CLINICAL ORAL IMPLANTS RESEARCH

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The effect of implant design on insertion torque and immediate micromotion

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Abstract

Objectives: To evaluate the effect of insertion torque on micromotion to a lateral force in three different implant designs.

Material and methods: Thirty-six implants with identical thread design, but different cutting groove design were divided in three groups: (1) non-fluted (no cutting groove, solid screw-form); (2) fluted (90° cut at the apex, tap design); and (3) Blossom™ (Patent pending) (non-fluted with engineered trimmed thread design). The implants were screwed into polyurethane foam blocks and the insertion torque was recorded after each turn of 90° by a digital torque gauge. Controlled lateral loads of 10 N followed by increments of 5 up to 100 N were sequentially applied by a digital force gauge on a titanium abutment. Statistical comparison was performed with two-way mixed model ANOVA that evaluated implant design group, linear effects of turns and displacement loads, and their interaction.

Results: While insertion torque increased as a function of number of turns for each design, the slope and final values increased ($P < 0.001$) progressively from the Blossom™ to the fluted to the non-fluted design (M ± standard deviation [SD] = 64.1 ± 26.8, 139.4 ± 17.2, and 205.23 ± 24.3 Ncm, respectively). While a linear relationship between horizontal displacement and lateral force was observed for each design, the slope and maximal displacement increased ($P < 0.001$) progressively from the Blossom™ to the fluted to the non-fluted design (M ± SD = 530 ± 57.7, 585.9 ± 82.4, and 782.33 ± 269.4 μm, respectively). There was negligible to moderate levels of association between insertion torque and lateral displacement in the Blossom™, fluted and non-fluted design groups, respectively.

Conclusion: Insertion torque was reduced in implant macrodesigns that incorporated cutting edges, and lesser insertion torque was generally associated with decreased micromovement. However, insertion torque and micromotion were unrelated within implant designs, particularly for those designs showing the least insertion torque.

The use of dental implants to replace missing teeth has become a safe treatment modality over the last four decades (Chuang et al. 2001). Despite the predictability of the conventional protocol involving two surgical stages established by Branemark and colleagues (Branemark et al. 1969; Branemark et al. 1977), the quest for decreased treatment time frames between device placement and its subsequent functional loading has fostered implant engineering design modifications at the macro, micro, and nanometer levels (Coelho et al. 2009). Of special interest is the challenge of immediate/early functional loading of single implant crowns that, unlike multiple units, lack mutual or cross-arch stabilization (Schnitman et al. 1997; Atieh et al. 2009), resulting in decreased primary stability that is strongly influenced by the combination of implant design, loading conditions, surgical technique, and bone density and quality (Javed & Romanos 2010).

An appreciation of the range of initial implant–bone movement that results in bone or fibrous tissue formation around implants has gained special attention in porous-surfaced orthopedic implants in the 1970s due to the need to establish patient rehabilitation schedules (Cameron et al. 1972, 1973). *In vivo* animal studies were able to demonstrate that a range of movement up to 28 μm would result in bone fixation to Co–Cr–Mo alloy implants, whereas movement of 150 μm or more would result in fibrous connective tissue formation (Pilliar et al. 1986). Later animal studies involving the use of Ti–6Al–4V porous -surfaced implants showed that micromovements of 40 μm or less are compatible with complete or partial ingrowth of bone, whereas in the magnitude of 150 μm prevent

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osseous stability (Jasty et al. 1997). Specific to the use of titanium in implant dentistry, comprehensive reviews of *in vivo* studies have suggested that micromotion at the bone–implant interface in the range of 50–150 μm may negatively influence osseointegration and bone remodeling at the interface (Szmukler-Moncler et al. 1998; Szmukler-Moncler et al. 2000). Therefore, implant designs that provide optimized implant placement, stress distribution, and lower degrees of micromotion, thus improving the conditions for bone formation under immediate and early loading conditions, have been regarded as one crucial step in the rehabilitation process (Abuhussein et al. 2010).

The clinical perception of implant stability is commonly related to rotational resistance (insertion torque) during implant placement (Friberg et al. 1999). Considering that implant stability is influenced by the interplay between implant design and the surrounding bone, it has been suggested that high peak insertion torque is desirable for improved implant integration (O'Sullivan et al. 2000; Ottoni et al. 2005; Trisi et al. 2009), since several studies had suggested that insertion torque values in the range of 25–45 Ncm prevent adverse micromovements under loading above 100 μm.

Although high-insertion torque has been positively correlated with implant primary stability (Kahraman et al. 2009; Trisi et al. 2009), it has been pointed out that such correlation may not hold true for all implant designs and associated surgical drilling techniques (Akkocaoglu et al. 2005; Akkocaoglu et al. 2007; Akca et al. 2010). While changing design parameters are insightful from a purely engineering standpoint, it must be considered that bone is a dynamic tissue which will respond to surgical procedure stimulation and/or the interaction between the implant macrogeometry and its associated drilling dimensions (Coelho et al. 2010). Thus, while reduced micromotion under loading is desirable, low degrees of bone stress are also desirable since a lower amount of remodeling would be necessary during osseointegration, potentially resulting in slight decreases in implant stability over time.

Therefore, this study evaluated the influence of different implant macrodesigns in the insertion torque and the induction of micromotion under a lateral force. The null hypothesis that the higher the insertion torque the lower micromovement between designs was tested.

Materials and methods

A total of 36 Ti–6Al–4V implants with internal connection (Intra-Lock International, Boca Raton, FL, USA), 4 mm in diameter and 13 mm in length and with three different macrodesigns were evaluated. The thread design was identical for the three implants, with the difference residing in the cutting groove design. Groups were as follows: (1) non-fluted (no cutting groove, full screw); (2) fluted (90° cut at the apex, classic tap design); and (3) Blossom™ (Patent pending) (Fig. 1).

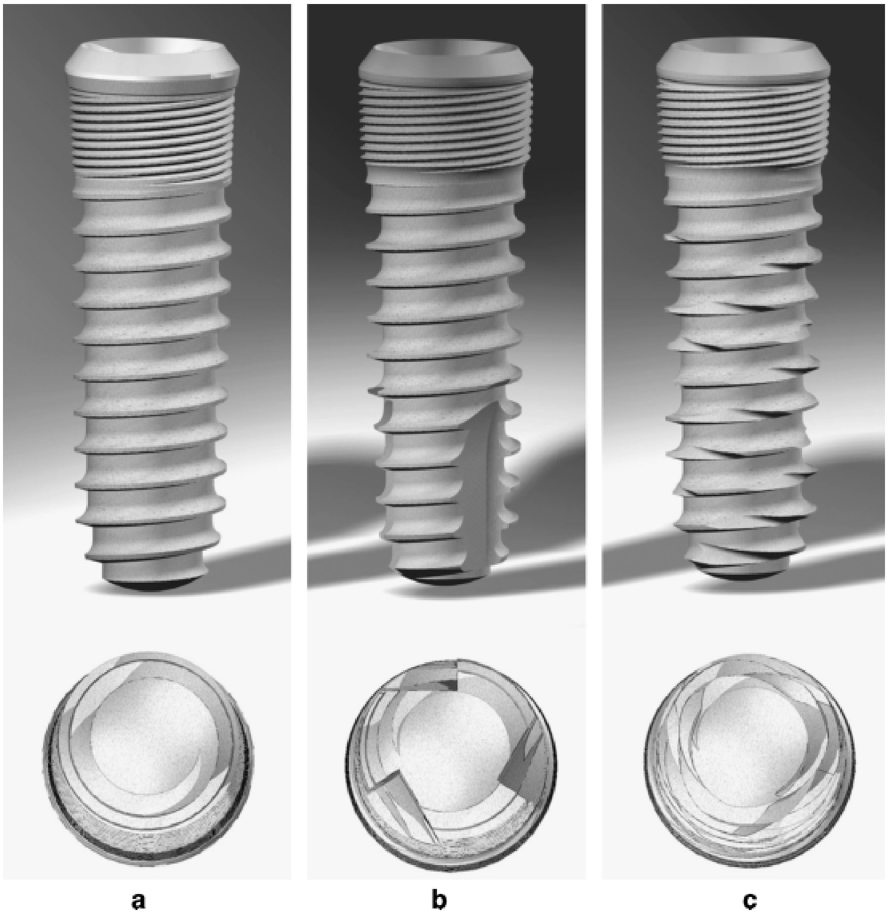

Fig 1. Lateral and bottom views of the implants used in the micromotion analysis and torque determination: (a) non-fluted implant; (b) fluted implant; (c) Blossom™ implant.

Six rigid polyurethane (PU) foam blocks (Sawbones, Pacific Research Laboratories, Vashon, WA, USA) in the dimensions of 5 × 5 × 4 cm were used (Battula et al. 2006; Bardyn et al. 2009) to simulate type II bone according to the classification proposed by Lekholm and Zarb (Lekholm 1985). The PU foam blocks were drilled according to the manufacturer's recommendation (pilot drill, 2.5 mm drill, 3.2 mm drill, and 3.5 mm drilling sequence), and the implants were placed in the PU foam blocks utilizing a digital torque gauge (Tohnichi BTGE 10CN, Tohnichi Torque, Northbrook, IL, USA). Insertion torque was recorded after each turn of 90° of the implant into the blocks. In order to test the effect of macrothread configuration, the implants were inserted into the PU block to the base of the microthreads (since the thread pitch was the same for all thread designs, the number of turns resulted in the same vertical displacement for all configurations).

Following placement into the PU foam block, each implant received a two-piece fixed straight titanium abutment (Intra-Lock International, Boca Raton, FL, USA) for mechanical loading application. The abutment was then screwed into the implant internal connection under a 30 Ncm torque (measured by the digital torque gauge). The PU foam blocks were then fixed on a customized loading apparatus for evaluation of micromotion under controlled lateral loading (Fig. 2). A customized loading device, consisting of a digital micrometer (Mitutoyo Absolute Digimatic, Mitutoyo America Corporation, Aurora, IL, USA) and a digital force gauge (Chatillon E-DFE-025, Chatillon Force Measurement Systems, Largo, FL, USA) (range of 10–2500 N 0.25% resolution over range) was used to determine implant micromotion (Fig. 3). The forces were achieved by turning a dial, which controlled the height of the force gauge. This dialed-in force was applied to the abutment via a lever. The digital micrometer was placed tangent to the crown of the abutment and detected the displacement after the load application (Fig. 3).

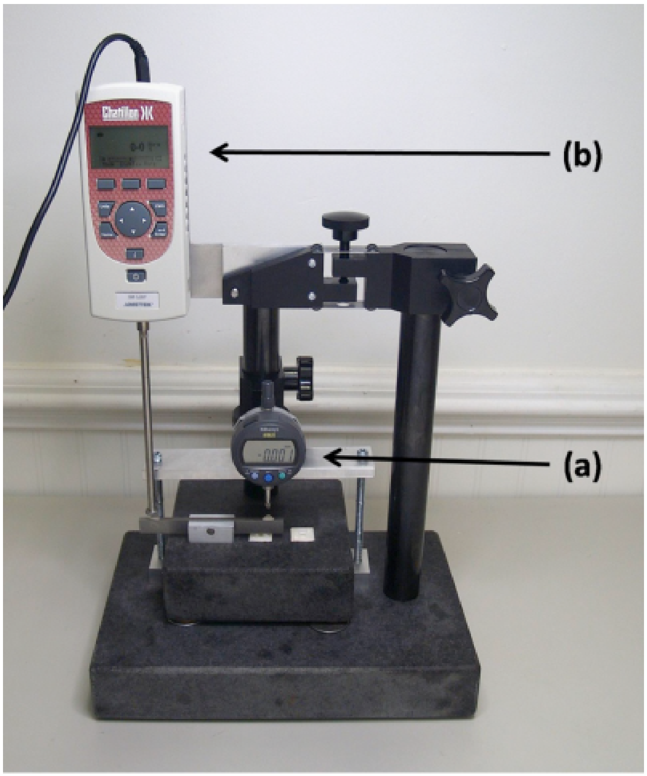

Fig 2. Image of the micromotion-test apparatus: Mitutoyo Digital Micrometer (a) used to measure the horizontal displacement of the abutment during loading application by the Chatillon Digital Force Gauge (b).

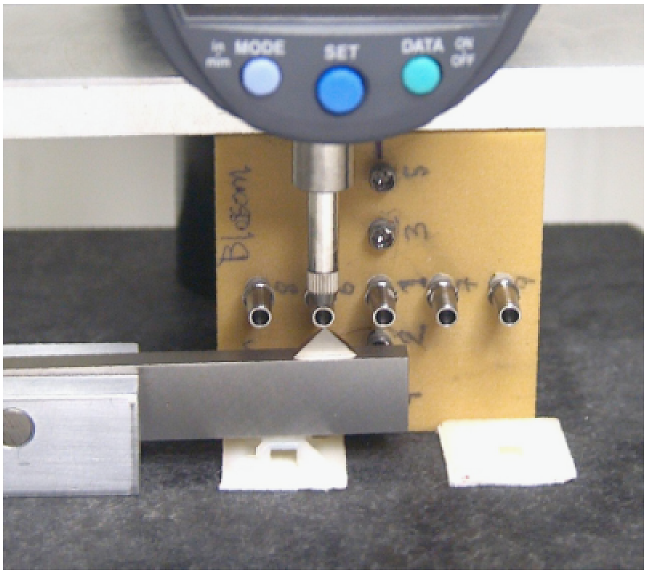

Fig 3. PU foam block with the implant/abutment set located between the Chatillon Digital Force Gauge and Mitutoyo Digital Micrometer.

For each implant, loads starting at 10 N were measured in increments of 5–100 N.

The mean and standard deviation (SD) of the torque measure was computed as a function of number of turns and implant thread design. Statistical comparison was performed with two-way mixed model ANOVA that evaluated implant design group, linear effects of turns, and their interaction. While the interpretation of the mixed model is conceptually similar to a completely randomized design, repeated measures over the turns factor requires this adjustment for dependent observations. To the extent that there is important variance attributable to these dependencies, this analysis also provides a more precise estimate of residual error. A similar analytic strategy was pursued for the displacement measure, as a function of implant design group, linear effect of load, and their interaction. Finally, Pearson correlation coefficients were computed to estimate the degree of association between insertion torque and subsequent micromotion, both within and across implant designs. We report obtained probabilities of a type 1 error for each test.

Results

The mean (± SD) insertion torque values are presented in Fig. 4 as a function of the number of turns and implant design group. The figure shows that the increase in insertion torque with additional turns increased most slowly in the Blossom™ implants, which also required the least final insertion torque. The fluted design showed an intermediate rate of increase and final value, and the non-fluted design showed the fastest rate of increase and highest final value. The insertion torque ranged from 2.1 to 64.1 N/cm for Blossom™ implants, 8.3 to 139.36 N/cm for fluted implants, and 9.6 to 205.2 N/cm for non-fluted implants. The mixed model ANOVA showed a significant linear effect of turns ($F[1,285] = 4654.3$, $P < .001$), as well as an interaction of linear slope by implant design group ($F[2,285] = 430.8$, $P < 0.001$), but no indication of implant design group main effect ($F[2,53] = 1.5$ $P = 0.23$). A one-way completely randomized analysis of the torque after the final turn also showed increased levels from Blossom™ to fluted to non-fluted designs ($F[2,33] = 111.8$, $P < 0.001$), and the grouping factor accounted for 87.1% of the total variance (Levene's test indicated homogeneous variances ($F[2,33] = 0.9$, $P = 0.43$ and data did not show significant departures from normality), Thus, not only did torque increase with turns in general, but the acceleration in that effect was greater for the fluted design than the Blossom™ design, and greater for the non-fluted than the fluted design.

The mean (± SD) micromotion values (horizontal displacement) are shown in Fig. 5 as a function of the different implant designs over the range of applied lateral forces. The figure shows that the increase in deflection with additional force increased most slowly in the Blossom™ implants, which also showed the least deflection at the maximal force. The fluted design showed an intermediate rate of increase and final value, and the non-fluted design showed the fastest rate of increase and highest final value. The average horizontal displacement ranged from 28 to 530 μm for Blossom™ implants, from 25 to 585.9 μm for fluted implants, and from 42.6 to 782.3 μm for non-fluted implants. The mixed model ANOVA showed a significant linear effect of force ($F[1,645] = 7711.7$, $P < 0.001$), as well as

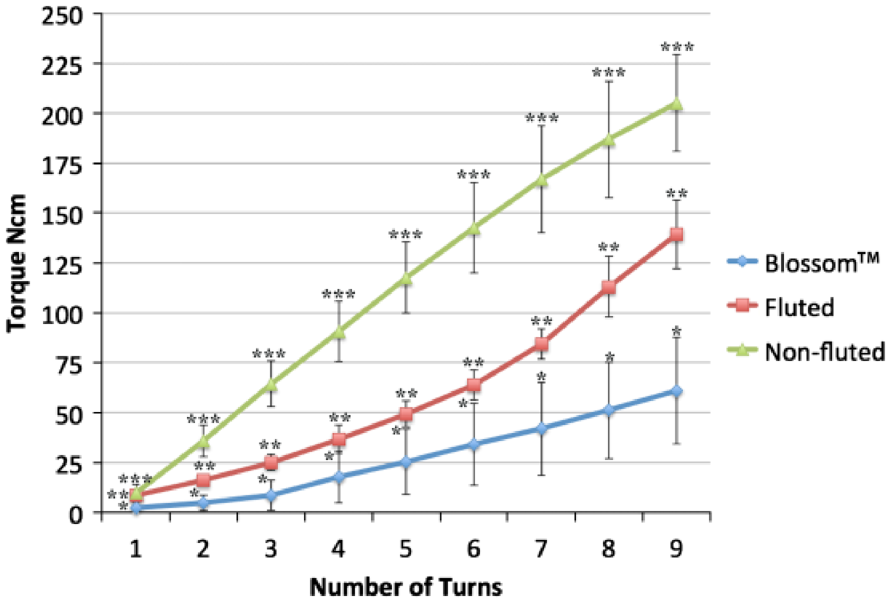

Fig 4. Insertion torque mean ± standard deviation for the different macrodesigns tested. One-way ANOVA revealed significant differences between groups ($P<0.001$). Note that with the exception of the first turn, where non-significant differences were observed between the fluted and non-fluted designs, significant differences were observed from the second to the ninth turn between all groups. The number of asterisks depicts statistically homogeneous groups for each number of turns.

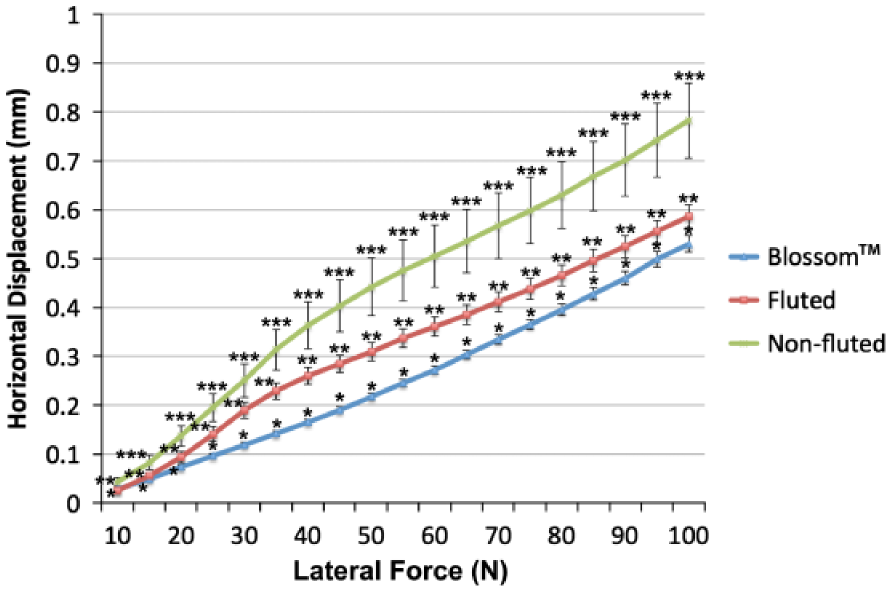

Fig 5. Horizontal displacement mean ± standard deviation for the different macrodesigns tested. One-way ANOVA revealed significant differences between groups ($P<0.001$). Note that with the exception of 10 and 15 N, where non-significant differences were observed, a significantly higher displacement was noted for the non-fluted design relative to Blossom™ and fluted designs, significant differences were observed from 20 to 100 N between all groups. The number of asterisks depicts statistically homogeneous groups for each lateral force applied.

an interaction of linear slope by implant design group ($F[2,645]=98.4$, $P<0.001$), but no indication of implant design group main effect ($F[2,33]=0.7$, $P=0.49$). While Levene's test indicated heterogeneous variances ($F[2,33]=17.0$, $P<0.001$), the result of three extreme values in the non-fluted group, omitting these outliers, which homogenized the variances, did not alter the results. A one-way completely randomized analysis of the deflection to the greatest force also showed increased levels from the Blossom™ to fluted to non-fluted designs ($F[2,33]=7{,}6$, $P=0.002$), and the grouping factor accounted for 31.7% of the total variance. Thus, not only did deflection increase with force in general, but the acceleration in that effect was greater for the fluted design than the Blossom™ design, and greater for the non-fluted than the fluted design.

These data show that the non-fluted implant design required the largest insertion torque and also deflected the most. In contrast the Blossom™ design required the least insertion torque and deflected the least. This suggests, indirectly, that insertion torque was associated with micromotion. As a direct test, Pearson's correlation coefficients were computed between final torque (turn 9) values and deflection to the largest lateral force (100 N) (data plot presented in Fig. 6). Collapsing over groups, $r=0.57$ ($P<0.001$), suggesting a moderately strong relationship between insertion torque and deflection. However, when these associations were computed separately for Blossom™, fluted and non-fluted groups, these correlations were −0.27, 0.04, and 0.43, respectively, all presenting $P>0.15$, indicating no relationship between torque and micromotion within any screw type. The scatter plot in Fig. 6 shows that over the range of insertion torques described by all samples, there is increasing motion with increasing torque, but little association within each group. As well, while the three outlying values (>100 um) positively bias the correlation, it remains $r=0.46$ ($P=0.007$) if they are removed, leaving unchanged the basic conclusion of a direct relationship between insertion torque and micromotion. Because all of the lowest insertion torque values occur in the Blossom™ group and all of the highest in the non-fluted group, however, this confounding between implant design group and insertion torque limits separate conclusions regarding those effects. Thus, while it is generally true that increased insertion torque is associated with increased micromotion, we cannot know, for example, the specific effect of low insertion torque in the Blossom™ group or high insertion torque in the non-fluted group.

Discussion

The primary stability of implants and its related clinical implication has traditionally been very difficult to assess since it is not only dependent on insertion torque and host bone density but also on implant geometry and surface characteristics. Over the last 5 years, the biomechanical aspects of implant primary stability has been studied by different methodologies such as resonance frequency analysis, implant stability quotient, histologic measurements, contact endoscopy, insertion torque, and removal torque. (Gotfredsen et al. 1995; Niimi et al. 1997; Cochran et al. 1998; O'Sullivan et al. 2000; da Cunha et al. 2004; Engelke et al. 2004; Ottoni et al. 2005; Akkocaoglu et al. 2007; Trisi et al. 2009; Turkyilmaz et al. 2009) However, while the ever increasing number of published work in this topic has shed light in different aspects of implant and prosthetic connection design and

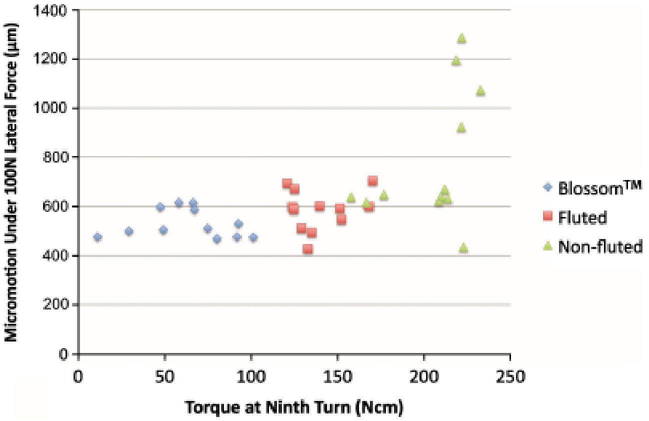

Fig 6. Scatterplot of torque at the ninth turn vs. micromotion at 100 N showing that all of the lowest insertion torque values occur in the Blossom™ group and all of the highest in the non-fluted group. While in general increased insertion torque is associated with increased micromotion, when the different implant designs are evaluated separately, the correlation between micromotion and torque was not significant.

primary stability, the complexity of the possible multivariable interaction including different implant designs, prosthetic connections, and timetables for the initiation of implant function unfortunately does not yet provide an informed platform for implant/prosthetic system design rationale.

Thus, based on the fact that one of the relevant factors that impact primary stability pertains to implant macrogeometry (Trisi et al. 2009), the present study was undertaken under the null hypothesis that the higher the insertion torque the lower the micromovement between designs. Since variations in thread pitch would result in substantial deviations in implant mechanical behavior during insertion, the present study utilized three different implant macrogeometries that presented an identical thread design but with different cutting groove designs.

Considering that all the implants evaluated in the present study have the same dimensions and the same thread pitch, the same number of turns was necessary for the implant placement into the PU block up to the base of the microthread. As expected, regardless of the implant design tested, the higher the number of turns during implant placement, the higher the vertical displacement into the PU foam block and the measured torque degree.

The results from the present study showed that the presence of the cutting edge significantly affected insertion torque values where both fluted and Blossom™ designs showed significantly lower insertion torque values relative to the non-fluted implants (no cutting edge). When implant micromotion was measured as a function of applied force, the same trend was observed while the non-fluted implant group presented significantly higher horizontal displacement relative to other groups, and the Blossom™ design presented significantly lower values compared with the fluted one.

Altogether, the results obtained in the present study showed that variation in the cutting edge in implants design presenting identical thread configuration significantly influenced both insertion torque peak and the subsequent implant/bone system ability to withstand displacement. It would consequently suggest that Blossom™ designed implant would induce lower bone stress, without loosening stability, potentially avoiding bone resorption, and consequently decreasing the likelihood of implant failure. Our results point toward an inverse relationship between insertion torque and immediate micromotion in contrast to a previous study which correlated high insertion torque with lower micromotion levels (Trisi et al. 2009). Nevertheless it should be noted that the independent variable in the previous investigation concerned bone density (Trisi et al. 2009) and not intrinsic implant design feature as the present study.

Previous studies (O'Sullivan et al. 2000; Turkyilmaz et al. 2009) have suggested that the quality and quantity of the host bone can be associated with the success of dental surgery, and thus several studies used samples of fresh animal bone (Engelke et al. 2004; Trisi et al. 2009) or samples of human cadaver bone. (Turkyilmaz et al. 2009) In the present study, the test was performed in PU foam blocks with a consistent and uniform material presenting physical properties in the range of human trabecular bone (Bardyn et al. 2009; Tabassum et al. 2010). When a test block with uniform properties is utilized to evaluate variations in biomechanical behavior due to implant design it does eliminate the variability encountered when testing with animal or human cadaver bone, allowing a clear scenario for an informed design rationale for future implant systems (Annual Book of ASTM Standards 2003; Battula et al. 2006). Nonetheless, it should be pointed that the case- and host-specific variation does require that controlled clinical trials are undertaken in varied treatment protocols to determine whether such design alterations and decrease in insertion torque and decrease in micromotion immediately after placement are advantageous in clinical practice (Turkyilmaz et al. 2009). Since it is general consensus (although not yet fully experimentally validated) that increased primary stability would improve implant integration, further studies concerning alterations in implant design are warranted.

Conclusion

Insertion torque was reduced in implant macrodesigns that incorporated cutting edges, and lesser insertion torque was generally associated with decreased micromovement. However, insertion torque and micromotion were unrelated within implant designs, particularly for those designs showing the least insertion torque.

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