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Original Article

The developing patterns of calibrated implant stability quotients of posterior implants

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Implant stability;
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Background/Purpose: Many surgical protocols were modified to improve implant stability. However, the conclusions of applying osteotome condensation technique could enhance implant stability were controversial. The evaluated implant stability quotients (ISQ) were calibrated to differentiate the implant stability improvement that applied by varied surgical techniques and the bone quality at recipient sites. Therefore, this study examine the developing patterns of calibrated ISQ values induced by osteotome bone condensation and conventional drilling technique at the posterior ridges.
Materials and methods: The ISQ values of 4.1/4.8-mm diameter implants were calibrated by 3.3-mm diameter implants (ISQ_b). Osteotome condensation technique was applied on the sites with $ISQ_b \leq 65$ while those with $ISQ_b > 65$ were treated with conventional drilling technique. The implant ISQ values at Week 0, 1, 2, 3, 4, 6, 8, 10, 12 were recorded. The detected and calibrated ISQ values were statistically analyzed.
Results: Maxillary 14 implants and mandibular 16 implants using osteotome technique, maxillary 15 implants and mandibular 16 implants with conventional drilling technique were studied. Both techniques showed a generally similar ISQ developing pattern at both arches. Without calibration, significantly less ISQ values were noted for the osteotome technique of posterior maxilla at initial four weeks; subsequently, both techniques presented a comparable ISQ developing pattern. Osteotome technique demonstrated a greater ISQ increase after calibration on both arches ($p < 0.05$). All implants reached an ISQ stability plateau between Week 8 and 10.

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Conclusion: With calibration, osteotome condensation technique could enhance greater primary and secondary implant stability for both arches.

Introduction

Clinically, dental implant treatments are predictable and encouraged. However, the success rates were differed between maxillary and mandibular, as well as between anterior and posterior ridges because of the bone condition.[1,2] Bone quality and implant primary stability correlated with the implant survival significantly. The ridges with poor bone quality could compromise implant primary stability; subsequently, an impeded secondary stability or implant failure might follow.[3–5]

Many surgical protocols were modified to improve implant primary stability. Nevertheless, there was still a weak or lack of evidence to prove whether any specific surgical technique could significantly affect implant stability.[6] Summers first presented the osteotome technique to accommodate dental implants into low-density alveolar ridges. Osteotome condensation compressed the trabecular bones laterally and apically to preserve existing bone, prevent too much bone removal, reduce heat production, increase local bone density, and improve implant stability.[7,8]

The conclusions of applying osteotome condensation technique could enhance implant stability were controversial. In some animal experiments, osteotome condensation achieved a higher implant fixation by increasing bone density rather than the conventional drilling technique did.[9–12] However, the micro bone fractures around implant associated with osteotome condensation led to insufficient bone regeneration, impaired bone-to-implant contact, and decreased implant stability were noted in some histological evidences.[13,14] Clinically, osteotome condensation improved implant stability in some short-term observations,[15–23] while no additional short-term or long-term benefits revealed in other studies. To the best of our knowledge, only few published data comparing the implant stability following the conventional drilling and osteotome condensation techniques in maxillary and mandibular posterior areas.

Implant stability partially represent the status of implant healing which can be evaluated quantitatively via resonance frequency analysis (RFA). The RFA was recorded as an implant stability quotient (ISQ) and provided a suggested value during healing; this ISQ was considered as a reliable reference to evaluate implant stability.[24] The purpose of this study was to compare the developing patterns of applying osteotome bone condensation and conventional drilling techniques by measuring with and without calibrated ISQ values of dental implants placed at posterior ridges for both arches during a 12-week observation period.

Materials and methods

Patient selection

Patients with missing maxillary and mandibular premolars or molars required dental implant treatments were enrolled. Exclusion criteria were 1) presence of systemic diseases that could affect wound healing (cardiac disease, uncontrolled diabetes: HbA1c $>$ 7.4%, osteoporosis, history of head and neck radiation therapy, and immunosuppressant therapy); 2) heavy smokers ($>$10 cigarettes per day); 3) implant sites with $<$3 months of healing time after tooth extraction; 4) history of guided bone regeneration (GBR) treatment or requiring GBR treatment if any surface of the implant showed a bony defect; 5) implant ISQ value was undetectable. This study was independently reviewed and approved by the Institutional Review Board for Clinical Research in Chang Gung Memorial Hospital (No. 201700018B0C601).

Surgical protocols and data collection

Before surgical intervention, patients were undergoing initial infection-control therapy and careful 2-dimensonal and/or 3-dimensional radiographic examinations. Dental implant treatment was performed with patients' signed consents. The flap was reflected under local anesthesia and the implant recipient sites were initially marked with a round bur to penetrate the cortical bone and then prepared using 2.2-mm and 2.8-mm pilot drills. Subsequently, a 3.3-mm diameter implant was placed then its resonance frequency was measured using an Osstell Mentor (Integration Diagnostics AB, Gothenburg, Sweden), and this ISQ value was recorded as the ISQ baseline (ISQ_b). The ISQ_b values were used for the calibration of the planned 4.1/4.8-mm diameter implants at recipient sites. The 3.3-mm diameter implant was then withdrawn and different surgical procedures were continued based on the ISQ_b.

The implant sites with bone quality of $ISQ_b \leq 65$ were allocated to the osteotome bone condensation group and subsequently prepared by using a series of increasing diameters osteotome instruments until the final width and depth were obtained. Thereafter, the planned 4.1-mm or 4.8-mm diameter implants were tagged in and the ISQ values were recorded. On the other hand, the alveolar

Table 1 Comparison of the detected and calibrated ISQ values for both techniques at tested time points at posterior maxilla and mandible.

	Osteotome		mean ± SD (n)		Conventional		mean ± SD (n)		*p* value							
	Posterior maxilla		Posterior mandible		Posterior maxilla		Posterior mandible									
	ISQ	ISQ-ISQ$_b$	ISQ	ISQ-ISQ$_b$	ISQ	ISQ-ISQ$_b$	ISQ	ISQ-ISQ$_b$	a vs e	b vs f	c vs g	d vs h	a vs c	b vs d	e vs g	f vs h
	a	b	c	d	e	f	g	h								
ISQ$_b$	57.85 ± 7.01 (14)	–	62.54 ± 5.13 (16)	–	71.48 ± 3.86 (15)	–	69.62 ± 5.37 (16)	–	<0.001	–	0.003	–	0.077	–	0.363	–
ISQ$_0$	70.75 ± 4.28 (14)	12.91 ± 7.30	74.46 ± 4.45 (16)	10.18 ± 4.66	78.33 ± 6.63 (15)	6.86 ± 5.96	76.90 ± 4.50 (16)	7.27 ± 7.07	0.003	0.055	0.193	0.152	0.041	0.739	0.313	0.953
ISQ$_1$	72.39 ± 3.99 (14)	14.55 ± 7.95	75.15 ± 5.20 (16)	11.81 ± 5.93	76.74 ± 7.76 (15)	5.27 ± 7.97	77.64 ± 4.60 (16)	8.01 ± 7.59	0.032	0.013	0.118	0.169	0.100	0.480	0.692	0.286
ISQ$_2$	72.55 ± 4.62 (14)	14.70 ± 7.96	75.79 ± 4.51 (16)	11.82 ± 6.05	74.26 ± 6.34 (15)	3.71 ± 8.31	78.22 ± 3.19 (16)	8.60 ± 6.73	0.396	0.005	0.090	0.067	0.124	0.618	0.178	0.265
ISQ$_3$	72.87 ± 2.90 (14)	15.02 ± 7.51	76.17 ± 3.37 (16)	11.80 ± 6.22	76.52 ± 6.34 (15)	5.04 ± 6.79	77.61 ± 3.52 (16)	7.98 ± 6.85	0.027	0.002	0.175	0.019	0.008	0.603	0.580	0.441
ISQ$_4$	74.05 ± 2.91 (14)	16.20 ± 7.71	76.79 ± 3.10 (16)	12.49 ± 5.51	77.09 ± 6.39 (15)	5.61 ± 7.08	77.32 ± 3.68 (16)	7.70 ± 6.85	0.049	0.001	0.458	0.005	0.020	0.454	0.782	0.635
ISQ$_6$	75.77 ± 1.97 (14)	17.93 ± 8.08	78.46 ± 2.00 (16)	14.22 ± 5.29	77.57 ± 5.32 (15)	6.09 ± 6.84	78.69 ± 3.02 (16)	8.97 ± 5.99	0.070	0.001	0.777	0.002	0.004	0.467	0.722	0.260
ISQ$_8$	76.47 ± 2.52 (13)	17.87 ± 8.15	79.89 ± 2.16 (16)	15.67 ± 5.66	78.48 ± 4.77 (15)	7.00 ± 6.69	80.70 ± 2.57 (16)	11.07 ± 5.78	0.102	0.001	0.346	0.005	0.002	0.844	0.220	0.101
ISQ$_{10}$	76.83 ± 2.78 (13)	18.23 ± 8.55	81.18 ± 2.09 (16)	16.31 ± 5.59	78.33 ± 4.55 (14)	6.32 ± 5.86	81.72 ± 2.78 (16)	12.10 ± 6.18	0.234	0.001	0.651	0.005	0.000	0.965	0.048	0.014
ISQ$_{12}$	77.50 ± 3.09 (12)	18.54 ± 8.63	81.25 ± 2.53 (16)	16.91 ± 6.26	78.68 ± 4.51 (14)	6.67 ± 6.40	81.51 ± 2.76 (16)	11.89 ± 6.04	0.368	0.001	0.880	0.006	0.003	0.963	0.077	0.028

Mann–Whitney test.
ISQ: implant stability quotient.
SD: standard deviation.
n = number.
ISQ$_b$: implant stability quotient at baseline.
ISQ$_{0,1,2,3,4,6,8,10,12}$: implant stability quotient at week 0,1,2,3,4,6,8,10,12.
ISQ-ISQ$_b$: calibrated ISQ (increase of ISQ values from baseline).
Differences were considered statistically significant when the *p* values were < 0.05.

ridges with bone quality of $ISQ_b > 65$ in conventional drilling group were prepared by using of 3.5-mm and 4.2-mm drills for planned 4.1-mm and 4.8-mm diameter implants respectively. The ISQ values of the final installed implants were recorded as ISQ_0. Finally, an appropriate healing abutment was screwed in the implant and the wound was closed using a 4-0 vicryl suture (Ethicon, Sommerville, NJ, USA). Postoperative wound care and oral hygiene instructions were given, and antibiotics (amoxicillin 500 mg/ thrice daily for 7 days), analgesics (acetaminophen 500 mg or ibuprofen 400 mg as needed for 7 days), and 0.12% chlorhexidine rinse (twice daily) were prescribed to the patients. Sutures were removed 1—2 weeks after the operation.

The implant stability quotients were recorded at weeks 1 (ISQ_1), 2 (ISQ_2), 3 (ISQ_3), 4 (ISQ_4), 6 (ISQ_6), 8 (ISQ_8), 10 (ISQ_{10}), and 12 (ISQ_{12}) after implant installation. The ISQ value was obtained as a mean value of six ISQ readings at the buccomesial, buccal, buccodistal, linguomesial, lingual, and linguodistal aspects of the individual implant.

Statistical analysis

Mann—Whitney U-test was used to determine the significance of the detected and calibrated ISQ values between the two surgical groups and between the maxilla and mandible. The calibrated ISQs of both arches with two techniques were assessed using repeated measure ANOVA for the unequal time intervals. All statistical analyses were performed using the SPSS version 20.0 software (SPSS, Inc., Chicago, IL, USA). Differences were considered statistically significant when the p values were <0.05.

Results

Totally, 61 Straumann SLA implants of 4.1/4.8 mm diameter and 10/12 mm length in 44 patients were analyzed. In the posterior maxilla, 14 implants were positioned using the osteotome technique, while 15 fixtures were installed using the conventional drilling technique. In the posterior mandible, 16 implants each were installed using the two techniques. Thirty-four 4.1-mm diameter implants were equally distributed in the two surgical groups while 13 and 14 of 4.8-mm diameter implants were distributed into the conventional and osteotome groups respectively. Only five and four of 12-mm length implants were included in the conventional and osteotome groups respectively. The mean age of the 44 evaluated patients was 52.38 ± 11.26 years (range 28—75 years) and 56.9% were females. One person in the osteotome group and three in the conventional group were current smokers.

The initial bone quality at the recipient sites (ISQ_b) of the osteotome group was significantly poorer than that of the conventional group in both arches ($p < 0.001$ and $p = 0.003$ of the maxilla and mandible). In the posterior maxilla, significantly lower ISQ values were tested in the osteotome group during the initial four weeks, except at week 2; subsequently, comparable ISQ readings developed in both groups (Table 1 a vs. e; Fig. 1a). However, the ISQ values measured at the posterior mandible were nonsignificant between two groups (Table 1 c vs. g; Fig. 1b). Generally, when the 3.3-mm diameter implant calibration was taken into account, osteotome technique yielded statistically greater calibrated ISQ values ($ISQ\text{-}ISQ_b$) than conventional drilling technique did in both arches. Whereas, the developing patterns of calibrated ISQs were similar for both techniques applied on both arches (Table 1 b vs. f, d vs. h; Fig. 2).

Significantly lower ISQ values were detected in the maxillary osteotome group except at week 1 and 2 compared to mandible (Table 1 a vs. c). However, the calibtrated ISQs applied with osteotome technique were comparable on both arches (Table 1 b vs. d). The developing patterns of detected and calibrated ISQs were similar for osteotome group on both arches (Fig. 3).

In conventional group, the differences of the detected and calibrated ISQ values between the two arches were nonsignificant, except for a greater detected ISQ value at week 10 and some significantly greater calibrated ISQs after week 10 in the mandible (Table 1 e vs. g, f vs. h). Primary stability declined obviously during week 0—2 in the maxilla, while during week 2—4 in the mandible (Fig. 4).

Overall, the developing patterns of calibrated ISQ values in both arches progressed differently in the intra-group and inter-group comparison during the observation period. Compared to mandibular implants, the calibrated ISQ values from ISQ_0 to ISQ_{12} with osteotome condensation were significantly greater than that with the conventional drilling applied on posterior maxilla (Table 2).

The assessments of the calibrated ISQs between two sequential test time for both groups and arches showed

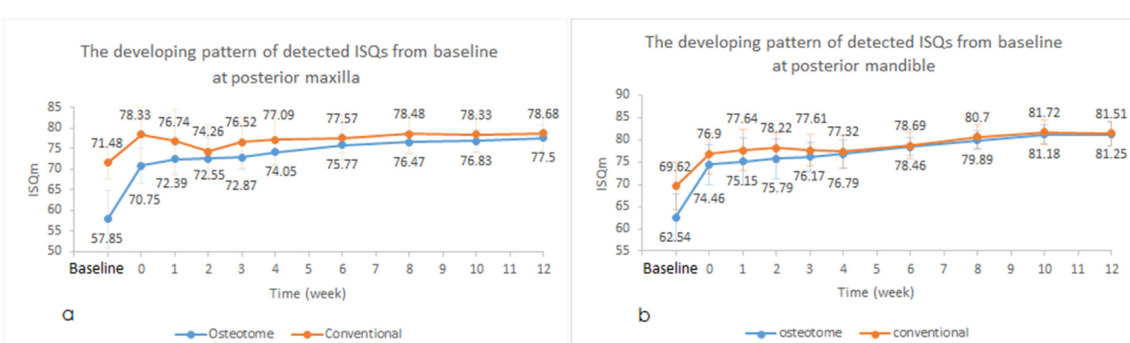

Figure 1 (a) The developing pattern of detected ISQs from baseline at posterior maxilla. (b) The developing pattern of detected ISQs from baseline at posterior mandible.

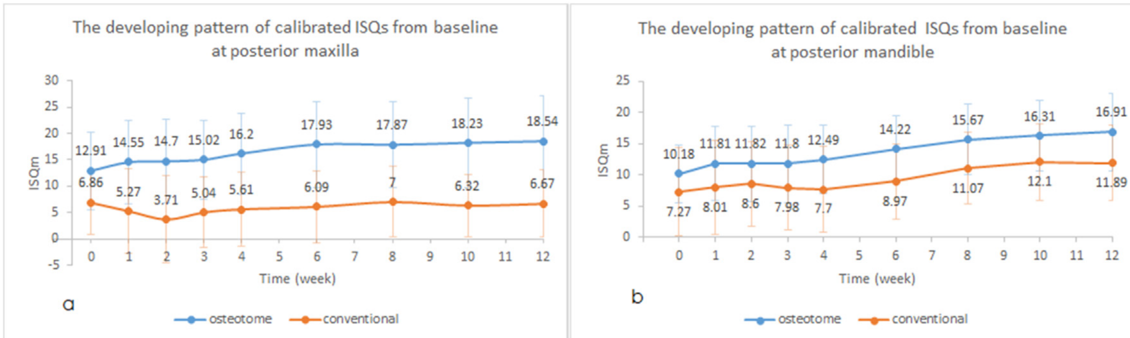

Figure 2 (a) The developing pattern of calibrated ISQs from baseline at posterior maxilla. (b) The developing pattern of calibrated ISQs from baseline at posterior mandible.

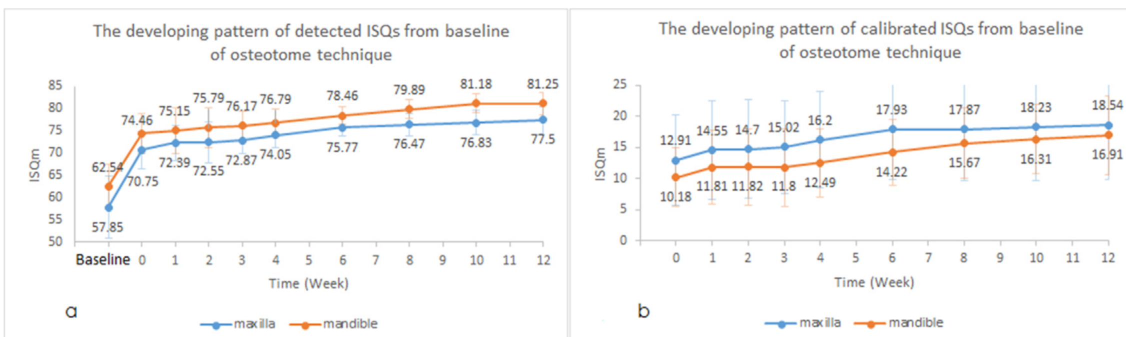

Figure 3 (a) The developing pattern of detected ISQs from baseline of osteotome technique. (b) The developing pattern of calibrated ISQs from baseline of osteotome technique.

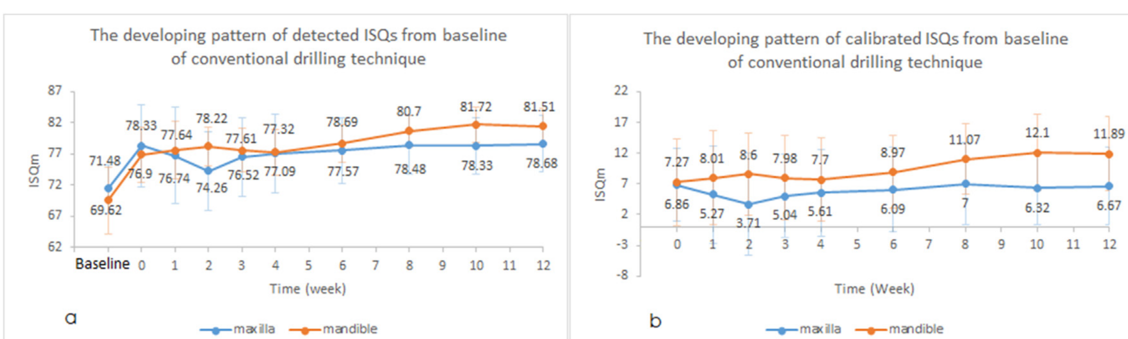

Figure 4 (a) The developing pattern of detected ISQs from baseline of conventional drilling technique. (b) The developing pattern of calibrated ISQs from baseline of conventional drilling technique.

significant differences between week 3—4 and week 4—6 of the maxillary implants in osteotome group; therefore, the developing pattern of calibrated ISQs depicted a significant increase from week 3 and reached a plateau at week 6. However, the calibrated ISQ values decreased nonsignificantly at week 1 and 2 in the conventional group of posterior maxilla and thereafter, the implant stability increased constantly until calibrated ISQs reached a plateau at week 8 (Table 3; Fig. 2a). In the posterior mandible, a significant increase of ISQ values were analyzed from week 4 to week 10 for both surgical groups before reaching a plateau (Table 3; Fig. 2b).

Discussion

The calibrated ISQ represented the increase of ISQ values with two techniques. Our results demonstrated that osteotome condensation not only contributed to higher detected and calibrated ISQs of the implants installed at posterior ridges, but also could eventually achieve comparable values to that of the conventional drilling technique.

After calibration, the results suggested that osteotome condensation could increase more implant stability quotients than conventional technique did during planned implant placement, the continuously increased stabilities

Table 2 The general developing pattern of calibrated ISQ values for both technique groups on both arches.

Calibrated ISQs	Posterior maxilla				Posterior mandible			
	mean (SD)		Repeated Measure ANOVA		mean (SD)		Repeated Measure ANOVA	
Time points	Osteotome	Conventional	Between groups	Intra groups	Osteotome	Conventional	Between groups	Intra groups
$ISQ_{0\text{-}b}$	12.91 (7.30)	6.86 (5.96)	F = 9.940	F = 9.152	10.18 (4.6)	7.27 (7.07)	F = 7.851	F = 27.980
$ISQ_{1\text{-}b}$	14.55 (7.95)	5.27 (7.97)	p = 0.005	p < 0.001	11.81 (5.93)	8.01 (7.59)	p = 0.009	p < 0.001
$ISQ_{2\text{-}b}$	14.70 (7.96)	3.71 (8.31)			11.82 (6.05)	8.60 (6.73)		
$ISQ_{3\text{-}b}$	15.02 (7.51)	5.04 (6.79)			11.80 (6.22)	7.98 (6.85)		
$ISQ_{4\text{-}b}$	16.20 (7.71)	5.61 (7.08)			12.49 (5.51)	7.70 (6.85)		
$ISQ_{6\text{-}b}$	17.93 (8.08)	6.09 (6.84)			14.22 (5.29)	8.97 (5.99)		
$ISQ_{8\text{-}b}$	17.87 (8.15)	7.00 (6.69)			15.67 (5.66)	11.07 (5.78)		
$ISQ_{10\text{-}b}$	18.23 (8.55)	6.32 (5.86)			16.31 (5.59)	12.10 (6.18)		
$ISQ_{12\text{-}b}$	18.54 (8.63)	6.67 (6.40)			16.91 (6.26)	11.89 (6.04)		

Repeated Measure ANOVA = repeated measure analysis of variance.
ISQ: implant stability quotient.
SD: standard deviation.
Differences were considered statistically significant when the p values were <0.05.

partially supported that osteotome condensation may accelerated the implant osseointegration as well.

Consisting with our observation, Markovic et al. assessed the implants placed at the posterior maxilla with type III-IV bone and showed that the osteotome technique significantly improved the implant primary and secondary stability during the 12-week observation period.[17] Whereas, Shayestech et al. found that the osteotome technique increased primary stability only for the implants placed in the type II-III bone at the anterior maxilla, and without a significant impact on secondary stability.[18] Both studies provided positive significance to support using osteotome condensation could enhance implant stability. Dissimilarly, one study's implant site was at the anterior region and the bone qualities among studies were varied.

Some clinical trials showed a nonsignificant difference of the implant stability at posterior maxilla explored by conventional drilling and osteotome condensation comparisons.[19,20] Moreover, osteotome condensation could compromise implant primary stability significantly at anterior maxilla.[16] Indefinite bone quality at the implant sites and the small sample size included in these studies could trigger statistical deviation and cause a noticeable diverse outcome. The consequences of the osteotome condensation application on implants with diverse macro-fixture and micro-surface structures could also induce variances.[10] Furthermore, the amount of applied force might be crucial as well because overload (>20 MPa) was destructive to the implant recepient site.[8]

An increase of ISQ after implant placement was followed by a detectable ISQ reduction at week 2 and 4 for the conventional group of the maxillary and mandibular implants respectively. The patterns partially coincided with previous studies that an ISQ value drop occurred during week 3–4 after implant placement.[25,26] Consisting with the well-known finding,[27] a decreased mechanical primary

Table 3 The comparison of calibrated ISQ values between two sequential time points.

Comparison	Osteotome				Conventional			
	Posterior maxilla		Posterior mandible		Posterior maxilla		Posterior mandible	
	Mean Dif. (SE)	LSD p	Mean Dif. (SE)	LSD p	Mean Dif. (SE)	LSD p	Mean Dif. (SE)	LSD p
week 1 vs week 0	1.64 (1.30)	0.229	0.69 (0.87)	0.439	−1.59 (0.84)	0.078	0.74 (0.53)	0.186
week 2 vs week 1	0.15 (0.55)	0.785	0.64 (0.46)	0.185	−0.97 (1.26)	0.457	0.59 (0.70)	0.417
week 3 vs week 2	0.32 (0.69)	0.646	0.38 (0.58)	0.520	1.06 (0.93)	0.281	−0.62 (0.36)	0.109
week 4 vs week 3	1.18 (0.42)	0.015	0.62 (0.40)	0.141	0.57 (0.39)	0.170	−0.28 (0.66)	0.674
week 6 vs week 4	1.73 (0.65)	0.020	1.67 (0.53)	0.006	0.48 (0.61)	0.444	1.27 (0.51)	0.026
week 8 vs week 6	0.44 (0.48)	0.378	1.42 (0.42)	0.004	0.91 (0.38)	0.029	2.10 (0.62)	0.004
week 10 vs week 8	0.36 (0.38)	0.361	1.30 (0.26)	<0.001	−0.06 (0.57)	0.921	1.03 (0.38)	0.016
week 12 vs week 10	0.82 (0.74)	0.294	0.06 (0.44)	0.888	0.34 (0.74)	0.651	−0.21 (0.48)	0.666

Mean Dif.: Mean difference for comparisons of week.
SE: standard error of mean.
LSD: Fisher least significant difference.
ISQ: implant stability quotient.
Differences were considered statistically significant when the p values were <0.05.

stability and an increased biological secondary stability also occurred at some of our earlier implant treatments. However, an assessable ISQ decrease was not identified in the osteotome group on both arches at earlier healing stage in this study (Fig. 1). The undetectable decreased ISQ values related with the primary stability was compensated conceivably by osteotome condensation.

To avoid the potential influence of the implant sites bone quality at both arches and for both techniques, ISQ values were calibrated. Corresponding to previous studies that osteotome condensation could enhance implant stability at posterior mandible,[22,23] this study also verified that the developing patterns of calibrated ISQs revealed a substantially higher ISQ value in the osteotome group for both arches (Fig. 2). The developing patterns of calibrated ISQ values at both arches showed a comparable increase, and therefore supported that osteotome condensation technique was applicable on both arches with an initial low bone density ($ISQ_b \leq 65$) (Fig. 3b). In the conventional group, the developing patterns of the calibrated ISQ values at two arches were diverse intangibly. However, a generally higher but nonsignificant calibrated ISQs on the mandible suggested that the denser mandibular bone resulted in a better implant healing as presented (Fig. 4b).

In one surgical group, under the same experimental circumstances, the bone quality/quantity at recipient site was the major factor to decide detected ISQ values. By using the threshold of $ISQ_b = 65$, bone quality of this analysis was categorized into a dense or a loose division; and this mean ISQ_b value (64.90) was close to the measurements assessed by previous studies.[15,28] ISQ_b examination also provided an alternative and site-specific method to explore the bone quality. A significant correlation between bone density and ISQ scales was reported as well.[29] According to the calibrated ISQ values, the implication of different implant site preparation techniques on implant stability could be further analyzed.

Implants with two widths (4.1/4.8 mm) and two lengths (10/12 mm) were studied in this study. The influences of implant length and diameter on the ISQ value seemed to vary among studies.[30] Since one study showed that there were nonsignificant ISQ variances observed when the difference of implant length was $\leq$2 mm,[15] we did not exclude 12-mm length implants from our study. Barikani et al. revealed that the ISQ values of 4.3-mm and 5.0-mm diameter platform implants were similar.[31] Additionally, the equivalent number of 4.1-mm and 4.8-mm diameter implants in two surgical groups partially decreased statistical variances.

Both insertion torque test and RFA are feasible to quantize implant primary stability.[3,32,33] Insertion torque test reflects the amount of consumed electric current during tapping insertion implant, while RFA measures the related strength of the implant, surrounding bone, and rigidity of the implant-bone union. A significantly positive correlation between insertion torque and ISQ have been proposed;[34,35] however, insertion torque test is infeasible to evaluate the biological secondary stability of inserted implants. Multiple ISQ measurements of the implant could review the dynamic ISQ changes during healing periods and indicate the appropriate loading time point.[36]

Reverse torque test was performed during abutment connection treatment; a critical shear stress was introduced between the implant-bone interface and disconnect the osseointegrated implant.[37] Although it was claimed that the reverse torque between 45 and 58 Ncm did not increase implant failure, it was an invasive test and could cause a peri-implant plastic deformation.[38] Besides, this test only provides the information regarding to whether implant was osseointegrated or not, the amount of osseointegration could not be quantized.[32,33,39] Therefore, RFA benefits as a simple and non-invasive method to assess the implant stability. However, an effective implant treatment does not depend on ISQ test simply. Other examinations, such as radiographic analysis and clinical examination are required.

Small sample size of this study might cause statistical variation; therefore, the results should be interpreted with caution. Despite the limitation of this study, it provided positive outcomes of using osteotome condensation techniques to improve implant stability at posterior ridges.

Based on our ISQs and developing patterns evaluations, this study demonstrated that osteotome condensation substantially increased primary and secondary implant stabilities of implants installed at posterior maxilla and mandible. Osteotome condensated implants could achieve an implant stability comparable to that of the conventional drilling technique and reached a stability plateau after week 8—10.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

Acknowledgments

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References

1. Adell R, Eriksson B, Lekholm U, Brånemark PI, Jemt T. Long-term follow-up study of osseointegrated implants in the treatment of totally edentulous jaws. *Int J Oral Maxillofac Implants* 1990;5:347—59.
2. Becker W, Becker BE, Alsuwyed A, Al-Mubarak S. Long-term evaluation of 282 implants in maxillary and mandibular molar positions: a prospective study. *J Periodontol* 1999;70:896—901.
3. Meredith N. Assessment of implant stability as a prognostic determinant. *Int J Prosthodont* 1998;11:491—501.
4. Turkyilmaz I, McGlumphy EA. Influence of bone density on implant stability parameters and implant success: a retrospective clinical study. *BMC Oral Health* 2008;8:32.
5. Javed F, Ahmed HB, Crespi R, Romanos GE. Role of primary stability for successful osseointegration of dental implants: factors of influence and evaluation. *Interv Med Appl Sci* 2013; 5:162—7.
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. Summers RB. A new concept in maxillary implant surgery: the osteotome technique. *Compendium* 1994;15:152—4. 156, 158 passim; quiz 162.
8. Summers RB. The osteotome technique: part 2-the ridge expansion osteotomy (REO) procedure. *Compendium* 1994;15: 422—4. 426, passim; quiz 436.
9. Hahn J. Clinical uses of osteotomes. *J Oral Implantol* 1999;25: 23—9.
10. Shalabi MM, Wolke JG, Jansen JA. The effects of implant surface roughness and surgical technique on implant fixation in an in vitro model. *Clin Oral Implants Res* 2006;17:172—8.
11. Shalabi MM, Manders P, Mulder J, Jansen JA, Creugers NH. A meta-analysis of clinical studies to estimate the 4.5-year survival rate of implants placed with the osteotome technique. *Int J Oral Maxillofac Implants* 2007;22:110—6.
12. Blanco J, Suárez J, Novio S, Villaverde G, Ramos I, Segade LA. Histomorphometric assessment in human cadavers of the peri-implant bone density in maxillary tuberosity following implant placement using osteotome and conventional techniques. *Clin Oral Implants Res* 2008;19:505—10.
13. Büchter A, Kleinheinz J, Wiesmann HP, Jayaranan M, Joos U, Meyer U. Interface reaction at dental implants inserted in condensed bone. *Clin Oral Implants Res* 2005;16:509—17.
14. Büchter A, Kleinheinz J, Wiesmann HP, et al. Biological and biomechanical evaluation of bone remodelling and implant stability after using an osteotome technique. *Clin Oral Implants Res* 2005;16:1—8.
15. Peng YC, Hong HH, Kuo SB, Shen YF, Chang YM. Factors affecting primary implant stability examined by resonance frequency analysis. *Taiwan J Oral Maxillofac Surg* 2009;20: 244—55 [In Chinese, English abstract].
16. Padmanabhan TV, Gupta RK. Comparison of crestal bone loss and implant stability among the implants placed with conventional procedure and using osteotome technique: a clinical study. *J Oral Implantol* 2010;36:475—83.
17. Marković A, Calasan D, Colić S, Stojčev-Stajčić L, Janjić B, Mišić T. Implant stability in posterior maxilla: bone-condensing versus bone-drilling: a clinical study. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2011;112:557—63.
18. Shayesteh YS, Khojasteh A, Siadat H, et al. A comparative study of crestal bone loss and implant stability between osteotome and conventional implant insertion techniques: a randomized controlled clinical trial study. *Clin Implant Dent Relat Res* 2013;15:350—7.
19. Sadeghi R, Rokn AR, Miremadi A. Comparison of implant stability using resonance frequency analysis: osteotome versus conventional drilling. *J Dent (Tehran)* 2015;12:647—54.
20. Xing Y, Khandelwal N, Petrov S, Drew HJ, Mupparapu M. Resonance frequency analysis (RFA) and insertional torque (IT) stability comparisons of implants placed using osteotomes versus drilling techniques: a preliminary case study. *Quintessence Int* 2015;46:789—98.
21. Lin YT, Huang YC, Lee LH, Hong HH. A comparison of osteotome technique and conventional bone preparation on implant stability quotient value in the posterior mandible. *Taiwan J Oral Maxillofac Surg* 2011;22:247—56 [In Chinese, English abstract].
22. Lin YT, Hong A, Peng YC, Hong HH. Developing stability of posterior mandibular implants placed with osteotome expansion technique compared with conventional drilling techniques. *J Oral Implantol* 2017;43:131—8.
23. Hong HH, Hong A, Yang LY, Chang WY, Huang YF, Lin YT. Implant stability quotients of osteotome bone expansion and conventional drilling technique for 4.1 mm diameter implant at posterior mandible. *Clin Implant Dent Relat Res* 2017;19:253—60.
24. Zanetti EM, Pascoletti G, Calì M, Bignardi C, Franceschini G. Clinical assessment of dental implant stability during follow-up: what is actually measured, and perspectives. *Biosensors (Basel)* 2018;8:68.
25. Huwiler MA, Pjetursson BE, Bosshardt DD, Salvi GE, Lang NP. Resonance frequency analysis in relation to jawbone characteristics and during early healing of implant installation. *Clin Oral Implants Res* 2007;18:275—80.
26. Boronat López A, Balaguer Martínez J, Lamas Pelayo J, Carrillo García C, Peñarrocha Diago M. Resonance frequency analysis of dental implant stability during the healing period. *Med Oral Patol Oral Cir Bucal* 2008;13:E244—7.
27. Atsumi M, Park SH, Wang HL. Methods used to assess implant stability: current status. *Int J Oral Maxillofac Implants* 2007; 22:743—54.
28. Ostman PO, Hellman M, Wendelhag I, Sennerby L. Resonance frequency analysis measurements of implants at placement surgery. *Int J Prosthodont* 2006;19:77—83. discussion 84.
29. Herekar M, Sethi M, Ahmad T, Fernandes AS, Patil V, Kulkarni H. A correlation between bone (B), insertion torque (IT), and implant stability (S): BITS score. *J Prosthet Dent* 2014; 112:805—10.
30. Sennerby L. Resonance frequency analysis for implant stability measurements. A review. *Integr Diagn Update* 2015;1:1—11.
31. Barikani H, Rashtak S, Akbari S, Badri S, Daneshparvar N, Rokn A. The effect of implant length and diameter on the primary stability in different bone types. *J Dent (Tehran)* 2013; 10:449—55.
32. Saurabh G, Rubina K. Implant stability measure: critical review of various methods. *Dent Implants Dentures* 2016;1:110—3.
33. Swami V, Vijayaraghavan V, Swami V. Current trends to measure implant stability. *J Indian Prosthodont Soc* 2016;16: 124—30.
34. Sarfaraz H, Johri S, Sucheta P, Rao S. Study to assess the relationship between insertion torque value and implant stability quotient and its influence on timing of functional implant loading. *J Indian Prosthodont Soc* 2018;18:139—46.
35. Baldi D, Lombardi T, Colombo J, et al. Correlation between insertion torque and implant stability quotient in tapered implants with knife-edge thread design. *Biomed Res Int* 2018; 2018:7201093.
36. McCullough JJ, Klokkevold PR. The effect of implant macro-thread design on implant stability in the early post-operative period: a randomized, controlled pilot study. *Clin Oral Implants Res* 2017;28:1218—26.
37. Roberts WE. Bone tissue interface. *J Dent Educ* 1988;52:804—9.
38. Sullivan DY, Sherwood RL, Collins TA, Krogh PH. The reverse-torque test: a clinical report. *Int J Oral Maxillofac Implants* 1996;11:179—85.
39. Kazazoglu E. An overview of implant stability measurement. *Mod App Dent Oral Health* 2018;2:212—5.