Original Article

Stability changes of miniscrew implants over time
A pilot resonance frequency analysis

Derid S. Ure[a]; Donald R. Oliver[b]; Ki Beom Kim[b]; Ana Cláudia Melo[c]; Peter H. Buschang[d]

ABSTRACT

Purpose: To quantify in vivo changes in miniscrew implant (MSI) stability over time using resonance frequency analysis, and to determine if pilot holes and placement sites affect changes in MSI stability.

Materials and Methods: Twenty-two self-tapping MSIs (1.6 mm wide and 9 mm long) were placed in the maxillae of 2 adult beagle dogs (20 months old). The Osstell Mentor was used to measure the implant stability quotient (ISQ) weekly for 8 weeks. A split-mouth design was used to evaluate the effects of 1.1-mm wide, 3-mm deep pilot holes.

Results: The MSIs that failed showed significantly ($P < .05$) greater decreases in ISQ values during the first 3 weeks than the MSIs that remained stable. All of the MSIs that failed (41%) had been placed in nonkeratinized tissue. MSIs that remained stable throughout the study also showed significant decreases in ISQ values during the first 3 weeks, followed by increases during the fourth and fifth weeks. Changes in ISQ values of MSIs inserted into bone with and without pilot holes were comparable ($P > .05$).

Conclusion: Stability of unloaded MSIs decreased during the first 3 weeks and increased thereafter. Although the effects of pilot holes on stability could not be confirmed, placement of MSIs into nonkeratinized tissue negatively affected their stability and increased the likelihood of failures. (*Angle Orthod.* 2011;81:994–1000.)

KEY WORDS: Miniscrew implants; Stability; Resonance frequency analysis; Pilot holes; Longitudinal; keratinized tissue

INTRODUCTION

Miniscrew implants (MSIs) have become a popular means of providing skeletal anchorage in orthodontics. However, reported success rates of these devices vary from less than 50% to more than 95%.[1–5] MSI failures have been related to various host factors,[1,2,6] miniscrew factors,[1,2,7–9] and treatment protocol factors.[10–14] The ultimate cause of MSI failures is the loss of bone-to-implant contact, which changes throughout the primary and secondary phases of stability. To understand how bone-to-implant contact changes, and its relationship to healing, longitudinal assessments of MSI stability are necessary.

The stability of MSIs left in situ for some period of time has traditionally been measured using removal torque,[15,16] histology,[17,18] and pullout tests.[19] Because these measures require the destruction of the bone-to-implant interface, they are not useful for longitudinal studies. The most promising noninvasive method to measure implant stability is resonance frequency analysis (RFA), which has been successfully used to study the stability of dental implants over time.[20–22] RFA measures vibrations of the implant within bone.[23,24] The stiffer the bone surrounding the implant, the higher the frequency of the measured vibration. Peri-implant bone density, cortical bone thickness, and percussion test values are all closely related to resonance frequencies of MSIs.[25]

Temporal changes in the stability of dental implants have been quantified using resonance frequencies. RFA measurements of endosseous implants placed in

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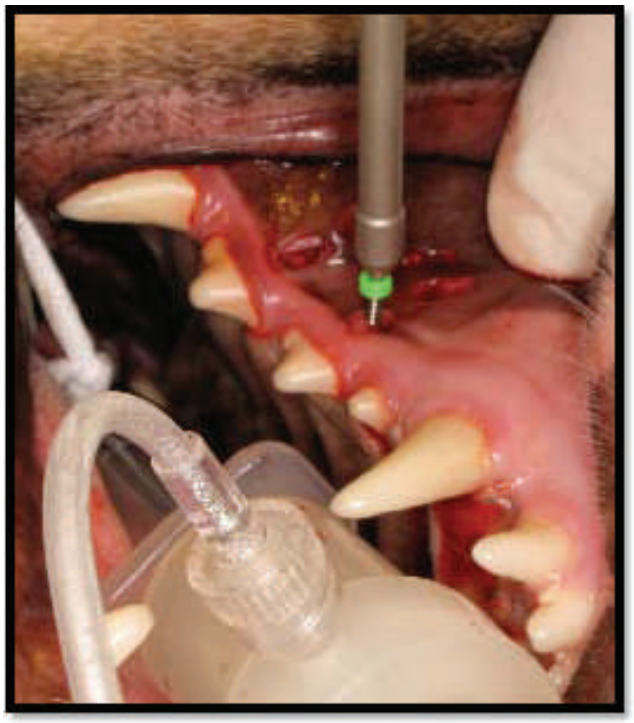


Figure 1. Placement of miniscrew implants in keratinized tissue of a dog.

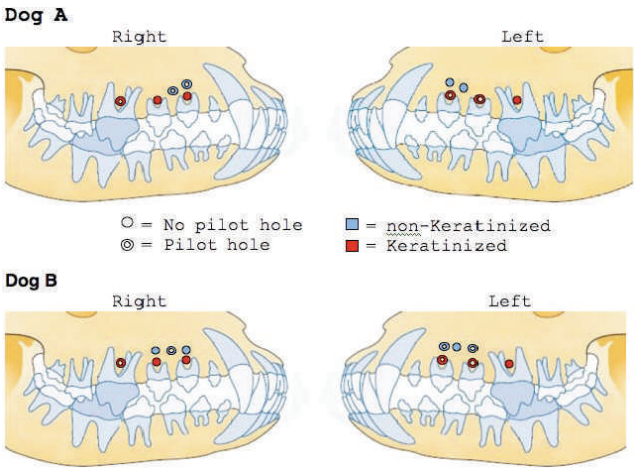


Figure 2. Miniscrew implants in dog A and dog B by pilot hole and soft-tissue location.

humans have shown significant decreases during the first 3–4 weeks and increases thereafter.[20,22,26] Longitudinal changes in the stability of MSIs have not been experimentally investigated.

The primary aim of this pilot study was to determine how MSI stability changes over time using the longitudinal RFA to quantify MSI stability. The secondary aim was to determine whether pilot holes and tissue type affect MSI stability.

MATERIALS AND METHODS

The sample included 2 healthy, male, 20-month-old beagle dogs weighing approximately 15 kg. All procedures were approved by the Saint Louis University Animal Care Committee. Of animal models commonly used, human bone characteristic are best approximated by the properties of dog bone.[27]

As a prophylactic, 25 mg/kg of enrofloxacin (Bayer Health Care, Shawnee Mission, Kans) was administered intravenously during MSI placement and intramuscularly for 2 days after surgery. Carprofen (Pfizer Animal Health, Exton, Pa) was administered (4 mg/kg) subcutaneously as an analgesic. Induction of general anesthesia was accomplished by the intravenous (IV) administration of 7 mg/mL propofol (Abbot Animal Health, Chicago, Ill). Maintenance was achieved by 2–3% isoflurane (Baxter Healthcare Corporation, Deerfield, Ill) Postoperatively, the animals were given 0.2 mL IV acepromazine maleate (VEDCO, St Joseph, Mo) to calm postanesthetic excitement.

Lateral head films were used to determine MSI placement sites, which were chosen based on the availability of adequate space. MSI length prevented their insertion into the mandible without risk of fracture. Ten MSI insertion sites were identified for the first dog, and 12 insertion sites were identified for the second dog. One screw of each right- and left-side pair was randomly assigned to receive a pilot hole. All MSIs were placed in the maxillary premolar region: 12 were placed apical to the furcation in keratinized tissue (Figure 1), and 10 were placed apical to the root tips in nonkeratinized gingiva (Figure 2). The animals served as their own controls for evaluating the effects of pilot holes and placement sites.

A 3.0-mm tissue punch (Premier Medical Products, Plymouth Meeting, Pa) was used to visualize the placement sites and prevent soft-tissue complications. Pilot holes were drilled using a 1.1-mm diameter drill (Sendax Spiral Drill, Imtec Corporation, Ardmore, Okla) at 1000 rpm and under constant irrigation with sterile saline solution. To control the depth of the hole, an endo stop was placed 3 mm from the drill tip.

The MSIs were Ancoragem Ortodontica screws manufactured by Neodent (Curitiba, Brazil); they were self-drilling; were 9-mm long; and had a 1.6-mm external diameter, a 1.1-mm internal diameter, and a 0.7-mm pitch (Figure 3). The head of the screw was modified to include a 1.1-mm internal thread that accepts the Osstell Mentor Smartpeg type A3 (Osstell, Göteborg, Sweden). All MSIs were inserted by the primary author (DSU) using a hand driver.

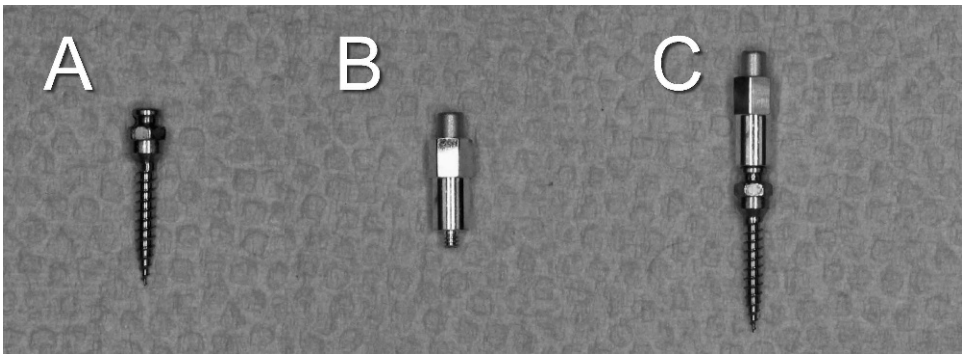


Figure 3. (A) Miniscrew implants (MSIs). (B) Smartpeg. (C) MSI attached to Smartpeg.

Resonance Frequency Analyses

RFA were conducted using an Osstell Smartpeg type A3, which was screwed into the head of the MSI and tightened with finger pressure according to the manufacturer's instructions. With the Osstell Mentor transducer held perpendicular to the MSI's long axis, resonance frequencies were taken parallel and perpendicular to the maxillary occlusal plane. All resonance frequencies were measured weekly by the primary author for 8 weeks and reported as implant stability quotients (ISQs).

Statistical Analysis

RFA was performed on MSIs that were immobile, partially mobile, or had been displaced. Because of the number of MSIs that failed, two data sets were evaluated, pertaining to (1) all the MSIs during the first 3 weeks, and (2) only those MSIs that remained intact throughout the study.

Preliminary analyses of all the MSIs that provided ISQ values over the first 3 weeks showed no statistically significant interaction between pilot holes and placement sites. Because of the small sample size, nonparametric tests were used to evaluate differences in ISQ values between screws placed (1) with and without pilot holes and (2) in keratinized gingiva and nonkeratinized gingival tissues. Wilcoxon signed-rank tests were used to evaluate changes in average ISQ between each successive time point. All statistical tests were performed using SPSS software Version 17.0 (SPSS, Chicago, Ill).

RESULTS

Failures

Of the 22 MSIs that were placed, nine (41%) failed during the course of the study (Figure 4). MSIs failed during the third ($n = 4$), fifth ($n = 2$), sixth ($n = 2$), and eighth ($n = 1$) weeks. All but one of the MSIs placed into nonkeratinized tissue failed. All failures occurred while attempting to unscrew the Smartpeg from the MSI.

Changes Over the First 3 Weeks

Decreases in ISQ values over the first 3 weeks were significantly greater for the MSIs that failed than for those that did not (Table 1). The differences between the MSIs that failed and those that did not increased significantly, from 3.1 at the end of the first week to 5.1 at the end of the third week. MSIs placed in nonkeratinized tissue also showed significantly greater decreases in ISQ values over the first 3 weeks than MSIs placed in keratinized tissue (Figure 5). Although decreases in ISQ values tended to be greater for MSIs with pilot holes than for those without pilot holes, the differences were not statistically significant (Figure 6).

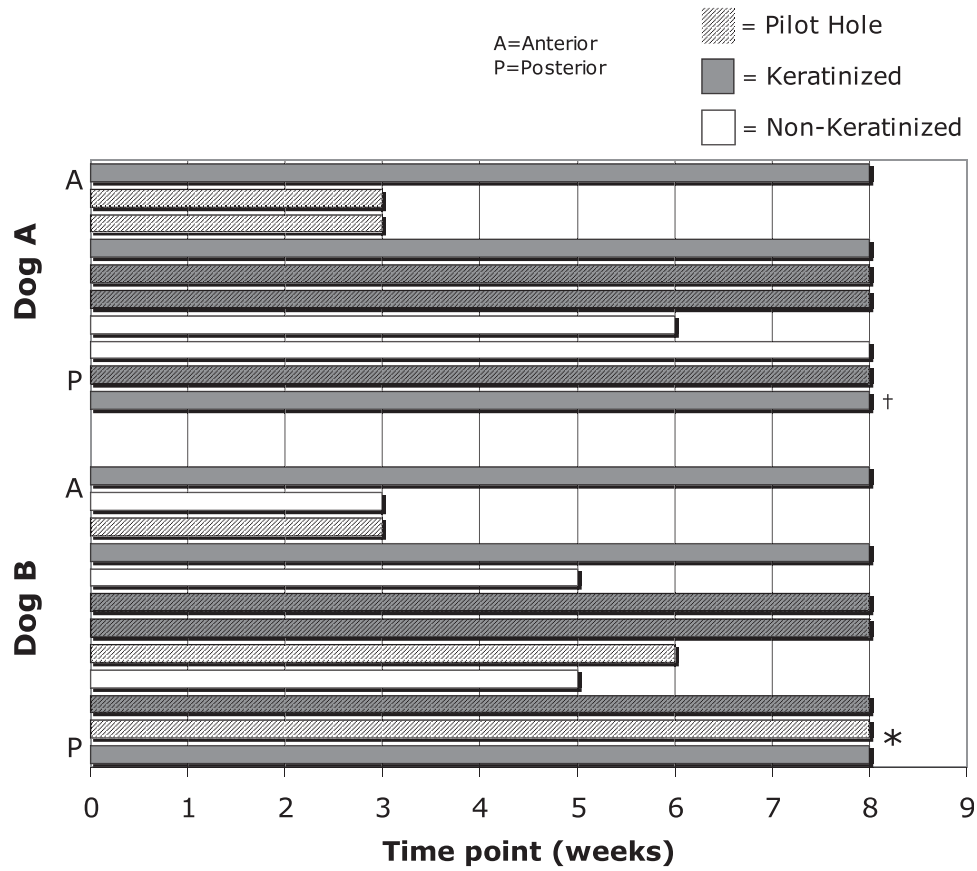
Changes Over 8 weeks

Based only on the MSIs that remained intact during the entire 8 weeks of the study (Figure 7), ISQ values decreased significantly during the first 3 weeks and increased significantly during the fourth and fifth weeks. The decrease that occurred during the sixth week, as well as the increases that occurred during the seventh, eighth and ninth weeks, were not statistically significant.

DISCUSSION

The failures that occurred pertained exclusively to MSIs placed in nonkeratinized tissue. None of MSIs placed in keratinized tissue failed. The high success rate for MSIs placed in keratinized tissues compares well with rates reported for MSIs placed in keratinized tissue, which range from 91.7% to 100%.[20,28,29] The consistency of these finding validates the use of RFA.

Placing MSIs in nonkeratinized mucosa is thought to be a clinical risk factor,[1,2] and placement in nonkeratinized tissues has been shown experimentally to be problematic in dogs.[30] The greater decreases in ISQs during the first 3 weeks indicated more bone loss



† = This MSI had a failure of the internal threading so that RFA measures could not be taken after week 1
* = This screw failed on week eight

Figure 4. Timing of miniscrew implant failures by dog, anteroposterior location, tissue type, and pilot hole.

around MSIs placed in nonkeratinized than in keratinized tissues. The failures were more likely due to periimplant inflammation, which has been associated with the lack of keratinized tissue.[2] The 3-mm tissue punch could have increased the risk of infection in nonkeratinized tissues, although it appeared to have had no effect in keratinized tissues.

Screwing the Smartpeg into the head of the MSI and unscrewing it after the recordings may have contributed to the high failure rate, because all of the failures occurred while attempting to unscrew the Smartpeg. This suggests that RFA may be limited, or perhaps even not appropriate, for measuring the stability of MSIs placed in regions of nonkeratinized tissues or in other regions with thin, less dense, cortical bone.

Upon placement, all of the MSIs in the present study exhibited adequate primary stability. It was the loss of stability during the first 3 weeks that determined whether or not MSIs remained stable or failed. Changes in stability have been previously used to identify dental implants at risk of failure.[24,31–33] Based on the present findings, changes in stability might someday be used clinically to identify MSIs that are at the greatest risk of failing.

The overall stability of any MSI is due to the combined effects of primary and secondary stability.[34] Based on the results in the present study, the point of transition from primary to secondary stability appears to occur at approximately 3 weeks (Figure 7), which compares closely to the point of transition identified for dental implants.[20,21,33]

Primary stability decreased immediately and significantly over the first 3 weeks following MSI placement. Decreases in ISQ values during the first 3 to 4 weeks have been previously reported after dental implant placement.[20,26] Stability might be expected to start decreasing within the first week, when osteoclasts and mesenchymal cells, which appear by day four, begin removing bone damaged during MSI placement.[17] Strategies to reduce trauma to bone during insertion or ways to accelerate healing should produce greater MSI stability.

Table 1. Means and SDs of Cumulative Changes of ISQ Values From Date of Insertion (T0) to 3 Weeks (T3), Along with Statistical Comparisons of MSIs That Failed Versus Those That Did Not Fail, Pilot Holes Versus No Pilot Holes, and Keratinized Versus Nonkeratinized Tissue.[a]

Group	T0	T0–T1	T0–T2	T0–T3
Failed (N = 9)				
Mean	33.7	−3.9	−8.6	−10.2
SD	6.0	2.6	6.5	9.0
Did not fail (N = 13)				
Mean	31.4	−0.8	−3.1	−5.1
SD	9.1	1.6	3.7	4.6
P value	.519	.001*	.009*	.032*
Pilot hole (N = 11)				
Mean	32.5	−1.9	−6.5	−7.9
SD	7.9	2.5	5.9	6.1
No pilot hole (N = 11)				
Mean	32.2	−2.5	−4.7	−6.9
SD	8.3	2.9	5.8	8.6
P value	.938	.084	.201	.168
Keratinized tissue (N =12)				
Mean	34.6	−0.5	−3.1	−4.7
SD	5.8	1.3	3.8	4.7
Nonkeratinized tissue (N = 10)				
Mean	30.1	−3.9	−8.1	−10.1
SD	9.3	2.5	6.4	8.6
P value	.186	.001*	.013*	.037*

[a] ISQ indicates implant stability quotient; MSI, miniscrew implant.
* Significant change at the a = .05 level.

Secondary stability, which is associated with healing and increases in total MSI stability, first became evident 4 weeks after miniscrew placement. For dental implants, increases in stability have been reported to begin around the fourth week after placement.[21,26,35] Increases in overall stability can be explained by the new bone formation, which has been reported to begin around dental implants approximately 3 weeks after placement in dogs.[36]

Although secondary stability might be expected to increase until complete healing around the MSI has taken place, it leveled off after the fifth week in the present study. The dental implant literature indicates increases in stability well beyond 5 weeks.[21,26,33] The lack of increase between weeks five and eight might be explained by the fact that Rimadyl (Pfizer, NY, NY), a nonsteroidal anti-inflammatory drug (NSAID), was administered by the veterinarian to both dogs during this time period to control pain. NSAIDs have been previously shown to inhibit bone formation because they inhibit prostaglandin formation.[37]

Whether or not the MSIs were placed with or without pilot holes appeared to have no appreciable effect on changes of ISQ values in the present study. Previous studies have shown that pilot holes decrease insertion torque and pullout strength.[38–40] It is possible that small differences actually exist that RFA may not be sensitive enough to detect. A more plausible explanation relates to the stiffness of the bone, which is one of the factors that determine the resonance frequency of an implant. Because the stiffness of the bone is a function of its physical composition, it might be expected to remain the same whether or not a pilot hole is placed. It is also possible that the placement of a pilot hole causes as much trauma to the bone as does the placement of a MSI without a pilot hole.

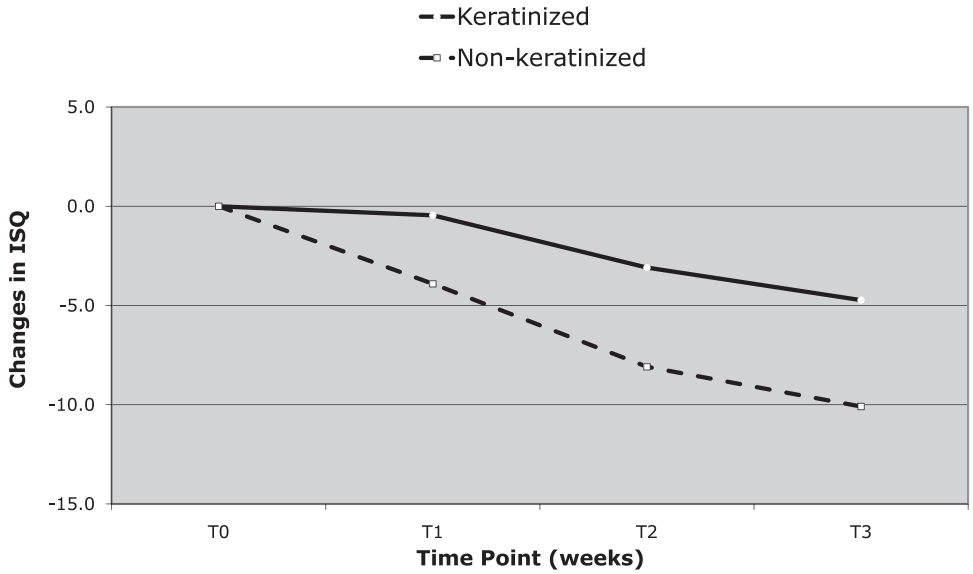


Figure 5. Change in implant stability quotient over time for miniscrew implants placed in keratinized and nonkeratinized tissue over the first 3 weeks.

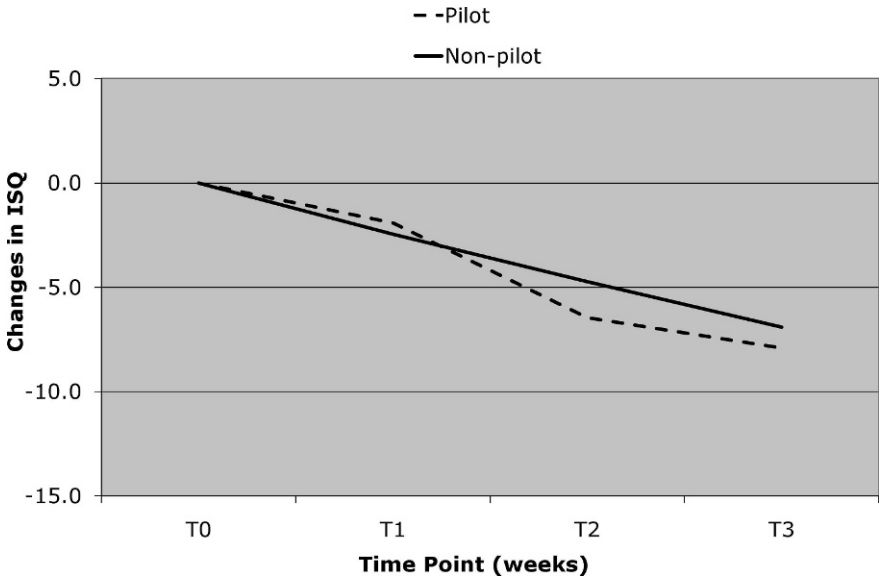


Figure 6. Change in implant stability quotient over time for miniscrew implants with pilot hole and no pilot hole over the first 3 weeks. No significant changes were found.

CONCLUSIONS

Because of the small sample size, the results of this study should be considered preliminary. Within the limits of the study, it can be concluded that:

- RFAs show that MSI stability changes over time; it decreases during the first 3 weeks after placement and increases between weeks three and five.
- MSIs that fail show significantly greater decreases in stability during the first 3 weeks after placement than MSIs that remain stable.
- MSIs placed in nonkeratinized tissue show significantly greater decreases in stability during the first 3 weeks after placement than MSIs placed in keratinized tissue.
- Changes in stability of MSIs placed with or without pilot holes are comparable.

ACKNOWLEDGMENT

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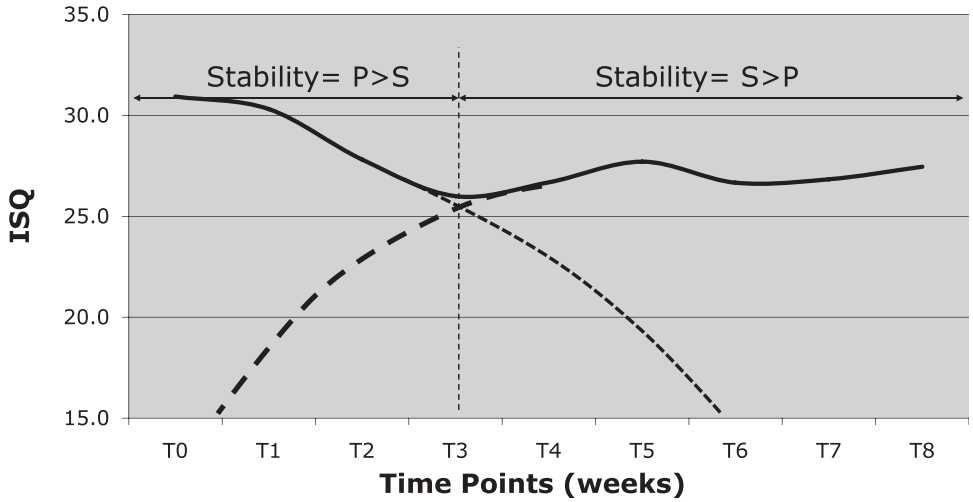

Figure 7. Changes in implant stability quotient over time for miniscrew implants that remained stable throughout the 8-week experimental period, with primary and secondary stability curves (dashed lined) superimposed.

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