
RS/RSX
Ø2.5
3.75/1
S Line
Ø2.5
Ø3.25
S3.75/3

CLINICAL

Insertion Torque and Resonance Frequency Analysis in Tapered and Parallel Dental Implants

Joaquín de Elío Oliveros, DDS, PhD*
Alejandro Gago García, DDS, PhD
Hernán López Sacristán, DDS
Patricia Truchuelo Díez, DDS
Cayetana Barrilero Martín, DDS
Mariano del Canto Díaz, DDS
Mariano del Canto Pingarrón, MD, DDS, PhD

Primary implant stability (PIS) is known to vary with recipient bone mass and density, dental implant design and surgical technique. The objective of this preliminary study was to compare rotational and lateral PIS of same-coronal-diameter conical and parallel implants, using insertion torque recorded with a dental implant motor set and implant stability quotient obtained from resonance frequency analysis (performed with both Osstell and Penguin systems) as measures of rotational and lateral stability, respectively. Additionally, the relationship between PIS and alveolar ridge width (ARW) was explored in both implant types. Sixty dental implants (30 tapered and 30 parallel) were randomly placed with a split-mouth design in 17 patients. Bone density and ARW were estimated from cone beam computed tomography images taken with radiological-surgical templates. Density and width values were similar in the 2 groups ($P > .05$). Implant coronal diameters were 3.75 mm in all cases, while consistent with the manufacturer's recommendations, final drill bit diameters used were 3.25 and 3.4 mm for parallel and tapered implants, respectively. Insertion torque was higher ($P < .05$) with parallel implants, but between-group differences in implant stability quotient were not significant ($P > .05$). In tapered implants, insertion torque was inversely correlated with ARW ($P < .001$). Notably, significant differences were observed between resonance frequency analysis values from Osstell and Penguin systems ($P < .001$). In conclusion, future studies should explore how PIS may be influenced by final drill bit size regardless of implant design and potential limits on the effectiveness of tapered implants to achieve good stability in thick low-density bone.

Key Words: bone density, alveolar bone width, insertion torque, implant stability quotient, tapered implant, parallel implant

Introduction

Primary implant stability (PIS) can be defined as a lack of mobility assessed clinically immediately after dental implant placement and is related to the mechanical contact of the implant with the surrounding bone,[1] while secondary implant stability refers to the stability obtained through osseointegration. Good PIS helps in achieving secondary stability[2] and conditions implant loading times, good stability being required for immediate loading, in which there is growing interest from both patients and practitioners.[3] On the other hand, there is a wide range of implants on the market and surgeons need to know the pros and cons of each to choose the most suitable design in given cases, for example, when there is thin cortical bone width or low alveolar ridge bone mass and density, conditions that increase the risk of not achieving adequate PIS.

Evidence suggests that PIS is closely associated with the amount and density of recipient bone, and especially with cortical bone density (BD) and thickness.[4] Recently, a positive relationship has been observed between alveolar ridge width (ARW) following tooth extraction and PIS.[5] Greater PIS may also be achieved by the use of certain surgical techniques, such as undersized drilling in the implant bed,[6] and PIS might be influenced by the choice of approach to drilling of the implant bed in relation to the implant design.[7] Regarding design, endosseous dental implants (such as Brånemark implants) that emerged in the 20th century were mostly parallel/straight-walled/cylindrical (ie, equal in diameter along the entire body of the implant), while tapered/conical forms (which have a decreasing diameter towards the apex) have emerged more recently.[8] As tapered implants imitate the shape of the natural tooth, they tend to fit more readily into an edentulous space than parallel implants.[9] Further, while there is limited evidence from studies in humans,[10] it has been suggested that tapered/conical implants obtain greater PIS than parallel/straight-walled implants, particularly in bones with low density and that this is due to the lateral compression of the bone wall by the implant in its final position.[11,12] Indeed, the use of tapered implants has been specifically indicated for type 4 bone, in which it may be difficult to achieve good PIS.[13] On the other hand, tapered implants are smaller in volume than parallel implants of the same coronal diameter and length, and therefore have less bone-to-implant contact area in the surrounding bone after implant placement, and similarly, the contact area is smaller

Oral Surgery, Implantology and Periodontics, University of León, Spain.
* *Corresponding author*, e-mail: jeo161@hotmail.com
https://doi.org/10.1563/aaid-joi-D-21-00305

with short than long implants.[14] That is, in comparing different designs, it is important to consider implant size (diameter and length) as well as the potential interaction of the implant with the bone, taking into account BD and the contact between the cortical bone (crestal, vestibular, or palatal/lingual) and the implant surface.

Regarding measures of stability, rotational PIS can be assessed in terms of insertion torque (IT) in Ncm using a contra-angle or a dynamometric ratchet wrench. Torque values are directly related to bone-to-implant contact, in particular, the percentage of implant surface that has close contact with bone over the entire implant.[15] Lateral PIS can be quantified in terms of the implant stability quotient (ISQ) by resonance frequency analysis (RFA). There is evidence that RFA is a reliable approach for assessing ISQ,[16] but to our knowledge, few studies have compared the different systems available.

Given all this, the primary objective of this study was to compare the rotational and lateral PIS, assessed in terms of IT and ISQ values, respectively, achieved with tapered and parallel bone-level implants of the same coronal diameter and length. The secondary objective was to analyze the relationship of PIS in both types of implants with ARW.

Materials and Methods

Study population

This preliminary observational clinical study was approved by the local ethics committee (reference number: ÉTICA-ULE-010-2019). Participants were recruited consecutively at the Centre for Continuing Education of the College of Dental Surgeons and Stomatologists of Leon, from candidates for rehabilitation for tooth loss (upper or lower; anterior, posterior, or both). We included patients who were smokers or had a history of gum disease, in the latter case, gum treatment being performed before implant placement. On the other hand, we excluded patients with uncontrolled systemic disease, a history of treatment with bisphosphonates, radiotherapy or chemotherapy, bone regenerated with biomaterials or unhealed sockets ($<$24 weeks since tooth extraction). Regarding sample size, we obtained a slightly larger sample of implants than that used in a similar study, in which it was estimated that 57 implants would be needed to achieve a power of 80% with $\alpha = .05$ to detect clinically meaningful differences in torque of around 4 Ncm between implants.[11]

The procedures were carried out in 2019 and 2020, in accordance with the principles of the Declaration of Helsinki, in patients who had given written informed consent to participate in the study. Procedures were performed by 7 different dental surgeons with different levels of experience.

Outcome measures

The outcome measures assessed were rotational and lateral PIS, assessed in terms of IT and ISQ values, respectively.

Other variables assessed

As potential explanatory variables, we assessed BD and ARW. Data were also collected on patients' characteristics including sex, age, smoking status, and any systemic diseases, as well as whether they were taking medications for these diseases at the time of the study.

Dental implants and instruments

Following a split-mouth design, parallel and tapered implants (BEGO Semados SCX and RSX, BEGO Implant Systems, Bremen, Germany, noting that the manufacturer describes the SCX implants as "cylindrical" and the RSX implants as "conical" in form) were randomly assigned to the right and left sides of each patient's mouth. All the implants analyzed measured 3.75 mm in diameter and 10 mm in length and were placed at bone level.

Surgeons measured the IT using the Bien-Air iChiropro implant motor set with micro-series contra-angle 20:1 L (Bien-Air Dental, Bienne, Switzerland) calibrated by the manufacturer. Given that we have 2 systems for performing RFA and the aforementioned paucity of studies comparing the systems (evidence that might justify opting for one system over another), data were gathered on ISQ values using both the Osstell ISQ instrument (Osstell, Göteborg, Sweden) with SmartPegs Type 26 (Osstell); and the Penguin RFA system (Integration Diagnostics, Gothenburg, Sweden), in all cases calibrated for 3.75-mm BEGO Semados RSX/SCX implants.

Preoperative radiological assessment of the alveolar ridge: BD and ARW

All patients underwent a cone beam computed tomography (CBCT) scan preoperatively (Carestream 9300, Carestream Health, Rochester, NY) with a surgical template that also served as a radiological guide. In all cases, the template was placed seeking to achieve optimal implant positioning, defined as an implant inclination as close as possible to perpendicular to the occlusal plane and parallel to the nearest abutment (natural or implant), as well as at least 1.5 mm away from adjacent teeth and 1 mm below the bone crest. The radiation doses were adjusted for patient body weight (591, 685, and 856 mGy.cm^2 for weights $<$60 kg, 60–90 kg, and $>$90 kg, respectively). Values of BD and ARW were obtained from a CBCT image of the corresponding patient using BTI Scan 3 software (BTI Biotechnology Institute, Miñano, Spain) as in a previous study.[5]

In brief, an outline of an implant of the size used (3.75 mm in diameter and 10 mm in length) from the BTI Scan 3 database was overlaid on a computed tomography image of the implant placement site (indicated by the radiological and surgical template), in an appropriate position at 1 mm below the bone crest and oriented at an appropriate angle (that is, seeking to optimize implant placement as defined above) (Figure 1). Subsequently, 3 linear measurements were made (at the coronal, mid, and apical parts of the implant) in mm perpendicular to the axial axis of the implant from the buccal to lingual cortical plates. Bone densitometry was used to estimate three BD values in Hounsfield units (HU): the mean density within the area of the implant, the mean at 0.5 mm outside this area and the maximum value in the first 3 mm inside this area, the last value reflecting crestal BD.

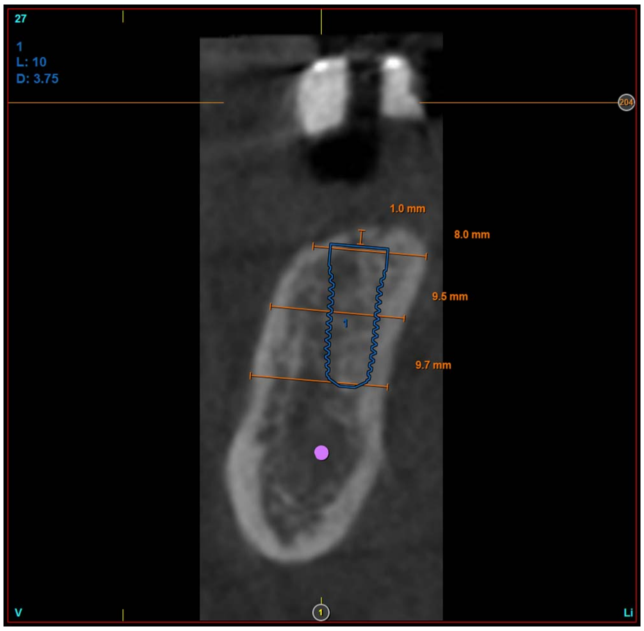

Figure 1. Preoperative computed tomography image. Example of a 3.75 × 10 mm implant (from the BTI Scan 3 database) superimposed on a cross-section at the alveolar ridge corresponding to the implant placement area, appropriately inclined and 1 mm below the bone crest.

Implant placement

Both types of implants analyzed (SCX and RSX) were placed in the position indicated by the radiological and surgical template previously assessed by CBCT. The drilling sequence recommended by the manufacturer was strictly followed (Figure 2); all the implants were countersunk to 1 mm below the bone crest, but the diameter of the largest drill bit used differed between the implants (3.25 and 3.4 mm for SCX and RSX implants, respectively).

Assessment PIS: IT and ISQ

For each implant, we recorded the insertion time (in seconds) and the IT (values lying between 0 and 70.5 Ncm) with the iChiropro (as illustrated in Figure 3), allowing us to obtain an objective numerical assessment of the rotational PIS. Specifically, the IT value was obtained from a single measurement taken on insertion when the implant reached its final position (maximum torque reached with the iChiropro) in line with the method described elsewhere.[17] Once inserted, the position of the implants was not modified.

Further, lateral PIS in terms of ISQ was assessed using RFA with both Osstell and Penguin systems, screwing the SmartPeg Type 26 and the Multipeg Type 26 to the implant, respectively. Two readings were taken with each system, one with the device oriented in the buccolingual direction (ISQ-BL) and the other with it oriented mesiodistally (ISQ-MD). Repeat measurements were taken of each value until the same value was obtained in 3 consecutive readings. The ISQ values lie in the range of 0 to 100, values below 60 being considered to indicate low stability, 60–69 medium stability, and >70 high stability (https://www.osstell.com/clinical-guidelines/the-isq-scale/).

Figure 2. Protocol for preparing the implant bed for a tapered (RSX) implant (upper row) and a parallel (SCX) implant (lower row). Note that the diameter of the final drill bit was 3.25 and 3.4 mm for SCX and RSX implants, respectively.

Statistical analysis

The statistical analysis was designed and carried out by a statistician external to our research group using IBM SPSS Statistics for Windows version 25.0 (Armonk, NY). P values <.05 were considered significant and <.001 highly significant. The qualitative variables characterizing the groups were expressed as frequencies and compared using χ^2 tests, as expected cell counts were greater than 5. Means with SDs and medians were calculated for quantitative variables. It was assessed whether the data for quantitative variables (BD [in HU], ARW, IT, and ISQ) followed a normal distribution graphically using normal Q-Q plots, measures of skewness and kurtosis, and using the Kolmogorov-Smirnov test. The means of quantitative variables were compared between groups using Student t tests in the case of normally distributed data and the medians using nonparametric Mann-Whitney U tests. Associations between quantitative variables were explored using Pearson and Spearman correlation coefficients, as appropriate. The

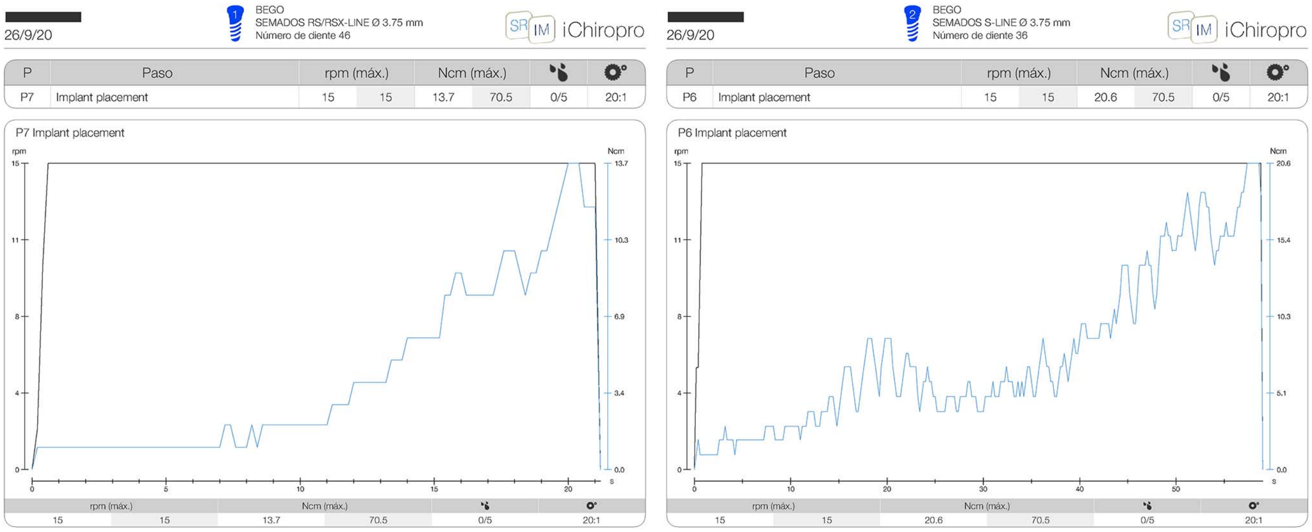

Figure 3. Plots of insertion torque as a function of implant time for a tapered (RSX) implant (left) and a parallel (SCX) implant (right) obtained with the iChiropro implant motor set.

effect size was assessed using R^2 (indicating the percentage of variance explained) to express the magnitude of between-group differences.

Results

Study population and dental implants

We recruited a total of 17 patients (9 men and 8 women) aged between 40 and 61 years of age. Fourteen of the participants were smokers. Twelve had active gum disease at the time of inclusion; this was treated by scaling and root planing and their gums had healed before implant placement in all cases. That is, all patients were deemed periodontally healthy at the time of implant placement.

Overall, 60 BEGO Semados implants were placed, 30 RSX and 30 SCX, following the split-mouth design. Between 2 and 6 implants were placed per arch and 2 to 10 per patient, with a total of 18 in posterior and 6 in anterior maxillary regions and 21 in posterior and 5 in anterior mandibular regions, considering the area between the canines to be anterior and that from the first premolar to the first molar posterior (no implants being placed posterior to the first molar).

Characteristics of the patients receiving the implants are summarized in Table 1 by implant type. As expected, given the split-mouth design, there were no significant differences between the RSX and SCX implant groups in sex, age, smoking status, rate of systemic diseases, or medication intake; notably, the groups were also comparable in terms of BD and ARW ($P > .05$ in all cases).

Primary implant stability: IT and ISQ

Comparing IT between the groups, we found significantly higher mean values for SCX implants (32.02 $\pm$ 18.72 vs 22.72 $\pm$ 13.08 Ncm in RSX implants, $P = .03$). The difference was associated with a moderate effect size (7.9%). Insertion time was longer for the SCX than the RSX implants (57 $\pm$ 5 vs 22 $\pm$ 6 seconds). On the other hand, between-group differences in ISQ did not reach significance, considering values obtained using Osstell or Penguin systems ($P > .05$; Table 2).

Association of BD and ARW with PIS in each group

For both types of implants, we observed significant correlations between the values of BD at all the sites considered and both rotational and lateral PIS (Tables 3 and 4). These correlations tended to be stronger in the SCX implant group and using the ISQ values obtained with the Penguin system. Regarding bone dimensions, in the RSX implant group, IT was inversely correlated with coronal and apical ARW ($P < .001$ in both cases): the greater the ARW, the lower the IT, and vice versa (Table 3). Such correlations were not observed in the SCX implant group (Table 4). Further, we observed significant correlations between various ARW values and ISQs obtained with both RFA systems (Osstell and Penguin) in the RSX implant group; these correlations were negative, except in the case of bone mid width, which was positively correlated with ISQ-MD as measured by the Penguin system. In contrast, in the SCX implant group, only the correlation between the mean ARW and ISQ-BL as measured with the Osstell system reached statistical significance ($P < .05$). Given the small number of patients, we were unable to control for patient characteristics that might influence PIS. In particular, as most participants were smokers and similar in age, subgroups were too small to obtain statistically significant results.

Comparison between ISQ values obtained with 2 RFA systems

Differences between the values provided by the Osstell and Penguin systems were all highly statistically significant ($P < .001$). Specifically, in our study, ISQ values from the Penguin system were slightly lower than those from the Osstell instrument (Table 5). These differences may partially explain the aforementioned patterns of correlations, in particular, the finding

TABLE 1

Descriptive analysis: characteristics of patients receiving the implants (N = 60) by implant type

Variables	Total Sample (N = 60)	Implant Type RSX (n = 30)	SCX (n = 30)
Sex			
Man	63.3% (38)	66.7% (20)	60.0% (18)
Woman	36.7% (22)	33.3% (10)	40.0% (12)
Age (y) Mean (SD)	47.9 (8.7)	48.4 (8.8)	47.5 (8.82)
Smoker (yes)	85.0% (51)	86.7% (26)	83.3% (25)
Systemic disease (yes)	61.7% (37)	63.3% (19)	60.0% (18)
Hypertension	(13)	(7)	(6)
Diabetes	(9)	(4)	(5)
Bruxism	(6)	(3)	(3)
Hypothyroidism	(5)	(3)	(2)
Anemia	(5)	(3)	(2)
Hypercholesterolemia	(4)	(2)	(2)
Chronic obstructive pulmonary disease	(3)	(2)	(1)
Asthma	(3)	(2)	(1)
Chronic bronchitis	(3)	(2)	(1)
Epilepsy	(3)	(2)	(1)
Taking medication (yes)	66.7% (40)	66.7% (20)	66.7% (20)
History of gum disease (yes)	75.0% (45)	76.7% (23)	73.3% (22)

that correlations of lateral stability with BD were somewhat stronger in the case of ISQ values obtained with the Penguin system than those from the Osstell system (Tables 3 and 4).

Discussion

In this preliminary study comparing rotational and lateral PIS of tapered and parallel implants, we found significantly higher IT values with BEGO Semados SCX (parallel) than RSX (tapered) implants, but no significant between-group differences in ISQ. In contrast, Menicucci et al[11] found greater IT values with tapered than straight-walled Osseotite implants, based on a study of 57 implants (in 20 patients). Further, Markovic et al[12] compared PIS in terms of the ISQ of 56 self-tapping and 56 nonself-tapping implants and reported that higher ISQ values were obtained with self-tapping than non-self-tapping implants after preparing the implant bed by bone drilling. While there is a paucity of studies in humans, several in vitro studies have compared the PIS of tapered and parallel implants. These studies have mainly used polyurethane foam blocks of various densities,[7,18,19] pig bones,[20,21] or rabbit tibias,[22] and all have indicated greater PIS with tapered than parallel implants.

The difference observed between our results and those of the aforementioned studies might be explained by the diameters of the final drill bit used in each group (3.25 and 3.4 mm for SCX and RSX implants, respectively) in relation to the coronal diameter of the BEGO Semados implants used (3.75 mm in all cases). In Menicucci et al,[11] surgeons selected different implant sizes and drill bits on a case-by-case basis, hindering comparisons, and in Markovic et al,[12] various bone condensers and drills were used to prepare the implant bed. In contrast, in our patients, the final drill bit diameter used was always the same for each implant design and closer to the diameter of the implant in the case of the tapered implants. The choice of drill bit sizes sought to avoid excessive compression of the marginal bone that could result from a high IT, and, in turn, the potential consequences of high compression, namely ischemia and necrosis, and the subsequent reabsorption of peri-implant cortical bone.[23] Further, the placement of implants with a high IT goes against the usual recommendations of the manufacturers[24] due to potential distortion of the geometry of the implant that could cause prosthetic complications such as a worsening in the fit of connections and loosening of screws. Nonetheless, some studies have reported no statistically significant relationships

TABLE 2

Inferential analysis: comparison of primary implant stability between implant designs, based on ISQ values as measured with Osstell and Penguin systems

Variable	Mean (SD)/Median: Tapered (RSX) Implants (n = 30)	Mean (SD)/Median: Parallel (SCX) Implants (n = 30)	Mann-Whitney *U* test: /*U* Statistic/	Mann-Whitney *U* test: *P* Value	Effect Size: R^2, %
Osstell ISQ-BL	77.53 (7.39)/80.00	79.10 (10.35)/82.50	0.67[NS*]	.503	0.8
Osstell ISQ-MD	78.47 (6.47)/81.00	79.93 (8.52)/82.00	0.75[NS]	.456	1.0
Penguin ISQ-BL	76.00 (7.99)/78.50	77.87 (10.38)/82.00	0.78[NS]	.438	1.0
Penguin ISQ-MD	77.43 (6.04)/79.00	79.00 (8.58)/82.00	0.82[NS]	.417	1.1

*NS indicates not significant; ISQ-BL and -MD indicate implant stability quotient measured in buccolingual and mesiodistal directions, respectively.

TABLE 3

Correlational analysis: Spearman coefficients. Relationship of bone density and width with primary implant stability in tapered (RSX) implants (n = 30)

	Insertion Torque	Osstell ISQ-BL	Osstell ISQ-MD	Osstell Total ISQ	Penguin ISQ-BL	Penguin ISQ-MD	Penguin Total ISQ
Bone density							
Within IPA	.516**	.409*	.544**	.466**	.477**	.542**	.530**
0.5 mm outside IPA	.567**	.438**	.572**	.499**	.490**	.537**	.534**
Maximum in first 3 mm within IPA	.390*	.307*	.402*	.321*	.433**	.517**	.485**
Bone width							
Coronal	−.575**	−.379*	−.231NS	−.353*	−.348*	−.237NS	−.314*
Mid	−.181NS	.192NS	−.239NS	.225NS	.228NS	.331*	.277†
Apical	−.554**	−.241†	−.209NS	−.213NS	−.285†	−.127NS	−.240NS

*Significant ($P < .05$).
**Highly significant ($P < .001$).
†Marginally significant.
NS indicates not significant; ISQ-BL and -MD indicate implant stability quotient measured in buccolingual and mesiodistal directions, respectively; IPA, implant placement area.

between high IT and peri-implant bone remodeling.[25,26] In our study, the difference in the diameter of the drill bit used in the 2 groups together with the fact that tapered implants have a 20% to 30% smaller surface area than equivalent parallel implants[20] may have led to greater PIS in the parallel (SCX) implant group.

Secondly, regarding the characteristics of the recipient bone, in line with other studies,[5,27,28] PIS in our patients was associated with BD in HU as measured with CBCT. This association was clearer in the SCX than in the RSX implant group. More notably, we observed a highly significant negative correlation between ARW and IT in the RSX implant group; that is, the narrower the ARW, the higher the IT. This may be due to narrower ARW implying a shorter distance between vestibular and palatine/lingual cortical bone and the surface of the implant. In contrast, no such relationship was found in the SCX implant group. To our knowledge, no other studies have assessed this relationship. In our sample, we also found significant associations between ARW and ISQ, similar to observations in a previous study using the same methodology for measuring these variables.[5] There is a need for more studies analyzing the relationship of rotational and lateral PIS with ARW in larger samples.

Lastly, we found highly significant differences between the parameters obtained with the 2 systems, ISQ values obtained with the Penguin system being slightly lower than those from the Osstell ISQ instrument. This finding contrasts with the results of Becker et al,[29] who found marginally higher values with the Penguin than the Osstell system. These authors also commented that the Penguin system was somewhat easier to use. In our case, the differences between values from the 2 systems led to somewhat different statistical results in terms of the correlations of ISQ with ARW and BD. We believe that further comparison studies are required for these systems.

We recognize that our preliminary study has certain limitations. First, given the nature of the study, we cannot draw conclusions about causality. Second, we used consecutive sampling,

TABLE 4

Correlational analysis: Spearman coefficients. Relationship of bone density and width with primary implant stability in parallel (SCX) implants (n = 30)

	Insertion Torque	Osstell ISQ-BL	Osstell ISQ-MD	Osstell Total ISQ	Penguin ISQ-BL	Penguin ISQ-MD	Penguin Total ISQ
Bone density							
Within IPA	.859**	.608**	.625**	.619**	.705**	.699**	.705**
0.5 mm outside IPA	.909**	.642**	.702**	.671**	.737**	.747**	.741**
Maximum in first 3 mm within IPA	.797**	.576**	.634**	.612**	.643**	.629**	.639**
Bone width							
Coronal width	−.018NS	.062NS	−.059NS	−.008NS	.064NS	.053NS	.078NS
Mid width	−.080NS	.309*	.162NS	.254†	.227NS	.186NS	.224NS
Apical width	−.287†	.052NS	−.109NS	−.028NS	−.030NS	−.071NS	−.046NS

*Significant ($P < .05$).
**Highly significant ($P < .001$).
†Marginally significant.
NS indicates not significant; ISQ-BL and -MD indicate implant stability quotient measured in buccolingual and mesiodistal directions, respectively; IPA, implant placement area.

Table 5

Inferential analysis: repeated measures. Primary implant stability in terms of ISQ as measured with the Osstell vs Penguin systems (N = 60)

Variable	Mean (SD)/Median		Wilcoxon Test		Effect Size: R^2, %
	Osstell ISQ	Penguin ISQ	*W* Statistic	*P* Value	
ISQ-BL	78.32 (8.96)/80.50	76.93 (9.24)/80.00	4.30**	<.001	28.1
ISQ-MD	79.20 (7.54)/82.00	78.22 (7.40)/81.00	4.24**	<.001	25.3

**Highly significant ($P < .001$); ISQ-BL and -MD, indicate implant stability quotient measured in buccolingual and mesiodistal directions respectively.

with the bias inherent to this method, and the sample size is relatively small (a total of 60 implants in 17 patients), limiting the statistical power of the study. Third, due to the exclusion criteria, the sample is not representative of cases in which there is insufficient bone or in which radiological BD may be affected by the use of biomaterials or the presence of immature bone tissue, as in incompletely healed sockets, after tooth extraction. Further, patients were recruited in a single center and all were young to middle aged. Therefore, our findings cannot be generalized to populations in other regions or groups such as older adults or those with poor bone quality. Fourth, though the use of a split-mouth design helps control for confounding factors in the between-group comparisons, given the small number of patients, we have not been able to control for patient characteristics in the correlation analysis or perform subgroup analysis. Further research is needed with larger samples to explore the associations observed. Fifth, while ISQ measurements were taken with both systems by a single researcher and repeated, enhancing their reliability, IT values were recorded by one of 7 different surgeons, which might bias the results, and not repeated, given the nature of the variable (the maximum final torque on insertion of each implant). Nonetheless, in all cases, IT was measured using the same device which has been shown to deliver an accurate torque and no modifications were made after implant placement. Further, all surgeons completed the implant placement procedure following the same standardized procedure, which should make it more reproducible, and notably, despite the relatively small sample sizes, differences between the implant groups reached significance. On the other hand, comparisons are facilitated by the fact that we have focused on studying PIS with a single brand of parallel and tapered implants (SCX and RSX implants from Bego Implant Systems), using the same implant sizes and final drill bits in all cases in each group, and strictly following the protocol recommended by the manufacturer.

Overall, given the aforementioned limitations, caution should be exercised in extrapolating our findings to other populations treated with different implants. Nonetheless, our finding of higher IT values with parallel implants is interesting in that it differs from the trends observed in other studies in the literature. There is a need for further research in larger samples and with different types of implants to investigate potential relationships between PIS and both implant design and drilling protocols.

Conclusions

To achieve the best possible PIS, dental surgeons need to know the factors that determine this stability. Our results indicate that the choice of a tapered rather than a parallel implant may be secondary to factors related to the surgical technique and the relationship between the diameter of the final drill bit and that of the implant itself. Specifically, unlike previous studies, we achieved higher rotational PIS (in terms of IT) and similar lateral PIS (in terms of ISQ) with parallel (SCX) implants compared with values obtained with tapered (RSX) implants of the same diameter having used a smaller final drill bit in the former group. We conclude that there is a need to explore whether the use of different-sized final drill bits leads to different PIS values regardless of the implant design (tapered versus parallel). Further, in our patients, PIS (IT and ISQ values, respectively) obtained with tapered (RSX) implants were significantly correlated with ARW, while this relationship was not generally observed in the case of parallel (SCX) implants. In clinical practice, this finding implies that in cases with relatively low BD but in which there is considerable bone width the use of a tapered implant may not be an effective approach to achieving good stability.

Abbreviations

ARW: alveolar ridge width
BD: bone density
CBCT: cone beam computed tomography
HUs: Hounsfield units
ISQ: implant stability quotient
ISQ-BL: implant stability quotient measured in a buccolingual direction
ISQ-MD: implant stability quotient measured in a mesiodistal direction
IT: insertion torque
PIS: primary implant stability
RFA: resonance frequency analysis

Acknowledgments

The authors are grateful to BienAir® for the loan of the iChiropro implant motor, José Manuel García de Cecilia and Drs Miguel Ángel Alobera Gracia, Jorge Pesquera Velasco and Jesús Seco Calvo for their support with this research, and the editors of Ideas Need Communicating Language Services for help redrafting the manuscript.

Note

The authors have no conflicts of interest to declare.

References

1. Al-Sabbagh M, Eldomiaty W, Khabbaz Y. Can osseointegration be achieved without primary stability? *Dent Clin North Am*. 2019;63:461–473.

2. Monje A, Ravidà A, Wang HL, Helms JA, Brunski JB. Relationship between primary/mechanical and secondary/biological implant stability. *Int J Oral Maxillofac Implants*. 2019;34:S7–S23.

3. Tettamanti L, Andrisani C, Bassi MA, Vinci R, Silvestre-Rangil J, Tagliabue A. Immediate loading implants: review of the critical aspects. *Oral Implantol (Rome)*. 2017;10:129–139.

4. Chrcanovic BR, Albrektsson T, Wennerberg A. Bone quality and quantity and dental implant failure: a systematic review and meta-analysis. *Int J Prosthodont*. 2017;30:219–237.

5. de Elío Oliveros J, del Canto Díaz A, del Canto Díaz M, Jacobo Orea C, del Canto Pingarrón M, Seco Calvo J. Alveolar bone density and width affect primary implant stability. *J Oral Implantol*. 2020;46:389–395.

6. Shadid RM, Sadaqah NR, Othman SA. Does the implant surgical technique affect the primary and/or secondary stability of dental implants? A systematic review. *Int J Dent*. 2014;2014:204838.

7. Gehrke SA, Calvo Guirado JL, Bettach R, del Fabbro M, Pérez-Albacete Martínez C, Shibli JA. Evaluation of the insertion torque, implant stability quotient and drilled hole quality for different drill design: an in vitro investigation. *Clin Oral Implants Res*. 2018;29:656–662.

8. Abraham CM. A brief historical perspective on dental implants, their surface coatings and treatments. *Open Dent J*. 2014;8:50–55.

9. Jokstad A, Ganeles J. Systematic review of clinical and patient-reported outcomes following oral rehabilitation on dental implants with a tapered compared to a non-tapered implant design. *Clin Oral Implants Res*. 2018;29(suppl 16):41–54.

10. Atieh MA, Alsabeeha N, Duncan WJ. Stability of tapered and parallel-walled dental implants: a systematic review and meta-analysis. *Clin Implant Dent Relat Res*. 2018;20:634–645.

11. Menicucci G, Pachie E, Lorenzetti M, Migliaretti G, Carossa S. Comparison of primary stability of straight-walled and tapered implants using an insertion torque device. *Int J Prosthodont*. 2012;25:465–471.

12. Markovic A, Calvo Guirado JL, Lazic Z, et al. Evaluation of primary stability of self-tapping and non-self-tapping dental implants. A 12-week clinical study. *Clin Implant Dent Relat Res*. 2013;15:341–349.

13. Alves CC, Neves M. Tapered implants: from indications to advantages. *Int J Periodontics Restorative Dent*. 2009;29:161–167.

14. Ibrahim A, Heitzer M, Bock A, et al. Relationship between implant geometry and primary stability in different bony defects and variant bone densities: an in vitro study. *Materials (Basel)*. 2020;13:4349.

15. Liu C, Tsai MT, Huang HL, et al. Relation between insertion torque and bone-implant contact percentage: an artificial bone study. *Clin Oral Invest*. 2012;16:1679–1684.

16. Herrero Climent M, Falcao A, López Jarana P, Díaz Castro MC, Ríos Carrasco B, Ríos Santos JV. In vitro comparative analysis of two resonance frequency measurement devices: Osstell implant stability coefficient and Penguin resonance frequency analysis. *Clin Implant Dent Relat Res*. 2019;21:1124–1131.

17. Silva KC, Zenóbio EG, Souza PEA, Soares RV, Cosso MG, Horta MCR. Assessment of dental implant stability in areas previously submitted to maxillary sinus elevation. *J Oral Implantol*. 2018;44:109–113.

18. Comuzzi L, Tumedei M, Pontes AE, Piattelli A, Lezzi G. Primary stability of dental implants in low-density (10 and 20 pcf) polyurethane foam blocks: conical vs cylindrical implants. *Int J Environ Res Public Health*. 2020;17:2617.

19. Aleo E, Varvara G, Scarano A, Sinjari B, Murmura G. Comparison of the primary stabilities of conical and cylindrical endosseous dental implants: an in-vitro study. *J Biol Regul Homeost Agents*. 2012;26:89–96.

20. Staedt H, Palarie V, Staedt A, et al. Primary stability of cylindrical and conical dental implants in relation to insertion torque. A comparative ex vivo evaluation. *Implant Dent*. 2017;26:250–255.

21. Sakoh J, Wahlmann U, Stender A, Nat R, Al-Nawas B, Wagner W. Primary stability of conical implant and hybrid, cylindric screw-type implant in vitro. *Int J Oral Maxillofac Implants*. 2006;21:560–566.

22. Leocadio ACS, Junior MS, Oliveira G, et al. Evaluation of implants with different macrostructures in Type I bone-pre-clinical study in rabbits. *Materials*. 2020;13:1521.

23. Barone A, Alfonsi F, Derchi G, et al. The effect of insertion torque on the clinical outcome of single implants: a randomized clinical trial. *Clin Implant Dent Relat Res*. 2016;18:588–600.

24. De Santis D, Cucchi A, Rigoni G, Longhi C, Nocini PF. Relationship between primary stability and crestal bone loss of implants placed with high insertion torque: a 3-year prospective study. *Int J Oral Maxillofac Implants*. 2016;31:1126–1134.

25. Berardini M, Trisi P, Sinjari B, Rutjes AWS, Caputi S. The effects of high insertion torque versus low insertion torque on marginal bone resorption and implant failure rates: a systematic review with meta-analyses. *Implant Dent*. 2016;25:532–540.

26. Li H, Liang Y, Zheng Q. Meta-analysis of correlations between marginal bone resorption and high insertion torque of dental implants. *Int J Oral Maxillofac Implants*. 2015;30:767–772.

27. Arisan V, Karabuda ZC, Avsever H, Özdemir T. Conventional multi-slice computed tomography (CT) and cone-beam CT (CBCT) for computer-assisted implant placement. Part I: relationship of radiographic gray density and implant stability. *Clin Implant Dent Relat Res*. 2013;15:893–906.

28. Sennerby L, Andersson P, Pagliani L, et al. Evaluation of a novel cone beam computed tomography scanner for bone density examinations in preoperative 3D reconstructions and correlation with primary stability. *Clin Implant Dent Relat Res*. 2015;17:844–853.

29. Becker W, Hujoel P, Becker BE. Resonance frequency analysis: comparing two clinical instruments. *Clin Implant Dent Relat Res*. 2018;20:308–312.