ORIGINAL RESEARCH

Influence of Cortical Layer and Surgical Techniques on the Primary Implant Stability in Low-density Bone: An *In Vitro* Study

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Abstract

Aim: This study aimed at evaluating the influence of cortical layer and surgical techniques on the primary stability of implants in low-density bone.

Materials and methods: Two solid rigid polyurethane blocks with a density equivalent to 0.32 g/cm^3 simulating cancellous bone were used. A short fiber-filled epoxy resin sheet of 2 mm was layered to one block to simulate cortico cancellous bone. A total of 40 implants were used in this study ($n = 40$). Twenty implants each ($n = 20$) were inserted in cancellous (Group 1) and cortico-cancellous bone (Group 2), of which 10 implants each ($n = 10$) were placed using undersized preparation technique with surgical drills—A and osteotomes—B, in both the groups. Insertion torque (IT) and implant stability quotient (ISQ) for each implant placed were assessed to determine the primary stability of each implant using a digital torque meter and resonance frequency analyzer, respectively. The values were statistically analyzed using an independent *t*-test ($p < 0.05$). Pearson's correlation analysis was performed to correlate between IT and ISQ.

Results: Technique B resulted in significantly higher IT and ISQ values in Group 1 (27.69 ± 1.2 N cm; 52.5 ± 1.05 ISQ) and Group 2 (38.8 ± 0.87 N cm; 70.1 ± 1.04 ISQ) compared to those with technique A (22.40 ± 1.62 N cm; 41.75 ± 1.20 ISQ and 33.24 ± 0.67 N cm; 63.72 ± 1.33 ISQ), respectively. Group 2 exhibited significantly higher IT and ISQ values as compared to Group 1 irrespective of the surgical technique employed ($p < 0.05$).

Conclusion: The presence of the cortical layer significantly influenced the primary stability and preparing low-density bone with an undersized preparation technique using osteotomes that significantly increased the IT and ISQ.

Clinical significance: Undersizing the preparation site considerably will help achieve a significant increase in primary stability in the poor quality bone as in the posterior maxilla, thereby contributing to the success of the implant.

Keywords: Insertion torque, Osteotomes, Primary stability, Resonance frequency analysis, Undersized preparation.

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Introduction

Osseointegrated dental implants have been successfully used to treat partial and completely edentulous arches. A good bone to implant contact is essential for the immediate and long-term efficiency of an implant.[1] Primary stability being a valuable identity of osseointegration is a benchmark of a clinically stable implant.[2] During the osseointegration period where the bone to implant contact takes place, primary stability has an impact on rigidity, strength, and resistance to implant movement. This primary stability increases with higher resistance during implant insertion. Various factors like the bone quality and quantity, the surgical technique, and the microscopic and macroscopic characteristic features of the implant are decisive in achieving a good primary stability.[3,4]

The underlying bone plays a significant role in determining the long-term prognosis of implant treatment. The density feature of the bone is of utmost importance in predicting the primary stability of an implant.[5] Success rates mainly depend on the quality and quantity of the bone, adjacent to the implant.[6] Maxillary arch when compared to the mandibular arch has a thin cancellous bone. The reasons for failure in the posterior sites include resorbed bone, open trabecular network, and very thin or even absence of cortical layer. Many studies have reported significant failure rates in the posterior maxilla owing to its porous architecture.[7–9]

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The standard surgical technique is to prepare the site slightly lesser than the diameter of the implant. Many adaptations have been made to the standard surgical techniques to enhance the primary stability of implants in low-density bone. A smaller final drill diameter than that of the implant has been suggested by a few authors,[10,11] and few others recommend bone condensing technique, which converts a D4 type of a bone to D3 or D2 by laterally compacting bone instead of losing bone as in drilling.[12,13]

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Laboratory studies supporting these clinical methods have used solid rigid polyurethane foam blocks as a standard testing material to simulate human bone. Its homogenous properties make it an ideal material for comparative testing of dental implants.[10] Studies with polyurethane foam have generated positive results to support these surgical techniques.[10]

Implant design characteristics, such as thread pattern and surface modifications, affect the primary stability and the ability of the implant to sustain loading during and after osseointegration.[14] Self-tapping, wider-diameter implants are available since 1983 and have been used for the bone of soft quality.[10,15]

Several methods of testing the primary implant stability have been proposed to provide the practitioner with an objective indicator of osseointegration.[4,5,10] At the time of implant placement, insertion torque (IT; cutting resistance analysis), resonance frequency analysis (RFA), periotest, histologic analysis, and dental mobility checker have been used to assess primary stability.[5] During implant placement IT values can be a reliable clinical indicator of primary stability.[5,14,16] Ongoing osseointegration can be determined by using RFA of the implant-bone complex by reading an implant stability quotient (ISQ) value.

The determination of the IT is done by a torque gauge incorporated within the drilling unit at the time of placement. It is a relatively simple method to perform at the chairside during implant placement. Hence, it is regularly used in both *in vitro* and *in vivo* studies.[10,11,14,15] A digital torque meter can be used to check for the IT values. RFA offers an objective measurement of implant primary stability and the observation of implant stability during the healing period and in the longer term.[17–19] RFA is extensively used in clinical research to monitor implant stability due to its higher reliability and reproducibility. With this method, implant stability is measured either by determining the resonance frequency of the implant-bone complex or by reading an ISQ value.[5,18,20]

Although many studies have been conducted on the primary stability of dental implants, the mutual relationship between implant design, bone quality, and surgical technique remains uncharted. Considering the less success rates in D4 bone, challenges still exist in achieving good primary stability in such bone. In view of the above mentioned, this *in vitro* study was aimed at evaluating the influence of surgical techniques on the primary stability of tapered implants placed in artificial low-density bone.

Materials and Methods

Bone Specimens

Solid rigid polyurethane foam blocks with a density equivalent to 0.32 g/cm[3] (Sawbones, Pacific Research Laboratories, Vashon Island, WA, USA) (Fig. 1) has been used as a standard testing material[1,10,20] for dental implants. They have mechanical properties that simulate maxillae. To mimic the cortical layer, short fiber-filled epoxy resin sheet measuring 2 mm × 130 mm × 180 mm (Sawbones, Pacific Research Laboratories, Vashon Island, WA, USA) was used. Of the two cancellous bone blocks, one was made to simulate cortico-cancellous bone by gluing the epoxy resin sheet to it.

Fabrication of a Customized Aluminum Case

An aluminum case (Fig. 2) was fabricated to hold the foam blocks in place and to prevent it from moving during implant placement and measurement of values. On top of this case, an aluminum plate which consisted of 20 holes was fabricated. A total of 5 holes were made in four rows and each hole was 10 mm in diameter. The holes were made to facilitate implant placement in the foam block after enclosing in the aluminum case.

Fig.1: Polyurethane foam blocks

Fig. 2: Aluminum case

Implant Placement

The sample size was determined by a pilot test of 10 samples (5 in each group) using the formula to compare two means with a 95% confidence level, a statistical power of 90%, and an alpha error of 5%. A total of 40 self-tapping implants of 5.0 mm diameter and 11.5 mm length (Touareg-S, Adin Dental Implant System Ltd., Alone Tavor, Israel) were used in this study. Touareg-S type of Adin Dental implant system offers self-tapping and wider-diameter implants. The aggressive threading feature binds the bone to the implant more readily with minimal preparation by eliminating the bone tapping procedure. Wider-diameter implants with a flared coronal portion also aid in bone compression and bicortical stabilization, thus routinely used in soft bone quality. A 5 mm of Touareg-S is a wide-diameter implant. A length of 11.5 mm was chosen since the maxillary posterior sites are porous and require an increased surface area for good primary stability.[8] Twenty implants ($n = 20$) each were placed in cancellous bone (Group 1) and cortico-cancellous bone (Group 2). Ten implants were placed using undersized preparation technique with surgical drills—A ($n = 10$) and osteotomes—B ($n = 10$) both in Groups 1 and 2.

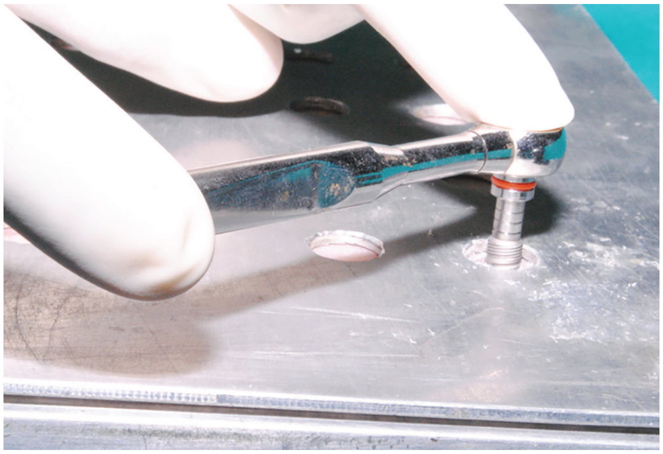

Fig. 3: Implant placement

Technique A: The surgical drills (Adin Dental Implant System Ltd., Alone Tavor, Israel) were used in a 20:1 reduction gear handpiece (NSK S-Max SG20) with external saline irrigation at a speed of 800 rpm. Initially pilot drill of size 2.0 mm was used to prepare the osteotomy site up to a depth of 11.5 mm. A sequential osteotomy was performed using drills of 2.8, 3.2 up to 3.65 mm drill diameter. The final drill was one size lesser than the manufacturer's recommendation of 4.2 mm, resulting in the undersizing of the osteotomy site. All the drills were inserted only once to ensure that there was no inadvertent widening of the osteotomy site. For every change in the drill, the site was irrigated with chilled saline to simulate and the debris was flushed out.

Technique B: The osteotomy site was prepared using osteotomes (Uniti, Equinox Medical Technologies, BV, Mumbai). Initially, the osteotomy site was prepared with a 2.0-mm pilot drill. Then a 3.0-mm osteotome was placed in the prepared site and the osteotomy was performed by slightly striking the osteotome with a mallet to compress the bone laterally up to a depth of 11.5 mm. Subsequently, a 3.3-mm osteotome followed by 3.7 mm was used. Each instrument remained in the implant site for 1 min before the next diameter was used. The final osteotomy size of 3.7 mm, resulted in the undersizing of the osteotomy for placement of a 5.0-mm-diameter implant.

Implants were placed in the prepared sites (Fig. 3), and mechanical testing was performed to assess the primary stability. The placement and the testing were performed by the principal investigator of the study only. This is to avoid variations in testing and reporting by multiple observers.

Mechanical Testing

A: Insertion torque: During implant placement, the peak IT value was measured at the time of final seating of the implant with a digital torque meter (Screw Torque Checker, Model STC50CN, Tonichi Corporation, Japan). B: Resonance frequency analysis: ISQ was measured for each implant after insertion using the Transducer (Smartpeg) (Type 49) and the resonance frequency analyzer (Osstell AB, Goteborg, Sweden).

Statistical Analysis

The IT and the ISQ values were tabulated for all the 40 implants placed by two surgical techniques in two different types of polyurethane blocks. The results obtained were then subjected to statistical analysis using SPSS 24 software (SPSS Inc., Armonk, NY, USA) for Windows. Parametric tests, such as independent "*t*" tests have more statistical power than nonparametric tests. The sample size was estimated with reference to the previous study by Bajaj et al. to assess the primary stability of implants.[21] Independent *t*-test was used to compare the means between the groups. Pearson's correlation analysis was used to identify the correlation between the testing parameters. The statistically significant level was set at 5% ($p < 0.05$).

Results

The mean IT and ISQ values for implants placed using undersized preparation technique in Groups 1 and 2 with techniques A and B are shown in Tables 1 and 2, respectively. Also, the mean IT and ISQ values for implants placed with technique A in Groups 1 and 2 and with technique B in Groups 1 and 2 are shown in Tables 3 and 4, respectively.

Table 1: Mean IT and ISQ values for implants placed in Group 1 with surgical techniques A and B

Group 1 (cancellous bone)	*No. of samples*	*Mean/SD Insertion torque (IT) (N cm)*	*Mean/SD ISQ*
Technique A	10	22.40/±1.6215	41.75/±1.0341
Technique B	10	27.69/±1.2061	52.5/±1.0541
p-value		0.000*	0.000*

Table 2: Mean IT and ISQ values for implants placed in Group 2 with surgical techniques A and B

Group 2 (cortico-cancellous bone)	*No. of samples*	*Mean/SD Insertion torque (N cm)*	*Mean/SD ISQ*
Technique A	10	33.24/±0.6786	63.725/±1.3357
Technique B	10	38.8/±0.8731	70.1/±1.0488
p-value		0.000*	0.000*

Table 3: Mean IT and ISQ values for implants placed with technique A in Groups 1 and 2

Technique A	*No. of samples*	*Mean/SD Insertion torque (N cm)*	*Mean/SD ISQ*
Group 1	10	22.40/±1.6215	41.75/±1.0341
Group 2	10	33.24/±0.6786	63.725/±1.3357
p-value		0.000*	0.000*

Table 4: Mean IT and ISQ values for implants placed with technique B in Groups 1 and 2

Technique B	*No. of samples*	*Mean/SD Insertion torque (N cm)*	*Mean/SD ISQ*
Group 1	10	27.69/±1.20	52.50/±1.05
Group 2	10	38.80/±0.87	70.10/±1.04
p-value		0.000*	0.000*

Table 5: Pearson's correlation analysis

	IT		*ISQ*	
Group	*r-value*	*p-value*	*r-value*	*p-value*
1A *vs* 1B	−0.36	0.31	0.05	0.89
2A *vs* 2B	−0.23	0.51	−0.24	0.50
1A *vs* 2A	−0.3	0.41	0.21	0.57
1B *vs* 2B	0.27	0.44	0.02	0.95

r, correlation coefficient; range −1 to +1; *p*-value < 0.05—significant

Technique B resulted in significantly higher IT and ISQ values in Group 1 (27.69 ± 1.2 N cm; 52.5 ± 1.05 ISQ) and Group 2 (38.8 ± 0.87 N cm; 70.1 ± 1.04 ISQ) compared to those with technique A in Group 1 (22.40 ± 1.62 N cm; 41.75 ± 1.20 ISQ) and Group 2 (33.24 ± 0.67 N cm; 63.72 ± 1.33 ISQ), respectively. Group 2 exhibited significantly higher IT and ISQ values as compared to Group 1 irrespective of the surgical technique employed ($p < 0.05$).

Although the IT and ISQ values were higher, as bone quality increased and osteotome was used, no statistically significant difference could be observed with Pearson's correlation analysis as shown in Table 5.

Discussion

Primary stability plays a major role in achieving a firm implant–bone interface. Although many clinical and animal studies have demonstrated the importance of enhancing bone quality to improve the primary stability, laboratory studies using polyurethane foam are limited.[17–19] Solid rigid polyurethane foam blocks (Sawbones, Pacific Research Laboratories, Vashon Island, WA, USA) are approved by the American Society for testing and material.[1,19,20] In the present study, the perplexing factor of inter-specimen bone variability was eliminated by the use of this synthetic bone model.

Many authors have stated that the standard surgical technique (manufacturer-recommended surgical protocol) results in low primary stability in the low-density bone due to the porous architecture of soft bone.[14,19,22] Refining innate bone features of low-density trabecular bone, by undersizing the osteotomy site has shown to increase the primary stability.[14,17,18,23] In the present study, implants were therefore placed using the undersized preparation technique only.

The use of tapered osteotomes has been explored in clinical and animal studies.[2,11,24–26] The convex tip of the osteotome shaves the bone off and condenses it laterally, thereby converting a D4 bone to D3 bone.[3,13,26,27] Considering the fact that research on undersized preparation techniques with osteotomes has been meager in literature, the present study explored the use of osteotomes with this technique.

In the present *in vitro* study, the mean IT and ISQ values for implants placed with undersized preparation technique in Group 1 exhibited low primary stability. The results are in accordance with the previous studies, wherein undersizing the osteotomy site with technique A resulted in low primary stability owing to the poor bone architecture.[19,28] In the same group, implants placed with technique B exhibited higher IT and ISQ values when compared to technique A. Our study is supported by previous animal studies that reveal that modifying the surgical technique by using osteotomes in cancellous bone exhibited higher primary stability.[22,24,25,29] In the osteotome technique, the compression is higher because of force-fitting stresses, which arise when an implant is placed into an implant bed of smaller diameter.[30] Considering the fact that research on undersized preparation technique with osteotomes has been meager in literature, the present *in vitro* study explored the use of osteotomes with this technique in improving the primary stability of implants.

The mean IT and ISQ values for implants placed in Group 2 were found to be statistically significant when compared to Group 1. There was a marked increase in primary stability in Group 2. This was in accordance with the previous studies that stated that the presence of the cortical layer significantly increased the primary stability, and the IT and ISQ values increased as the thickness of the cortical layer was increasing.[18,20,31] The dominant role of the cortical layer has been demonstrated in various studies, and engaging the implant threads into the cortical layer resulted in greater primary stability.[32,33]

The results obtained in this study revealed that the undersized preparation technique with techniques A and B have increased the primary stability of implants in both Groups 1 and 2. This increase in primary stability could be attributed to the degree of undersizing followed in this study. A 5.0-mm-diameter implant was placed in an osteotomy site of 3.65 mm diameter. Thus, the undersizing was to an extent of 25% as demonstrated in previous studies with surgical drills only.[17,19] Our study has incorporated 25% undersizing in technique B that has resulted in such high values. The apical portion of the implant that narrows to 4.0 mm and the thread depth of 0.8 mm compressed and engaged the bone without the need for additional drilling to place the implant, thereby increasing the primary stability.[17,20] A 5-mm-diameter implant, which tapers evenly to an apical diameter of 4 mm, the whole of the preparation, can be 1 or 2 mm narrower and the implant generally will thread into place and provide bone compression.[14,34]

The results acquired by undersizing with technique B revealed that this technique has increased the primary stability of the implants in both the groups. The values obtained for implants placed with technique B in Group 2 (38.8 N cm and 70.1 ISQ) are quite appealing and even satisfies the clinical requirement of 35 N cm IT, which is necessary for immediate loading of implants.[35] From this *in vitro* study, it is thus clear that the undersizing with technique B offers a much better primary stability than with technique A. Also, the presence of a cortical layer of 2 mm thickness has proven to increase the primary stability markedly compared to the cancellous bone alone.

The correlation between the IT (mechanical interlocking) and ISQ (stiffness of the bone at the implant–bone interface) was nonsignificant among all the four groups. Although both the parameters increase with technique B and the presence of cortical layer, there was a nonsignificant correlation between the two, suggesting that both are independent factors that can assess primary stability. Thus, no single parameter was found superior to the other for evaluating primary stability. This was in harmony with the previous studies by other authors.[31,36]

The drawbacks of the present *in vitro* study could be attributed to the host bed (polyurethane foam unlike clinical conditions), heat production, limited access to the posterior maxilla, traumatic expansion and microfractures, and paroxysmal positional vertigo while using osteotome technique.[37] The results of our study are specific to one particular design of the implant. The varying thickness of the cortical layer was not studied too. The influence of surgical techniques on secondary stability could not be assessed because of the *in vitro* nature. Hence, further studies evaluating the primary stability of different implant designs and different bone thickness are to be done. Also, longitudinal studies on both the primary and secondary stability of implants placed with the modified surgical techniques in the posterior maxilla are suggested.

Conclusion

Within the limitations of this study, it is concluded that the use of osteotomes with an undersized preparation technique for preparing the implant osteotomy site increases the primary stability of the implants placed in the cancellous and cortico-cancellous bone. The presence of the cortical layer adds to the primary stability of implants placed in low-density bone using both surgical techniques. The primary stability achieved with osteotomes in the cortico-cancellous bone meets the clinical requirement of immediate loading. Individuals placing self-tapping implants in the posterior maxilla must consider the use of an undersized preparation technique with osteotomes for obtaining optimal primary stability. Longitudinal studies are necessary to confirm the effectiveness of this modified surgical technique to enhance the primary stability in the low-density bone.

Clinical Significance

Achieving primary stability in the posterior maxilla always remains a challenge due to its porous bone architecture. The right choice of host bed, implant design, and surgical site preparation will result in optimal primary implant stability. Undersizing the preparation site and the use of osteotomes will considerably help achieve a significant increase in primary stability, thereby contributing to the success of implant treatment.

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