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Research Paper
Dental Implants

Compensating for poor primary implant stability in different bone densities by varying implant geometry: a laboratory study

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Abstract. The aim of this study was to determine the influence of implant diameter and length on primary stability in artificial bone blocks. In total, 240 implants of various diameters (Ø 3.3, 4.1, and 4.8 mm) and lengths (8 and 12 mm) were inserted in four artificial bone blocks of different densities (D1–D4). The primary stability for each bone block density was measured and compared with the primary stability of a narrow and short implant (Ø 3.3 mm, length 8 mm) in the next higher density block. Analysis was done by three-way ANOVA, and mean differences were determined with the 95% confidence interval. Levels of primary stability achieved by choosing the next higher diameter or length were not comparable to those of the next level of block density. However, equivalent values could be achieved by selecting the largest diameter for short and long implants in the lowest block density D4, as well as for long implants in bone type D2. The diameter of an implant has greater influence on primary stability than length. In particular, in the case of poor bone quality, a variation of implant geometry can lead to significant improvement in primary stability.

Key words: dental implant; primary stability; resonance frequency analysis; bone density; bone quality; implant length; implant diameter.

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An important prerequisite for osseointegration and subsequently the success of implant dentistry is primary stability (PS) immediately after insertion and followed by implant loading.[1] PS can be described as the absence of implant movement immediately after insertion, and it is mainly dependent on mechanical conditions such as bone quantity and quality, implant geometry, and the surgical techniques used for implant site preparation.[1,2] Bone quality and implant length and diameter are known to influence the implant–tissue interface and subsequently implant stability.[3] Secondary stability is observed after the implant is completely osseointegrated.

Inadequate PS, along with inflammation, bone loss, and biomechanical

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overloading, is one of the major causes of implant failure. Low PS presents a higher risk of early implant failure or loss, whereas high stability creates optimum conditions for osseointegration, as smaller micro-motions between implant and bone become possible.[4] Micro-motions of >50–100 μm can lead to the formation of fibrous bone at the bone–implant interface. Therefore, a high level of PS is positively associated with secondary implant stability.[5]

Various techniques have been described to measure the stability of an implant. These include insertion torque, resonance frequency analysis (RFA), percussion energy response, and removal torque.[6–8] Although insertion torque is important for assessing primary implant stability, RFA, which was developed more recently, provides an increased ability to monitor PS and secondary stability.[9] This makes it possible to measure stability at the time of insertion as well as at any stage of osseointegration and prosthetic rehabilitation.[10] In addition, RFA is the only method that has demonstrated a significant influence of various factors on PS.[11]

The design of a dental implant is crucial for the achievement of sufficient PS.[12] Various components and features characterize the three-dimensional structure of an implant body, of which the implant surface and diameter greatly influence PS. Clinical studies have reported that implants with a diameter <3.0 mm provide sufficient PS in cases with limited bone volume.[13,14]

Another important parameter is bone quality. According to the classifications of Misch[15] and of Lekholm and Zarb,[16] bone quality can be classified into types 1–4. Investigations have reported implant failure of approximately 3% after insertion in bone types 1, 2, and 3, and of 35% after insertion in bone type 4.[17] Therefore, primary implant stability is lower in type 4 bone than in bone of other types.[18]

The bone density affects the amount of bone–implant contact. High bone density around the implant site preparation can positively influence PS.[3] Usually, the bony structures of the jaw are not homogeneous. To remove the influence of this variable bone quality, artificial bone substitutes such as homologous foam can be used.[11,19–23] These blocks are available in the bone qualities described. However, there is no evidence to show that varying implant size in the case of low bone density can improve PS to the level expected with a higher quality of bone.

Various studies have analyzed the influence of implant length, diameter, and bone density on PS. However, there has been no study investigating the interaction of these parameters and the feasibility of compensating for poor primary implant stability by varying implant geometry Therefore, the purpose of this in vitro study was to determine if changing the diameter and length of an implant would help achieve the level of PS that could be expected with higher bone density.

Materials and methods

Bone model

Implant site preparations were made in artificial polyurethane bone blocks (#1522-04, #1522-03, #1522-01, #1522-23; Sawbones, Malmö, Sweden). The American Society for Testing and Materials has approved this material, has recognized it as a standard for testing orthopaedic devices and instruments, and has declared it to be an ideal material for comparative testing of bone screws (ASTM F-1839-08). The solid rigid polyurethane foam (SRPF) blocks used in the present study are classified into the following groups based on density: D1, 0.48 g/cm^3; D2, 0.32 g/cm^3; D3, 0.16 g/cm^3; and D4, 0.08 g/cm^3.

Implant drill

In total, 240 implant site preparations and implant insertions were performed. Surgical twist drills with diameters of 2.8, 3.5, and 4.2 mm were used to prepare implant beds of 8 or 12 mm in length (Institute Straumann AG, Basel, Switzerland) 10 times in each artificial bone block. Drilling was performed using a surgical hand-piece connected to a surgical motor unit (Implantmed SI-923, Surgical Control S-N1; W&H Dentalwerk Bürmoos GmbH, Bürmoos, Austria) along with constant irrigation (50 ml/min). The drilling speed for drill diameters of 2.8 and 3.5 mm was 600 rpm, whereas that for drill diameter 4.2 mm was about 500 rpm. Finally, implants with various diameters (3.3, 4.1, or 4.8 mm) and lengths (8 or 12 mm) were inserted (Straumann Bone Level; Institut Straumann AG, Basel, Switzerland).

Resonance frequency analysis

After implant insertion, PS was measured using the RFA with hand-screwed SmartPegs (types 53 and 54; Osstell, Gothenburg, Sweden). The implant stability quotient (ISQ) ranges from 0 to 100 (measured between 3500 and 8500 Hz), and is divided into low (<60 ISQ), medium (60–70 ISQ), and high stability (>70 ISQ) for in vivo investigations. For each specimen, the RFA measurement was repeated three times. Measurements were performed in two orientations separated by a 90-degree angle, and the average ISQ values were calculated.

Statistical analysis

The mean values, corresponding standard deviations (SD), minimum and maximum implant length for each subgroup, implant diameter, and block density were reported for the primary outcome (ISQ). A three-way analysis of variance (ANOVA) was performed for implant length (8/12 mm), implant diameter (3.3/4.1/4.8 mm), and block density (D1/D2/D3/D4). The model also included all two- and three-way interaction terms. Linear comparisons of the various combinations of implant lengths, diameters, and block densities were performed. Estimated differences in ISQ and corresponding 95% confidence intervals (CIs) were calculated to show that clinically comparable levels of PS can be reached in different bone types by varying the diameter and length of implants. *P*-values of ≤0.05 were regarded as statistically significant. Because of the explorative nature of the study, no adjustment to the significance level was made. All statistical analyses were performed using SAS version 9.3 software (SAS Institute Inc., Cary, NC, USA).

Results

All mean values and SD of the measured ISQ as a function of implant length, diameter, and block density are shown in Table 1, and the corresponding box plots are given in Figure 1. Table 2 shows comparisons of the average values for the different diameters of implants (3.3, 4.1, and 4.8 mm), depending on implant length and block density. For all comparisons *P*-values of ≤0.05 were regarded as statistically significant.

The comparison of narrow and wide implant diameters (3.3 mm vs. 4.8 mm) demonstrated a statistically significant increase in PS for all bone block densities, irrespective of the implant length (all *P*-values <0.05) (8 mm: D1, 58.30 ± 3.68 vs. 64.30 ± 2.87; D2, 47.90 ± 5.02 vs. 53.40 ± 4.60; D3, 10.90 ± 4.04 vs. 22.80 ± 5.14; D4, 2.20 ± 1.93 vs. 10.60 ± 4.22; 12 mm: D1, 59.20 ± 0.79 vs. 69.80 ± 2.49; D2, 53.70 ± 4.06 vs. 60.30 ± vs. 3.30; D3, 26.40 ± 4.20 vs. 31.00 ± 4.69; D4, 3.20 ± 1.48 vs.