Displacement of Dental Implants in Trabecular Bone under a Static Lateral Load in Fresh Bovine Bone

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ABSTRACT

Aim: The study aims to provide objective data for the displacement of titanium screw implants in trabecular bone specimens.

One hundred Semados implants (Bego, Bremen, Germany) were inserted in bovine type IV bone specimens. All implants had a diameter of 3.75 mm; 50 implants had a length of 8.5 mm and 50 implants had a length of 15 mm. Insertion torque was determined at intervals of 10, 20, and 30 Ncm. Implants were loaded horizontally with 10, 20, and 30 N for 2 seconds. An indicator strip was attached to the implant abutment to allow direct observation of implant movement relative to the bone surface. Horizontal displacement was assessed with an accuracy of measurement of 10 μm.

Seven implants got lost by visible loosening. Degree of displacement was subject to evaluation with all others. Those implants showed a mean displacement of 59 μm for 10 N ($n = 100$), 173 μm for 20 N ($n = 99$), and 211 μm for 30 N ($n = 93$).

The mean displacement of 15-mm implants (16, 37, 51 μm) was significantly lower compared with 8.5-mm implants (103, 311, 396 μm) corresponding to 10, 20, and 30 N as lateral loads.

Conclusions: Displacement of screw implants in trabecular bone can be detected and visualized using commercially available endoscopes with a high magnification. A lateral load of 20 N indicates a mean displacement of over 100 μm and therefore results in a critical displacement.

KEY WORDS: contact endoscopy, displacement, implant length, insertion torque, lateral loading, primary stability

INTRODUCTION

According to Sennerby and colleagues,[1] the stability of dental implants depends on a direct contact between the surrounding bone and the surface of the implant. A distinction is made between primary and secondary stabilities. Primary stability on placement is a mechanical component dependent on local bone quality and quantity, the type of implant, and the placement technique. Secondary stability is attributable to bone formation and remodeling at the implant interface.

Studies by Jaffin and Berman[2] showed that types I, II, and III bone offer good primary stability. Type IV bone has a thin cortex and weak medullary trabecular structure with low density, and Jaffin and Berman have reported 35% failures of fixtures placed in type IV bone.

A number of studies of bone density and implant bone contact after application of a load to implants have been undertaken. Duyck and colleagues[3] showed that excessive dynamic load causes crater-like defects lateral to osseointegrated implants. Tabassum and colleagues[4] observed that the placement of etched implants in synthetic bone models using an undersized preparation technique resulted in enhanced primary implant stability. In considering the placement technique, Cavallaro

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and colleagues[5] concluded that to enhance primary implant stability, modifications to the drilling protocol are necessary for different bone densities.

Szmukler-Moncler and colleagues[6] suggested that there is a critical threshold of micromotion above which fibrous encapsulation prevails over osseointegration. However, this critical level was not found to be zero micromotion, as has generally been assumed: the tolerated micromotion threshold was found to lie between 50 and 150 μm. Brunski[7] suggested that a critical limit below 100 μm of relative movement between implant and bone is a functional stimulus and does not disturb bony healing in relation to the implant.

Several tests have been developed to measure implant stability and displacement, including radiographic assessment,[8] resonance frequency analysis,[9,10] Periotest,[11,12] and the insertion torque method.[13] Radiographic assessment is difficult to standardize and not sufficient to enable an evaluation on a short-term basis.[1] Both the Periotest and the resonance frequency analysis provide no direct measurement of an implant in vivo in relation to the surrounding bone. Periotest values (PTVs) may be affected by the position and length of the implant and by bone quality.[14] The observed mean PTV for implants subjected to an immediate nonfunctional load at 8 weeks was −2.4 (−4 to +1).[15]

Another method routinely used is to define primary stability by measurement of the insertion torque by screwing in the implant.[16] A value for insertion torque of the implants of >35 Ncm enables the most successful implants.[17]

A study of displacement during application of lateral forces in dental implants was conducted by Engelke and colleagues.[18] Displacement of the implant was measured using contact endoscopy. Loading different types of bone with forces between 5 and 30 N produced displacements in the range from 39.2 to 156.6 μm. According to Engelke and colleagues,[18] contact endoscopy in combination with the support immersion technique could be a valuable tool for verifying implant stability under functional loading during surgery. It was observed that trabecular bone, in particular, was the most critical bone type for providing primary implant stability. Therefore, this study was performed using the method referred to, and focused on the following features: relation of implant length and ability to resist lateral force application, considering also the factor of insertion torque. The null hypothesis in the present study was that there would be no significant difference in terms of the micromovement of implants with two different lengths and at different lateral loads.

MATERIALS AND METHODS

The investigation was carried out on fresh bovine bone specimen cubes measuring 2 cm × 2 cm × 2 cm, fulfilling the criteria for the Lekholm and Zarb category IV. The type of the bone was determined using cone beam tomography. All specimens exhibited bone densities between 150 and 400 HU. One hundred Semados implants (Bego, Bremen, Germany), with a diameter of 3.75 mm, were inserted; 50 implants had a length of 8.5 mm and 50 implants had a length of 15 mm. They were placed in accordance with the manufacturer's instructions using 2.5, 2.8, and 3.25 mm twist drills.

The insertion of the implants was performed using a ratchet with a reading accuracy of 2 Ncm and a torque display indicating 10, 20, and 30 Ncm (Bego), to register the maximum torque necessary to place the implant at bone level. Implants were provided with a 4 mm × 8 mm measuring indicator strip (dental film, Kodak, Buenos Aires, Argentina). The indicator strip was fixed between the implant and the prosthetic abutment (Bego) by tightening the abutment screw. To assess displacement, horizontal forces of 10, 20, and 30 N were applied with a tension spring balance (reading accuracy: 1 N; PCE, Regeltechnik, Meschede, Germany) to the upper third of the abutment for 2 seconds, to simulate a load applied by the patient. In total, 300 measurements were obtained. Implants were loaded irrespective of any observable movement and these were classified as being nonstable once complete loosening was observed. A tungsten wire with a diameter of 600 μm was placed as a reference at a distance of <500 μm from the end of the indicator strip (Figure 1). The movement of the indicator strip relative to the reference was registered using the micro-endoscope 7215 BA (Karl Storz, Tuttlingen, Germany), with a range of magnification from 70× to 150×, depending on the distance to the object. Images were digitalized with the software Pinnacle Systems (Avid Technology, Munich, Germany), and displacement was determined with an accuracy of 10 μm at 70× magnification. Displacement was defined as the difference of the distance between the indicator strip and the reference wire before and during loading (Figure 2), and was measured by the software Image Pro Plus v.1.1 (Media Cybernetics Inc., Bethesda, MD, USA).

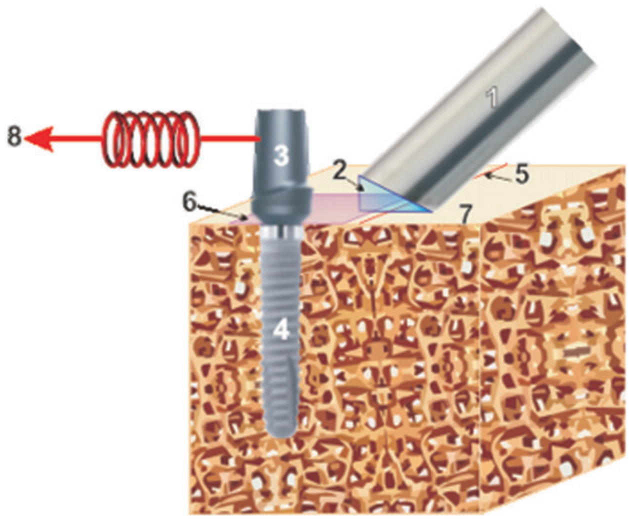

Figure 1 (1) Contact endoscope; (2) field of vision; (3) screw; (4) dental implant; (5) reference wire; (6) indicator strip; (7) sample of bone; (8) lateral load.

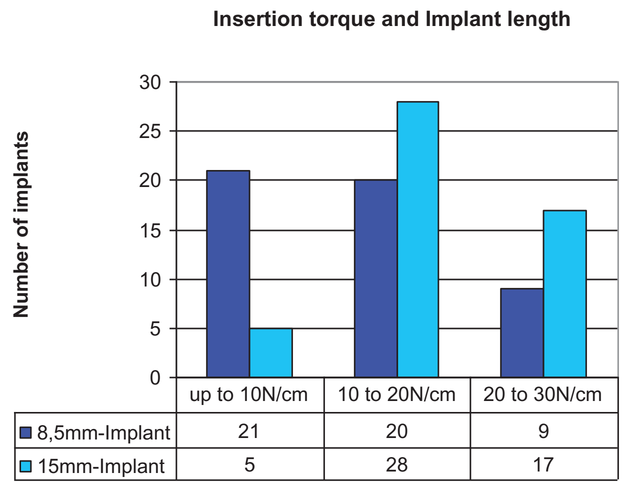

Figure 3 Frequency distribution of implants according to implant length and insertion torque.

Statistical Analysis

Displacements after the application of a force application for the distinct groups with 8.5- and 15-mm implant length, respectively, were compared using the Kruskal–Wallis test and the Mann–Whitney *U* test. Statistical analyses were carried out using the program R (R Foundation, Vienna, Austria), adopting an a-level of 5%.

RESULTS

All implants were placed with an insertion torque below 30 Ncm (Figure 3). During loading, seven implants with a length of 8.5 mm loosened completely: one implant during 20 N force application, and another six implants during 30 N force application showed insufficient capability to resist the lateral load applied. For those implants that resisted lateral loading, a mean displacement of 59 µm was observed ($n = 100$) after the application of 10 N. Application of 20 N resulted in a mean displacement of 173 µm ($n = 99$) and 30 N lateral force application resulted in a mean displacement of 211 µm ($n = 93$).

Increasing lateral force produced greater displacement. The differences observed were significant (Kruskal–Wallis test, $p < .0001$) Comparing implants of 8.5- and 15-mm length, the displacement of 8.5-mm implants was significantly higher for every load condition (Mann–Whitney *U* test, $p < .0001$) The mean values for 8.5-mm implants showed values of critical displacement above 100 µm when loaded with 10 N laterally. All mean values for 15-mm implants did not exceed the 100-µm threshold under the 10 to 30 N loading condition (Table 1).

DISCUSSION

A terminal insertion torque value of approximately 30 Ncm is considered to be a threshold for indicating

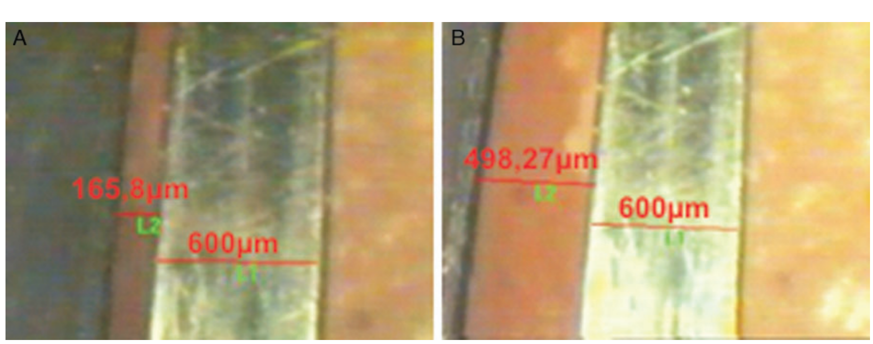

Figure 2 (A) The reference strip before applying the load; and (B) during application of the load.

TABLE 1 Mean Values and Standard Deviations of Displacement

	10 N			20 N			30 N		
	8.5 mm	15 mm	Total	8.5 mm	15 mm	Total	8.5 mm	15 mm	Total
N	50	50	100	49	50	99	43	50	93
$\bar{x}$ (μm)	103	16	59	311	37	173	396	51	211
SD (μm)	181	22	136	494	79	376	600	61	211

primary stability for immediate loading of implants.[19] Ottoni and colleagues[20] found that an insertion torque greater than 32 Ncm was necessary to achieve osseointegration of implants restored within a 24-hour period. In their study, insertion torque was associated with the potential for risk, which can be decreased by 20% for each 9.8 Ncm added. Degidi and colleagues,[21] Testori and colleagues,[22] and Neugebauer and colleagues[17] demonstrated success rates of over 97% when a torque greater than 25 Ncm was applied by using different loading protocols. Schincaglia and colleagues[23] concluded that an immediate loading of implants using fixed partial dentures in the posterior mandible may be considered as a treatment option, if implants are inserted with an insertion torque of >20 Ncm into non-augmented bone. Wentaschek and colleagues[16] reported a mean insertion torque of 37.5 Ncm for the lower jaw. These clinical studies indicate that an insertion torque greater than 30 Ncm should be recommended for achieving adequate primary stability of implants. No data have been obtained from clinical studies that correlate torque measurements with a resulting displacement under certain loading conditions. Our data show that the insertion torque in trabecular bone generally was below 30 Ncm and therefore should be considered as fundamentally critical when immediate loading of implants is planned. This is in agreement with Wentaschek and colleagues who concluded that a terminal insertion torque ≤11 Ncm is a relevant risk factor for implant failures when placed for prosthetic rehabilitation, even under unloaded conditions.[16]

In this study, seven implants of 8.5-mm length showed an absence of primary stability when loaded with 20 and 30 N. For 15-mm implants, a lack of primary stability was not observed. Insertion torque does not allow the direct measurement of displacement during the application of a load.

In the present study, we were able to observe that when the lateral force magnitude increased, the implant displacement was significantly higher. These results are consistent with the observation of Engelke and colleagues[18] in whose study displacement was found to vary with the force applied. A lateral force of 5 N resulted in a mean displacement of 39 μm. For 30 N, the mean displacement was 157 μm. Bone type also influenced the amount of movement.

Brunski[7] put forward the hypothesis that displacement over 100 μm must be avoided, as larger displacements interfere with the remodeling process of the interface observed during osseointegration. Direct measurement of micromovement may aid in the application of recommendations based on bone physiology in implant therapy, to avoid failures resulting from unknown or undetected factors of primary stability.

It is clinically difficult to determine the amount of force acting on an implant recently inserted. Generally, implants show a higher degree of resistance during vertical force application. Schwarz and Gerlach[24] and Haraldson and Carlsson[25] considered forces ranging from 25 to 50 N applied during daily food intake, whereas Wang and Stohler[26] determined the breakage force characteristics of foods of various consistency, measuring forces between 52 and of 104 N. Assuming only chewing forces for soft food of nearly 30 N, a mean displacement of 211 μm was measured in our study in trabecular bone with 8.5 mm implants. In this context, the decreased surface area of these implants in comparison with those with a length of 15 mm may be considered as a relevant factor. Therefore, loading conditions of 8.5-mm implants in trabecular bone do not provide sufficient stability before remodeling of the peri-implant interface. Kato and colleagues[27] reported that forces on the labial surface of an upper central incisor were 1.5 N during rest, 10.9 N during swallowing, and 5.0 N during speech. Horn and colleagues[28] observed lip mean pressures of up to 9.5 N. Consequently, 10 N loading conditions represent the magnitude of soft tissue forces acting on implant abutments. From our study, the conclusion can be drawn that soft tissue forces do not result in a critical displacement of implants in trabecular bone in the majority of implants placed; in particular, when long implants are applied.

CONCLUSIONS

- Displacement of screw implants in trabecular bone can be detected and visualized using commercially available endoscopes with high magnification.
- Lateral load of 20 N implies a mean displacement of >100 μm and therefore represents a critical displacement.
- Reduced implant length in trabecular bone is associated with an increased number of implant failures during lateral load.

DISCLOSURE

The authors have no financial interest in any company or any of the products mentioned in this article.

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