Osseodensification in Different-Dimension Dental Implants: A Split-Mouth Clinical Study

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The purpose of this study was to compare the insertion torque (IT) and temporal implant stability quotients (ISQ) of different-dimension dental implants placed using subtractive drilling (SD) or osseodensification instrumentation (OD). Twenty-three patients with edentulous spaces received at least 2 implants. Narrow or regular-diameter implants as well as short or regular-length implants were placed in the anterior or posterior maxilla. A split-mouth model was used with 105 implants placed. After osteotomies were performed following the manufacturer's recommendation, IT was recorded with a torque indicator, and ISQ with resonance frequency analysis was immediately performed after surgery and then weekly up to 6 weeks and at 10 weeks. IT data were analyzed using linear mixed models, whereas ISQ data were analyzed using repeated measures analysis of variance and Tukey tests. Multivariate regression models were used to assess correlations between changes in IT, ISQ, and covariates. The study included 11 females and 12 males (mean age 60.5 ± 14 years). Within the studied cohort, OD was associated with higher IT values than SD across the evaluated implant dimensions and sites. ISQ values were also higher in the OD group during the first 2 weeks. In multivariate regression, increased IT was correlated with implants placed in the anterior maxilla, regular diameter, and use of OD drilling. Whereas the investigated factors did not affect the baseline ISQ value, an increased ISQ during the early healing process was correlated with implants placed in the anterior maxilla and the use of an OD bur. Within the limitations of this study, OD demonstrated higher IT and early ISQ values compared with SD independent of implant dimension or surgical site. These findings suggest a potential impact of drilling technique on early implant stability within the study's parameters. Additional studies with larger and more diverse samples are needed to explore clinical relevance.

Key Words: ***clinical trial, dental implants, osseodensification, osseointegration, osteotomy***

INTRODUCTION

In contemporary dentistry, endosteal dental implants are considered the primary treatment choice for replacing missing teeth. Whereas complications are, to a certain degree, frequent, particularly with implant-supported prostheses, prospective studies have consistently revealed high long-term implant survival rates (>95% after a mean follow-up of 10 years).[1] Several factors contribute to dental implant success with the mechanical interlocking between osteotomy walls and implant threads at the time of placement, known as primary stability, being considered paramount to prevent disruption of the healing process and facilitate the establishment of secondary stability.[2] However, primary stability is significantly influenced by several factors, such as surgical drilling technique, implant design, and the quantity and quality of bone, particularly in cases in which immediate loading is expected.[3]

At the time of placement, the implant's primary stability can be indirectly assessed through insertion torque (IT) values obtained with surgical handpieces or quantitatively measured through implant stability quotients (ISQ) using resonance frequency analysis.[4] Any IT values greater than 35 Nścm and/or ISQ values surpassing 68 have been regarded as suitable benchmarks for ensuring a predictable and successful osseointegration process, thereby enabling immediate loading.[5] This underscores the importance of achieving and maintaining these values throughout the initial phases of osseointegration.[6]

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Whereas a robust body of literature focuses on the effect of dental implant surface engineering to reduce the time for functional loading, less attention has been drawn to the impact of surgical drilling protocols on the implant's primary and secondary stability and the resulting osseointegration pathways.[7] Understanding the effects is critical, particularly in challenging scenarios such as a lack of bone quality or availability, in which reduced primary stability may be expected or even contraindicated for implant placement. In such scenarios, clinicians may rely on undersized drilling osteotomies to achieve satisfactory primary stability.[8–11] However, primary stability achieved by bone compression due to undersized drilling often leads to bone strain and microcrack formation, followed by extensive interfacial remodeling at the bone–implant interface, which eventually decreases secondary stability and may increase the time required for prosthetic functional loading. A systematic review with meta-regression reveals higher mismatches between osteotomy sites and implant diameters due to under-drilling during implant site preparation, and this has been associated with increased marginal bone level alteration, potentially leading to compromised implant treatment.[12]

Among the various treatment approaches to overcome challenging scenarios with reduced bone density, an osteotomy preparation technique, known as osseodensification, has been proposed. This technique utilizes burs designed with a negative rake angle and noncutting edges, and these expand the osteotomy and thereby increase bone density.[13] The method operates on the principle that the burs do not excavate the osteotomy but instead compact the bone fragments into the osteotomy walls, thereby densifying the region and creating nucleating sites for regeneration. The densifying burs have been designed with 4 or more land flutes that gently compact autograft bone tissue, making them particularly beneficial in cases of poor bone quality.[13]

Osseodensification (OD) osteotomies have demonstrated a reduction in the actual osteotomy diameter when left unfilled, primarily due to residual strain and the bone's spring-back effect.[14–16] This effect generates mild compressive forces on the implant, thereby bolstering the initial biomechanical connection between the bone and the implant, resulting in increased primary stability. Furthermore, OD drilling, especially in a counterclockwise direction, demonstrates osteogenic activity through the compaction of autografted bone chips that bridge the gaps between the implant surface and the osteotomy, ultimately increasing bone apposition compared with a conventional subtractive drilling protocol.

A previous clinical study demonstrates through cone-beam computerized tomography a significant increase in immediate bone density at areas subjected to OD drilling and its maintenance over a period of 6 months, and this was not observed in subtractive drilling (SD).[17] A 12-month follow-up of implants placed through the OD drilling technique in private practices has shown a 99.2% survival rate when implants were immediately loaded and 100% for delayed loading.[18] Whereas there is increasing clinical evidence of higher IT and improved temporal ISQ reported for implants placed using OD drilling compared with conventional SD drilling in clinical studies,[17–20] as well as in systematic reviews,[21–24] scarce information is available regarding the effect of OD drilling on implants of different lengths.

In a recently published, multicenter, controlled clinical trial comparing the OD technique with the conventional subtractive drilling technique, significantly higher IT and ISQ values were reported for OD regardless of arch, area operated (anterior versus posterior), and implant design. Remarkably, this study showed no positive influence of OD for short implants, likely because no specific densifying burs had been developed for this implant length range at that time.[25] Such burs have been recently tailored and added to the surgical kit in an attempt to improve short implant primary stability, which is critical for its success. Therefore, the present study aimed to evaluate the IT and temporal ISQ (immediate, weekly up to 6 weeks, and then at 10 weeks) of short dental implants in a split-mouth prospective study. The null hypothesis of the present study was that there would be no difference in the IT and ISQ between different-dimension implants placed with the OD technique compared with the SD drilling technique.

Materials and Methods

Study design

The clinical study was reviewed and approved by the research ethics committee, registered in the clinical trials registry, and conducted according to the Declaration of Helsinki guidelines. All patients received comprehensive explanations about the study and signed an informed consent form, documenting their understanding of the study's scope, including procedures, follow-up assessments, and potential risks involved.

The exclusion criteria included alcoholism, excessive smoking ($>$20 cigarettes per day),[26] use of illicit drugs, heart diseases, diabetes, previous bone regenerative or augmentation procedures, bleeding disorders, compromised immune system, irradiated patients, and prior or active treatment with steroids or bisphosphonates. Inclusion criteria included the presence of 1 or 2 edentulous arches, a minimum bone height of 7 mm at both sites, a minimum cervical bone thickness of 4 mm at the buccal and lingual or palatal sides, minimum age of 18 years, patients classified as American Society of Anesthesiologists (ASA) I or ASA II, healthy adjacent teeth or teeth requiring no prosthetic restoration, and patients who have signed the informed consent form.

At the beginning of the investigation, a sample size calculation was performed based on the preliminary data of IT, which was considered the primary dependent variable of the current study. Considering that arch (maxilla and mandible), area operated (anterior and posterior), implant diameter (narrow and regular), implant length (short and regular), and osteotomy (SD and OD) were the independent variables, the minimum sample size calculated to obtain a statistical test power of 80% and a 5% alpha error within an effect size of 12 N.cm (Cohen's $d = 0.6$ based on a standard deviation of 20 N.cm) was 8 implants per factor level. Accounting for all the study factors and a 20% increase for potential losses and refusals, a total sample of approximately 96 implants was required. Therefore, the total sample of 105 implants included in the present study was considered adequate for multivariable analysis (G*Power 3.1, HHU University, Germany).

Each patient received at least 2 internal conical connection implants (Strong SW Plus, S.I.N. Implant System, São Paulo, SP, Brazil) in the posterior and/or anterior region of the maxilla. For implant planning and bone volume analysis, cone-beam computerized tomography was performed for all patients. The selection of implant diameter and length was performed at this stage using planning software (Invivo5 3D, Kavo, Biberach, Germany). Implants with diameters of 3.5 or 3.8 mm and lengths of 8.5, 10, 11.5, or 13 mm were selected based on the available bone height and thickness. The following implant classification system was used:[27]

		Classification
Length	≤ 6 mm	Extra short
	> 6 mm to < 10 mm	Short
	≥ 10 mm to < 13 mm	Standard
	≥ 13 mm	Long

		Classification
Diameter	< 3 mm	Extra narrow
	≥ 3 mm to < 3.75 mm	Narrow
	≥ 3.75 mm to < 5 mm	Standard
	≥ 5 mm	Wide

Surgical technique

All implants were placed by the same experienced surgeon under local anesthesia using a 2% mepivacaine hydrochloride solution with 1:100 000 adrenaline (Mepiadre 2%, Nova DFL, Rio de Janeiro, RJ, Brazil). After incision and complete flap reflection, osteotomies were performed under saline irrigation. The osteotomies were performed at 1100 rpm with the use of sequential burs of the same diameter of both surgical techniques (SD or OD), and the instrumentation was performed according to the recommended drilling protocols for each implant diameter; OD drilling was conducted in 1 side of the mouth with densifying burs (Densah Burs, Versah, LLC, Jackson, MI) in the counterclockwise direction, whereas the contralateral side received standard implant placement through SD using the implant manufacturer drilling kit (Strong SW Plus, S.I.N. Implant System). The osteotomy dimensions followed the manufacturer's recommendations, and both burs presented a similar mismatch to the implant dimension (Figure 1). The OD drilling dimension is designed to follow the implant primary diameter (0.5 mm smaller in the maxilla and 0.2 mm smaller in the mandible).

To prevent allocation bias, the right and left sides for both techniques were alternated among consecutive patients. The implant placement process was performed using a motor handpiece running at a speed of 20–50 rpm without irrigation. The installation was then finalized using a manual surgical torque wrench indicator of the implant system. The maximum torque value (Nścm) achieved at the end of implant insertion was documented as the IT value.

After the implant was securely placed, a corresponding Smart Peg (Ref: 100848/lot: 106458, Osstell/Integration Diagnostics, Gothenburg, Sweden) tailored to the implant system and restorative platform diameter was installed. Subsequently, an immediate (T0) resonance frequency analysis was conducted using an Osstell Mentor device (Osstell/Integration Diagnostics) to document ISQ values across all implant surfaces (the average of mesial, distal, vestibular, lingual, and occlusal values) to obtain a mean ISQ value per implant. ISQ values were additionally documented during weekly follow-up appointments from baseline to 6 weeks (T1, T2, T3, T4, T5, and T6) and then at 10 weeks (T10). To facilitate access for ISQ readings, healing abutments were gently screwed on the day of surgery and during the first 10 evaluation weeks. After implant placement and the T0 ISQ reading, new and sterile healing abutments were installed, and the incision was sutured using Vicryl 4.0 (Ethicon Inc, Johnson & Johnson, Somerville, NJ) to facilitate wound closure. These sutures were removed 1 week after the surgery.

For each implant, IT and ISQ were evaluated by the same experienced operator. Each measurement was repeated 3 times, and the average was used for analysis to reduce variability. The intra-examiner reliability was assessed using a pilot set of 10 implants, yielding an intraclass correlation coefficient greater than 0.90 for both IT and ISQ.

After surgery, all patients were advised to follow a gentle and lukewarm diet for the initial 3 days following the surgical procedure, and guidance on maintaining oral hygiene was provided. They were provided with a prescription for amoxicillin with a dosage of 500 mg to be taken every 8 hours for a duration of 7 days, starting 1 hour before surgery. Furthermore, additional prescriptions encompassed anti-inflammatory and pain-relieving medications for a period of 3 days, including nimesulide 100 mg every 12 hours and 1 g paracetamol every 8 hours if necessary.

Following T10, an impression of the implant's spatial position and orientation was taken, and a final restoration was made based on the clinical requirements.

Statistical analysis

Data analysis revealed that the data followed a normal distribution (Shapiro-Wilk test, all *p*s $> .05$) and exhibited homogeneity of variance across the groups (Levene test, all *p*s $> .25$). Additionally, Mauchy's sphericity tests validated that the data set is spherical concerning both IT ($P = 1$) and ISQ ($P = 1$) with the high *p*-values indicating no violation of sphericity. To compare IT values, the linear mixed model test and least significant difference for multiple comparisons were employed. Repeated-measure analysis of variance and Tukey tests were used for numerous analyses in the analysis of ISQ data. Additionally, multivariate linear regression was used to examine the relationship between study predictor variables (age, gender, smoking, implant area, implant diameter, implant length, and drilling protocol) and the dependent variables,

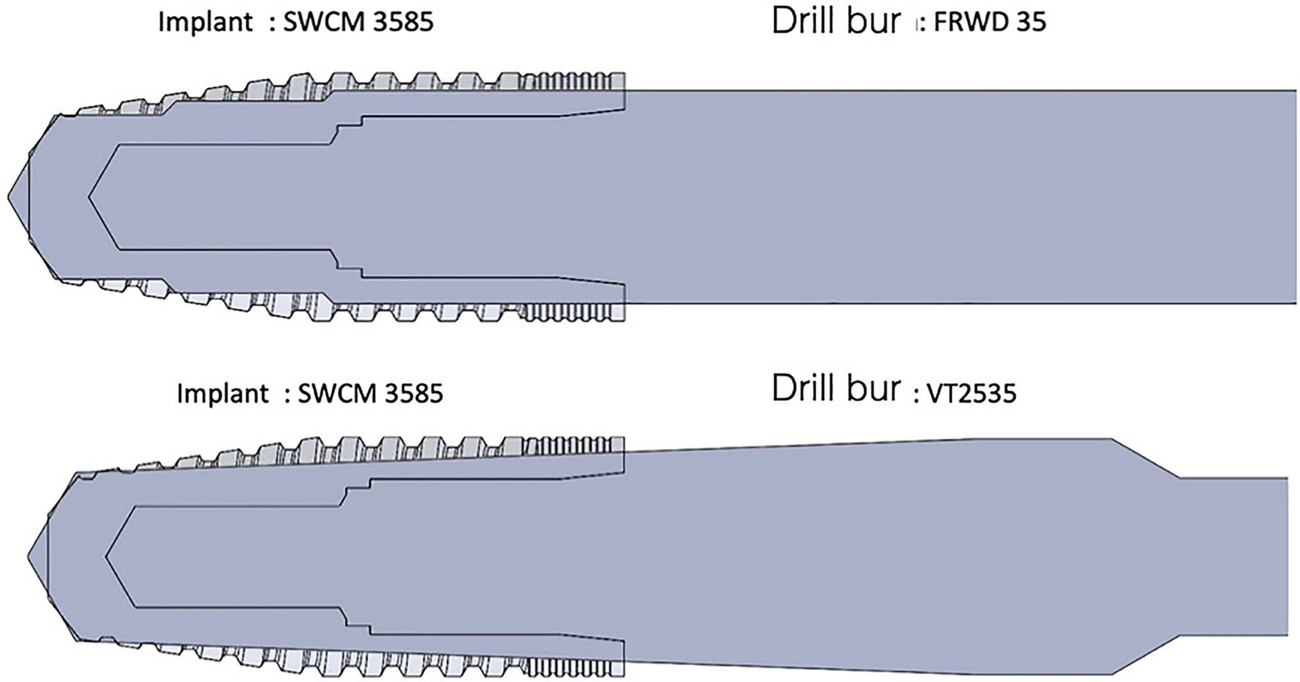

Figure 1. Diagram of the osteotomy dimensions performed using Versa (VT2535) and STRONG SW drills (FRWD 35), showing the designed mismatch between the burs and implant diameters (0.5 mm smaller in the maxilla and 0.2 mm smaller in the mandible).

namely, insertion torque, immediate ISQ, and 2-week ISQ. After excluding missing data through listwise deletion, all predictors were entered into the model. The model fit was evaluated using the R^2 value, and the significance of the overall model was assessed via analysis of variance (ANOVA). Regression coefficients, along with 95% confidence intervals and *p*-values, were used to determine the influence of each predictor variable on the outcome variable. Analyses were conducted using SPSS (IBM SPSS 23, IBM Corp, Armonk, NY) and the Python software package.

Results

The study consisted of 23 patients, 11 (48%) female and 12 (52%) male with a mean age of 60.5 years (±14 years). A total of 105 implants were placed using various osteotomies. An independent statistician reviewed the results. Osseodensification (OD, n = 53) and subtractive (SD, n = 52) drillings were evaluated as a function of different factors: area operated (anterior and posterior) and implant dimensions, such as diameter (narrow, n = 54, and regular, n = 51) and length (short, n = 50, and regular, n = 55). Overall, the clinical findings demonstrate an uneventful implant healing process with no indication of peri-implant tissue inflammation, infection, or implant mobility throughout the ISQ evaluation time points up to 10 weeks. Patients received healing abutments to protect the implants and tissues between the appointments.

The statistical analysis of IT as a function of osteotomy indicated that OD (51 ± 5.4 Nścm) presented higher IT compared with SD (36 ± 5.4 Nścm), representing an approximately 30% increase ($p < .001$) (Figure 2), and OD outperformed conventional SD irrespective of area operated in the maxilla, anterior, and posterior ($p < .001$) (Figure 3a). Whereas there was no significant difference on IT values for implants placed using OD in the anterior region relative to the posterior region of the maxilla ($p = .407$), implants placed using SD in the anterior region evidenced higher IT values than the implants placed in the posterior region of the maxilla ($p = .005$) with a difference of approximately 10% (Figure 3a). This significant difference is confirmed by ANOVA ($p < .001$) with a type II error rate of 0.30 (Supplemental Table 1).

The IT data, as a function of implant diameter, narrow and regular, and drilling technique, exhibited higher values for OD relative to SD in all pairwise comparisons ($p < .001$) (Figure 2b). No significant difference was observed between narrow- and regular-diameter implants in the IT values ($p > .091$) (Figure 3b). Similarly, IT

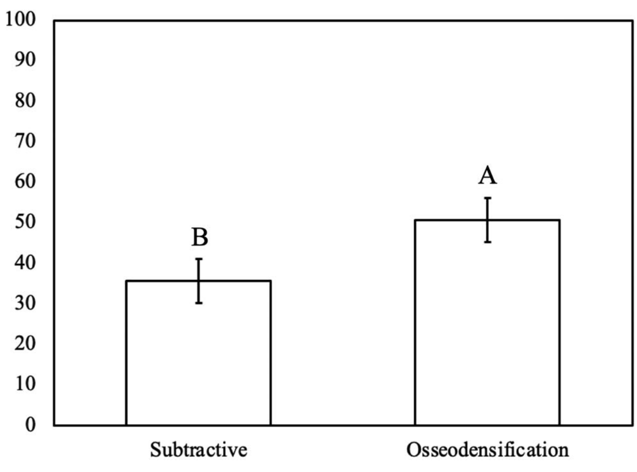

Figure 2. Insertion torque as a function of osteotomy protocol. Different letters indicate a statistically significant difference.

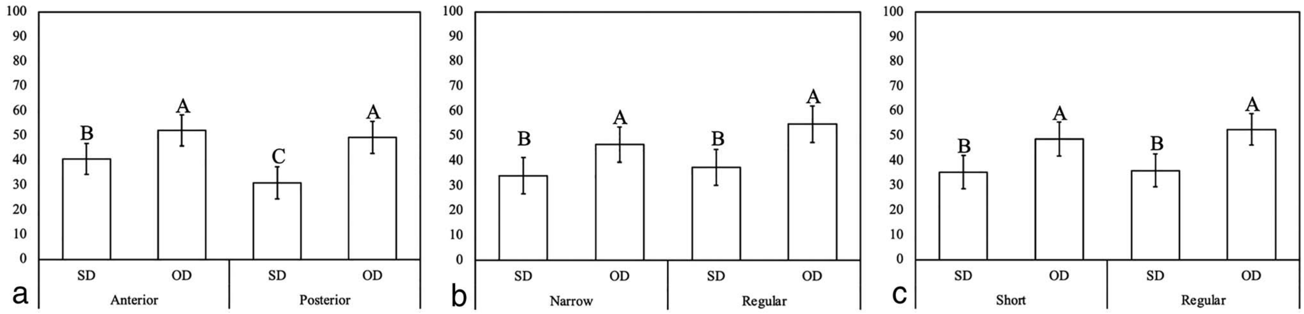

FIGURE 3. (a) Insertion torque as a function of osteotomy protocol (osseodensification-OD vs subtractive-SD) and area operated (anterior vs posterior). Different letters indicate a statistically significant difference. (b) Insertion torque as a function of osteotomy protocol (osseodensification-OD vs subtractive-SD) and implant diameter (narrow vs regular). Different letters indicate a statistically significant difference. (c) Insertion torque as a function of osteotomy protocol (osseodensification-OD vs subtractive-SD) and implant length (short vs regular). Different letters indicate a statistically significant difference.

data, as a function of implant length (short and regular) and drilling technique, exhibited higher values for OD relative to SD in all pairwise comparisons ($p < .001$) (Figure 3c). Moreover, no significant difference in the IT values was observed between short- and regular-length implants ($p > .324$) (Figure 2c). The ANOVA analyses comparing the means between groups confirmed the significant differences observed (Supplemental Table 1).

The compiled ISQ data demonstrated significantly higher values for OD compared with the conventional SD technique for weeks 1 and 2 following implant placement ($p < .022$). The ISQ values increased dramatically from the day of the surgical procedure to 6 and 10 weeks for implants placed using the SD technique ($p < .025$), whereas ISQ values showed no significant difference between baseline and the 10-week follow-up for implants placed using the OD technique ($p < .135$). Regardless of the drilling technique, ISQ values remained above 60 throughout the follow-up period (Figure 4).

The statistical analysis of ISQ data as a function of area operated and osteotomy demonstrated higher ISQ values for OD relative to SD osteotomies for implants placed in the anterior region of the maxilla up to 3 weeks after surgery ($p < .033$). For implants placed in the posterior region of the maxilla, ISQ values were significantly higher for OD relative to SD osteotomies only at 2 weeks after the surgical procedure ($p = .017$) (Figure 5).

Data, as a function of implant diameter and osteotomy, indicated that, irrespective of surgical technique, the ISQ values showed no significant difference between narrow- and regular-diameter implants at all time points ($p > .133$). Whereas no significant difference was observed between OD

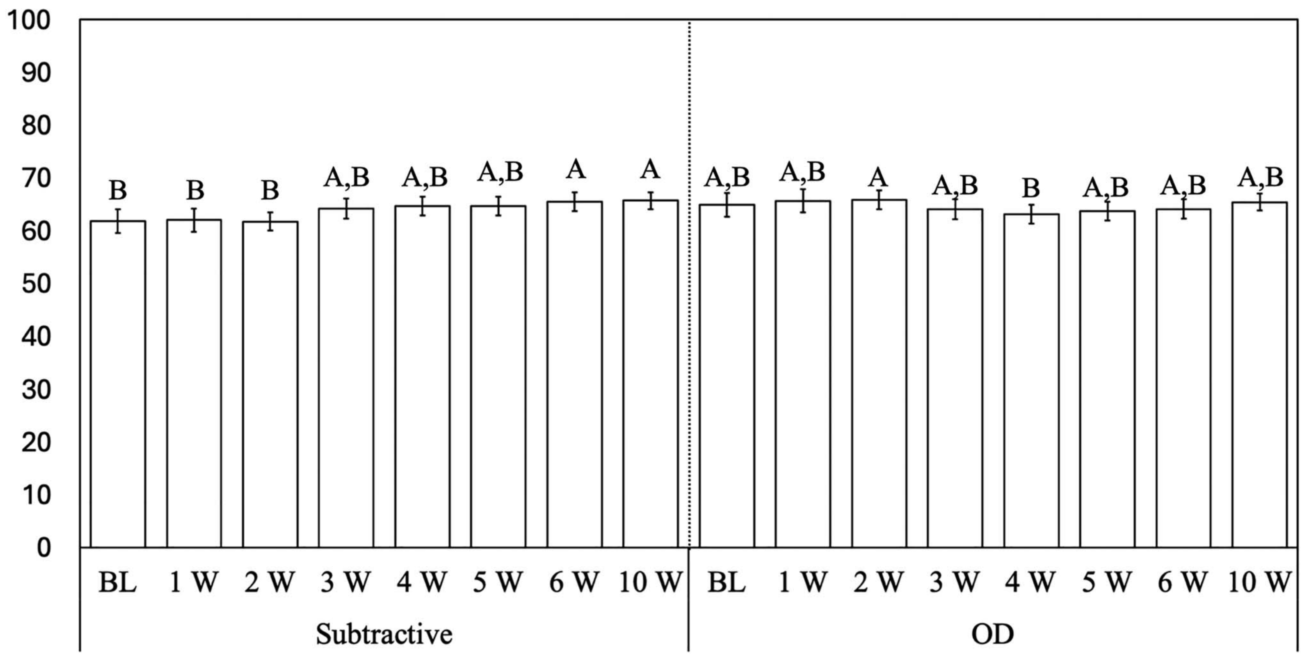

FIGURE 4. Implant stability quotient as a function of osteotomy protocol. Different letters indicate a statistically significant difference. BL indicates baseline; W, week.

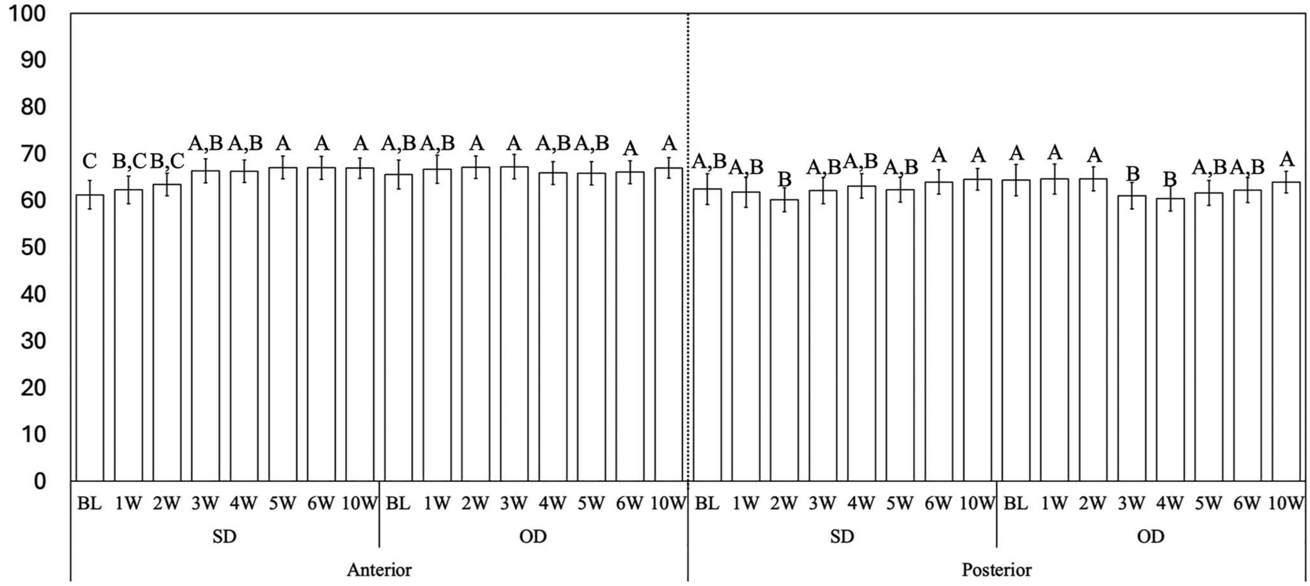

Figure 5. Implant stability quotient as a function of osteotomy protocol (osseodensification-OD vs subtractive-SD) and area operated (anterior vs posterior). Different letters indicate a statistically significant difference. BL indicates baseline; W, week.

and SD techniques for narrow-diameter implants, OD outperformed SD drilling for regular-diameter implants up to 3 weeks after implant placement ($p < .039$) (Figure 6).

Similarly, ISQ data analyzed as a function of implant length and osteotomy indicated that the ISQ values presented no significant difference between short- and regular-length implants for all evaluation time points ($p > .114$) ($p < .003$). Whereas no significant difference was observed between OD and SD techniques for short-length implants, implants placed in osteotomies prepared using OD outperformed those placed in osteotomies prepared with SD drilling for regular-length implants up to 2 weeks after implant placement ($p < .036$) (Figure 7). The presence of a significant difference between the means of the aforementioned groups was confirmed using ANOVA with a type II error rate of 0.78 (Supplemental Table 2). Whereas the Tukey test has taken the family-wise error rate (FWER) into account, the ANOVA analysis has not, and therefore, the FWER for the ANOVA results was determined to be 0.004.

Multivariate regression was used to correlate changes in IT and ISQ at baseline with several factors, including age, gender, and smoking status as well as area operated, implant diameter, length, and drilling technique. Multivariate regression revealed that increased IT was correlated with implants placed in the anterior region of the maxilla, regular diameter, and use of OD

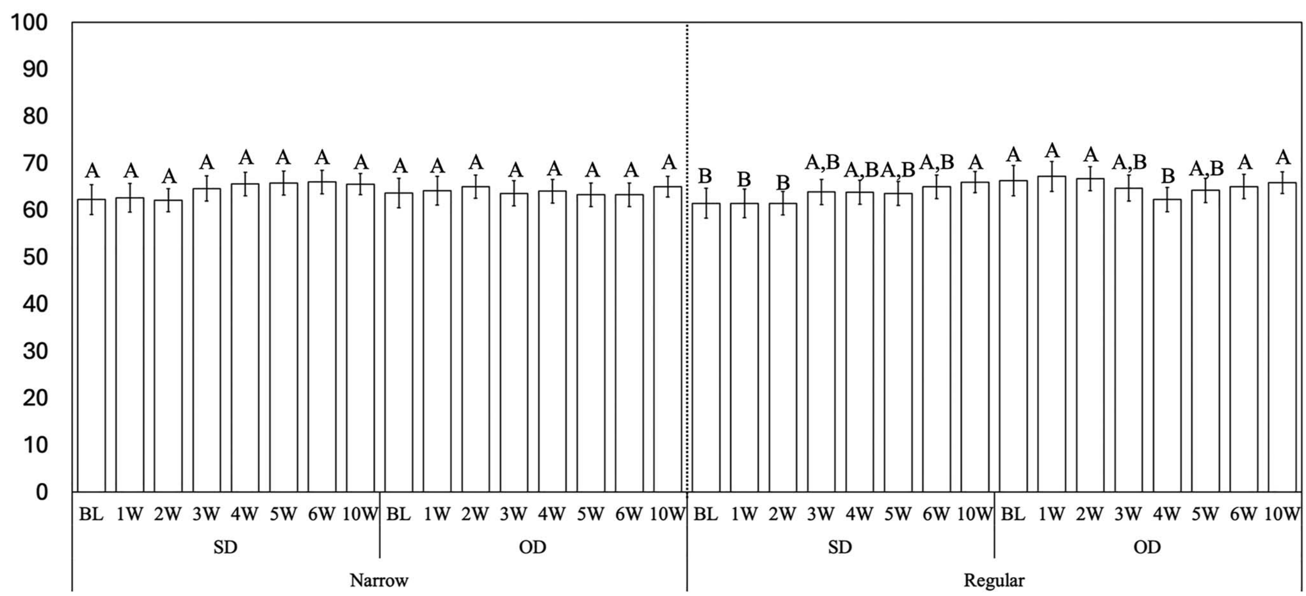

Figure 6. Implant stability quotient as a function of osteotomy protocol (osseodensification-OD vs subtractive-SD) and implant diameter (narrow vs regular). Different letters indicate a statistically significant difference. BL indicates baseline; W, week.

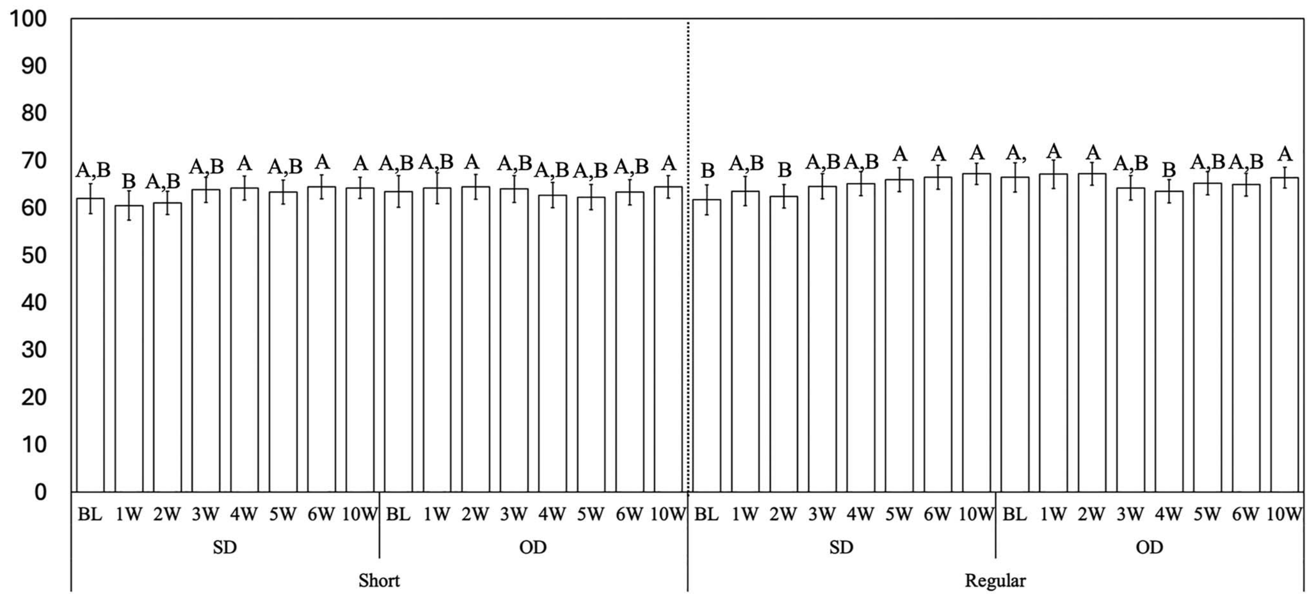

FIGURE 7. Implant stability quotient as a function of osteotomy protocol (osseodensification-OD vs subtractive-SD) and implant length (short vs regular). Different letters indicate a statistically significant difference. BL indicates baseline; W, week.

drilling (Table 1). Multivariate regression analysis revealed that the investigated factors did not affect the baseline ISQ value (Table 2); however, an increased ISQ was correlated with implants placed in the anterior region of the maxilla and the use of OD drilling at the early healing stage, specifically at 2 weeks (Table 3).

Discussion

Among the clinical steps associated with dental implant procedures, osteotomy site preparation can significantly impact both primary (mechanical) and secondary (biological) stability of the implant, which is crucial for successful osseointegration and long-term implant success.[2,9,28] In this split-mouth, prospective clinical study, the impact of 2 different drilling techniques—osseodensification and subtractive drilling—on the stability of implants with various dimensions and locations in the maxilla was evaluated. The results of the statistical analysis revealed that implants placed using the osseodensification technique exhibited significantly higher IT values compared with those placed using the SD technique, irrespective of the location in the maxilla and implant dimensions (diameter and length). The compiled ISQ data showed that implants placed using OD presented significantly higher ISQ values during the first 2 weeks after surgery compared with those placed using SD. Furthermore, ISQ values remained consistently above 60 throughout the follow-up period, indicating good implant stability and osseointegration. Therefore, the postulated null hypothesis of the present study—that there would be no difference in the IT and ISQ between different-dimension implants placed with the OD technique compared with the SD drilling technique—was rejected.

Achieving high levels of implant biomechanical stability is highly desirable in clinical practice as it reduces treatment time and enables the implementation of immediate or early loading protocols. Implant primary stability is frequently evaluated through the measurement of IT and ISQ values.[4,29] Although both factors are widely accepted in implant literature and high values are positive indicators of primary stability, they are independent and incomparable to each other.[4,30] Moreover, IT evaluations assess implant stability only at implant placement, whereas ISQ, as a parameter related to time, is most significant when it allows for comparison of subsequent measurements over prescribed time intervals; therefore, as a 1-time measurement, it may not

TABLE 1

Results of the multivariate regression analysis for insertion torque

Factor	B	SE	Beta	*t*	Significance	95% Lower CI Odds Ratio	95% Upper CI Odds Ratio
Age	0.023	0.119	0.019	0.191	0.849	−0.213	0.259
Gender	−8.989	3.393	−0.265	−2.649	0.010	−15.742	−2.237
Smoking	4.200	4.462	0.093	0.941	0.349	−4.680	13.079
Area	−9.424	3.085	−0.284	−3.055	0.003	−15.563	−3.285
Diameter	10.461	3.310	0.315	3.160	0.002	3.873	17.049
Length	5.194	3.240	0.156	1.603	0.113	−1.253	11.642
Drilling	15.800	2.932	0.476	5.389	0.000	9.965	21.634

Table 2

Results of the multivariate regression analysis for implant stability quotient at the moment of implant placement

Factor	B	SE	Beta	*t*	Significance	95% Lower CI Odds Ratio	95% Upper CI Odds Ratio
Age	−0.061	0.066	−0.113	−0.926	0.357	−0.193	0.070
Gender	−0.806	1.890	−0.052	−0.426	0.671	−4.567	2.955
Smoking	3.295	2.485	0.160	1.326	0.189	−1.651	8.241
Area	−0.306	1.718	−0.020	−0.178	0.859	−3.726	3.113
Diameter	0.080	1.844	0.005	0.044	0.965	−3.589	3.750
Length	2.845	1.804	0.189	1.577	0.119	−0.746	6.436
Drilling	1.990	1.633	0.132	1.219	0.226	−1.259	5.240

yield much significance. At implant installation, the IT results, as a function of osteotomy technique, suggest that osseodensification outperformed the standard subtractive drilling technique regardless of the surgical site. These results suggest a higher mechanical engagement in surgical sites prepared through osseodensification due to bone compaction, autografting, and the spring-back effect of OD drills, which increase bone density and promote higher bone-to-implant contact as demonstrated in previous histomorphometric data.

Remarkably, osteotomy preparation through osseodensification yielded similar IT values in the anterior and posterior regions of the maxilla. In contrast, conventional subtractive drilling resulted in lower IT values for implants placed in the posterior compared with those in the anterior maxilla. Because the primary stability depends on the interplay between osteotomy walls and implant hardware,[7] the cortical and trabecular bone availability has been suggested to play a significant role in the biomechanical engagement of dental implants.[31–34] The IT results of the OD group indicate that the instrumentation technique was able to produce predictable densification of the trabecular bone in the posterior maxilla, resulting in IT values similar to those observed in the anterior region. On the other hand, the conventional subtractive technique resulted in lower IT in the posterior maxilla, likely due to the lower trabecular bone density of the posterior maxillary region and the absence of osteotomy densification in the standard drilling technique.

In challenging scenarios, such as low-density regions, a frequent clinical practice involves preparing undersized osteotomies and placing dental implants with larger dimensions to increase IT values.[35] Moreover, the achievement of high IT values through osteotomy diameter and implant misfit produces a significant shift in the bone remodeling and interfacial healing pathway accompanied by evidence of excessive bone strain, deformation, microcracking, and extensive areas of bone remodeling. The clinical implications of undersized drilling are expressed in higher degrees of marginal bone level alterations in the short term.[12] The osteotomy preparation through osseodensification allowed for an osteotomy that is slightly smaller or equal to the implant primary diameter and for the interplay of implants' macrogeometry with the densified osteotomy walls to obtain high IT values through the beneficial spring-back effect of the trabecular bone in the posterior maxilla.[36–38] This was observed in the analysis of IT data as a function of implant dimensions, in which OD resulted in higher IT values regardless of the implants' length and diameter when compared with subtractive drilling. These findings differ significantly from the results of a recently published multicenter study, in which OD presented higher IT and ISQ values for all clinical scenarios except for short implants.[25] Whereas it was suggested that such results may be explained by the reduced contact area available for the benefits provided by the OD drilling, no specific short, densifying burs were available on the market at the time. Therefore, the benefits of osseodensification drilling may be related to the utilization of densifying burs with varying lengths and diameters.

Implant hardware and its relationship with the osteotomy preparation have been identified as paramount factors to determine the osseointegration and bone healing pathway.[7,36] For instance, the tight fit obtained by undersized osteotomies and the intimate contact between bone and the implant's surface have been shown to produce an interfacial remodeling pathway, where high IT values result in bone strain and significant bone remodeling around the implanted device. This scenario has been confirmed by the loss of mechanical interlocking and

Table 3

Results of the multivariate regression analysis for implant stability quotient 2 weeks after implant placement

Factor	B	SE	Beta	*t*	Significance	95% Lower CI Odds Ratio	95% Upper CI Odds Ratio
Age	0.096	0.057	0.191	1.688	0.095	−0.017	0.208
Gender	−0.457	1.621	−0.032	−0.282	0.779	−3.684	2.769
Smoking	0.372	2.132	0.019	0.175	0.862	−3.871	4.615
Area	−4.427	1.474	−0.316	−3.004	0.004	−7.360	−1.494
Diameter	2.216	1.582	0.158	1.401	0.165	−0.932	5.364
Length	3.046	1.548	0.218	1.968	0.053	−0.034	6.127
Drilling	3.446	1.401	0.246	2.460	0.016	0.658	6.234

stability dip due to extensive bone interfacial remodeling after implant placement.[7,39] In the present study, higher ISQ values were observed for the OD group at 2 weeks compared with the SD group, suggesting a shift in the healing pathway for implants placed using different osteotomy techniques. Whereas subtractive drilling and implant tight fit produces a remodeling process with significant osteoclastic activity that resorbs the bone in intimate contact with the implant,[7,40,41] osseodensification has been suggested to create an earlier shift in the healing pathway with reduced remodeling around the implant with more areas of bone proliferation likely due to the presence of bone chips that act as autografts between the implant's threads.[16] Histological evaluations suggest that the autograft particles act as nucleating sites for new bone formation, which may hasten the achievement of secondary stability.[42]

To reduce clinical time between implant surgery and prosthesis installation, immediate loading protocols are frequently recommended when implants are inserted with IT values between 30 and 45 Nścm or an ISQ above 60 with no need for simultaneous bone augmentation.[43] Irrespective of drilling technique, both experimental groups presented IT and ISQ means above the minimum requirements for immediate loading at insertion and throughout the follow-up period, respectively. However, the implants installed through subtractive osteotomy presented a slower increase in ISQ values from the baseline to the 10-week follow-up, which differed from implants installed with osseodensification, for which no significant differences were observed in ISQ values over time. Even at a higher level of physical interlocking, no detrimental bone response could be observed for OD, which showed ISQ values above the minimum requirements for load-bearing capacity over time (ISQ: 68). Previous studies also indicate that OD drilling might result in a temporally stable implant device irrespective of area placed in the mouth and its dimensions with values remaining above 70 up to 6 weeks of follow-up.[44,45]

Overall, the results of this study highlight the significant impact of drilling technique on implant stability and osseointegration. The use of OD for osteotomy preparation resulted in higher IT and ISQ values compared with conventional SD drilling, indicating improved initial stability at early stages of osseointegration. These findings have important implications for dental implant surgery as they suggest that the choice of drilling technique can play a crucial role in enhancing implant osseointegration times and treatment outcomes.

Whereas the present study provides valuable insights into the effects of OD on implant stability, some limitations must be acknowledged. Although split-mouth designs offer advantages in controlling intersubject variability, they are not without limitations. These include the potential for carry-across effects, difficulty ensuring site equivalence, and increased complexity in statistical interpretation. Moreover, the generalizability of findings from split-mouth studies may be limited due to these methodological constraints. This study used a convenience sample of systemically healthy volunteers, and this further restricts external validity. Therefore, the findings presented here should be interpreted as preliminary and hypothesis-generating rather than definitive or broadly generalizable. Additionally, only 1 implant system was tested; future studies should evaluate different implant macrogeometries, including extra-short dental implant designs. Long-term follow-up beyond the early osseointegration phase is warranted to provide a more comprehensive understanding of the effects of OD on implant survival and marginal bone stability.

Conclusion

In conclusion, OD provided higher IT and ISQ at the early healing stage relative to conventional, SD, and OD outperformed SD regardless of the area operated in the maxilla with no significant effect of implant dimensions, narrow- and regular-diameter or short- and regular-length implants.

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Author Contributions

Abbas Zahoui: data curation, formal analysis, investigations, methodology, and writing; Edmara T.P. Bergamo: data curation, investigations, methodology, and writing; Paulo G. Coelho: conceptualization, methodology, writing, review, and editing; Ernesto B. Benalcázar-Jalkh: data curation, investigations, methodology, writing, and editing; Larissa M.M. Alves: data curation, investigations, methodology, and writing; Marco A.M.A. Alves Junior: data curation, investigations, and methodology; Lukasz Witek: conceptualization, methodology, writing, review, and editing; Leonardo R. Bonjardim: conceptualization, review, and editing; Yu-Chi Cheng: interpretation of data for the work, reviewing the draft version, approval of the submitted version, agreement to be accountable for the integrity of the work; and Estevam A. Bonfante: conceptualization, data curation, investigations, methodology, writing, review, and editing.

Note

None of the remaining authors have any conflicts to declare related to this study.

Supplemental Material

Supplemental data associated with this article can be found at https://doi.org/10.1563/aaid-joi-D-25-00037

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