

The Developing Patterns of Calibrated Implant Stability Quotients of Posterior Implants

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2. Key words

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1. Abstract

1.1. Purpose: Many surgical protocols were modified to improve dental implant primary stability for the ensurance of implant success. However, the conclusions of applying osteotome condensation technique could enhance implant stability were controversial. The evaluated ISQs were calibrated to differentiate the stability improvement that applied by varied surgical technique and bone quality at recipient sites. Therefore, this study was aim to examine the developing patterns of calibrated ISQ values induced by osteotome bone condensation and conventional drilling technique at the posterior ridges.

1.2. Materials and Methods: The ISQ values of 4.1/4.8 mm diameter implants were calibrated by which of 3.3 mm diameter treatment implant (ISQ_b). Osteotome condensation technique was applied on the sites with ISQ_b ≤65, and the locations with ISQ_b >65 were treated with conventional drilling technique. The implant ISQ values of at Week 0, 1, 2, 3, 4, 6, 8, 10, and 12 were recorded. The developing patterns of detected and calibrated ISQ values for both techniques at both arches were statistically analyzed.

1.3. Results: Maxillary fourteen implants and mandibular 16 implants using osteotome technique, maxillary 15 implants and mandibular 16 implants by 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.

1.4. Conclusions: Based on our calibrated and measured ISQ values, osteotome condensation technique potentially enhanced greater primary and secondary stability (increased ISQ values) for the implants at both arches.

3. Key findings from the study: the osteotome bone condensation technique can substantially increase primary and secondary implant sites healing at posterior area on both arches

4. Introduction

Clinically, dental implant treatments are predictable and encouraged. However, with respect to the bone condition of the recipient sites, the success rates of implant treatment were differed between maxillary and mandibular, as well as between anterior and posterior ridges[1, 2]. Bone quality and implant primary stability

correlated with the implant survival significantly. The ridges with poor bone quality at the treatment site could compromise implant's primary stability; subsequently, an impeded secondary stability or implant failure might follow[3-5].

Many surgical protocols were modified to improve implant primary stability, such as adding growth factors, undersized drilling technique, piezo-surgery, low-level laser, and osteotome condensing techniques. Summers first presented the osteotome technique to accommodate dental implants into low-density alveolar ridges.

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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 [6, 7].

Nevertheless, it was stated that there was still a weak or lack of evidence to prove whether any specific surgical technique could significantly affect implant stability[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 associated with osteotome condensation around implant 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, while no additional short-term or long-term benefits revealed in other studies [15-20].

Limited clinical studies discussed the effect of applying osteotome condensation on implant stability in the posterior mandible. To avoid negative impaction, previous studies applied osteotome condensation on D3/D4 bone to increase the implant stability substantially after calibration [15, 21-23].

Originally, the recommended healing periods before loading were 6 months for maxillary implants and 3 months for mandibular implants[24]. However, these protocols have been modified based on the improvement of implant materials and surgical techniques. The goal of the healing is to achieve an implant osseointegration at the light microscopic level[25]. The healing process involved mechanical and biological dynamic alterations between implant and tissue interface. 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[26].

To the best of our knowledge, only few published data comparing the implant healing patterns following the conventional drilling and osteotome condensation techniques with and without implant stability quotient calibration in maxillary and mandibular posterior areas.

The purpose of this study was to compare the healing 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.

5. Materials and Methods

5.1. Patient Selection

Patients with missing maxillary and mandibular premolars or molars required dental implant treatments in the Department of Periodontics, Dental Section of Chang Gung Memorial LinKou Medical Center 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; 6) uncooperative patients who couldn't follow the scheduled recall appointments. This study was independently reviewed and approved by the Institutional Review Board (IRB) of Chang Gung Medical Foundation (No. 201700018B0C601) and supported by Chang Gung Memorial Hospital (CMRPG3H0531). The study was conducted in accordance with the Declaration of Helsinki and the Guidelines on Good Clinical Practice[27].

5.2. Surgical Protocols and Data Collection

Before surgical intervention, patients were carefully examined and evaluated using radiographs (periapical films, panoramic x-ray films and/or computed tomography). Initial infection-control treatment and oral hygiene instruction were offered. Dental implant treatment was performed with patients' signed consent, in accordance with the IRB guidelines, and routine clinical procedures complied with surgical guidelines of the Straumann protocol. With adequate local anesthesia, the flap was elevated. 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 and the resonance frequency of this implant was measured using an Osstell Mentor (Integration Diagnostics AB, Gothenburg, Sweden), and this ISQ value was recorded as the ISQ baseline (ISQ_b). The 3.3-mm diameter fixture was then withdrawn and the different surgical procedures were continued based on the ISQ_b. The ISQ_b values of 3.3 mm diameter implant were used for the calibration of the 4.1/4.8 mm diameter treatment implants at recipient sites.

Participants with bone quality of ISQ_b ≤65 were allocated to the osteotome bone condensation group, and the implant sites were subsequently prepared using osteotome instruments comprising of a series of osteotomes with increasing diameters until the final width and depth were obtained. Finally, 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 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 instead of applying osteotome bone conden-

sation for planned 4.1-mm and 4.8-mm diameter implants respectively. The ISQ value of the final installed implants were recorded as ISQ₀. 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 (ISQ₁), 2 (ISQ₂), 3 (ISQ₃), 4 (ISQ₄), 6 (ISQ₆), 8 (ISQ₈), 10 (ISQ₁₀), and 12 (ISQ₁₂) 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.

5.3. 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 ISQ values at two different time-points were compared using the paired t-test. The main results between groups of both arches were assessed using repeated measure ANOVA for the unequal time intervals between assessments. All statistical analyses were performed using the SPSS version 20.0 software (SPSS, Inc., IBM, USA). Differences were considered statistically significant when the P-values were <0.05.

6. Results

Totally, 61 Straumann SLA implants of 4.1/4.8 mm diameter and

10/12 mm length in 44 patients were analyzed in this study. 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 osteotome technique and conventional drilling technique respectively. Thirty-four 4.1-mm diameter implants were equally distributed in the conventional and osteotome groups while 13 and 14 of 4.8-mm diameter implants were distributed into the conventional and osteotome groups respectively. Only 5 and 4 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 (ISQ₀) of the osteotome group was significantly poorer than that of the conventional group in both arches (p < 0.001 vs. p= 0.003 in the maxilla and mandible). In the posterior maxilla, significantly lower ISQs values before calibration were noted with the osteotome technique during the initial four weeks, except at week 2; subsequently, comparable ISQ readings developed in both osteotome and conventional drilling groups. (Table 1 a vs. e; Figure 1 a) However, the differences of ISQ values measured at the posterior mandible were insignificant between the two surgical techniques groups during the observation periods. (Table 1 c vs. g; Figure 1b) Generally, when the 3.3-mm diameter implant calibration was taken into account, osteotome technique yielded statistically greater ISQ value increments than conventional technique did in both arches. Whereas, the developing patterns trends of calibrated ISQ values were similar for both techniques applied on both arches. (Table 1 b vs. f, d vs. h; Figure 2).

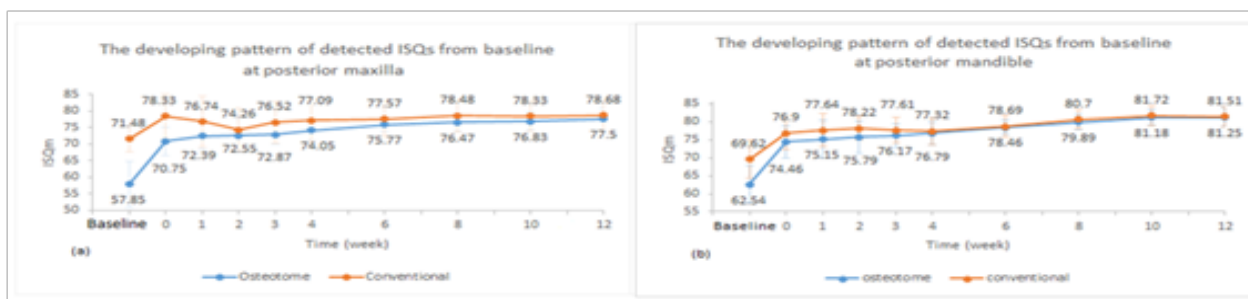


Figure 1: The developing pattern of detected ISQs from baseline at posterior maxilla and mandible

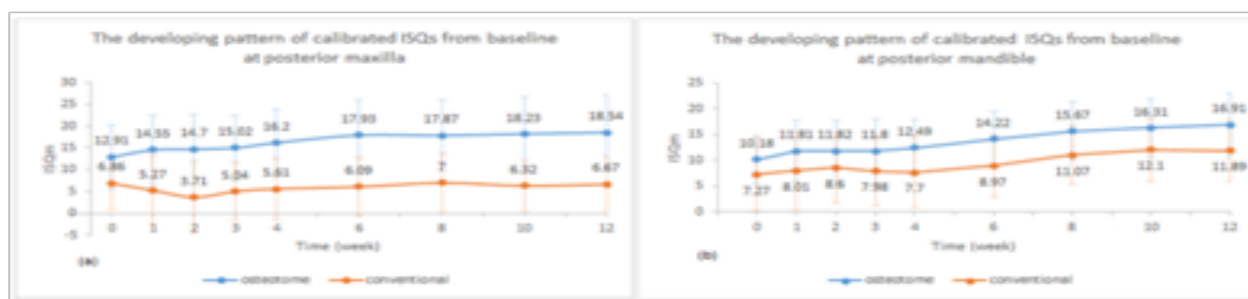


Figure 2: The developing pattern of calibrated ISQs from baseline at posterior maxilla and mandible

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)							
	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	b	c	d	e	f	g	h	P a vs e	P b vs f	P c vs g	P d vs h	P a vs c	P b vs d	P e vs g	P f vs 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	0.1	0.48	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	0.09	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	0.58	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	0.02	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	0.07	0.001	0.777	0.002	0.004	0.467	0.722	0.26
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	0.22	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	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	0.88	0.006	0.003	0.963	0.077	0.028

Mann-Whitney test

SD=standard deviation; ISQ_b = baseline implant stability quotient.

Differences were considered statistically significant when the P-values were <0.05.

6.1. Osteotome Condensation

Significantly lower ISQ values were detected in the maxillary osteotome group except at weeks 1 and 2 compared to mandible. (Table 1 a vs. e) The increased ISQ values of osteotome condensation were greater after calibration for both arches. (Table 1 b vs. f; d vs. h) The developing patterns of detected and calibrated ISQs were similar for osteotome technique applied on both arches. (Table 1 a vs. c and b vs. d; Figure 3).

6.2. Conventional Technique

In conventional group, the difference between the detected and calibrated ISQ values between the two arches was insignificant, except for a greater detected ISQ value at week 10. (Table 1 e vs. g) Some significantly greater calibrated ISQs after week 10 was noted in the mandible. (Table 1 f vs. h) Primary stability declined obviously during weeks 0-2 in the maxilla, while the primary stability of mandibular group decreased during weeks 2-4. (Figure 4).

6.3. Calibrated ISQ

A significant difference of the calibrated ISQ values was noted

among week 3-4 and week 4-6 of the maxillary implants in osteotome group (Table 2). The developing pattern of calibrated ISQs depicted a significant increase from week 3 and reached a plateau at week 6. (Figure 2b) However, the implant primary stability decreased insignificantly after installation at week 1 and week 2 in the conventional drilling group of posterior maxilla. Thereafter, the implant stability increased constantly until ISQs reached a plateau pattern at week 8. (Table 2; Figure 2a) In the posterior mandible, a significant increase of ISQ values were analyzed from week 4 to 10 for both surgical groups before reaching a plateau (Table 2; Figure 2b).

Overall, the 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 increased amount of ISQ values from ISQ₀ to ISQ₁₂ with osteotome condensation were significantly greater than that with the conventional technique applied on posterior maxilla (Table 3).

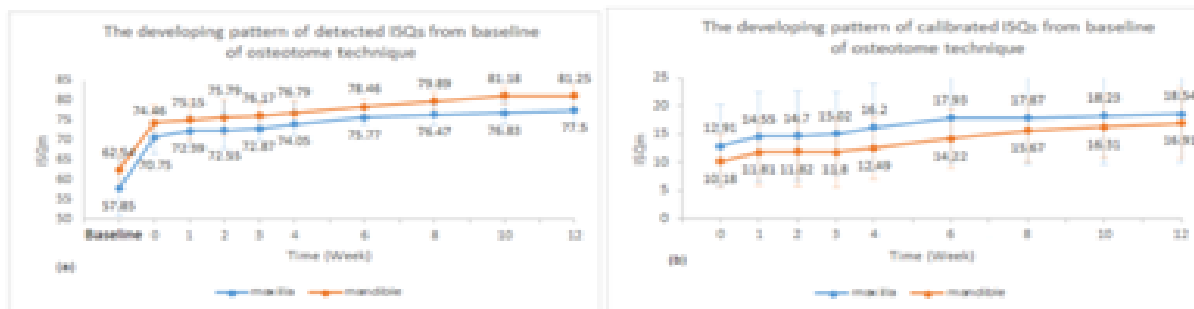


Figure 3: The developing pattern of detected and calibrated ISQs from baseline of osteotome technique

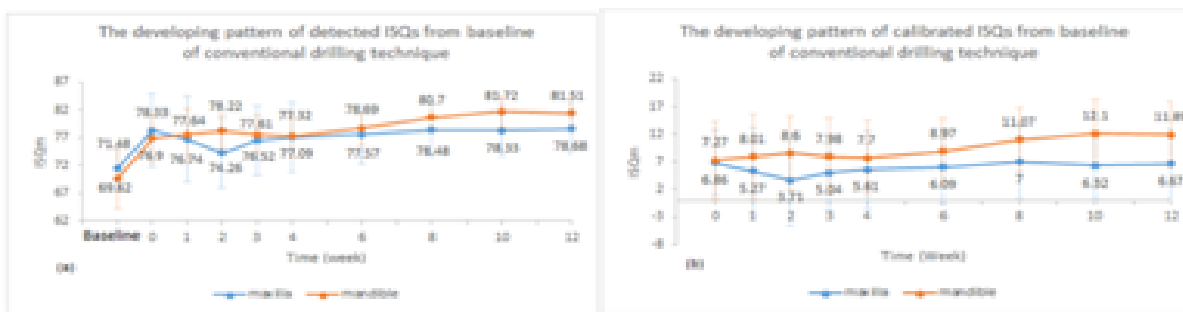


Figure 4: The developing pattern of detected and calibrated ISQs from baseline of conventional drilling technique

Table 2: 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 <i>p</i>	Mean Dif. (SE)	LSD <i>p</i>	Mean Dif. (SE)	LSD <i>p</i>	Mean Dif. (SE)	LSD <i>p</i>
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)	0.52	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)	0.17	-0.28 (0.66)	0.674
week 6 vs week 4	1.73 (0.65)	0.02	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. Differences were considered statistically significant when the P-values were <0.05.

Table 3: The General Developing Pattern of Calibrated ISQ Values for both Technique Groups on both arches

Calibrated ISQs	Repeated Measure ANOVA				Repeated Measure ANOVA			
	Posterior maxilla mean (SD)		Posterior mandible mean (SD)		Posterior maxilla		Posterior mandible	
Time points	Osteotome	Conventional	Between groups	Intra groups	Osteotome	Conventional	Between groups	Intra groups
ISQ _{0,b}	12.91 (7.30)	6.86 (5.96)	F=9.940	F=9.152	10.18 ± 4.66	7.27 ± 7.07	F=7.851	F=27.980
ISQ _{1,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,b}	14.70 (7.96)	3.71 (8.31)			11.82 ± 6.05	8.60 ± 6.73		
ISQ _{3,b}	15.02 (7.51)	5.04 (6.79)			11.80 ± 6.22	7.98 ± 6.85		
ISQ _{4,b}	16.20 (7.71)	5.61 (7.08)			12.49 ± 5.51	7.70 ± 6.85		
ISQ _{6,b}	17.93 (8.08)	6.09 (6.84)			14.22 ± 5.29	8.97 ± 5.99		
ISQ _{8,b}	17.87 (8.15)	7.00 (6.69)			15.67 ± 5.66	11.07 ± 5.78		
ISQ _{10,b}	18.23 (8.55)	6.32 (5.86)			16.31 ± 5.59	12.10 ± 6.18		
ISQ _{12,b}	18.54 (8.63)	6.67 (6.40)			16.91 ± 6.26	11.89 ± 6.04		

7. Discussion

As mentioned above, previous studies showed contradictory effects about whether osteotome condensation technique contributed to increase primary and/or secondary implant stability.

7.1. Osteotome Condensation Positively Enhance Implant Stability

Our results demonstrated that osteotome condensation not only substantially increased primary and secondary measured ISQs of the implants installed at posterior maxillary and mandibular areas, but also could achieve an implant stability comparable to that of the conventional drilling technique did.

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 primary and secondary stability of the implants during the entire 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 significances to support using osteotome condensation could enhance implant stability. Dissimilarly, positions of maxillary implant installed sites were inconsistent with ours in one study. The maxillary bone quality at implant sites of both studies was not standardized and the effects of osteotome condensation on mandibular implant stability were not tested.

7.2. Osteotome Condensation Improved Implant Stability Irrelevantly

The implant stabilities at posterior maxilla explored by conventional drilling and osteotome condensation comparisons showed an insignificant differences in some clinical trials with small sample size[19, 20]. Moreover, osteotome condensation potentially compromised implant primary stability quotient significantly at ante-

rior maxilla[16]. However, bone qualities at the implant sites were not shown or standardized before comparison in these studies.

7.3. Potential Expositions Attributed To The Inconsistency

Indefinite bone quality at the implant recipient sites, (Padmanabhan et al. and Sadeghi et al.) [16, 19] and the small sample size included in the studies (Padmanabhan et al. and Xing et al.) [16, 20] could trigger statistical deviation and cause a noticeable diverse outcome. The consequences of the osteotome condensation application on implants with diverse macro-fixtured and micro-surface structures could also induce variances [10]. Furthermore, only limited reports discussed individual factors of inter- or intra-operators, and the amount of force with the osteotome applied on the implant sites by surgeons previously. Overload (>20 MPa) was destructive to the recipient sites and initiated a longer period of angiogenesis and bone repairing. In contrast, a physiological adoptable compression could stimulate a mechanism of trauma dependent bone repair which was different from the process of bone repair associated with conventional drilling technique[18]. Therefore, an appropriate condensation force is essential to improve the implant stability of osteotome technique.

7.4. Stability Patterns Without Calibration

Generally, osteotome and conventional techniques presented a similar pattern of ISQ related stability. (Figure 1) An increase after implant placement was followed by a detectable ISQ reduction at week 2 and 4 for the conventional drilling group of the maxillary and mandibular implants, respectively. (Figure 1 and 4) These patterns partially coincided with the observations of previous studies that a ISQ value drop occurred during week 3–4 after implant placement[28, 29]. Consistent with the well-known finding[30], a decreased mechanical primary stability and an increased biological secondary stability also occurred at our earlier implant treatment. However, an assessable ISQ decrease was not identified at both arches in the osteotome group at earlier healing stage in this study. (Figure 1) An initial higher primary stability and a poorer bone quality at the posterior maxilla accelerated the decrease of primary stability of conventional drilling group in this study; which was coincided with previous studies, the stability of the implants with a low ISQ₀ (ISQ<68) increased stably during the healing process, while the stability decreased in implants with high initial stability (ISQ>72) [31, 32]. However, the undetectable decreased ISQ stability related with the primary stability was compensated conceivably by osteotome condensation.

In the osteotome groups, both arches presented a similar developing pattern of the detected ISQs; nevertheless, a significantly different ISQ values between maxilla and mandible were measured. A higher bone density at mandible partially describe the occurrence.

7.5. Stability Patterns of Calibrated ISQs

To avoid the potential influence of the bone quality at implant recipient sites at both arches and for both techniques, ISQ values

were calibrated. Corresponding to 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 with a lower bone density at baseline. (Figure 2) The developing patterns of calibrated ISQ values at both arches showed a comparable increase, and supported that osteotome condensation technique was applicable on both arches with an initial low bone density(Figure 3b).

In the conventional groups, the developing patterns of the calibrated ISQ values with two arches were diverse intangibly. However, a generally higher but insignificant calibrated ISQs on the mandible suggested that the denser mandibular bone resulted in a better implant healing as presented (Table 1, f vs.h; Figure 4b).

7.6. Measurement Effects After ISQ Calibration

ISQ values were influenced by many factors, such as implant placement technique, implant design, healing time, and exposed implant height above the alveolar crest[33]. In one surgical group, the bone quality/quantity at recipient site was the major variable to decide ISQ values among individuals. By using the threshold of ISQ_b = 65 measurement, 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, 34]. Dental cone beam computed tomography is a proper appliance to appraise the bone quality at implant sites; however, 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[35]. According to the calibrated ISQ values, the implication of different implant site preparation techniques on implant stability could be further analyzed.

7.7. Contribution of Different Implant Length and Width

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 between the studies[33]. Since one study showed that there were no significant ISQ variances observed when the difference of implant length was ≤2 mm, [15] we did not exclude 12-mm in-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[36]. Additionally, the equivalent number of 4.1-mm and 4.8-mm diameter implants between the surgical groups partially decrease statistical variances.

7.8. Correlation Between Insertion Torque and ISQ

Both insertion torque test and resonance frequency analysis (RFA) are feasible to quantize implant primary stability. Insertion torque test reflects the amount of consumed electric current during tapping insertion implant; and is correlated with bone density, implant site preparation technique, and implant macrostructure[37,

38]. Sennerby and Meredith[3, 39] first introduced RFA for assessing implant stability. It measures the related strength of the implant, surrounding bone, and rigidity of the implant-bone union. The commercially available product (Osstell Mentor, Integration Diagnostic AB, Goteborg, Sweden) was applied in this study[38].

A significant and positive correlation between insertion torque and ISQ have been proposed[40, 41]; 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[42].

7.9. Correlation Between Reverse Torque and ISQ

Reverse torque test was performed during abutment connection treatment; [43] a critical shear stress was introduced between the implant-bone interface and disconnect the osseointegrated implant. Implants could rotate and were indicated to be removed. Although it was claimed that the reverse torque between 45-58 Ncm did not increase implant failure possibility, it was an invasive test and caused a peri-implant plastic deformation[44]. The drawback of this trial was that it only provided the information regarding to whether implant was osseointegrated or not, the amount of osseointegration could not be quantized[37, 38, 45].

Therefore, a simple and non-invasive method is indicated to assess the implant stability, such as RFA. However, an effective implant treatment does not depend on ISQ test simply. Other examinations, such as radiographic analysis and clinical examination are required.

7.10. Limitations of the study

Small sample size recruited in this study might cause statistical variation, the results should be interpreted with caution. Despite the limitations of this study, it demonstrated a substantial increase of the primary and secondary stability along with a shorter healing time and reach a stability plateau.

8. Conclusion

Based on our calibrated and detected ISQ values, this study demonstrated that osteotome condensation substantially increased primary and secondary measured ISQs of the implants installed at posterior maxillary and mandibular areas. Osteotome condensed implants could achieve an implant stability comparable to that of the conventional drilling technique and reached a stability plateau after week 8-10.

9. Acknowledgement

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