The Influence of Implant Shape on Primary Stability of Implants With a Thread Cutting and Forming Design: An Ex Vivo Study

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The design of an implant has a great effect on primary stability. The purpose of this study was to determine the differences in primary stability between straight and tapered Neoss ProActive implants in type I and type III bones using resonance frequency analysis (RFA) and electronic percussive testing (EPT) methods. Fresh cow vertebrae and pelvis were used as models of type III and type i bone, respectively. Implants of 2 different designs—straight and tapered Neoss ProActive implants with a thread cutting and forming (TCF) design, both 3.5-mm wide and 11-mm long—were placed in both types of bone ($n = 60$). The primary stability of all implants was measured by an experienced clinician blinded to the study protocol using the EPT and RFA devices. No statistically significant difference was found between the implant stability quotients and the percussive test values of straight and tapered implants in either bone type. Within the limitations of this ex vivo study, it may be concluded that the shape of an implant with a TCF design does not affect primary stability.

Key Words: primary implant stability, implant macro-design, thread geometry, resonance frequency analysis, electronic percussive testing, dental implant

INTRODUCTION

The stability of a dental implant, which is a prerequisite for establishing osseointegration,[1] has been defined as "mechanical stabilization both during surgery and the healing phase."[2] The stability of an implant during surgery is referred to as primary stability, and the steadiness of the implant after surgery during the healing phase and thereafter is referred to as secondary stability.[3] Previous studies have found a direct correlation between primary implant stability and successful osseointegration.[4–6] Bone density, surgical procedure, and the shape and geometry of an implant are the main determinants of primary stability.[7,8] The bone density of the implant placement site plays an important role in establishing stability. When implants are placed in bone with low density, it is not easy to provide stability. Because of the development of mechanical locking, implant macrogeometry is believed to play a key role in maintaining stability, especially in such regions.[9] Although many modifications have been developed over the years, most manufacturers still use 2 main implant macrogeometries: tapered and cylindrical. Tapered implants have been shown to provide higher primary stability than cylindrical implants in many clinical and in vitro studies.[10–12] Despite their advantageous stability, the use of tapered implants in the posterior mandible is usually not advised because of the microarchitecture of this region.[13]

Implant stability can be measured using several methods.[14] The most frequently used techniques are resonance frequency analysis (RFA) and electronic percussive testing (EPT).[7,15,16] These 2 methods are noninvasive and reliable and ensure quick display of the results and ease of routine use.[17] Researchers can measure RFA using magnetic devices such as Osstell (Osstell ISQ, Gothenburg, Sweden) and Penguin (Penguin Integration Diagnostics, Gothenburg, Sweden). Both of these devices record resonance frequencies, which, through their respective transducers, are translated into a user-friendly implant stability quotient (ISQ), which is quantified on a scale of 1 to 100.[18] It has been shown that the threshold ISQ that ensures loading of an implant is 70 when the stability is measured using a wireless device.[19] The EPT is clinically performed using commercially available cabled or cordless devices that have an electromagnetically driven and electronically controlled tapping metallic rod in a handpiece. The percussive test value (PTV) is transformed into a microcomputer and displayed on the screen of the EPT device. The PTVs range from -8 (low mobility) to $+50$ (high mobility).

More recently, Neoss (Neoss System, Neoss Ltd, Harrogate, UK) produced a novel implant system with an innovative design, the Neoss ProActive. The manufacturer stated that the surface of ProActive was created by exposing commercially pure titanium implants to multistage blasting, etching, and superhydrophilicity treatment, all of which provide the implant

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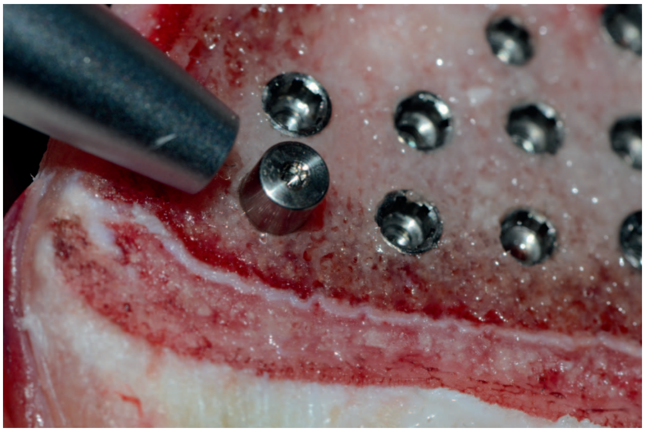

Figure 1. Measurement of primary stability using the electronic percussive testing device.

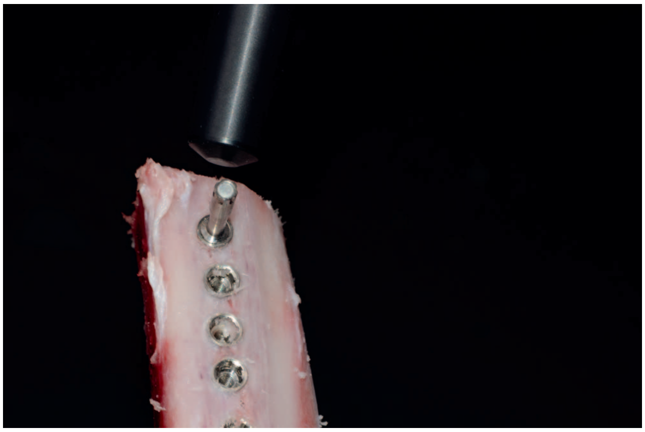

Figure 2. Measurement of primary stability using the resonance frequency analysis instrument.

with a high level of wettability and allow a low contact angle between the bone and implant. Neoss ProActive implants are available in 2 different designs, with a tapered or straight macrogeometry. The tapered implants have a conical coronal flange with additional threads, and the apical profile provides ease of placement in soft bone situations where there are narrow bone walls; the straight implants have a parallel coronal flange. Both macrogeometries have a unique thread cutting and forming (TCF) design, which is a secondary cutting face. The manufacturer claims that with the aid of this TCF design, implants achieve maximum primary stability in all bone types. Therefore, maintenance of higher primary stability in tapered implants may not be achieved for an implant with a secondary cutting face. This study was conducted to determine the differences in primary stability between straight and tapered Neoss ProActive implants in type I and type III bones using the RFA and EPT methods.

MATERIALS AND METHODS

For the experimental procedures, fresh vertebrae and pelvis from a steer weighing 700–800 kg were collected from a butcher's shop. The vertebrae were used to simulate bones of type III and IV, whereas the pelvis was used to simulate harder bones (due to its macroscopic composition[15]) such as type I and II, according to the Lekholm and Zarb classification.[20]

Thirty tapered (Neoss tapered ProActive) and 30 cylindrical (Neoss straight ProActive) implants with TCF design made by the same manufacturer were chosen for comparisons. The implants were all 3.5-mm wide and 11-mm long. Implant beds were prepared following the drilling protocols recommended by the manufacturer for each implant design. Fifteen cylindrical and tapered implants were placed in the vertebrae, and 15 cylindrical and tapered implants were placed in the pelvis, a total of 60 implants with a safe distance from each other. Healing abutments (3 mm in height) were screwed onto the implants immediately after insertion.

All devices were accurately calibrated before starting the study, and all measurements were performed by an experienced clinician blinded to the study protocol.

After placement of the implants, the primary stability of all implants was measured using the wireless EPT device (Figure 1; PerioTest M, Medizintechnik Gulden, Modautal, Germany) and the wireless RFA instrument (Figure 2; Osstell Mentor, Integration Diagnostics, Savedalen, Sweden) after unscrewing the healing abutments and inserting the magnetic pegs calibrated for the implants using a plastic driver and hand pressure. The PTVs were measured in the buccal direction, while the ISQs were measured in both the buccal and mesial directions; the mean of the 2 values was considered the final ISQ of each implant.

The methodology was reviewed by an independent statistician. Statistical analysis was performed using Statistical Package for Social Sciences (SPSS) for Windows software (SPSS Statistics for Windows, version 22.0, IBM Corp, Armonk, NY). The Shapiro-Wilk test was used to determine whether the measured parameters met the assumptions of normal distribution. The results indicated that the data were not normally distributed. The 2 different implant and bone groups were compared using the Mann-Whitney U test. Although there were deviations in some small values, the distributions of the compared scores had similar shapes. Therefore, the Mann-Whitney U test was selected to compare differences between 2 independent groups when the dependent variable was either ordinal or continuous but not normally distributed. The results were assessed with 95% confidence intervals at a significance level of .05.

RESULTS

The results were analyzed by an independent statistician. The ISQs were significantly higher in type I bone than in type III bone ($P < .001$) and the PTVs were significantly lower in type I bone than in type III bone ($P < .001$; Table 1) for both implants.

No statistically significant difference was found between the ISQs of straight and tapered implants in either bone type ($P > 0.5$; Table 2). In addition, there was no significant difference

Table 1

Comparison of primary stability with respect to bone type*

Macrogeometry	Stability Values	Bone Type Type I (Median)	 Type III (Median)	*P*
Straight	ISQ	78.13 ± 3.52 (77.5)	73.66 ± 2.94 (75)	.001
	PTV	−5.28 ± 1.1 (−5.2)	−2.74 ± 0.60 (−2.7)	.001
Tapered	ISQ	77.86 ± 2.96 (77)	73.76 ± 3.11 (74)	.001
	PTV	−4.9 ± 0.87 (−5.2)	−2.33 ± 1.44 (−2.2)	.001

*ISQ indicates implant stability quotient; PTV, percussive test value.

between the PTVs of straight and tapered implants in either bone type ($P > 0.5$; Table 2).

Discussion

Primary stability is a major concern in successful osseointegration and is of utmost importance for implant survival and success.[19,21,22] The macrogeometry and thread design of an implant are believed to be vital features affecting primary stability.[7] It has been clearly demonstrated that tapered implants show higher primary stability than cylindrical implants, especially in regions with low bone densities or fresh extraction sockets.[23,24] However, as manufacturers develop different thread designs and alternative body features for enhancing stability, the shape of an implant may lose its importance to a certain extent. The aim of this study was to investigate how shape affects primary stability in implants with a TCF design.

The RFA and EPT methods have shown satisfactory intra- and interobserver reliability, reproducibility, and invasiveness in previous studies.[3,15] For this reason these 2 methods were used to assess primary stability in the present study. It has been shown that EPT is not capable of evaluating mesiodistal stability.[15,25] Therefore, the measurements were only performed in the buccal direction. Significant negative correlations between PTVs and ISQs have been reported in previous studies.[26,27] Hence, the correlation of the 2 methods was not considered in our study so previously evaluated outcomes would not be duplicated.[26,27]

Anterior or posterior maxilla, which are regarded as the ideal sites for using a tapered implant, were simulated by using the vertebrae in the present study. Regions in which tapered implants show lower initial stability values than cylindrical implants, such as the posterior mandible, were simulated using the pelvis. Misch[28] reported that the bone classification can be confirmed by an expert surgeon while drilling. In the present study, tactile feedback while drilling implants and suggestions from previous studies[3,7,15] were both used to determine the bone type classification. It is well known that the greater the bone density, the greater the primary stability of an implant.[7,29,30] The lower stability found in the softer bone in the present study was consistent with this observation.

The similar primary stability of tapered and cylindrical implants in type I and II bone detected in the present study is consistent with previous studies.[13,31] It should be emphasized that the quality of bone is an important factor in determining the primary stability of an implant. Given that tapered implants cause overcompression on the surrounding tissues compared with cylindrical implants,[32] it may be advisable to use parallel-sided cylindrical implants instead of tapered ones when the bone density is high. The most interesting finding of the present study is the lack of significant differences in stability values of the 2 implant geometries in softer bone. This finding contradicts the results of previous in vitro and clinical investigations.[8,10,12,21,33,34] It has been shown that greater tapering had a critical effect on the stability results in softer bone due to the compression of the bone tissue in a lateral direction and clamping of bone between the threads and collar in an axial direction.[8] This contradictory result may be the reason for the unique design of the evaluated implants. Today, many current implant manufacturers use thread-cutting geometry in macrogeometry. According to Meredith,[35] an implant with a TCF design has a secondary cutting face that is much shallower than the apical cutting face, and this unique secondary modification generates optimal stability in all bone densities without creating compression. This overwhelming effect of the TCF design may be the reason for the similar stability values of the tapered and cylindrical designs in softer bone detected in the present study. Additionally, our results revealed that the stability values in softer bone were between

Table 2

Comparison of primary stability with respect to macrogeometry

Bone Type	Stability Values	Macrogeometry Straight (Median)	 Tapered (Median)	*P*
Type I	ISQ	78.13 ± 3.52 (77.5)	77.86 ± 2.96 (77)	.688
	PTV	−5.28 ± 1.1 (−5.2)	−4.9 ± 0.87 (−5.2)	.805
Type III	ISQ	73.66 ± 2.94 (75)	73.76 ± 3.11 (74)	.717
	PTV	−2.74 ± 0.60 (−2.7)	−2.33 ± 1.44 (−2.2)	.653

*ISQ indicates implant stability quotient; PTV, percussive test value.

the acceptable threshold scores for both of the microgeometries, which may also be a result of this unique design.

Primary stability of an implant is a mechanical phenomenon, but its secondary stability is a biological phenomenon.[18] In a study performed in non-living bone like ours, it is only possible to measure the mechanical security of an implant that is not affected by the following cellular response that can only be evaluated in living bone. Therefore, further randomized clinical studies are needed for a clear understanding as to whether this particular design is really an advantage.

The present study had 3 limitations. First, although cadavers, animal bones, and sawbones have been used for the assessment of primary stability in previous in vitro or ex vivo studies,[7,8,15,16] the results achieved with cow vertebrae and pelvis may not be completely applicable to humans. Furthermore, clinical situations, such as intraoral difficulties due to lips and cheeks, saliva, or the surgical flap were not present because of the in vitro nature of the present study. Therefore, the present ex vivo study lacks external validity, and the results cannot be generalized to clinical situations. Second, all the tested implants were the same size; therefore, it was not possible to compare macrogeometries according to implant diameter or height change. Third, as secondary stability, surface characteristics and cellular response also affect the healing period after implant treatment, measuring only a single parameter such as primary stability, may be regarded as a limitation of the current study. However, this study was mainly aimed at determining whether the macro-design differences of implants with a TCF design affect the primary stability in poor-quality bone. Nevertheless, further prospective clinical trials assessing both the primary and secondary stability of tapered and cylindrical implants with a TCF design are needed to achieve more accurate results.

CONCLUSION

Within the limitations of this ex vivo study, it may be concluded that the shape of an implant with a TCF design does not affect primary stability. Cylindrical implants with a TCF design showed comparable primary stability to tapered implants with a TCF design. However, due to the study design, the findings cannot be extrapolated to other populations until further clinical studies have been carried out.

ABBREVIATIONS

EPT: electronic percussive testing
ISQ: implant stability quotient
PTV: percussive test value
RFA: resonance frequency analysis
TCF: thread cutting and forming

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NOTE

The authors report no conflict of interest.

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