Primary Stability of Short Implants Inserted Using Piezoelectric or Drilling Systems: An In Vitro Comparison

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The primary objective of the present in vitro study was to evaluate the influence of implant site preparation technique (drills vs ultrasonic instrumentation) on the primary stability of short dental implants with two different designs inserted in simulated low-quality cancellous bone. Eighty implant sites were prepared in custom-made solid rigid polyurethane blocks with two different low cancellous bone densities (5 or 15 pounds per cubic foot [PCF]), equally distributed between piezoelectric (Surgysonic Moto, Esacrom, Italy) and conventional drilling techniques. Two short implant systems (Prama and Syra, Sweden & Martina) were tested by inserting 40 fixtures of each system (both 6.0 mm length and 5.0 mm diameter), divided in the four subgroups (drills/5 PCF density; drills/15 PCF density; piezo/5 PCF density; piezo/15 PCF density). Insertion torque (Ncm), implant stability quotient values, removal torque (Ncm), and surgical time were recorded. Data were analyzed by 3-way ANOVA and Scheffé's test ($\alpha = 0.05$). With slight variations among the considered dependent variables, overall high primary implant stability was observed across all subgroups. Piezoelectric instrumentation allowed for comparable or slightly superior primary stability in comparison with the drilling procedures in both implant systems. The Prama implants group showed the highest mean reverse torque and Syra implants the highest implant stability quotient values. Piezoelectric implant site preparation took prolonged operative time compared to conventional preparation with drills; among the drilling procedures, Syra system required fewer surgical steps and shorter operative time.

Key Words: implant site preparation, piezoelectric surgery, polyurethane foam blocks, posterior maxilla, short implants

INTRODUCTION

Dental implantology has greatly evolved and improved during the last decades, and a wide choice of predictable implant-supported therapeutic options is available today for clinicians.[1] Following tooth extraction in the posterior maxilla, the residual bone height is often insufficient for standard implant placement due to the combination of alveolar bone resorption and maxillary sinus pneumatization.[2] Moreover, thin cortical and low-density trabecular bone are also common occurrences.[3] However, even in this area, the use of short implants today may represent a minimally invasive treatment option, reducing costs, surgical time, and morbidity in comparison to sinus floor elevation.[4] Recent randomized clinical trials and systematic reviews revealed no differences between the survival rates of short implants (5–8 mm) and longer implants (>8 mm) associated with augmentation procedures; moreover, longer implants resulted in higher complication rates.[5–7]

Several factors play a critical role in the healing phase of hard and soft tissues after implant insertion, including fixture macro- and micro-geometry, primary stability, bone anatomical conditions and metabolism, early use of a provisional prosthesis, and occlusion pattern.[8] Among these factors, primary stability—defined as the absence of implant movement after surgical insertion[9]—is surely one of the most relevant ones, particularly in short implants.[10,11] It is known that primary stability derives from the mechanical interlocking of the implant inside the host bone[3] and depends on the surgical technique for implant site preparation, as well as on implant geometry and on the structural characteristics of the alveolar bone.[9,12]

The conventional and most widespread approach for implant site preparation is represented by the use of rotary instrumentation, consisting of a series of calibrated surgical drills provided by the manufacturer and matching implant geometry of the specific system. Conventional drilling techniques are effective, well-standardized, relatively affordable—but not free from drawbacks. The non-selective cutting action of the drills does not prevent involuntary lesions to delicate anatomical structures, such as nerves and blood vessels.[13] Moreover, the low rotational speed of the surgical motor results in the transmission of macro-vibrations to the handpiece, limiting surgical control during osteotomy. The use of piezoelectric devices has been proposed as an alternative technique for implant site preparation, with the aim of

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addressing the aforementioned shortcomings of the conventional systems by improving intra-operative control and minimizing the risk of soft tissue injury.[14] Furthermore, ultrasonic implant site preparation seems to enhance bone healing response[15–17] resulting in limited decrease of implant primary stability and in an earlier shifting from a decreasing to an increasing stability pattern.[13,18,19]

The drilling sequence of implant systems is designed to produce an osteotomy with a specific shape, fitting with implant macrogeometry, with the aim of obtaining a satisfactory stability, especially with short implants placed in low bone quality. Conversely, ultrasonic tips for site preparation are not implant-specific and may be used to insert fixtures with different morphologies: the discrepancy between implant bed and fixture shape could possibly jeopardize primary stability.

However, some ex vivo studies reported promising results on the primary stability of implants inserted with ultrasonic techniques: standard-length fixtures inserted in bovine ribs showed no significant differences in terms of primary stability following either conventional or piezoelectric instrumentation.[20,21]

The aim of the present study was to compare the influence of conventional and ultrasonic site preparation techniques on the primary stability of 6-mm long implants, placed in synthetic models simulating low quality cancellous bone.

Materials and Methods

Operator training and calibration

In a preliminary phase, a single operator underwent a training session with the selected piezoelectric device aimed at calibrating hand pressure to 300 $\pm$ 50 g. This pressure has been reported in literature as ideal to maximize cutting efficiency of ultrasonic devices and, at the same time, limiting unwanted heat generation.[22]

Polyurethane specimens

Custom-made solid rigid polyurethane blocks (Laminated Foam Blocks, Sawbones Europe AB, Malmö, Sweden) were manufactured to simulate different bone densities, which were originally measured in pounds per cubic foot (PCF). The blocks were composed of either 5 PCF (0.08 g/cm^3) or 15 PCF (0.24 g/cm^3) solid foam laminated with 1 mm 40 PCF (0.64 g/cm^3) solid foam on top and bottom surfaces. The blocks were cut to obtain bars measuring 120 $\times$ 10 $\times$ 8 mm (Figure 1) and were then mounted on a bench vise.

Implants

Two different short implant systems were tested (Prama and Syra, Sweden & Martina, Due Carrare, Italy); both fixtures are tapered and screw-shaped but with different core and thread design (Figure 2). Both implant systems present threads with a triangular profile but with different pitch (Prama 1.5 mm; Syra 0.75 mm) and depth (constant for Prama, 0.40 mm; variable for Syra, from 0.30 to 0.70 mm). The same implant diameter (5.0 mm) and length (6.0 mm) were selected for both implant systems for testing in the present study.

Preparation of the implant site

The implant site preparation techniques tested here were the conventional drilling technique recommended by the manufacturer for each implant system, and a piezoelectric preparation by using an ultrasonic surgical unit (Surgysonic Moto, Esacrom, Imola, Italy). For Prama implants, the drilling procedure began with a 2.30-mm diameter lance pilot drill, followed by a 2.0-mm twist drill, a 2.00–2.80 mm tapered intermediate drill, 3.00- and 3.40-mm twist drills, a 3.40–4.25-mm tapered intermediate drill, and a 4.25-mm final twist drill. The procedure for Syra implant bed preparation involved the same first two steps, followed by a final 2.23–4.06-mm conical drill. All drilling procedures were performed by a surgical drilling unit (Implantmed, W&H Dentalwerk, Bürmoos, Austria) set at 1000 rpm with external cooling.

The piezoelectric site preparation was performed with SUS tips system (Esacrom, Imola, Italy) for both the tested implants. All SUS tips share the same octagonal star cross-section but differ in size and taper. The sequence involved six consecutive steps with an initial sharp-point tip (ES052XGT), followed by a series of conical tips with progressively increasing diameter: 2.8 (ES02.8T), 3.2 (ES03.2T), 3.6 (ES03.6T), 4.0 (ES04.0T), and 4.4 mm (ES04.4T) (Figure 3). The tips were operated under cool water irrigation according to the tip-specific settings suggested by the manufacturer. The operator imparted up-and-down vertical movements coupled with alternate rotation on tip axis (Figure 4).

The time required for each implant site preparation procedure was registered with a digital chronometer.

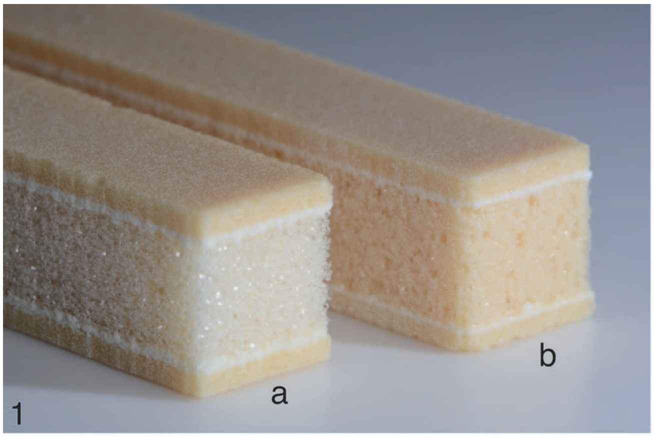
Five implant sites were prepared in each polyurethane bar for a total of 40 conventional and 40 piezoelectric implant sites. Four 5 PCF bars and four 15 PCF bars were assigned to each implant system, preparing 40 sites per implant system. Table 1 summarizes the experimental groups.

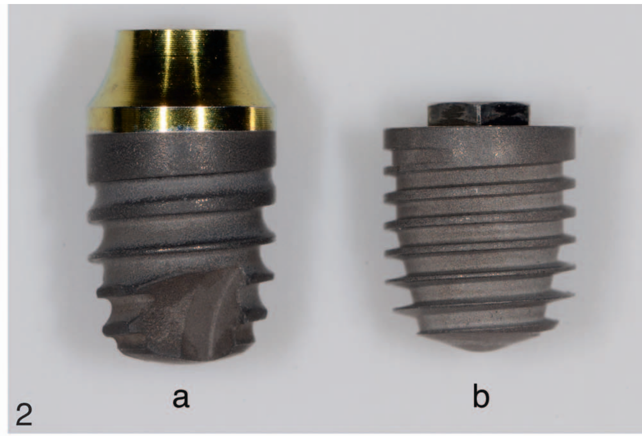
Insertion and removal torque measurement and resonance frequency analysis

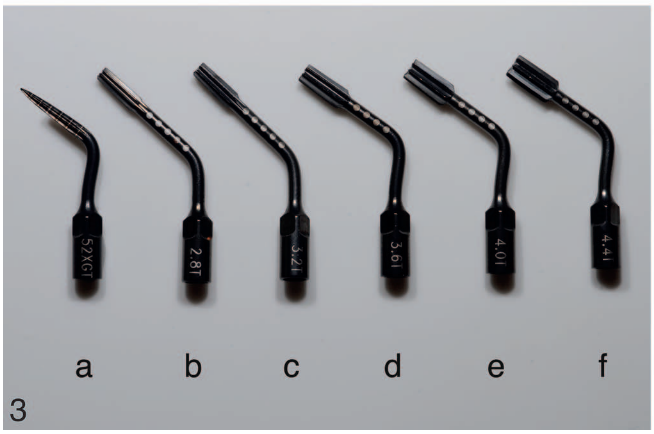
The aforementioned surgical drilling unit with automatic torque control and integrated Implant Stability Quotient (ISQ) module was used to measure peak insertion and removal torque, as well as implant stability. After implant placement, primary stability was assessed by manually screwing to the fixture the specific SmartPeg transducer (#1 for Syra and #32 for Prama, Osstell, Göteborg, Sweden) to record two ISQ values per implant (mesio-distal and bucco-palatal), the mean of which was regarded as the statistical unit.

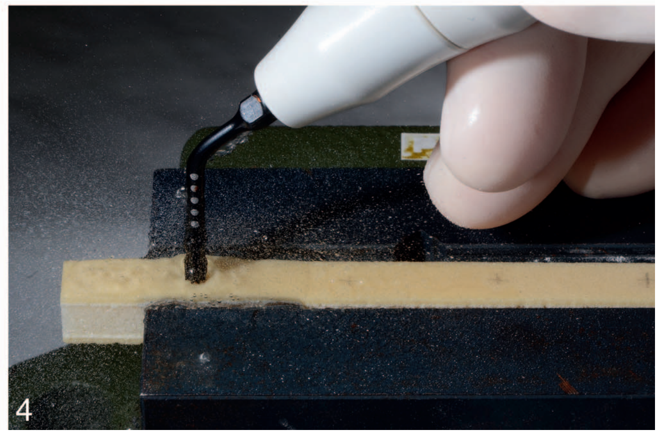
Statistical analysis

An independent statistician analyzed all datasets with statistical software (Statistical Package for Social Sciences v.15, SPSS Inc, Chicago, Ill). The dependent variables tested in the present study were all measured at the continuous level. The final considered groups were eight, categorical and independent, and there was no relationship between the observations within each group or among the groups. The normality of the distribution and the equality of variances of continuous data were assessed with a Shapiro-Wilk and a Levene test,









Figures 1–4. Figure 1. Bars of custom-made solid rigid polyurethane blocks with different density of simulated cancellous bone. (a) 5 pounds per cubic foot (PCF). (b) 15 PCF. **Figure 2.** Tested implants. (a) Prama. (b) Syra. **Figure 3.** Sequence of SUS tips for ultrasonic implant site preparation: (a) ES052XGT; (b) ES02.8T; (c) ES03.2T; (d) ES03.6T; (e) ES04.0T; (f) ES04.4T. **Figure 4.** Ultrasonic implant site preparation under water irrigation.

respectively. Three-way multivariate analysis of variance with Scheffé's post hoc test was carried out to assess the difference of the following variables: implant site preparation time, insertion torque, ISQ and removal torque. The value of α was set to 0.05.

Results

The distribution of the variables considered in the present study was presented as box and whiskers plots in Figure 5, attesting to the absence of significant outliers. Insertion torque values recorded after piezoelectric implant site preparation and conventional drilling techniques were comparable in all groups, excluding the Syra-5 PCF subgroup, which showed significantly lower insertion torque values with ultrasonic preparation ($P <$ .001). Excluding this subgroup, a moderate trend of higher insertion torque values resulted associated with denser bone, with slight differences between the two implant types. Complete results are listed in Table 2.

There were no differences in terms of implant stability

Table 1

Experimental groups*

Implant Type	Implant Site Preparation Technique	Simulated Cancellous Bone Density	N
Prama (Sweden & Martina, Due Carrare, Italy)	Conventional drilling	5 PCF	10
		15 PCF	10
	Piezoelectric	5 PCF	10
		15 PCF	10
Syra (Sweden & Martina)	Conventional drilling	5 PCF	10
		15 PCF	10
	Piezoelectric	5 PCF	10
		15 PCF	10

*PCF indicates pound per cubic foot.

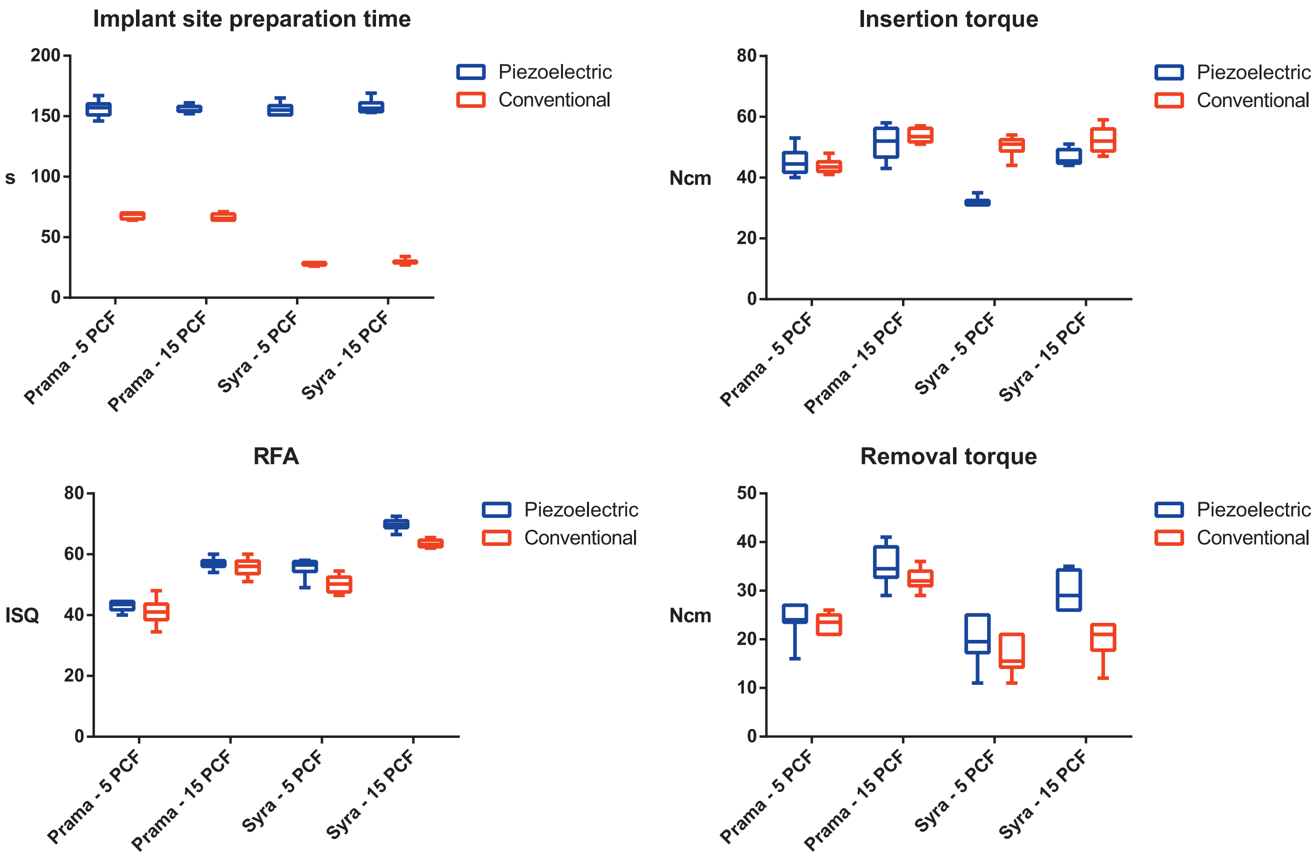


FIGURE 5. Box and whiskers plots showing the distribution of the values of the variables of interest of the present study for each considered subgroup (different implant site preparation techniques, implants, and simulated cancellous bone density). ISQ indicates implant stability quotient; PCF, pound per cubic foot; RFA, resonance frequency analysis.

between the two implant site preparation techniques in Prama subgroups, while in Syra implant subgroups piezoelectric preparation resulted in significantly higher ISQ values compared to the conventional technique ($P < .05$). Under equal subgroups conditions, Syra implants and denser bone were associated with significantly higher ISQ values than the respective counterparts ($P < .001$). Complete results are listed in Table 3.

Removal torque testing revealed that piezoelectric implant site preparation can yield similar or higher resistance to unscrewing compared to conventional techniques. Prama implants and 15 PCF bone were associated with a trend of significantly higher values of removal torque ($P < .01$). Complete results are listed in Table 4.

The three-way multivariate analysis of variance found significant between-subjects effects of all factors considered by the corrected model ($P < .01$)—namely, site preparation technique, implant type, and bone density—with regard to all dependent variables (implant site preparation time, insertion torque, ISQ, removal torque), with the only exception being bone density, which did not influence implant site preparation time ($P < .813$). Complete results of the multivariate analysis are reported in Table 5.

The piezoelectric technique required the longest time for implant site preparation (mean 156 ± 5 s), while the drilling

TABLE 2

Means and standard deviations of insertion torque values registered in the experimental groups*

		Implant Site Preparation Technique			
		Piezoelectric		Conventional Drilling	
Implant Type	Simulated Cancellous Bone Density	n	Insertion Torque (Ncm)	n	Insertion Torque (Ncm)
Prama	5 PCF	10	45.0 ± 4.0	10	43.8 ± 2.1
	15 PCF	10	51.1 ± 5.4	10	53.9 ± 2.3
Syra	5 PCF	10	32.1 ± 1.4	10	50.3 ± 3.4
	15 PCF	10	46.8 ± 2.7	10	52.2 ± 4.0

*PCF indicates pound per cubic foot.

TABLE 3

Means and standard deviations of implant stability quotient (ISQ) values registered in the experimental groups*

		Implant Site Preparation Technique			
		Piezoelectric		Conventional Drilling	
Implant Type	Simulated Cancellous Bone Density	n	ISQ	n	ISQ
Prama	5 PCF	10	43.1 ± 1.6	10	41.2 ± 4.1
	15 PCF	10	57.1 ± 1.6	10	55.7 ± 2.7
Syra	5 PCF	10	55.5 ± 2.8	10	50.2 ± 2.6
	15 PCF	10	69.8 ± 1.7	10	63.6 ± 1.2

*ISQ indicates implant stability quotient; PCF, pound per cubic foot.

procedure for Syra implants the shortest one (29 ± 2s); implant site preparation for Prama implants took an intermediate time (67 ± 3 s). The differences among the three groups were statistically significant ($P < .001$). Implant site preparation in blocks of higher density (15 PCF) did not take prolonged time in comparison to the less dense ones (5 PCF) ($P < .05$).

Discussion

The present in vitro study tested the influence of implant site preparation technique—rotary vs piezoelectric instrumentation—on the primary stability of 6 mm-long dental implants with two different designs inserted in simulated low quality cancellous bone. Since the considered variables showed significant differences among the various subgroups, the findings of the present study may be useful to optimize primary stability of short implants by combining implant type with the most appropriate site preparation technique.

Using both conventional and piezoelectric techniques, the implant site was prepared with a smaller diameter than the actual size of the fixture, regardless of the implant type. A correct undersizing of the recipient site has a critical importance in assuring an adequate primary stability to implants, especially when inserted in poor quality bone.[23,24] However, considering that the final shapes of the osteotomies obtained by drill systems and ultrasonic tips were different, as well as implant designs, forecasting primary stability in the subgroups of this study was not feasible. The sharp star-shaped implant site prepared by ultrasonic tips in the cortical bone (Figure 6) could possibly improve implant stability by offering more high-quality bone to be compressed by the implant during the insertion phase. Nonetheless, the most notable differences among the tested subgroups results were related to bone density and implant type rather than preparation technique.

In the attempt to improve the standardization of the experimental procedures, we used rigid polyurethane foam blocks, adhering to the standard specifications for rigid polyurethane foam to use as a standard material for testing orthopedic devices and instruments.[25] Artificial cellular foam bone specimens can appropriately exhibit stress-strain curves comparable to those of the human bone[26] and have been used to simulate trabecular bone in biomechanical tests.[27–29] Previous studies conducted with objectives similar to the present study used bovine ribs as a substrate for implant placement,[20,21] thus partially compromising the possibility of results comparison with the present study. This choice could hypothetically affect the reliability of the simulation since animal bone may be characterized by relevant anatomic variations within the same specimen and, even more, among different specimens. Furthermore, the described procedure of flattening the top of the rib does not allow a proper simulation of the clinical setting, nor standardization of the experimental conditions; specifically, an absent or uneven cortical bone thickness is likely to significantly alter the final results. Nevertheless, our results are in partial agreement with the two aforementioned studies, which found no difference in primary stability of standard-length implants placed by using piezoelectric or conventional technique[21] or a slight superiority of the ultrasonic approach.[20] In the present study, where various conditions of bone density and different short implant designs were also taken into account, a general trend of similar primary stability was obtained by the two surgical techniques, with some significant differences in specific subgroups,

TABLE 4

Means and standard deviations of removal torque values registered in the experimental groups*

		Implant Site Preparation Technique			
		Piezoelectric		Conventional Drilling	
Implant Type	Simulated Cancellous Bone Density	n	Removal Torque (Ncm)	n	Removal Torque (Ncm)
Prama	5 PCF	10	24.0 ± 3.2	10	23.3 ± 1.8
	15 PCF	10	35.0 ± 4.0	10	32.4 ± 2.1
Syra	5 PCF	10	20.2 ± 4.8	10	16.4 ± 3.6
	15 PCF	10	29.6 ± 3.8	10	19.8 ± 3.6

*PCF indicates pound per cubic foot.

Table 5

Results of the three-way multivariate analysis of variance reporting the between-subjects effects of implant site preparation technique, implant type, simulated cancellous bone density and their interactions on the considered independent variables†

Source	Dependent Variable	Sum of Squares	df	Mean Squares	F	Sig.
Corrected model	Insertion torque	3386	7	484	42.59	<.001*
	ISQ	6515	7	931	153.13	<.001*
	Reverse torque	3038	7	434	35.17	<.001*
	Preparation time	249 724	7	35 675	2516.01	<.001*
Implant site preparation technique (A)	Insertion torque	794	1	794	69.90	<.001*
	ISQ	278	1	278	45.66	<.001*
	Reverse torque	357	1	357	28.93	<.001*
	Preparation time	234 686	1	234 686	16 551.47	<.001*
Implant type (B)	Insertion torque	192	1	192	16.93	<.001*
	ISQ	2216	1	2216	364.53	<.001*
	Reverse torque	1030	1	1030	83.44	<.001*
	Preparation time	7125	1	7125	502.52	<.001*
Simulated cancellous bone density (C)	Insertion torque	1345	1	1345	118.43	<.001*
	ISQ	3934	1	3934	647.28	<.001*
	Reverse torque	1353	1	1353	109.64	<.001*
	Preparation time	7	1	7	0.47	.497
A × B	Insertion torque	605	1	605	53.28	<.001*
	ISQ	84	1	84	13.83	<.001*
	Reverse torque	133	1	133	10.75	.002*
	Preparation time	7861	1	7861	554.38	<.001*
A × C	Insertion torque	97	1	97	8.52	.005*
	ISQ	0	1	0	0.03	.857
	Reverse torque	78	1	78	6.32	.014*
	Preparation time	2	1	2	0.11	.745
B × C	Insertion torque	0	1	0	0.02	.895
	ISQ	1	1	1	0.13	.718
	Reverse torque	67	1	67	5.40	.023*
	Preparation time	44	1	44	3.07	.084
A × B × C	Insertion torque	353	1	353	31.07	<.001*
	ISQ	3	1	3	0.46	.499
	Reverse torque	21	1	21	1.70	.196
	Preparation time	0	1	0	0.02	.882
Error	Insertion torque	818	72	11		
	ISQ	438	72	6		
	Reverse torque	889	72	12		
	Preparation time	1021	72	14		

*Statistically significant differences (Bonferroni, $P < .05$).

†ISQ indicates implant stability quotient.

The sole accepted contrast was the simulated bone density deviation contrast relative to site preparation (sum of squares = 6.613, df = 1, mean square = 6.613, F = 0.466, $P = .497$).

sporadically favoring the conventional over the piezoelectric technique or vice versa.

With regard to the absolute values of the considered dependent variables, though at the moment a threshold value defining acceptable implant stability in the posterior maxilla has yet to be well established,[30] all of the subgroups reached substantially high insertion torque values, despite the simulation of poor cancellous bone quality. The most commonly used threshold for immediate loading (45 Ncm)[31] was often exceeded, confirming the crucial importance of the presence of a cortical bone layer (1 mm in the present study) in enhancing implant stability.[28] Furthermore, the conical shape of both implant systems and their triangular deep threads contributed to the satisfactory stabilization of the fixtures in the experimental conditions of simulated poor bone quality.

The selective micrometric cutting action of piezoelectric surgical instruments allows for better surgical control and safety compared to conventional rotary instruments[32,33]—showing promising results in clinical studies[34,35] but requiring a longer time to perform the osteotomy.[17,18] Moreover, the longer operative time recorded in the present study was also influenced by the greater number of steps required by the piezoelectric technique (6 tips, with relative changes); a similar situation also occurred in the comparison between the two drilling systems because Prama surgical sequence requires a greater number of steps than does Syra (7 drills vs 3). Conversely, the density of the polyurethane blocks did not affect the duration of either piezoelectric or conventional procedures of preparation. It may be speculated that in the presence of poor bone quality, some of the steps of both conventional and piezoelectric techniques could be skipped to save time, but this aspect was not considered in the present study that required strict standardization of the surgical tips sequence, following manufacturer recommendations.

The choice of synthetic bone models could also represent a limitation. Since insertion torque values recorded in the present

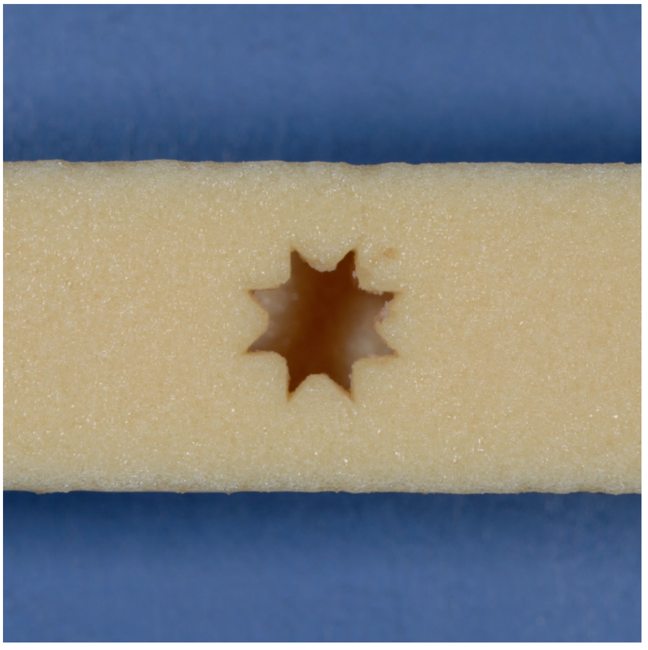


Figure 6. Eight-point star-shaped cross-section of the implant site left by the ultrasonic tips.

study are higher than those reported by studies conducted on the posterior maxilla of human cadavers (23.8 ± 2.2 Ncm), it can be speculated that insertion torque values in polyurethane specimens may be higher than in the human posterior maxilla, even in the case of proper simulation of low-density cancellous bone.[3]

Moreover, the findings of the present study cannot be generalized to different implant systems, as macrogeometry and surface characteristics of the investigated devices play a fundamental role in reaching primary stability.[28,36,37]

Another limitation of the study consists in the use of a single piezoelectric system for implant site preparation; even if other systems for ultrasonic drilling are available, to the best of our knowledge, no study has been published comparing the effect on implant stability of different protocols for ultrasonic implant site preparation involving different tips or devices.

The findings from the present study suggest that specific combinations of surgical technique and implant type may perform better in different conditions of bone density; hence, the clinician may choose the best surgical protocol, maximizing primary stability without reaching excessive insertion torques, with the aim to reduce mechanical stress imparted to the cortical bone and implant components.[32,38,39] For instance, Syra implant placement after piezoelectric site preparation in 15 PCF cancellous bone required slightly lower insertion torque comparing to conventional technique, yielding higher ISQ and removal torque values.

Further investigations on human subjects are needed to confirm the present in vitro findings in order to couple the biological advantages of ultrasonic site preparation with satisfactory primary stability when placing short implants in low-quality bone.

Conclusion

The two types of short implants investigated in the present in vitro study, when inserted after ultrasonic implant site preparation, showed comparable or slightly higher primary stability in comparison with the conventional drilling techniques. Site preparation with drills was significantly faster than the piezoelectric device; the operative time can be further reduced by surgical sequences with fewer instruments. Prama implants showed greater resistance to unscrewing, while Syra implants had improved RFA performance.

Once confirmed by future studies, the findings of the present work may guide the clinician in choosing appropriate surgical technique and short implant type to optimize primary stability in low density cancellous bone.

Abbreviations

ISQ: implant stability quotient
PCF: pound per cubic foot
RFA: resonance frequency analysis

Note

The authors declare that there is no conflict of interest.

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