical, physical, and chemical techniques. Because nanotechnology surfaces have only recently been introduced, not much information is yet available. It is of great importance to know and understand the ISQ values on these surfaces because of their clinical and practical application.

Therefore, the aim of this case series was to perform RFA mapping during the healing of implants with nanostructured hydroxyapatite surfaces to describe the behavior of ISQ values related to individual factors.

Materials and Methods

The present study was developed in the teaching clinic of the Specialty of Periodontology and Implantology of the Faculty of Stomatology of the Inca Garcilaso de la Vega University, Lima-Peru, between 2017 and 2019, after obtaining the informed consent of all the patients. This research was approved by an ethics committee of the same faculty with resolution No. 007-2020-DFE-UIGV.

Eight patients with partial edentulism (five women and three men; age range: 20–79 years) requiring dental implant treatment were included in the study. In addition, a form was prepared to collect information from patients. Patients with the periodontal disease received motivational sessions, oral hygiene instructions, and periodontal treatment. Inclusion criteria were: controlled systemic diseases, no known allergies, nonsmokers, and adequate quantity and quality of remaining bone to achieve primary implant stability. Exclusion criteria were: bruxism, active periodontal disease or untreated periapical pathology, and pregnant women.

Before the surgeries, bone locations were analyzed by radiographic (periapical and panoramic radiographs) and tomographic examinations for the planning of future implant placement. The 23 SIN-UNITITE implants (Unitite; S.I.N. Implant System, São Paulo, Brazil) were placed by conventional surgical protocol and by the same surgeon.

RFA was performed using the Osstell device (Integration Diagnostics AB, Göteborg, Sweden) according to the manufacturer's recommendations. First, the Smartpegs were screwed onto the implants and three consecutive measurements were performed using the device probe directed laterally from buccal to lingual/palatal and from mesial to distal, displaying the ISQ on the device screen. Then, the ISQ value was calculated for each implant considering the average value of the two sides. This procedure was performed at the end of implant placement, at the time of suture removal, and every 7 days thereafter, with follow-up until week 20. The implants received healing screws after placement, were unscrewed at each ISQ measurement, and did not receive any provisional prostheses during the observation period.

Postoperative pain and edema were controlled with ibuprofen (400 mg tablets three times a day for the next 3 days).[15] Patients were instructed to rinse twice daily with 0.12% chlorhexidine digluconate and to use oral hygiene procedures in the treated area for the first 4 weeks postoperatively.

ISQ values were analyzed considering the average values obtained from 21 implants from baseline to week 20 since two implants failed to osseointegrate and were lost. Likewise, the 21 implants were grouped in

proportional quantities to describe the ISQ behavior considering diameter, length, torque, and placement area.

Results

The age of the patients ranged from 20 to 79 years, of which 5 (62.5%) were female and 3 (37.5%) were male. In addition, most patients had a history of systemic disease (diabetes and osteoporosis), pathology (carcinoma and benign bone tumor), or periodontal disease. [Table 1].

Of the 23 implants, 17 (73.91%) were placed in the mandible and regardless of bone type, 16 (69.57%) were placed in the posterior sector. Similar proportional amounts were used in relation to diameter and length, with 11 implants (42.83%) with length up to 10 mm, 12 (52.17%) with 10.5 mm or more, 11 with a diameter of 4.3 mm, and 12 with 3.5 mm. On the other hand, 22 implants (95.6%) were placed in ridges without alveolar preservation (healed sites), whereas 1 (4.4%) was placed in a ridge with alveolar preservation. In relation to the type of bone, the largest number of implants were placed in bone type II (10 implants) and type III (6 implants), according to the Lekholm and Zarb classification. The insertion torque achieved at the time of implant placement presented symmetrical proportional distribution with values <40 N-cm in 11 implants (47.83%) and ≥40 N-cm in 12 implants (52.17%). The lowest ISQ recorded at the time of implant placement was between 30 and 39 in two implants (8.7%) and the highest ISQ was 70–79 in eight implants (34.78%). [Table 2].

Implants of length ≤10 mm and >10 mm, presented similar average ISQ values after placement (58.1 and 62.5 ISQ, respectively). Implants of length ≤10 mm, presented maximum descent values at weeks 3 and 4 (41.6 and 41.9 ISQ, respectively), while in implants of length >10 mm this occurred at week 2 (49.4 ISQ). Subsequently, for implants of length ≤10 mm and >10 mm, the ISQ values increased progressively until week 10 (64.7 ISQ) and week 8 (69.4 ISQ). In addition, both implant types presented close ISQ values at week 14 with 67.4 ISQ (≤10 mm) and 71.8 ISQ (>10 mm), reaching week 20 with 68.8 ISQ and 71.8 ISQ, respectively [Figure 1].

The 3.5 mm and 4.3 mm diameter implants presented average values of 54.3 and 69.0 ISQ, respectively at the time of placement. In addition, the 3.5 mm diameter implants had a lower average value at week 3 (35.3 ISQ), whereas the 4.3 mm diameter implants had a lower average value at week 2 (57.2 ISQ). On the other hand, the 3.5 mm diameter implants presented a marked ascent until week 5 (53.1 ISQ), being then progressive until week 12 (66.8 ISQ) and ending week 20 with 68.1 ISQ; however, the 4.3 mm diameter implants presented an ascent until week 3 (61.2 ISQ), a slight drop in week 4 (60.2) and then a progressive ascent until week 8 (70.8 ISQ), ending week 20 with 73.7 ISQ [Figure 2].

Implants placed with torque ≥40 N-cm had higher average initial values (67.9 ISQ) compared to implants with torque <40 N-cm (52.6 ISQ). Implants with torque ≥40 N-cm presented maximum downward values at week 2 (50.8 ISQ), while implants with torque <40 N-cm presented lower values at week 3 (39.7 ISQ)

Table 1: Patient demographics

Considerations	Distribution	Number	Percent
Age (years)	20–29	1	12.5
	30–39	2	25
	40–49	3	37.5
	50–59	1	12.5
	60–69	0	0
	70–79	1	12.5
Sex	Female	5	62.5
	Male	3	37.5
Diabetes	Yes	1	12.5
	No	7	87.5
Carcinoma	Yes	1	12.5
	No	7	87.5
Periodontal disease	Yes	1	12.5
	No	7	87.5
Bening bone tumor	Yes	1	12.5
	No	7	87.5
Osteoporosis	Yes	1	12.5
	No	7	87.5

and subsequently with a marked upward trend until week 5 (58.2 ISQ). Overall, starting at week 5, implants with torque ≥40 N-cm and <40 N-cm showed a slight progressive increase with similar values up to week 10 (69.5 and 66.8 ISQ, respectively), maintained steadily until week 20 with final values of 72.2 ISQ and 68.6 ISQ, respectively [Figure 3].

After implant placement, the average ISQ values in the maxillary area were similar to those in the mandible (60.5 and 60.7 ISQ, respectively). The maximum decrease in ISQ values at the maxilla was at week 1 (42.7 ISQ), while in the mandible it was between weeks 3 and 4 (45.7 and 46.1 ISQ, respectively). In addition, ISQ values increased stepwise in the maxilla until week 8 (66.3 ISQ), while in the mandible the rise in ISQ values was marked until week 5 (57.7 ISQ) and progressive until week 10 (68.0 ISQ). From this week on, the ISQ values remained relatively stable and similar in the maxilla and mandible, reaching values of 68.1 and 71.1 ISQ at week 20. [Figure 4].

Table 2: Implant related specifications

Considerations	Distribution	Number	Percent
Jaw	Maxilla	6	26.09
	Mandible	17	73.91
Position	Anterior	7	30.43
	Posterior	16	69.57
Implant length	8 mm	2	8.7
	10 mm	9	39.13
	11.5 mm	9	39.13
	13 mm	2	8.7
	15 mm	1	4.35
Implant diameter	3.5 mm	12	52.17
	4.3 mm	11	47.83
Site type	Healed site	22	95.65
	Alveolar ridge preservation	1	4.35
Bone quality (Lekholm/Zarb)	Type I	3	13.04
	Type II	10	43.48
	Type III	6	26.09
	Type IV	4	17.39
Insertion torque (Ncm)	10–19	3	13.04
	20–29	5	21.74
	30–39	3	13.04
	40–49	10	43.48
	50–59	1	4.35
	60–69	1	4.35
Implant stability quotient (ISQ)	30–39	2	8.7
	40–49	3	13.04
	50–59	4	17.39
	60–69	6	26.09
	70–79	8	34.78

Discussion

RFA is a noninvasive intraoral method used to quantitatively assess the stiffness of the bone-implant junction by means of ISQ values. The recent introduction of bioactive surfaces with nanotechnology in dental implants requires further research. The aim of the present study is to map the RFA during the healing of implants with nanostructured hydroxyapatite surface to describe graphically the behavior of ISQ values related to individual factors such as length, diameter, torque, and implant placement zone.

When analyzing the ISQ values it was evident that all implants decreased their values in the first 3 weeks after placement and this decrease in stability has also been reported in other studies using conventional surfaces.[7,8,14,16] After that, the ISQ values increased, showing values similar to those obtained at the time of placement and even higher. The physiological decrease of ISQ values in the first 3 weeks suggests the existence of an interval between primary and secondary stability. Berglundh *et al.*[17] studied the sequence of healing events around dental implants and demonstrated that mechanical stability occurs in the areas of the implant thread pitch and then the process of bone resorption develops, thus decreasing stability for a short period of time. This means that bone resorption processes will yield to apposition processes during the early stages

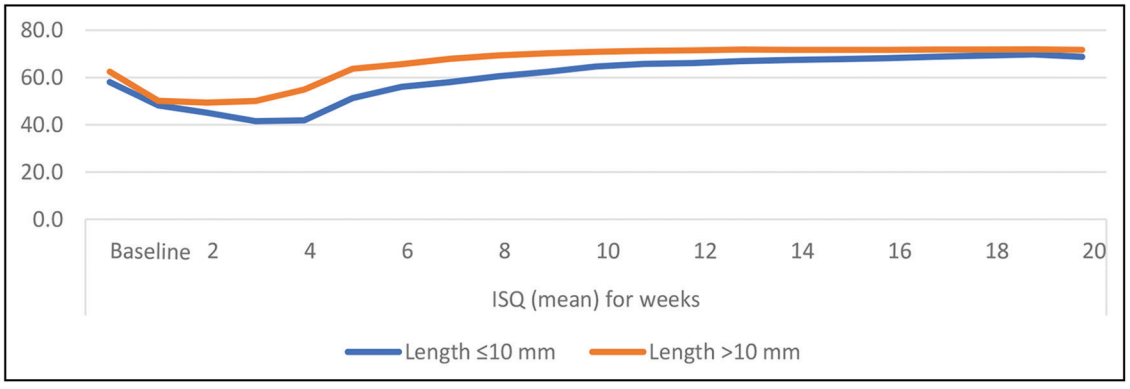

Figure 1: ISQ curve according to implant length

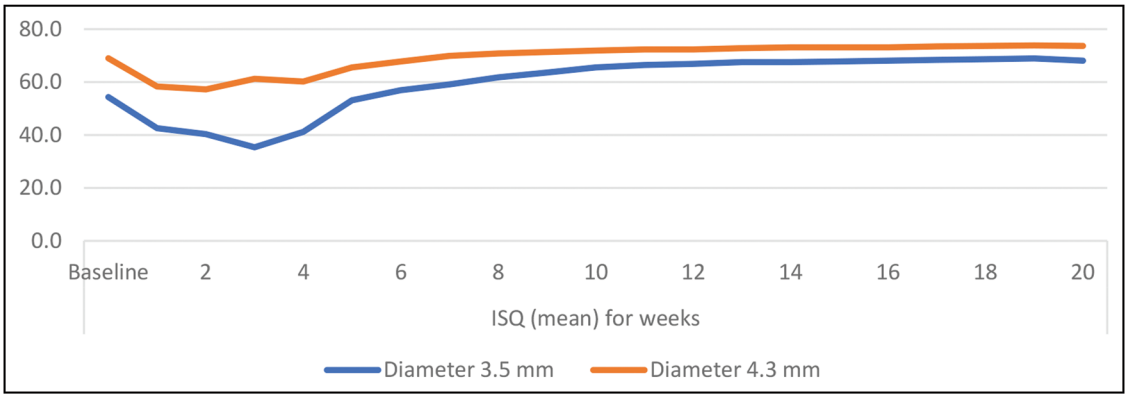

Figure 2: ISQ curve according to implant diameter

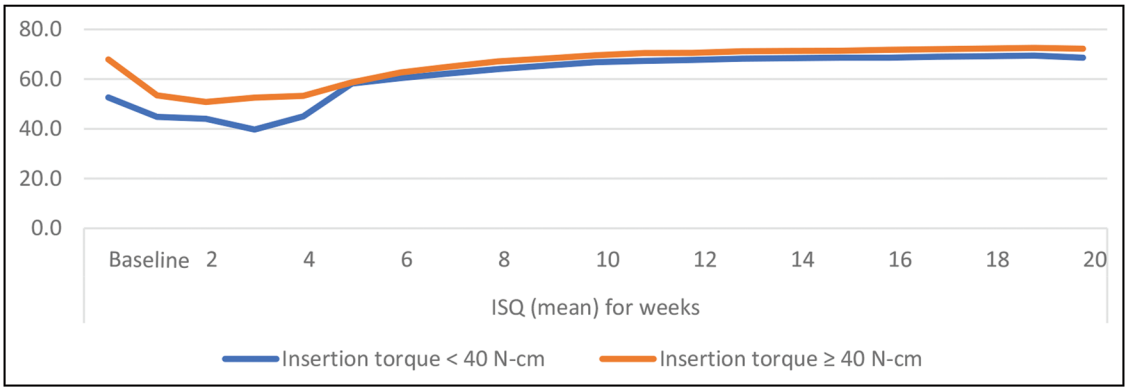

Figure 3: ISQ curve according to the implant insertion torque

of healing. It then increases osteogenesis and lamellar bone maturation, providing secondary stability, which is evidenced by progressively increasing ISQ values.

Considering implants with conventional surfaces, some clinical studies have reported that length does not significantly influence implant stability.[18,19] However, other studies report some influence.[16,20,21] Others agree that length may only influence stability when using implants up to 15 mm of length in type IV bone.[22] This information indicates that the greater length of the implant could be an influential factor in stability, but only in those cases where there are special clinical situations and with particular implant geometries. In the present study, implants with length ≤10 mm showed the lowest ISQ values from baseline, being close to the value of implants >10 mm from week 14 onwards, and coinciding with the results reported by Sim *et al.*[16] who concluded that ISQ values are affected by implant length.

On the other hand, some studies have reported that implant diameter may significantly influence ISQ values, with higher values with increasing implant diameter.[18,23,24] However, other studies have not been able to identify a clear correlation between these values.[25] In the present study, implants with a diameter of 3.5 mm presented the lowest values in relation to implants with a diameter of 4.3 mm, the difference being noticeable up to week 9, although the ISQ values never intersected during the entire follow-up period.

Another important aspect corresponds to the insertion torque. The possible correlation between insertion torque and ISQ values has been studied. However, the results are contradictory, making it clear that the replacement of insertion torque by ISQ measurements remains questionable and the results should be interpreted with great caution. In some studies, a very weak correlation was found between both values during implant placement.[12,26] However, other studies did report a strong correlation between the same.[27,28] A recent systematic review concludes that insertion torque and RFA are independent and incomparable methods for measuring primary stability, suggesting that a high insertion torque does not necessarily correspond to a high ISQ value.[12] Considering the results of this study, implants with torque <40 N-cm presented the lowest values compared to implants with torque ≥40 N-cm mainly in the first 5 weeks and this could be influenced by the

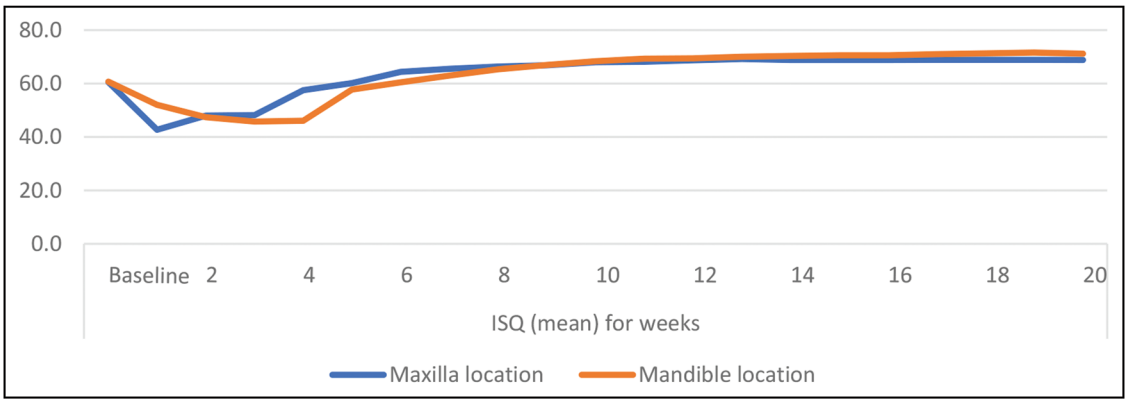

Figure 4: ISQ curve according to the implant placement area

bone quality in the different areas where the implants were placed.[29]

Another factor analyzed in the present study was the ISQ values in relation to the implant placement area. In this regard, no pattern of higher or lower ISQ values was observed. Sreerama *et al*.[30] reported higher ISQ values for implants placed in the maxillary and mandibular anterior region compared to the posterior regions. However, other studies agree with our results, finding no marked differences between the ISQ values of implants placed in the mandibular anterior region, mandibular posterior region, or maxillary anterior region.[31,32] Other authors reported that ISQ values are significantly higher in implants placed in the mandibular region compared to those placed in the maxillary regions.[33] These contradictions could be due to the differences between the bone quality evaluated in both the maxilla and mandible, since most researchers use a subjective scheme based on the Lekholm and Zarb classification, making it very difficult to perform a clinical analysis of bone type that is reproducible among specialists. Because of this, there is a need to develop new methods that allow a more precise identification.

Development and innovation in dental implant manufacturing are constantly evolving. One of the strengths of the present study is the mapping of ISQ values on implants with nanostructured hydroxyapatite surface because some studies have shown that this coating influences cell adhesion and osseointegration, improving osteoconductive properties by including a rougher surface.[29,34] Recently, Martinez *et al*.[35] in an *in vitro* study reported that the use of hydroxyapatite-coated implants promotes greater cell proliferation and dissemination, as well as greater secretion of type I collagen and osteopontin, favoring the early stages of osseointegration. For all these reasons, the use of bioactive surfaces such as nanostructured hydroxyapatite could be a promising alternative in challenging treatments such as immediate loading in posterior maxillary areas and in patients with systemic compromises.

The present study describes the behavior of the ISQ values of 21 implants treated with nanotechnology since two implants were lost and did not achieve osseointegration. The description considers different lengths, diameters, insertion torque, and placement zone, being one of the first studies to show these characteristics despite being presented in a series of cases. Future randomized clinical studies with adequate follow-up are recommended to determine the effect of this novel surface technology.

Conclusion

RFA mapping using ISQ values during healing of dental implants with nanostructured hydroxyapatite surface shows a decrease in values between weeks 2 and 3 considering implant length, diameter, insertion torque, and maxillary or mandibular placement zone.

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Conflicts of interest

None to declare.

Authors contributions

They conceived the research idea (JCRD), elaborated the manuscript (VMC, LACG), collected, tabulated the information (NECL, CFCR, JJPZ), carried out the bibliographic search (LACG, JCRD, MEGA, NECL), interpreted the statistical results and helped in the development from the discussion (VMC,

CFCR, JCRD), he performed the critical revision of the manuscript (JCRD, VMC, NECL, MEGA, JJPZ, LACG, CFCR). All authors approved the final version of the manuscript.

Ethical policy and institutional review board statement

This research was approved by an ethics committee of the Faculty of Stomatology of the Inca Garcilaso de la Vega University with resolution No. 007-2020-DFE.

Patient declaration of consent

All procedures performed and reported in this study signed an informed consent.

Data availability statement

The data that support the study results are available from the author (Dr. José Carlos Rosas-Díaz, e-mail: josecarlos.rosas@upsjb.edu.pe) on request.

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