*European Journal of Orthodontics* 31 (2009) 232–240
*doi:10.1093/ejo/cjn091*
*Advance Access publication10 December 2008*



# The effect of force, timing, and location on bone-to-implant contact of miniscrew implants

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SUMMARY This study was conducted to evaluate the effect of timing and force of loading, as well as implant location, on bone-to-implant contact (BIC) of loaded and control miniscrew implants (MSI). Using seven skeletally mature male beagle dogs, 1–2 years of age, followed over a 110 day period, a randomized split-mouth design compared immediate versus delayed loading, 50 versus 25 g loading, and 25 g loads in the maxilla versus the mandible. Mobility was evaluated using a 0–3 point scale before the MSIs were prepared for histological analysis. Histomorphometric analyses were performed under light microscopy using Metamorph® software on undecalcified sections. The percentage BIC was measured at three levels (coronal, middle, and apical) of the MSI. BIC was compared statistically using pairwise Wilcoxon signed-rank tests.

Mobility was detected in three of the 56 (5.4 per cent) MSIs. The mobile implants were all unloaded controls and showed no BIC. All remaining stable MSIs showed some BIC. However, variation in BIC was large, ranging from 2.2 to 100 per cent. There were no significant ($P > 0.05$) differences in BIC associated with timing of force application, amount of force applied, or implant location. There was a tendency for less BIC at the coronal level, but the differences between levels were not statistically significant. Within the limits of this study, it is concluded that the timing and amount of force at loading and location of implant placement do not affect BIC. Moreover, it appears that only limited amounts of osseointegration are necessary to ensure implant stability.

## Introduction

Since their introduction as an endosseous form of orthodontic anchorage (Turley *et al.*, 1988; Roberts *et al.*, 1989), miniscrew implants (MSIs) have gained rapid and wide acceptance due to their versatility, ease of placement and removal, and reasonable costs. While case reports pertaining to MSIs are numerous (Kanomi, 1997, Costa *et al.*, 1998; Lee *et al.*, 2001; Nojima *et al.*, 2001; Park *et al.*, 2001, 2002; Bae *et al.*, 2002; Chung *et al.*, 2002; Paik *et al.*, 2002; Kyung *et al.*, 2003), experimental studies evaluating the response of the surrounding bone after placement and during the use of MSIs are lacking.

In contrast to MSIs, the response of bone to traditional implants has been well established. Much of the original work was performed by Brånemark, who defined osseointegration as the 'direct—on the light microscopic level—contact between living bone and implant' (Brånemark *et al.*, 1969). Since then, it has been shown that the surface characteristics of traditional endosseous implants can be modified to substantially enhance bone-to-implant contact (BIC). Brånemark (1983) originally recommended that implants placed in bone should be left unloaded for a period of 4–6 months. In contrast, some recent case reports (Salama *et al.*, 1995; Tarnow *et al.*, 1997; Malo *et al.*, 2003a,b; Rocci *et al.*, 2003b) and histological studies (Degidi *et al.*, 2002; Romanos *et al.*, 2002; Rocci *et al.*, 2003a; Siar *et al.*, 2003) have reported success with immediate loads on dental implants when factors such as primary stability and splinting between implants are considered. Romanos *et al.* (2003) found no difference in BIC between immediately (64.25 per cent) and delayed (67.93 per cent) loaded dental implants. It has also been established that bone response is dependent on the direction, magnitude, and repetition rate of the loading force (Sammarco *et al.*, 1971; Lanyon and Rubin, 1984; Frost, 1990; Rubin *et al.*, 1990). Interestingly, studies comparing dental implants placed in hyperocclusion and used with orthodontic forces (1–3 N) have shown no statistical differences in BIC or osseointegration between loaded versus unloaded implants or between the pressure and non-pressure side (De Pauw *et al.*, 2002; Heitz-Mayfield *et al.*, 2004). The importance of initial bone quality has also been shown to be important for successful implant placement (Piattelli *et al.*, 1993, 1998; Romanos *et al.*, 2001). Several clinical trials have reported no difference in the success rates between immediately loaded dental implants placed in the maxilla and mandible (Levine *et al.*, 1998; Horiuchi *et al.*, 2000; Buchs *et al.*, 2001).

Traditional implants and MSIs differ in many important respects (e.g. size, shape, and surface characteristics), hence the response of the surrounding bone should be different. Due to differences in the amount of force applied to traditional implants versus MSIs, the amount of bone required for orthodontic applications might also be expected to be different. Moreover, MSIs must be able to be easily removed, which implies only limited amounts of integration (Melsen and Verna, 2000). Even though the direct relationship between BIC and force in MSIs has not been established, the stability of MSIs does not appear to be related to force (Carrillo *et al.*, 2007; Owens *et al.*, 2007).

There have been few experimental studies conducted evaluating the BIC of MSIs. Melsen and Costa (2000) placed 16 vanadium screws (two in the infrazygomatic crest and two in the mandibular symphysis) in four adult monkeys and loaded them immediately with either 25 or 50 g. The screws were followed for 1, 2, 4, and 6 months and evaluated histologically for osseointegration. Two of the screws (both in the mandible) were lost immediately, and at the time of sacrifice, 12 (75 per cent) screws showed osseointegration. The osseointegration ranged from 21.8 ± 24.4 to 59.7± 47.5 per cent. A recent study by Buchter *et al.* (2006) placed 200 MSI in the mandibles of eight Göttingen minipigs. True implants were loaded with forces ranging from 100 to 500 cN. Only five of the implants showed loosening. Histological analysis confirmed that the MSIs were well osseointegrated with BIC ranging from a low of 50.1±14.7 per cent at 22 days to a high of 82.5±12.6 per cent at 70 days. Variability in the designs and outcome of experimental studies make it necessary to perform more detailed research to understand the osseointegration of MSIs, especially for those placed adjacent to teeth and loaded with orthodontic forces.

The purpose of this split-mouth, randomized, design was to determine differences in BIC of MSIs subjected to (1) immediate versus delayed loads, (2) 50 versus 25 g loading, and (3) 25 g loads in the maxilla versus the mandible.

## Materials and methods

The Institutional Animal Care and Use Committee at Baylor College of Dentistry (Dallas, Texas, USA) approved the housing and care of animals and the experimental protocols.

### *Animals*

Seven skeletally mature male beagle dogs 1–2 years of age and weighing 10–15 kg were used for this study. The beagle dog was selected because it is an established model for investigating the amount of force required to move the teeth (Pilon *et al.*, 1996; van Leeuwen *et al.*, 1999, 2003; Ohmae *et al.*, 2001; Nakamoto *et al.*, 2002; Daimaruya *et al.*, 2003; Von Bohl *et al.*, 2004a,b). Furthermore, the alveolar bone of the beagle dogs resembles that of humans (Bartley *et al.*, 1970).

### *Materials and appliances*

The MSIs used for this experiment (IMTEC Corporation, Ardmore, Oklahoma, USA) were 6 mm long and 1.8 mm in diameter. To prevent contact with the lingual cortical plate, the length of the MSI used was based on measurements of mandibular intercortical width taken on the dried skull of a beagle dog. Fabrication of the crowns and orthodontic appliances used has been previously described (Owens *et al.*, 2007).

A total of eight MSIs (four randomly assigned experimental and four unloaded controls) were placed in each animal (Figure 1). One loaded experimental and one unloaded control MSI were placed in each quadrant. The effect of delayed (26 days) versus immediate loading was tested in the maxilla using a constant force of 25 g. In the mandible, the effects of two different forces were tested (25 versus 50 g), with immediate loading of the respective experimental MSIs. Because MSIs in both jaws were immediately loaded with a 25 g force, the maxilla and mandible were also compared.

All experimental and control MSIs were placed in buccal alveolar bone. The experimental MSIs were placed anterior to the fourth premolar and perpendicular to the cortical plate or parallel to the occlusal plane in interradicular bone at the level of the mucogingival junction. Unloaded controls were placed 4 mm apical to their respective MSI, on the same day the experimental MSIs were placed. Each of the MSIs was placed using a 1.1 mm pilot drill to perforate the buccal cortex. The surgical procedures and evaluation of MSIs *in situ* have been previously described (Owens *et al.*, 2007).

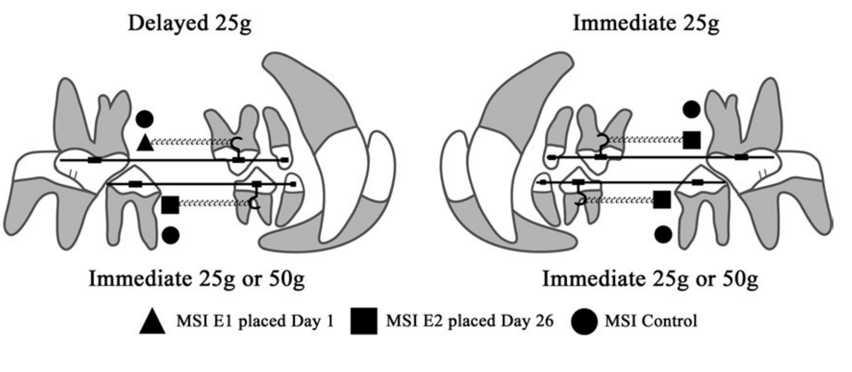


**Figure 1** Experimental design. Drawing illustrating experimental miniscrew implants (E1 and E2) with corresponding controls. In the maxilla, the effect of timing of force application was tested. In the mandible, the effect of force level (25 versus 50 g) on immediate loading was evaluated after random allocation.

The animals were killed with sodium pentobarbital (100 mg/kg/iv) and perfused with 1 litre of isotonic saline followed by 1 litre of 70 per cent ethanol. The maxillae and mandibles were resected *en bloc* and stored in 70 per cent ethanol prior to sectioning for histological examination. Each hemijaw was cut to include both the experimental and control MSIs. The sections were labelled using three colours of dye to code for orientation (pressure side versus non-pressure side) and implant type (experimental versus control).

The bone samples were dehydrated using an ascending series of ethanol, as described by Maniatopoulos *et al.* (1986). The samples were embedded in methyl methacrylate and sectioned on a Buehler Isomet Saw (Buehler Ltd., Irvine, California, USA) using a low-speed, low-deformation, saw with a diamond-wafering blade. The sections were cut in approximately 125 μm slices. The implant block was sectioned in a horizontal plane with six to eight sections per block.

The specimens were mounted on standard glass slides using a clear epoxy resin adhesive and ground to a thickness of 70 μm using silicon carbide paper (240, 320, 400, and 600 grit) under water lubrication. A final polish was accomplished using Buehler micropolishing solutions numbers 2 and 3. The specimens were then stained with Stevenel's blue with a Van Giesson picro-fuchsin counterstain (Maniatopoulos *et al.*, 1986). A Kodak Spot digital camera mounted on a Zeiss Axiophot microscope (Thornwood, New York, USA) was used to digitize each sample at ×2.5 magnification.

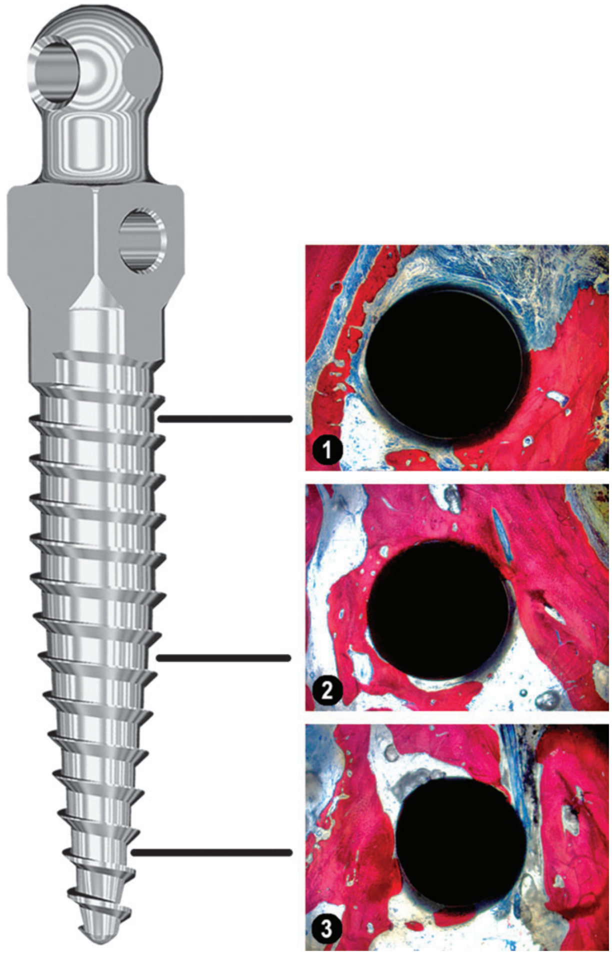

**Figure 2** Representative sections shown corresponding to the locations on the miniscrew implants (1, coronal; 2, middle; and 3, apical).

### *Analysis*

*Stability of MSI.* Stability of the MSI was determined by visual and gross physical assessment of implant mobility. This analysis was performed after the sample blocks had been cut for placement in sample bottles. Each MSI was evaluated for mobility using the handle end of an intraoral mirror. Mobility was defined and ranked using a periodontal scale for tooth mobility ranging from 0 to 3, with 0 indicating no mobility, 1 detectable mobility, 2 up to 1 mm of mobility, and 3 greater than 1 mm mobility (Fleszar *et al.*, 1980).

*Histological analysis.* Using the six to eight slices that were available for each MSI, the slices that most closely approximated the coronal, middle, and apical levels were evaluated. The anatomy and tapering diameter of the apical part of the MSI was used as a guide (Figure 2).

The samples were initially evaluated to determine if the mesial (pressure side) and the distal (tension side) needed to be evaluated separately. Photomicrographs of each sample were bisected from superior to inferior and each hemisection was evaluated subjectively on a scale from 0 to 3 (0 = no BIC, 1 = 1–50 per cent BIC, 2 = 51–99 per cent BIC, and 3 = 100 per cent BIC; Figure 3A).

Digitized images were saved as JPEG files and evaluated histomorphometrically using Metamorph® software (Universal Imaging Corp., Westchester, Pennsylvania, USA) to determine BIC. BIC was defined as bone or osteoid in actual contact with the implant surface at ×2.5 magnification. The circumference of the MSI was first traced and recorded and then the BIC was traced and recorded (Figure 3B). The percentage of BIC was calculated as total BIC divided by total circumference of MSI × 100. Percentage BIC was estimated at each of the three levels. Data are reported as averages ± maximum and minimum data points.

Due to the limited number of samples, BIC was compared using pairwise Wilcoxon signed-rank tests. All statistical analyses were calculated using the Statistical Package for Social Sciences version 10.0 (SPSS Inc., Chicago, Illinois, USA) with α set at 0.05.

## Results

### *Implant stability*

Of the 56 experimental and control MSIs, only three implants from three different animals demonstrated

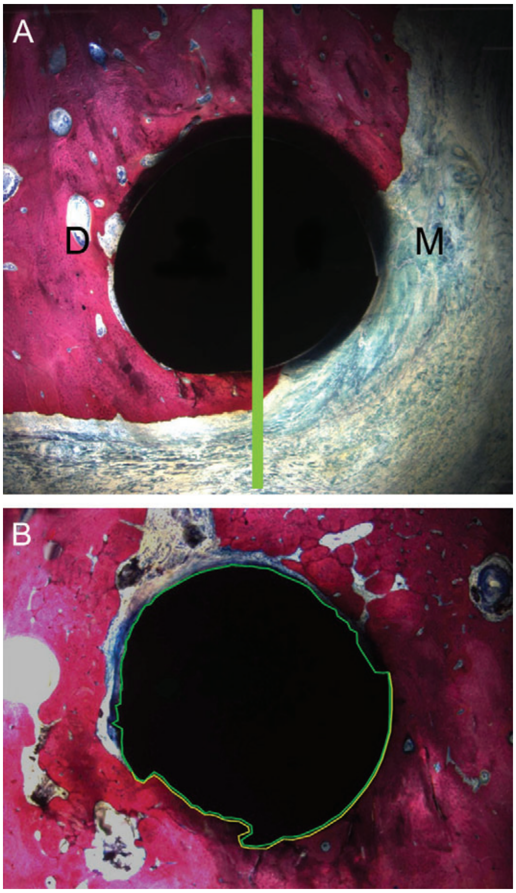


**Figure 3** (A) Photomicrographs of each section were bisected superior to inferior (green line) into mesial (M) and distal (D) regions and bone-to-implant contact (BIC) was evaluated in each region on a scale from 0 to 3. (B) Photomicrograph of representative section showing how the percentage BIC was calculated. The circumference of the miniscrew implants was first traced and recorded (green) and then BIC was traced and recorded (yellow).

mobility, and all three were unloaded control implants. The mobile implants were not confined to any particular quadrant or arch. A control MSI with a mobility of 2 was identified in a maxillary right quadrant (Figure 4A–C). Compared with its stable counterpart (Figure 4D–F) that had some BIC at all three levels, the mobile MSI showed no BIC at any of the three levels. Another control MSI with a mobility of 1 was identified in a mandibular left quadrant (Figure 4G–I); it also showed no BIC compared with its stable counterpart (Figure 4J–L). The third control MSI located in the mandibular right quadrant with a mobility of 3 also showed no BIC. All stable MSIs exhibited BIC at least at one level.

*Bone-to-implant contact*

There were no significant differences in BIC between the mesial and distal surfaces of the loaded MSIs. Based on the entire implant circumference, variable amounts (2.2–94.8 per cent in the mandible; 16.6–87 per cent in the maxilla) of BIC were noted in all but the three mobile control MSIs.

The average percentage BIC for the delayed loaded MSIs was 35.4 per cent, compared with an average of 40 per cent for their corresponding control MSIs (Figure 5A). The percentage BIC for all immediately loaded MSIs was 44.4 per cent and 38 per cent for their controls. The difference between the delayed and immediately loaded MSIs was not statistically significant. When evaluated separately, the coronal, middle, and apical regions showed a trend of increasing BIC from the coronal to the apical regions (Figure 5B–D). Wilcoxon signed-rank tests showed no significant ($P > 0.05$) differences in percentage contact between the coronal, middle, and apical regions.

The percentage BIC of MSIs loaded with 25 g was 43.4 per cent, compared with 63 per cent for their corresponding control MSIs. The percentage BIC of the MSIs loaded with 50 g was 37.9 per cent; the control BIC was 55.1 per cent (Figure 6A). Neither the difference between the experimental and the control MSIs nor the difference between the 25 and 50 g loaded MSIs was statistically significant.

MSIs loaded with 25 or 50 g showed the least amount of BIC in the coronal region and the most BIC in the middle and apical regions (Figure 6B–D). Wilcoxon signed-rank tests showed no significant ($P > 0.05$) differences in percentage contact between levels. The percentage BIC for the maxillary MSIs was 44.3 versus 43.4 per cent for the mandibular MSIs (Figure 7A). A non-significant trend was seen with the least amount of BIC in the coronal region and increasing amounts in the middle and apical regions (Figure 7B). Wilcoxon signed rank tests showed no significant ($P > 0.05$) differences in BIC between MSI location, at each of the three levels or for the averages of the three levels.

## Discussion

In this study, only 5 per cent of the MSIs were determined to be mobile post-necropsy, and all were confined to the control group. Histomorphometric evaluation of the mobile MSIs showed that increasing amounts of connective tissue encapsulating the MSI were correlated with increasing amounts of mobility. All stable MSIs showed some level of BIC.

Of the three mobile implants, one was located in the maxilla and the other two in the mandible. During the initial study evaluating tooth movement (Owens *et al.*, 2007), one of these three control implants was identified as a partial failure, displaying slight mobility but stable enough for clinical use. However, at the final records appointment of that study, none of these three implants were examined for mobility because they were covered with mucosa and not detectable. On microscopic evaluation, no bone contact was noted, and each implant had continuous connective tissue in contact with the implant surface at all three levels examined. Several factors could explain the lack of BIC, including: (1) placement of the MSI into incompletely healed extraction sites, as suggested by Owens *et al.* (2007), (2) communication

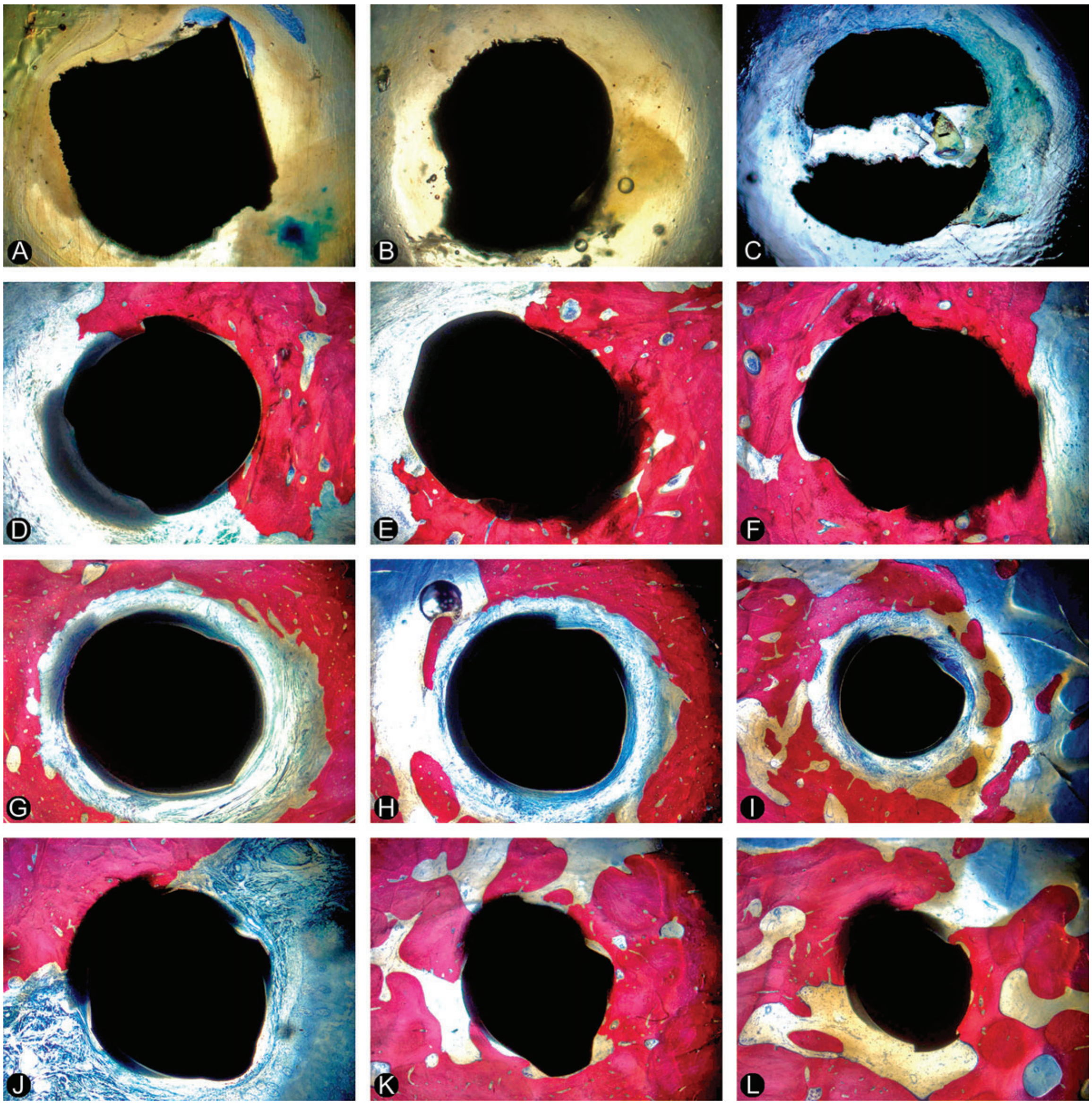


**Figure 4** Photomicrographs of miniscrew implants showing Maxilla: A, B, and C [mobile miniscrew (MSI)] versus D, E, and F (stable MSI); Mandible: G, H, and I (mobile MSI) versus J, K, and L (stable MSI).

with the sinus cavity in the maxilla with little cortical bone to provide stability (Jaffin and Berman, 1991), (3) overdrilling the depth and width of the pilot hole, and (4) possible overheating of the mandibular bone during drilling due to its density, therefore inducing an unfavourable healing environment (Melsen and Costa 2000; Deguchi *et al.*, 2003). Interestingly, all three mobile MSIs were placed in non-keratinized mucosa. It has been previously shown that MSI success rates are poorer in non-keratinized versus keratinized mucosa due to increased risk of infection (Cheng *et al.*, 2004).

Since the mobile implants were all unloaded controls, this supports the hypothesis that loading may provide a better environment for bone formation. Evidence for this exists for traditional implants (Romanos *et al.*, 2002; Degidi *et al.*, 2003; Rocci *et al.*, 2003a). In addition, Melsen and Costa (2000) reported that MSIs can be immediately loaded for orthodontic anchorage and that bone density and stability increase over time.

The results of the present investigation showed osseointegration, as defined by Brånemark *et al.* (1969), for most of the MSIs. While it has been suggested that MSIs do not have the surface treatment that allows for osseointegration with the surrounding bone (Melsen and Costa, 2000; Freudenthaler *et al.*, 2001), it has been demonstrated that integration is possible with MSIs (Melsen and Costa, 2000; Deguchi *et al.*, 2003; Kim *et al.*, 2005; Buchter *et al.*, 2006). Presently, there is no clear consensus regarding the minimum

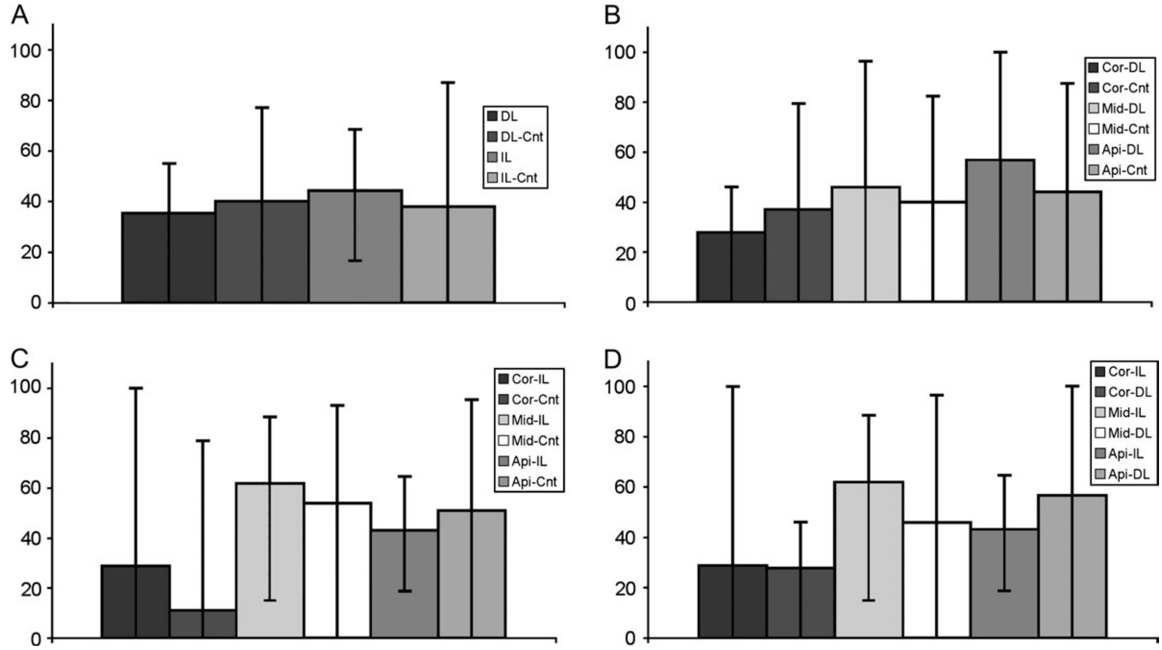


**Figure 5** (A) Percentage bone-to-implant contact comparing averages ± maximum and minimum data points of delayed loaded (DL) versus immediately loaded (IL) miniscrew implants and with their corresponding controls (Cnt). (B) Comparison of averages ± maximum and minimum data points calculated for delayed load for coronal (Cor-DL), middle (Mid-DL), and apical (Api-DL) regions and compared with their corresponding Cnt. (C) Comparison of averages ± maximum and minimum data points calculated for immediate loading for coronal (Cor-IL), middle (Mid-IL), and apical (Api-IL) regions and compared with their corresponding Cnt. (D) Comparison of IL and DL at the coronal (Cor), middle (Mid), and apical (Api) regions.

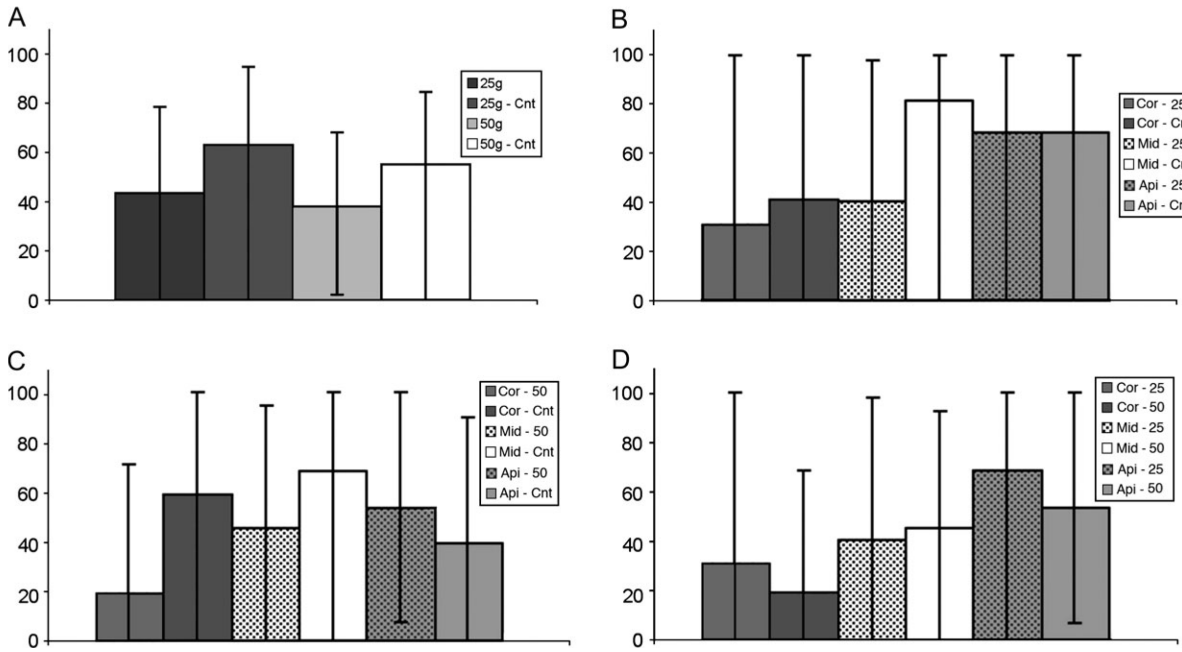


**Figure 6** (A) Percentage bone-to-implant contact comparing averages ± maximum and minimum data points of 25 (25) versus 50 g loads (50) g loads and their corresponding controls (Cnt). (B) Comparison of averages ± maximum and minimum data points calculated for 25 g load by slice: coronal (Cor-25), middle (Mid-25), and apical (Api-25) regions and compared with their corresponding controls (Cnt). (C) Comparison of averages ± maximum and minimum data points calculated for 50 g load by slice: coronal (Cor-50), middle (Mid-50), and apical (Api-50) regions and compared to their corresponding Cnt. (D) Comparison of 25 and 50 g load by slice: coronal (Cor), middle (Mid), and apical (Api) regions.

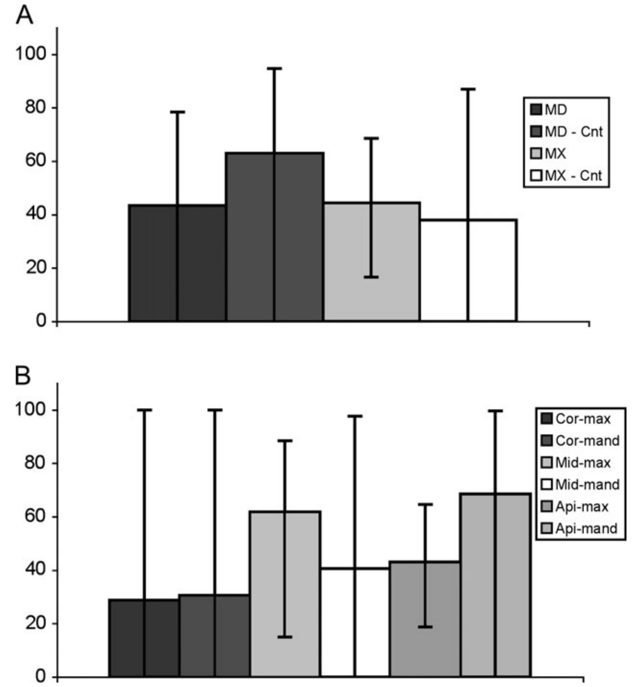


**Figure 7** (A) Averages ± maximum and minimum data points of percentage bone-to-implant contact comparing the maxilla (MX) versus mandible (MD) with their corresponding controls (Cnt). (B) Comparison of averages ± maximum and minimum data points calculated for the maxilla for coronal (Cor-max), middle (Mid-max), and apical (Api-max) regions and compared with averages calculated for the mandible for coronal (Cor-mand), middle (Mid-mand), and apical (Api-mand) regions.

amount of bone contact required for a successful dental implant. The results of this study suggest that as little as 2.2 per cent BIC may be sufficient for light continuous forces, an observation supported by those who state that only minimal amounts of BIC appear to be necessary for MSI success (Melsen and Costa, 2000; Buchter *et al.*, 2006).

Only small amounts of BIC may be required for stability because orthodontic forces are substantially less than the occlusal loads placed on traditional endosseous implants. Moreover, masticatory forces produce dynamic, or intermittent, loads with variable forces, as compared with constant loads produced by orthodontic forces. Compressive versus tensile forces also do not appear to make a difference to BIC as there was no significant difference in the amount of BIC between the mesial (compression) and distal (tension) surfaces of the MSIs. Interestingly, some MSIs showed new woven bone formation on the tension side and mature bone on the compression side. However, this was not a consistent finding across the loaded implants. Furthermore, timing of force application does not appear to influence BIC as no significant differences were found in percentage BIC between immediately and delayed loaded MSIs.

Similar to the timing of force application, different force levels on the MSIs showed no significant differences in percentage BIC. Melsen and Costa (2000) found similar results relating to the amount of load associated with percentage BIC. It is clear that the maximum load used in the present study did not have a negative effect on the amount of BIC around the immediately loaded MSI. As stated by Owens *et al.* (2007), this lack of effect on BIC indicates that the maximum load limit is likely to be above 50 g and that further studies will be needed in order to determine the maximum force level permissible for the loading of MSIs.

When percentage BIC at the coronal, middle, and apical levels was evaluated separately, a small but interesting trend was seen in both the immediate and delayed loaded MSI, with the coronal level having the least amount of bone contact. This correlates with studies on machine threaded traditional endosseous implants, in which most of the differences in the percentage BIC occurred in the coronal regions (Oyonarte *et al.*, 2005). However, Dalstra and Melsen (1999) and Kojima *et al.* (2006), through finite element analysis, determined that the majority of stress generated on the MSI during orthodontic force loading was around the first one to two threads, which corresponds to the level of cortical bone, supporting the notion that cortical thickness plays a critical role in primary stability of the MSI. Unexpectedly, the majority of BIC in this study was found at the apical two-thirds of both delayed and immediately loaded implants. These findings also hold true for the control MSIs. Since there were several MSIs that only showed BIC in the apical two-thirds, medullary bone may play an important role in long-term stability associated with healing.

The lack of power in this research is in large part due to the variability of the data. The variability observed is not unique to this study; large ranges of variability in BIC have previously been described (Melsen and Costa, 2000; Buchter *et al.*, 2006). Cancellous bone is, by definition, discontinuous, which may account for some of the demonstrated variability in BIC. Such variability would be particularly evident in the horizontal slice preparations used in this study. In addition, the smooth surface of the MSI used could also account for some of the variability in observed BIC. Endosseous implants have clearly shown a relationship between BIC and surface preparation (Buser *et al.*, 1997, 1998; Klokkevold *et al.*, 1997; Wennerberg *et al.*, 1997; Abrahamsson *et al.*, 2001). In order to understand MSI stability, the source or sources of this variability must be elucidated.

## Conclusions

Based upon the results of the present study, it can be concluded that some level of BIC is necessary for implant stability. The timing of force application, the force levels used, and the location (maxilla versus mandible) of MSI placement do not influence BIC. Furthermore, immediate loading (which stimulates bone formation) could be beneficial due to the fact that only unloaded control MSIs showed mobility.

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## Funding

Robert E. Gaylord Endowed Chair in Orthodontics; the Department of Orthodontics, Baylor College of Dentistry.

## Acknowledgement

The authors wish to acknowledge IMTEC and GAC International for their support of this project.


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