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Effect of time and local factors on the stability of hydrophilic self-tapping tissue-level implants: 1-year prospective study

KEYWORDS

alveolar bone loss, dental implants, implant stability quotient, osseointegration, wound healing

ABSTRACT

Purpose: To evaluate changes in implant stability quotient values of hydrophilic tissue-level implants over time, and to investigate the influence of local factors on variations in these values.

Methods: Fifty tapered, self-tapping, tissue-level implants with a hydrophilic surface were placed and monitored for 12 months. Implant stability quotient values were recorded at the time of insertion (T0) and monthly thereafter for 12 months. All implants were restored with screw-retained restorations 2 months after placement. A repeated measures analysis of variance was used to evaluate the trends in implant stability quotient values over time. A multiple linear regression model was employed to determine the impact of various factors on changes in implant stability quotient values.

Results: Implant stability quotient values decreased from T0 to T1, although this reduction was not statistically significant ($P = 0.28$). The greatest decrease was observed in implants with initially high implant stability quotient values at T0 ($P < 0.05$). Values increased significantly at each subsequent time point ($P < 0.001$). A significant time effect was noted between immediate and delayed placement protocols ($P < 0.05$), with immediate implants demonstrating lower initial implant stability quotient values but a steeper increase over time. Implants placed in the mandible and wider implants in molar sites showed higher implant stability quotient values compared to those placed in the maxilla and narrower implants (mandible vs maxilla $P < 0.05$; wide molar vs regular premolar $P < 0.05$). Insertion torque was positively correlated with implant stability quotient values at T0 ($P < 0.001$).

Conclusions: The lowest implant stability quotient value was recorded 1 month after implant placement, and then increased consistently throughout the study period without reaching a plateau. Implants placed immediately showed a steeper improvement in implant stability quotient values.

Conflict-of-interest statement: *The authors declare there are no conflicts of interest relating to this study.*

Introduction

The use of dental implants for oral rehabilitation has become a well-established procedure to achieve predictable results and patient satisfaction. This success is the result of decades of extensive research into the biology of implant wound healing and osseointegration.[1,2] Various implant features influence wound healing and osseointegration, either promoting or impeding these processes. These include implant macrodesign, microdesign and wound stability, as well as patient-specific factors. Macrodesign refers to an implant's macroscopic features, such as body shape, thread characteristics and neck design. These attributes have a significant impact on the implant's mechanical

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retention and primary mechanical stability at placement, bone compression and vascularity.[3-7] Microdesign includes features not visible to the naked eye, such as implant surface technology, microscopic geometry, topography, coating and surface chemistry.[8,9] Enhanced surface roughness and hydrophilicity enhance the surface area for cell attachment and facilitate protein deposition, thus accelerating osseointegration.[10-14]

Mechanical stability at implant insertion is essential to prevent relative motion between the implant and bone during healing, which would lead to a lack of osseointegration.[11,15] Primary, or mechanical, stability is usually measured by insertion torque (IT) and resonance frequency analysis (RFA), the latter clinically applied using implant stability quotient (ISQ) units.[16] The RFA method employs electromagnetic pulses to induce microvibrations in a magnetised transducer temporarily attached to the implant.[16-18] ISQ technology is a non-invasive approach to assessing the mechanical and biological stability of the implant-bone connection, which can be examined at multiple timepoints on the day of implant installation and during later follow-ups. The correlation between IT, ISQ and wound healing remains a topic of debate.[19-23]

Although osseointegration is fundamental in dental implantology, tools for quantitatively evaluating osseointegration and its progression in clinical settings are scarce. The usage and interpretation of those tools are often under-reported in the literature, resulting in standardised clinical protocols that lack customisation based on individual patient profiles. The current literature lacks systematic ISQ assessment for longer-term follow-up periods; often, there are no intermediate measurements reported to track changes between initial and final evaluations. Furthermore, there is a lack of ISQ data for specific anatomical areas and newly introduced implants with novel macro- and microdesigns.[24-33] Enhancing understanding of RFA as a clinical measure of subclinical events of wound healing could lead to significant clinical and research advancements and more personalised treatment protocols.

To further validate RFA technology and its application in clinical practice, this study aimed to assess longitudinal changes in ISQ values over 1 year, measured monthly, to better understand the dynamics of wound healing and the development of implant stability for hydrophilic self-tapping tissue-level implants. A secondary aim was to explore the impact of the arch (maxilla vs mandible), site (premolar vs molar), placement protocol (immediate vs delayed) and sex on ISQ values over time.

Methods

Study design

This observational human prospective study was approved by the ethical committee review board of the University of Rome Tor Vergata (PTV103.22) on 14/06/2022 and registered on 20/08/2022 in the International Standard Randomized Controlled Trial Number registry (https://doi.org/10.1186/ISRCTN15663606). Patients were recruited and consecutively treated by two well-trained clinicians (PC and CL) between August 2022 and April 2023. The study was conducted in compliance with the Declaration of Helsinki for biomedical research involving human subjects as amended in 2008 and revised in 2013 and according to the industry regulations (the International Conference for Harmonization Guideline for Good Clinical Practice and ISO14155). Patients of both sexes, aged ≥ 18 years and requiring at least one dental implant in the posterior zone of either arch were enrolled after signing an informed consent. Patients were informed of the nature of the study, benefits, risks and possible alternative treatments, and provided consent prior to inclusion in the study, as well as any follow-up evaluations required for the clinical study.

Inclusion and exclusion criteria

The inclusion criteria for enrolment were as follows:

- systemically healthy patients;
- clinical indication for placement of a dental implant in either arch;
- fresh extraction sockets with at least 4 mm bone beyond the root apex;
- minimum bone height of 7 mm for the placement of implants a least 6 mm in length without the need for vertical bone augmentation;

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- available bone width from 4 to 6 mm to place regular-diameter implants in premolar sites (3.75 to 4.5 mm diameter) and wide implants in molar sites (5.5 mm diameter) without the need for lateral bone augmentation;
- availability to attend monthly follow-up visits from the date of implant insertion for the following 12 months.

The exclusion criteria were as follows:

- general contraindication to oral surgical procedures, such as American Society of Anesthesiologists [ASA] class III or more;
- psychiatric contraindications;
- pregnancy or nursing;
- intake of medication known to affect bone remodelling;
- alcohol or drug abuse;
- self-reported smoking > 10 cigarettes/day;
- radiation therapy;
- untreated periodontitis;
- acute and chronic infection of the adjacent dentition;
- severe maxillomandibular skeletal discrepancy;
- rotational instability at the time of implant placement.

Preparation, surgical and prosthetic protocols

A CBCT scan (Orthophos XG 3D, Dentsply Sirona, Charlotte, NC, USA) and an intraoral scan (IOS) (TRIOS 3, 3Shape, Copenhagen, Denmark) were merged and analysed to digitally assess the characteristics of implant recipient sites following the prosthetic treatment plan using implant planning software (coDiagnostix, Dental Wings, Montreal, Canada).

On the day of treatment, implant osteotomies were prepared following the manufacturer's guidelines using a dedicated drill set (Straumann, Basel, Switzerland). Low-speed drilling (40 rpm) was performed from the second to the last drill in order to avoid bone overheating and to collect autogenous bone for possible grafting materials. Fully tapered tissue-level implants with a self-cutting and self-tapping design, a condensing body, a Roxolid core and a SLActive surface with a smooth machined neck of 1.8 mm height (TLX SP, Straumann) were placed by a single well-trained clinician (PC) in an ideal 3D position following the prosthetic design. After implant placement, the implant IT and ISQ values were measured and recorded. Transmucosal healing was accomplished for all the implants, and the healing abutments were screwed to 10 Ncm. Single interrupted, internal mattress or sling sutures were used to approximate the flaps (5-0 Vicryl, Ethicon, Somerville, NJ, USA). Patients were instructed to rinse twice a day with 0.2% chlorhexidine mouthrinse, to adhere to a soft diet and to avoid any trauma to the surgical sites for 1 month.

The prosthetic loading protocol started 2 months after implant placement according to Gallucci et al.[34] After 2 months of healing time, digital impressions were taken using an intraoral scanner to manufacture and deliver resin provisional prostheses. After a further 2 months, definitive screw-retained metal-ceramic single fixed prostheses were customised and delivered (Fig 1 to 14).



Fig 1 Occlusal view of a missing maxillary left molar.

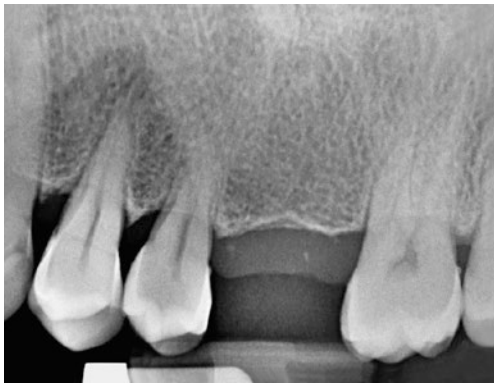


Fig 2 Preoperative periapical radiograph.

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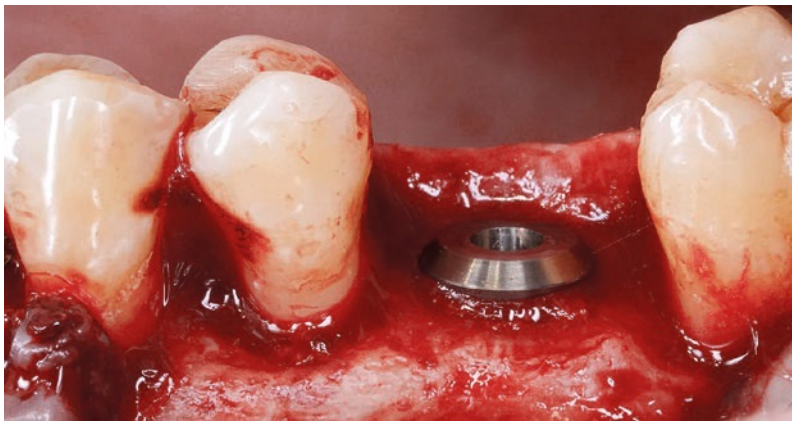


Fig 3 Implant placed without the need for bone augmentation procedures.

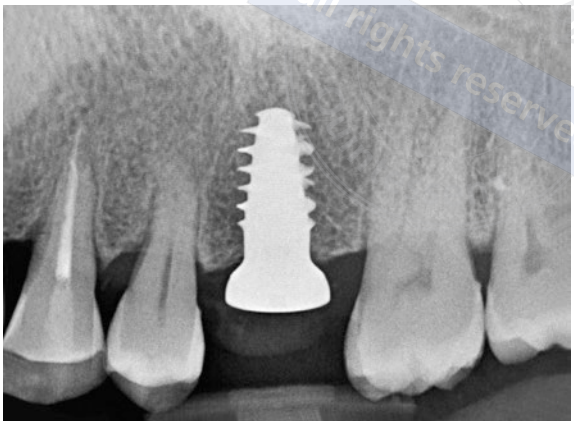


Fig 4 Postoperative periapical radiograph.

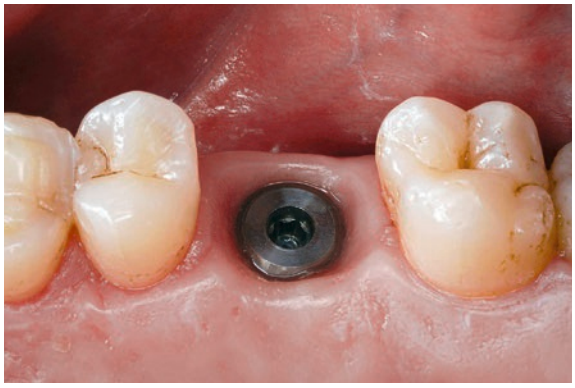


Fig 5 Peri-implant soft tissue stability at the last follow-up visit.



Fig 6 Occlusal view of the permanent restoration.

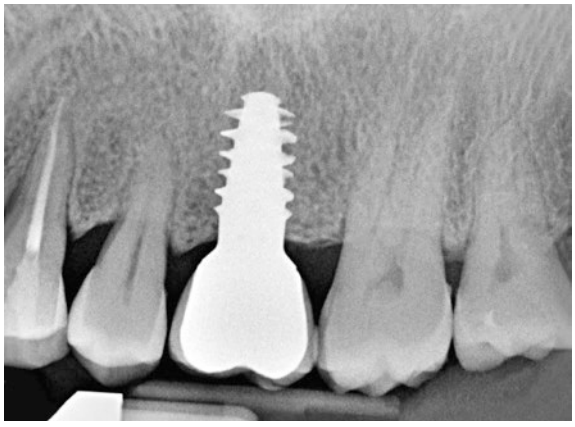


Fig 7 Periapical radiograph taken at the last follow-up visit.



Fig 8 Occlusal view of the fractured maxillary left premolar.

ISQ monthly assessment

Healing abutments were removed every month to screw into the implant high-precision small metal bars (SmartPeg, Osstell, Gothenburg, Sweden). Implant stability was assessed by a single well-trained examiner (CL) using a patented RFA detection device (Osstell). ISQ values were determined in duplicate with a third reading taken in case of any difference between the first two measurements. They were recorded at the time of implant placement (T0) and then every month for 1 year

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Fig 9 Preoperative periapical radiograph.

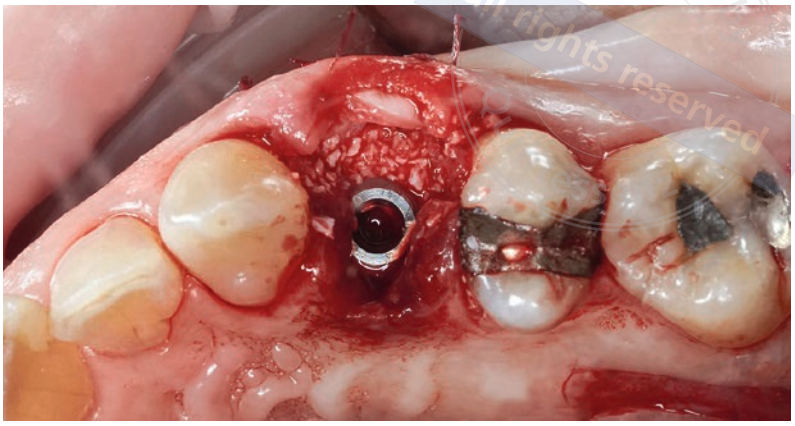


Fig 10 Implant placement in combination with socket augmentation and connective tissue graft.

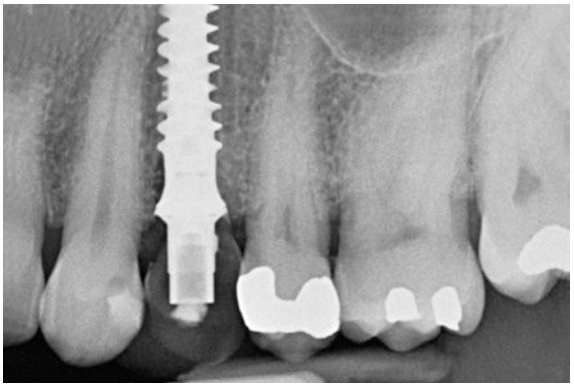


Fig 11 Postoperative periapical radiograph.



Fig 12 Peri-implant soft tissue stability at the last follow-up visit.



Fig 13 Occlusal view of the permanent restoration.



Fig 14 Periapical radiograph taken at the last follow-up visit.

(T1 to T12). Peri-implant diagnostic measurements were performed every 3 months according to Di Gianfilippo et al[35] and followed by supportive periodontal therapy. Restorative screws were replaced at the last study visit (T12).

Outcomes

The primary outcome of the study was changes in ISQ values for the entire population over the follow-up period. The secondary outcome was longitudinal effects on ISQ value based on arch (maxilla

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vs mandible), site (premolar vs molar), placement protocol (immediate vs delayed) and sex.

Statistical analysis

The sample size was calculated in G*Power software using analysis of within-subject variance with the level of statistical significance level set at 0.05 and a power of 0.80 based on a study conducted by Khandelwal et al,[33] and it was estimated that 20 implants per arch were required to identify statistically significant differences in ISQ values recorded monthly for 12 months. Moreover, a post-hoc analysis was performed. For the post-hoc power analysis of the repeated measures analysis of variance (ANOVA), a sample of 50 statistical units with 13 measurements over time and 4 between-subject factors, each with 2 levels, was considered. The effect of time, measured with a partial eta squared of 0.611, corresponds to a Cohen f effect size of approximately 1.25. The mean correlation between repeated measures was estimated at 0.75, and the Greenhouse-Geisser epsilon was 0.191, indicating a significant violation of sphericity. Using G*Power, the post-hoc power to detect an effect of this magnitude was estimated to be nearly 1, suggesting an extremely high capacity to detect the effect given the large observed effect and the high correlation among measures.

A univariate descriptive analysis of the variables being studied was conducted by calculating measures of central tendency and variability for the quantitative variables and frequency tables for the qualitative variables, both for the total sample and within different subgroups. The ISQ trend over time was then evaluated using the repeated measures ANOVA, arch (maxilla vs mandible), site (premolar vs molar), placement protocol (immediate vs delayed) and sex as between-subject factors. A multiple linear regression model was constructed to assess which of these factors had a statistically significant impact on the variation between the ISQ at the last measurement and at baseline. In all analyses, an alpha level of 0.05 was used. SPSS Statistics version 28 (IBM, Armonk, NY, USA) was employed for the statistical data analysis.

The present study was conducted in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement for improving the quality of observational studies.

Results

Thirty-one patients (19 women and 12 men, mean age 53.81 ± 9.48 years) were treated and followed up monthly for 1 year after implant placement. No dropouts were recorded. A total of 50 dental implants (mandible 25, maxilla 25; immediate 15, delayed 35) were inserted without protocol deviations and were followed up for 12 months without biological or mechanical complications (implant survival rate 100%; prosthesis success rate 100%). All implants maintained a diagnosis of peri-implant health throughout the study period. Descriptive analysis for the full set of patients and for individual subgroups is presented in Appendix 1 to 4 (available at http://ijoi.quintessenz.de).

Effect of time on ISQ values

Baseline values and monthly changes in ISQ for the full set of patients are reported in Fig 15. ISQ values showed an increasing trend throughout the study period, with an overall statistically significant time effect ($P < 0.001$). ISQ was significantly greater at each timepoint compared to the previous one ($P < 0.001$; T2–T1, T3–T2, T4–T3, … T12–T11), except for the pair T1–T0, where negative but non-statistically significant values were observed ($P = 0.28$) (Fig 15). From T3 onwards, every measurement was statistically significantly greater than at T0 ($P < 0.0001$; T3–T0, T4–T0, T5–T0, … T12–T0).

To test whether the ISQ at T0 affected the reduction in the ISQ from T0 to T1, the ISQ measurements at T0 were divided into high and low values based on the median. The authors then assessed whether the variation between T1 and T0 differed significantly between the two groups (high ISQ T0 vs low ISQ T0) using a non-parametric Mann-Whitney test. For the group with a low ISQ at T0, the median variation with respect to T1 was 0, whereas for the group with a high ISQ at T0, it was −2.5, indicating a greater reduction at T1 compared to T0 for implants with a high

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ISQ at T0. The difference in distribution between the two groups was statistically significant ($P < 0.05$).

The overall interaction of time with the implant placement protocol (immediate vs delayed) was statistically significant ($P < 0.05$). Delayed implants showed higher ISQ values during earlier follow-ups and a reduced increase in ISQ over time, whereas immediate implants had a lower baseline ISQ and a rapid ISQ increase over the follow-up period (Fig 16). The effect of the two groups in terms of ISQ difference tended to narrow over time until it was no longer significant.

For the interaction between time and placement protocol when evaluating the difference between each timepoint and the previous one, the difference TX–TPrevious was significantly different between the immediate and delayed placement groups for T4–T3, T5–T4, T6–T5, T7–T6 and T11–T10 ($P < 0.05$). For the interaction between time and placement protocol, the effect of time was significant between T0 and each time point starting from T4. In other words, the difference between each timepoint and T0 starting from T4–T0 (T5–T0, T6–T0, T7–T0, … T12–T11) was statistically significantly different between the immediate and delayed placement groups ($P < 0.05$). The interactions of time with sex, arch and site (regular diameter in premolar site vs wide diameter in molar site) were not statistically significant, and the ISQ trend over time was not influenced by these variables.

For the interaction between time and the comparisons between sites (regular diameter in premolar site vs wide diameter in molar site), the difference TX–TPrevious was significantly different between the premolar and molar groups from T1–T0 until T4–T3 (T1–T0, T2–T1, T3–T2, T4–T3) ($P < 0.05$). For the interaction between time and site when evaluating the difference between each timepoint and T0, the difference between each timepoint and T0 (T1–T0, T2–T0, T3–T0, … T12–T0) was significantly different between the premolar and molar groups ($P < 0.05$).

Effect of sex, site, placement protocol, arch and insertion torque on ISQ values

Post-hoc tests showed that ISQ values for the mandible were consistently higher by 2.391 units compared to the maxilla ($P < 0.05$). The increase in ISQ value over time did not differ between mandibular and maxillary implants (Fig 17).

Regarding site location, molar implants (wide implants in molar sites) showed significantly higher ISQ values compared to premolar implants (regular diameter implants in premolar sites) ($P < 0.001$) (Fig 18).

There was a statistically significant, positive and moderate correlation between insertion torque

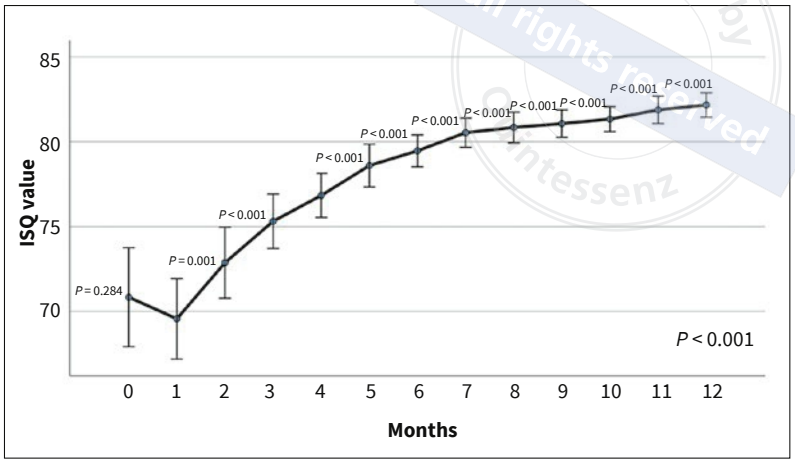


Fig 15 ISQ values for the full set of implants. The overall time effect was statistically significant ($P < 0.001$). Comparisons between consecutive timepoints showed statistically significant differences except for T0–T1. Data are reported as mean ± 95% confidence interval.

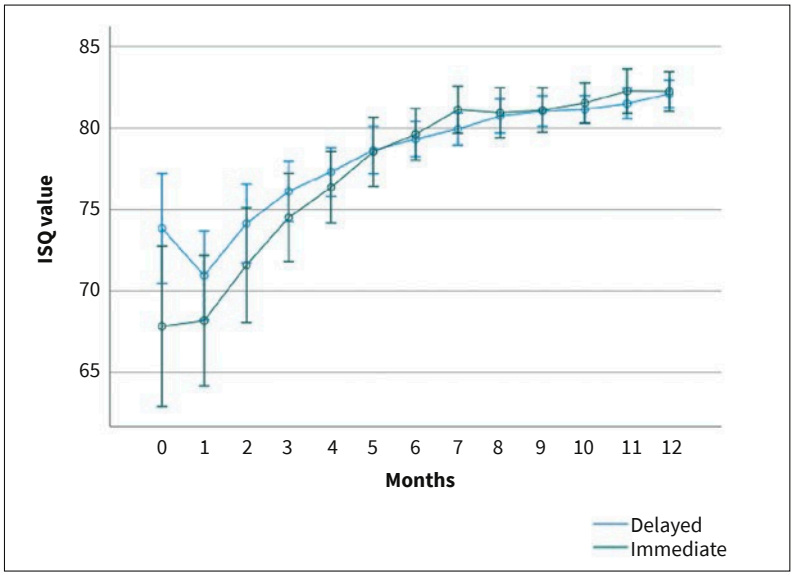


Fig 16 ISQ values for delayed and immediate placement protocols. No statistically significant differences existed between placement protocols; however, statistically significant differences were observed for the variation in ISQ values over time. Data are reported as mean ± 95% confidence interval.

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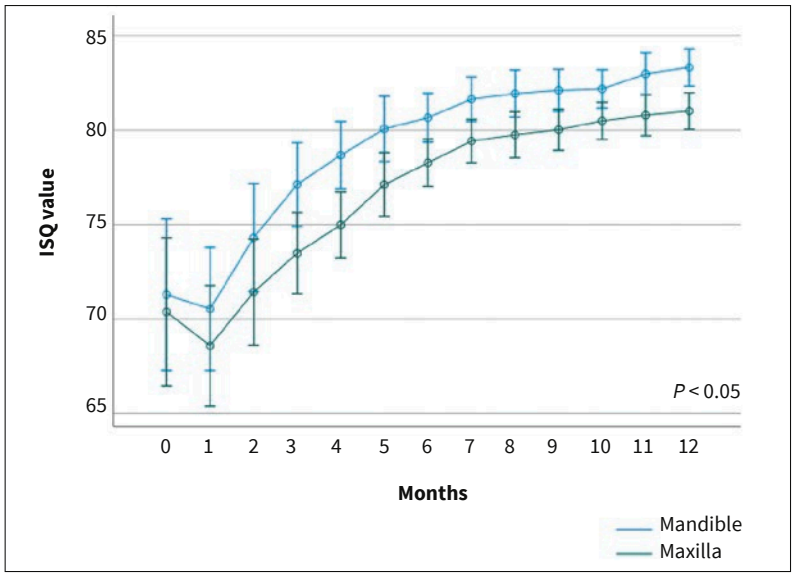


Fig 17 ISQ values for implants placed in the mandible and in the maxilla. A statistically significant difference existed between groups ($P < 0.05$). Data are reported as mean ± 95% confidence interval.

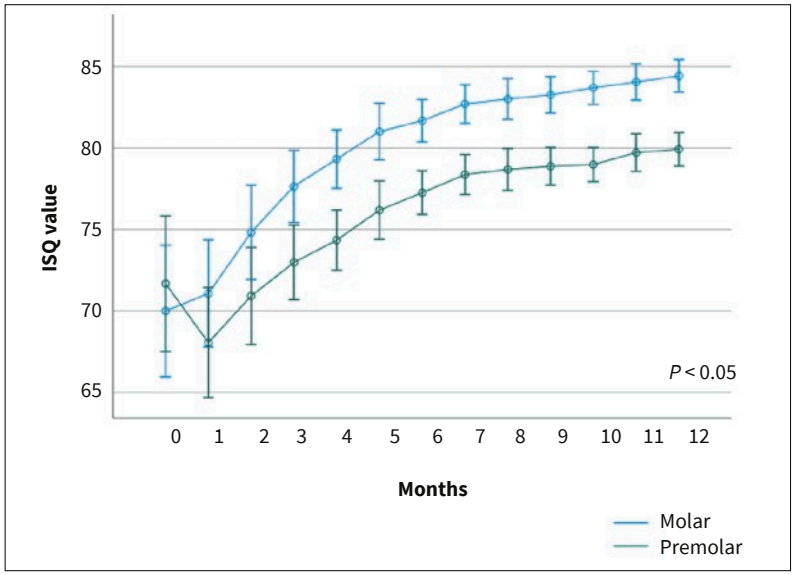


Fig 18 ISQ values for wide implants placed in molar sites and regular diameter implants placed in premolar sites. A statistically significant difference existed between groups ($P < 0.05$). Data are reported as mean ± 95% confidence interval.

and ISQ value at T0 (Pearson coefficient 0.661, $P < 0.001$).

A regression model was employed to understand whether sex, arch, site and placement protocol influenced ISQ variation from the last measurement to the first. The variables that influenced the delta of the two measurements were site and placement protocol. Specifically, it was observed that, holding other variables constant, the variation between the two time points showed an increase of 6.172 units for molar implants compared to premolar implants, and a decrease of 6.160 units for delayed compared to immediate implants. A model generated on the variables of sex, arch, site and placement protocol explained that 14.6% of the overall variability of ISQ values was based on the variables considered (Appendix 5).

Discussion

The success of modern implantology rests on osseointegration, specifically on the transition from mechanical retention to biochemical bonding of newly formed bone to the implant surface.[1,2] In-depth knowledge of the molecular and biological events responsible for osseointegration has led to exponential advancements in dental implantology, including the commercialisation of improved macrodesigns, implant roughness and hydrophilic surfaces.[3,12,14] However, clinical evaluation of the dynamics of implant wound healing, their interpretation and their application to personalised protocols is still lacking and represents an opportunity for improvement in the field. Therefore, the aim of the present study was to evaluate the temporal dynamics of stability in hydrophilic, self-tapping tissue-level implants in a human clinical setting and to assess the contribution of local factors to the fluctuation of implant stability. To the best of the present authors' knowledge, this is the first human clinical trial to investigate the potential effect of different clinical variables on the transition from primary to secondary stability using RFA technology for 1 year.

In terms of the temporal dynamics of implant stability, stability decreased until it was lowest at 1 month after implant placement, then consistently increased every month for 1 year without plateauing (Fig 1). Classical studies have reported an initial phase of bone remodelling where old bone used for primary mechanical retention is resorbed, and new bone is formed in contact with the implant surface.[11,15,36] This initial phase can lead to a temporary reduction in stability, with the overall lowest value at 1 month after implant placement,[33] which

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is in agreement with the present findings. On average, implant stability was significantly greater from the third month onward compared to at the time of implant placement. A translational interpretation of this clinical finding is that only at the third month does secondary stability surpass the mechanical retention that existed at the time of implant placement in terms of strength.

Implants with high ISQ values at the time of placement experienced a greater reduction in ISQ during the first month, whereas implants with lower ISQ values at placement showed no drop in the first month. It can be speculated that excessive bone compression and stress from high mechanical stability may interfere with the reparative processes.[37,38] A similar trend was noted between immediate and delayed implants. Delayed implants achieved higher ISQ values at the time of placement compared to immediate implants, possibly due to the lower volume of native bone engaging the immediate implants; however, immediate implants exhibited a more rapid increase in stability until no difference was found between the two groups (Fig 2). It is important to note that only four delayed implants showed 2 mm buccal dehiscence at implant placement and there was a need for contour augmentation; however, no differences in ISQ values were recorded if compared to the delayed group. This supports the idea that molecular processes toward secondary stability follow a similar path regardless of whether implant placement is immediate or delayed. While the remodelling process eventually eliminates the initial advantage of the higher mechanical stability of the delayed implants.[39] These results may be related to the macro- and microdesign of the implants. The improved macrodesign with self-cutting and self-tapping threads provides high mechanical stability in a large variety of ridge anatomy,[3,27,40] and the chemically modified airborne-particle-abraded, large-grit, acid-etched surface enhances wound healing events, leading to earlier osseointegration.[11,12,14,33]

It is noteworthy that the different placement protocols (immediate and delayed) exhibited dissimilar ISQ values at T0 (Fig 2), but similar IT values (Appendix 4). The observed difference in ISQ at T0 between immediate and delayed placement was likely because the immediate implant was largely outside the bone and surrounded by coagulum, whereas the delayed implant started with a larger surface area in contact with the bone at T0. The similar IT values recorded for both protocols can be attributed to the specific macro-design of the implant used, featuring a tapered body and threads that become progressively deeper towards the apical region. This design enhances bone compression and engagement in the apical site, particularly benefitting the IT of immediate implants by effectively engaging apical bone. This observation suggests a possible difference in the mechanisms of measuring mechanical stability between ISQ and IT.

Implants placed in the mandible consistently showed higher stability compared to those placed in the maxilla, with parallel ISQ curves over time (Fig 3). This suggests that the denser bone found in the mandible contributes to greater overall implant stability, from increased primary mechanical retention to greater secondary stability.[41-43] A steeper increase in ISQ value was noted for implants placed in molar sites compared to those placed in premolar sites, despite similar levels during early follow-ups. This can be attributed to the use of wider diameter implants for molar sites (diameter 5.37 ± 0.40 mm) as opposed to narrower implants for premolar sites (diameter 4.00 ± 0.36 mm). The increased diameter ultimately affects the overall surface area available for secondary stability and osseointegration, which justifies the findings presented in Fig 4.

This prospective human study demonstrates the possibility of taking repeated monthly ISQ measurements during the wound healing process towards osseointegration, despite the untorquing forces applied to the dental implants during unscrewing of the healing abutments, previously connected at 10 Ncm, and restorative abutments, at 35 Ncm. The present findings suggest that implants with deep threads and a hydrophilic surface may help clinicians to achieve osseointegration in several complex clinical scenarios, such those involving low-density bone or immediate implants, without a decrease in ISQ value after prosthetic loading. Moreover, the use of the ISQ may help clinicians to better understand the healing process and thus select the optimal time to load implants.

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It is important to interpret these findings with genuine transparency and acknowledge the existing limitations of the study. The results are limited to the specific implant used in this investigation, a tissue-level implant with a narrow core, deep threads and hydrophilic SLActive surface. Each implant received a provisional prosthesis 2 months after placement and a final prosthesis 4 months after placement, and no difference in ISQ values was recorded after loading. Since no control group with a different loading protocol was included, no conclusions can be drawn regarding the effect of the loading protocol on the development of implant stability. Future studies are encouraged to maintain the same methodology of taking monthly ISQ measurements, but include comparative designs to elucidate the effects of different implant macrodesign, microdesign, connection and timing of loading to ultimately stimulate updates in clinical protocols.

Conclusions

Within the limitations of the present study, it is possible to conclude that overall implant stability decreased to its lowest values 1 month after implant placement, and then increased consistently without reaching a plateau within the study period. A high ISQ value at placement predicted a larger drop in ISQ value at 1 month. Immediate implants had lower initial ISQ values but were followed by a steep increase, whereas delayed implants had higher initial ISQ values but were followed by a flatter increase, resulting in no final differences between the timing protocols. ISQ values were consistently higher for mandibular than maxillary implants, and for wide implants in molar sites compared to narrower implants in premolar sites. RFA ISQ value is a safe and non-invasive diagnostic tool of implant stability that showed fluctuations during wound healing events.

Acknowledgements

Institute Straumann provided the material for the execution of the study.

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Appendix 1 Descriptive statistics for the full sample

Variable		Mean ± standard deviation	Median	25th percentile	75th percentile	n (%)
Age, y		53.81 ± 9.48	57	49	61	NA
Sex	Female	NA	NA	NA	NA	19 (61.3)
	Male	NA	NA	NA	NA	12 (38.7)
Diameter, mm		4.79 ± 0.78	5.50	3.75	5.50	NA
Length, mm		11 ± 2	10	10	12	NA
Arch	Mandible	NA	NA	NA	NA	25 (50.0)
	Maxilla	NA	NA	NA	NA	25 (50.0)
Site	Molar	NA	NA	NA	NA	29 (58.0)
	Premolar	NA	NA	NA	NA	21 (42.0)
Implant placement protocol	Delayed	NA	NA	NA	NA	35 (70.0)
	Immediate	NA	NA	NA	NA	15 (30.0)
Insertion torque and ISQ	Insertion torque	38.7 ± 14.7	40.0	25.0	50.0	NA
	ISQ 0	71.8 ± 9.3	74.5	70.0	76.0	NA
	ISQ 1	70.4 ± 7.7	71.0	64.0	75.0	NA
	ISQ 2	74 ± 7.0	75.0	70.0	79.0	NA
	ISQ 3	76 ± 6.0	76.0	72.0	80.0	NA
	ISQ 4	77 ± 5.0	77.0	73.0	81.0	NA
	ISQ 5	79.1 ± 4.9	79.5	76.0	83.0	NA
	ISQ 6	79.8 ± 3.9	79.5	77.0	82.0	NA
	ISQ 7	80.7 ± 3.6	80.5	78.0	83.0	NA
	ISQ 8	81.0 ± 4.0	80.0	79.0	84.0	NA
	ISQ 9	81.0 ± 4.0	81.0	79.0	84.0	NA
	ISQ 10	81.7 ± 3.4	81.0	79.0	84.0	NA
	ISQ 11	82.1 ± 3.5	82.0	80.0	85.0	NA
	ISQ 12	82.0 ± 3.0	82.0	80.0	85.0	NA

NA, not applicable.

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Appendix 2 Descriptive statistics for location-based subgroups

Location	Variable		Mean ± standard deviation	Median	25th percentile	75th percentile	n (%)
Molar	Age, y		53.81 ± 9.48	57	48	61	NA
	Sex	Female	NA	NA	NA	NA	17 (58.6)
		Male	NA	NA	NA	NA	12 (41.4)
	Diameter, mm		5.37 ± 0.40	5.50	5.50	5.50	NA
	Length, mm		10.00 ± 1.00	10	10	10	NA
	Arch	Mandible	NA	NA	NA	NA	17 (58.6)
		Maxilla	NA	NA	NA	NA	12 (41.4)
	Implant placement protocol	Delayed	NA	NA	NA	NA	24 (82.8)
		Immediate	NA	NA	NA	NA	5 (17.2)
	Insertion torque and ISQ	Insertion torque	39.7 ± 13.9	45.0	35.0	50.0	NA
		ISQ 0	71.9 ± 10.3	74.0	70.0	78.0	NA
		ISQ 1	72.1 ± 7.4	75.0	67.0	78.0	NA
		ISQ 2	76.0 ± 6.0	77.0	73.0	80.0	NA
		ISQ 3	78.0 ± 5.0	80.0	75.0	82.0	NA
		ISQ 4	80.0 ± 5.0	81.0	79.0	83.0	NA
		ISQ 5	81.3 ± 4.8	81.5	80.0	85.0	NA
		ISQ 6	81.8 ± 3.6	82.0	79.0	85.0	NA
		ISQ 7	82.5 ± 3.1	82.0	80.0	85.0	NA
		ISQ 8	83.0 ± 3.0	83.0	80.0	86.0	NA
		ISQ 9	83.0 ± 3.0	83.0	82.0	86.0	NA
		ISQ 10	83.7 ± 2.7	83.0	82.0	86.0	NA
		ISQ 11	84.0 ± 3.0	84.0	82.0	86.5	NA
		ISQ 12	85.0 ± 3.0	85.0	83.0	87.0	NA
Premolar	Age, y		57.0 ± 7.0	57	51	62	NA
	Sex	Female	NA	NA	NA	NA	13 (61.9)
		Male	NA	NA	NA	NA	8 (38.1)
	Diameter, mm		4.00 ± 0.36	3.75	3.75	4.50	NA
	Length, mm		12.00 ± 1.00	12	12	12	NA
	Arch	Mandible	NA	NA	NA	NA	8 (38.1)
		Maxilla	NA	NA	NA	NA	13 (61.9)
	Implant placement protocol	Healed	NA	NA	NA	NA	11 (52.4)
		Immediate	NA	NA	NA	NA	10 (47.6)
	Insertion torque and ISQ	Insertion torque	37.4 ± 16.0	40.0	25.0	50.0	NA
		ISQ 0	71.6 ± 7.8	75.0	71.0	75.0	NA
		ISQ 1	67.9 ± 7.5	70.0	62.0	72.5	NA
		ISQ 2	71.0 ± 8.0	73.0	70.0	74.0	NA
		ISQ 3	73.0 ± 5.0	73.0	70.0	75.0	NA
		ISQ 4	74.0 ± 4.0	75.0	72.0	77.0	NA
		ISQ 5	75.9 ± 3.0	76.0	74.0	77.0	NA
		ISQ 6	77.0 ± 2.4	77.0	75.0	78.0	NA
		ISQ 7	78.1 ± 2.7	78.0	76.0	79.5	NA
		ISQ 8	78.0 ± 3.0	79.0	77.0	80.0	NA
		ISQ 9	79.0 ± 2.0	79.0	77.0	80.0	NA
		ISQ 10	78.8 ± 1.9	79.0	78.0	80.0	NA
		ISQ 11	79.5 ± 2.3	80.0	78.0	81.0	NA
		ISQ 12	80.0 ± 2.0	80.0	78.0	80.0	NA

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Appendix 3 Descriptive statistics for maxillary and mandibular subgroups

Arch	Variable		Mean ± standard deviation	Median	25th percentile	75th percentile	n (%)
Mandible	Age, y		55	57	49	63	NA
	Sex	Female	NA	NA	NA	NA	15 (60.0)
		Male	NA	NA	NA	NA	10 (40.0)
	Diameter, mm		4.96 ± 0.77	5.50	4.50	5.50	NA
	Length, mm		10.00 ± 1.00	10	10	10	NA
	Site	Molar	NA	NA	NA	NA	17 (68.0)
		Premolar	NA	NA	NA	NA	8 (32.0)
	Implant placement protocol	Delayed	NA	NA	NA	NA	18 (72.0)
		Immediate	NA	NA	NA	NA	7 (28.0)
	Insertion torque and ISQ	Insertion torque	39.0 ± 12.9	40.0	35.0	50.0	NA
		ISQ 0	72.2 ± 10.5	75.0	73.0	77.0	NA
		ISQ 1	71.7 ± 8.2	73.0	70.0	77.0	NA
		ISQ 2	76.0 ± 8.0	77.0	73.0	80.0	NA
		ISQ 3	78.0 ± 6.0	80.0	75.0	82.0	NA
		ISQ 4	80.0 ± 5.0	80.0	77.0	84.0	NA
		ISQ 5	81.0 ± 4.6	81.0	77.0	84.0	NA
		ISQ 6	81.5 ± 3.9	81.0	78.0	85.0	NA
		ISQ 7	82.2 ± 3.4	82.0	80.0	85.0	NA
		ISQ 8	83.0 ± 4.0	82.0	80.0	86.0	NA
		ISQ 9	83.0 ± 4.0	83.0	80.0	86.0	NA
		ISQ 10	83.0 ± 3.6	83.0	81.0	86.0	NA
		ISQ 11	83.6 ± 3.4	84.0	81.0	86.5	NA
		ISQ 12	84.0 ± 3.0	85.0	81.0	87.0	NA
Maxilla	Age, y		55 ± 7	55	50	61	NA
	Sex	Female	NA	NA	NA	NA	15 (60.0)
		Male	NA	NA	NA	NA	10 (40.0)
	Diameter, mm		4.63 ± 0.78	4.50	3.75	5.50	NA
	Length, mm		11.0 ± 2.0	12	10	12	NA
	Site	Molar	NA	NA	NA	NA	12 (48.0)
		Premolar	NA	NA	NA	NA	13 (52.0)
	Implant placement protocol	Delayed	NA	NA	NA	NA	17 (68.0)
		Immediate	NA	NA	NA	NA	8 (32.0)
	Insertion torque and ISQ	Insertion torque	38.5 ± 16.6	40.0	24.5	50.0	NA
		ISQ 0	71.4 ± 8.0	74.0	70.0	76.0	NA
		ISQ 1	69.0 ± 6.9	70.0	62.0	73.0	NA
		ISQ 2	72.0 ± 6.0	73.0	68.0	75.0	NA
		ISQ 3	74.0 ± 5.0	73.0	70.0	78.0	NA
		ISQ 4	75.0 ± 4.0	75.0	72.0	79.0	NA
		ISQ 5	77.1 ± 4.5	77.0	75.0	81.0	NA
		ISQ 6	78.2 ± 3.3	78.0	77.0	80.0	NA
		ISQ 7	79.2 ± 3.2	79.0	78.0	82.0	NA
		ISQ 8	80.0 ± 3.0	79.0	78.0	82.0	NA
		ISQ 9	80.0 ± 3.0	80.0	78.0	82.0	NA
		ISQ 10	80.4 ± 80.0	80.0	79.0	82.0	NA
		ISQ 11	80.6 ± 3.0	80.0	79.0	82.0	NA
		ISQ 12	81.0 ± 3.0	80.0	79.0	82.0	NA

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Appendix 4 Descriptive statistics for subgroups based on timing of implant placement

Implant placement protocol	Variable		Mean ± standard deviation	Median	25th percentile	75th percentile	n (%)
Delayed	Age, y		54 ± 9	57	48	61	NA
	Sex	Female	NA	NA	NA	NA	21 (60.0)
		Male	NA	NA	NA	NA	14 (40.0)
	Diameter, mm		4.86 ± 0.81	5.50	3.75	5.50	NA
	Length. mm		10.00 ± 2.00	10	10	12	NA
	Arch	Mandible	NA	NA	NA	NA	18 (51.4)
		Maxilla	NA	NA	NA	NA	17 (48.6)
	Site	Molar	NA	NA	NA	NA	24 (68.6)
		Premolar	NA	NA	NA	NA	11 (31.4)
	Insertion torque and ISQ	Insertion torque	38.9 ± 14.3	40.0	25.0	50.0	NA
		ISQ 0	73.4 ± 5.8	75.0	71.0	77.0	NA
		ISQ 1	71.5 ± 6.5	72.0	67.0	77.0	NA
		ISQ 2	75.0 ± 5.0	75.0	70.0	80.0	NA
		ISQ 3	77.0 ± 5.0	76.0	73.0	81.0	NA
		ISQ 4	78.0 ± 5.0	79.0	74.0	83.0	NA
		ISQ 5	79.6 ± 4.8	80.0	76.0	83.0	NA
		ISQ 6	80.2 ± 3.9	79.0	77.0	83.0	NA
		ISQ 7	80.8 ± 3.6	80.0	78.0	84.0	NA
		ISQ 8	82.0 ± 4.0	80.0	79.0	85.0	NA
		ISQ 9	82.0 ± 4.0	82.0	79.0	85.0	NA
		ISQ 10	82.1 ± 3.5	81.0	79.0	85.5	NA
		ISQ 11	82.4 ± 3.4	82.0	80.0	85.0	NA
		ISQ 12	83.0 ± 3.1	83.0	80.0	86.0	NA
Immediate	Age, y		57.0 ± 7.0	57.0	51.0	62.0	NA
	Sex	Female	NA	NA	NA	NA	9 (60.0)
		Male	NA	NA	NA	NA	6 (40.0)
	Diameter, mm		4.63 ± 0.71	4.50	3.75	5.50	NA
	Length, mm		11.00 ± 1.00	12	10	12	NA
	Arch	Mandible	NA	NA	NA	NA	7 (46.7)
		Maxilla	NA	NA	NA	NA	8 (53.3)
	Site	Molar	NA	NA	NA	NA	5 (33.3)
		Premolar	NA	NA	NA	NA	10 (66.7)
	Insertion torque and ISQ	Insertion torque	38.3 ± 16.1	40.0	25.0	50.0	NA
		ISQ 0	68.0 ± 14.0	74.0	65.0	76.0	NA
		ISQ 1	67.6 ± 9.5	71.0	58.0	75.0	NA
		ISQ 2	71.0 ± 10.0	73.0	65.0	79.0	NA
		ISQ 3	74.0 ± 7.0	75.0	67.0	80.0	NA
		ISQ 4	75.0 ± 6.0	77.0	70.0	80.0	NA
		ISQ 5	77.7 ± 5.0	79.0	74.0	81.0	NA
		ISQ 6	78.9 ± 3.9	80.0	76.0	81.0	NA
		ISQ 7	80.4 ± 37.7	81.0	78.0	82.0	NA
		ISQ 8	80.0 ± 4.0	80.0	79.0	82.0	NA

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Implant placement protocol	Variable		Mean ± standard deviation	Median	25th percentile	75th percentile	n (%)
Immediate	Insertion torque and ISQ	ISQ 9	80.0 ± 4.0	80.0	78.0	82.0	NA
		ISQ 10	80.7 ± 3.3	81.0	78.0	83.0	NA
		ISQ 11	81.5 ± 3.8	81.0	79.0	85.0	NA
		ISQ 12	81.0 ± 4.0	81.0	78.0	85.0	NA

Appendix 5 Regression model generated on the variables implant placement protocol, sex, arch and site justifies 14.6% of the overall variability in ISQ values

Model	R	R square	Adjusted R square	Standard error of the estimate
1	0.382[a]	0.146	0.070	9.15517

[a] Predictors (constant). Implant placement protocol, delayed; sex, female; arch, mandible; site, molar.