Insertion Torque and Resonance Frequency Analysis of Dental Implant Systems in an Animal Model with Loaded Implants

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Purpose: *The aim of this study was to compare insertion torque and resonance frequency analysis of different implant systems in an animal model with loaded implants.* ***Materials and Methods:*** *Three types of Brånemark implants (machined MkIII, TiUnite MkIII, and MkIV) and 2 types of Straumann implants (sandblasted, large-grit, acid-etched [SLA] and titanium plasma-sprayed [TPS]) were studied. Thirty-two implants of each type (n = 160) were placed in 16 beagle dogs. Maximum insertion torque values were recorded. After a healing period of 8 weeks, the implants were loaded for 3 months; the animals were then sacrificed. At placement, after healing, and at the end of the loading phase, resonance frequency analysis was performed and implant stability quotients (ISQs) were recorded.* ***Results:*** *Higher insertion torque values were seen for the conical MkIV than for the MkIII. No difference was seen between the Brånemark and Straumann implants on the basis of ISQ value at placement. ISQ and insertion torque values were lower for the cylindric Straumann implants than for the self-tapping implants. For all implant systems a significant decrease in median ISQ was observed, with a median decrease ranging from 3 to 6. ISQ values for self-tapping implants remained stable after loading, whereas the ISQ values for non–self-tapping cylinders decreased. The maximum insertion torque values for failed and successful implants were not significantly different. Significantly higher ISQ values at placement were seen for successful implants (*P *=.003). Based on this model for ISQ, a threshold of 65.5 was identified, with a sensitivity of 83% and specificity of 61% for prediction of implant loss. ISQ values at the start of loading were not predictive of implant loss in the loading period.* ***Conclusion:*** *Caution should be used when judging implant systems on the basis of resonance frequency analysis and torque measurement.* INT J ORAL MAXILLOFAC IMPLANTS 2006;21:726–732

Key words: *animal model, dental implants, insertion torque, primary stability, resonance frequency analysis*

In the last 30 years, reliable success rates for dental implants have been demonstrated in many clinical situations.[1] However, success still may not be achieved consistently in patients with poor-quality bone or in cases of early loading; the maintenance of long-term stability of hard and soft tissues is also an area of concern.[2–4] In vivo bone quality (primary stability), which is a prerequisite for early loading protocols,[5] is difficult to assess. The classification system of Lekholm and Zarb[6] is still the system most widely used to assess bone quality in clinical situations[7]; using this system, the surgeon grades the bone from D1 (hard) to D4 (soft) based on the way it feels during drilling.[8] Trisi and colleagues have shown that it is possible to identify D4 bone using this system; however, they found that it was not possible to differentiate between soft and medium-quality bone.[9] This is of importance, as clinically more "medium hard" bone (D2 and D3) is found than D1 or D4.[10] The assessment of bone quality through radiographic techniques remains controversial.[11–14] Ultrasonic techniques are under development but are still not available for routine use.[15]

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A more precise method for the evaluation of bone quality/primary stability is the measurement of the insertion torque during the tapping process. Friberg and associates demonstrated that insertion torque was correlated to bone-implant contact (assessed histomorphometrically) and radiologically assessed bone density and was not dependent on angulation, pressure, or threading geometry.[16,17] Other authors, however, were not able to reproduce the correlation between insertion torque and histologic bone-implant contact,[18] which leads to the hypothesis that different biologic aspects are studied with the 2 methods. Although the documentation of insertion torque for scientific purposes has been proposed by many different groups, its clinical usefulness and comparability between different implant systems is still unresolved.

Furthermore, a threshold above which primary stability is sufficient for early loading has not been defined. A threshold of > 32 Ncm for early loading for a self-tapping implant designed for soft bone has been proposed.[19] Moreover, an upper limit for primary stability has never been definitively established.[20,21]

The Periotest system was used for some years to quantify implant stability/mobility. The low sensitivity, in combination with low resolution and observer dependence,[22] have led to criticism of this technique by most research groups.[23,24] A more recent technique for the measurement of implant stability is resonance frequency analysis (RFA), which was introduced by Meredith and associates.[25,26] Their experiments with unloaded implants in animal models suggested that resonance frequency increases during the healing phase and that a low variability of bone quality correlates to a low variability of resonance frequency.[27] Other animal experiments showed comparable results between resonance frequency, histologically demonstrated bone-implant contact, and removal torque, without a statistical correlation.[28–30] Clinical data revealed an increase of resonance frequency for successful implants and a decrease for nonosseointegrated implants.[27,31]

In another study, resonance frequency was correlated with the insertion torque, which was used to categorize bone into 1 of 3 "density classes."[32] Interestingly, when RFA was repeated 1 year after the initial classification, no difference was found between the 3 classes.

Little research has been done to compare different implant systems under loaded conditions.[33] Therefore, the aim of this study was to compare the mechanical aspects of osseointegration, represented by insertion torque and RFA, of different implant systems in an animal model with loaded implants.

MATERIALS AND METHODS

To simulate a physiologic loading phase, 16 beagles (8 male, 8 female, with a mean age of 1.5 years) were chosen. Approval for the study protocol was obtained from the local authorities (Landesuntersuchungsamt Koblenz, Germany; reference nos. 177-07/001-1, 22.3.2000 and 04.12.2000). All animals were housed and surgically treated in an animal experiment unit. High-quality and low-quality bone were represented by the mandible and the maxilla, respectively. After extraction of the premolars under general anesthesia, the jawbones were allowed to heal for 3 months. Five different types of implants were used (Table 1); 1 implant of each type was placed in each jaw in a randomized premolar site. This resulted in 5 different implants in the mandible and 5 in the maxilla of each animal, for a total of 160 implants. A wide variety of implants was used to maximize the number of macrodesigns and surface roughnesses studied. All implants had a length of 8 mm and a mean standard diameter of 3.8 ± 0.3 mm.

General anesthesia was induced, and implant placement was performed as described by the manufacturer. The self-tapping MkIII and MkIV implants were placed following the standard drilling protocol without the countersink, as suggested for the implantation in nonesthetic regions. They were restored with a cover screw and allowed to heal in a submerged position. The Straumann implants were placed following the standard drilling procedure. Tapping was performed manually, and placement was carried out using a torque driver. As suggested by the manufacturer, the implants were allowed to heal transmucosally. All surgical procedures and examinations were carried out by the primary author (BAN).

The insertion torque was recorded during implant placement with the help of the torque driver (Nobel Biocare DEC 600). For statistical analysis, the maximum values for each procedure were used. In cases where the maximum value exceeded 50 Ncm and manual insertion was necessary, 50 Ncm was used for further calculations. The data analysis was also performed with the last torque value of each procedure without any difference in the results (data not shown).

RFA was performed at placement, at the start of loading, and at the end of loading with the Resonance Frequency Analyser (Ostell model 6.0; Integration Diagnostics, Göteborg, Sweden). Type F4 (art. no. 100063) and type F1 (art. no. 100053) transducers (Integration Diagnostics) were used. Resonance frequency is given in the form of an implant stability quotient (ISQ) to allow comparison between implant types.

Table 1 Properties of the Implants Used

	Implant type	Manufacturer	Surface	Surface roughness	Diameter*
A (control)	Brånemark MkIII standard	Nobel Biocare, Göteborg, Sweden	Machined	Minimally rough	3.75
B	Brånemark MkIII TiUnite	Nobel Biocare	Anodically etched	Medium rough	3.75
C	Brånemark MkIV TiUnite	Nobel Biocare	Anodically etched	Medium rough	4.0
D	Straumann SLA	Straumann, Basel, Switzerland	Sandblasted, large grit, acid-etched	Medium rough	4.1
E	Straumann TPS	Straumann	Titanium plasma-sprayed (TPS)	Very rough	4.1

*Length was 8 mm for all implants.

After 8 weeks of healing, the submerged implants were uncovered under general anesthesia. Five- to 6-mm suprastructures (nonsplinted healing abutments) were used to allow loading of all the implants separately. During this second-stage surgery, RFA was measured. As premolars of dogs naturally are not in contact, the suprastructures were also out of occlusion. To subject the implants to loading, the dogs were fed a hard diet throughout the loading phase of 3 months. Because of the scissorlike motion used by the dog to masticate this hard diet, the implants were subjected to a high amount of loading. Immediately after sacrifice of the animals for later histologic study of the specimens, RFA was measured again.

Data are illustrated using box plots. Univariate significance was examined using the Wilcoxon test for unpaired testing and the McNemar test for paired testing. A *P* value of less than .05 was interpreted as an indicator of local significance. For the primary (confirmatory) analysis the ablative implant surfaces (B, C, and D) were in sum compared with groups A and E. For the primary endpoint RFA a paired 2-test model was used; the influence of the macrodesign was ignored. The sample size of 32 jaws was verified pre-emptively as sufficient to identify intraindividual differences of > 15% with a significance of 5% and a power of 80%. Receiver operating characteristic (ROC) curve analysis was used to evaluate the prognostic properties of ISQ and insertion torque.

RESULTS

Figure 1 illustrates the ISQ values at implant placement. Interestingly the 3 self-tapping implants showed higher values than the non–self-tapping implants (ie, the Straumann implants), with median values of 70 and 65, respectively. It was necessary to use different transducers for the 2 implant systems. Remarkably, no significant difference was observed between the MkIII and MkIV implants. No value fell below the suggested "threshold" of 50. The maximum torque values at placement are given in Fig 2. The highest value was set to 50 Ncm. All self-tapping implants showed higher median torque values than the non–self-tapping. The highest values were reached by the MkIV implant. Both Straumann implants had large distributions of values, with medians below 30 Ncm. Figure 3 illustrates the association between insertion torque and ISQ (RFA). Torque values were classified[6,32] as high (> 40 Ncm), medium (30 to 40 Ncm), or low (< 30 Ncm). Very soft bone was not found in this animal model. Overlap of the ISQ distributions was found, with median values of 63, 66, and 68, respectively, for the 3 classes. No statistically significant differences were found between the 3 classes.

Intraindividual differences in the ISQ values between insertion and start of loading (after 8 weeks of unloaded healing) are given in Fig 4. For all implant systems a significant decrease of median ISQ values was observed, with a median decrease ranging from 3 to 6. There was a statistically significant difference between the implant systems, with a smaller decrease for the Straumann implants ($P >$ .05). The intraindividual changes of the ISQ values from the beginning of the loading phase to the end 3 months later are given in Fig 5. The self-tapping implants (Nobel Biocare MkIII and MkIV) showed high ISQ values, whereas the non–self-tapping Straumann implants showed significantly lower ISQ values after loading ($P <$ .001). With respect to the power planning (primary endpoint) of this study, no statistically significant difference was observed after loading between the ISQ values for the medium-rough test implants (B, C, D) compared to the smooth (A) or very rough (E) control implants.

The number and rate of implant losses is given in Table 2. Six implants (4%) were lost during the healing phase, and 5 (3%) were lost during the loading phase. There was no statistical correlation between implant loss and macrodesign or surface type, so the differences between the systems can be regarded as incidental.

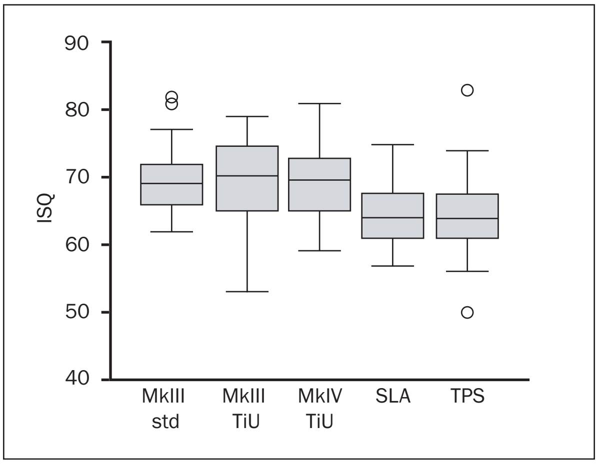

Fig 1 ISQ at placement by implant type. Circles represent outliers.

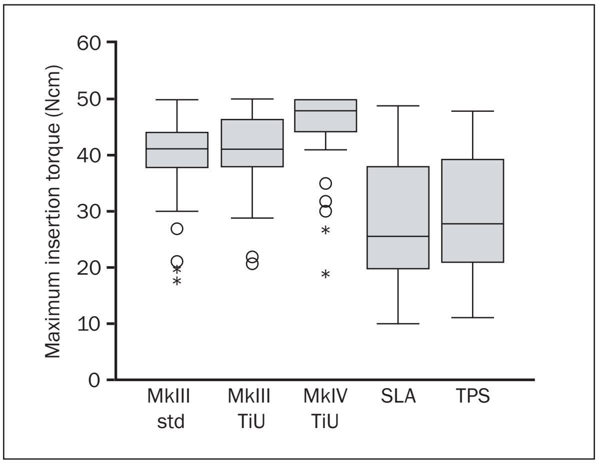

Fig 2 Maximum torque at implant placement by implant type.

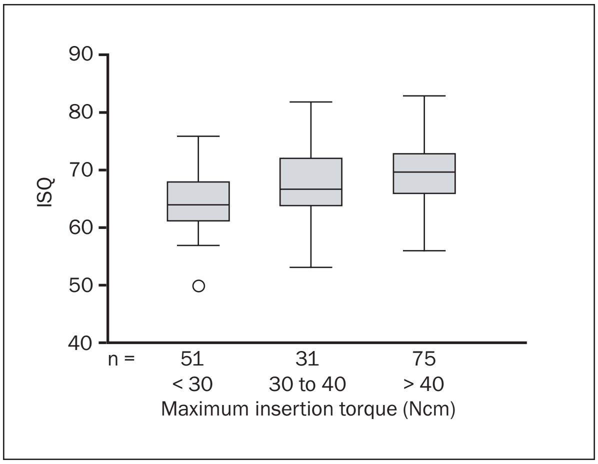

Fig 3 ISQ at implant placement by torque category.

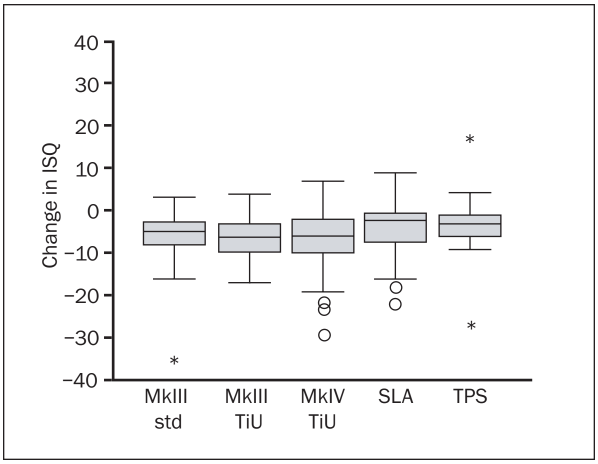

Fig 4 Intraindividual differences in ISQ between implant placement and start of loading (second-stage surgery) 8 weeks later by implant type .

To evaluate whether identification of high-risk implants with torque or ISQ values would be possible, the data for successful and unsuccessful implants were graphed separately (Fig 6). No statistically significant differences were observed between the maximum torque values for the 2 groups, with median values of 40 and 45 Ncm, respectively. Accordingly the ROC analysis revealed an area under the curve of 0.43 (0.14 to 0.71), which was not significantly different from an accidental distribution of 0.5 (*P* = .547). The corresponding analysis for ISQ showed significantly higher values for successful implants (*P* = .003). The ROC analysis revealed an area under the curve of 0.86 (0.72 to 0.99) (*P* = .003). Based on this model for ISQ, in contrast to torque values, a threshold of 65.5 was identified, with a sensitivity of 83% and specificity of 61% for the prediction of an implant loss. However, when ISQ values at the start of

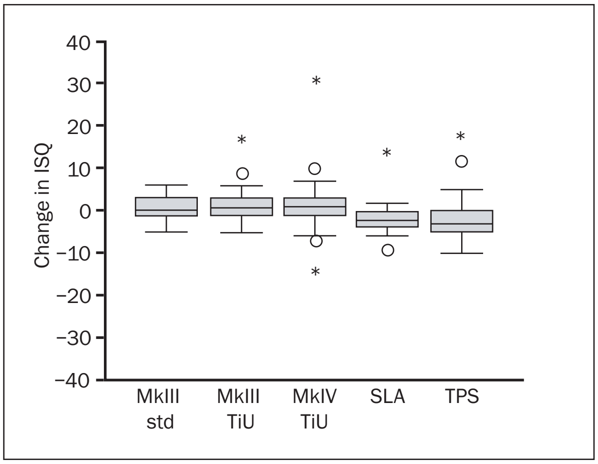

Fig 5 Intraindividual differences in ISQ between start of loading (second-stage surgery) and end of loading (a 3-month period) by implant type.

Table 2 Implant Losses in the Healing and Loaded Phases

		Implants lost					
		Healing phase		Loading phase		Total	
	n	n	%	n	%	n	%
MkIII standard	32	0	0	3	9	3	9
MkIII TiUnite	32	1	3	0	0	1	3
MkIV TiUnite	32	1	3	2	6	3	9
SLA	32	1	3	0	0	1	3
TPS	32	3	9	0	0	3	9
All implants	160	6	4	5	3	11	7

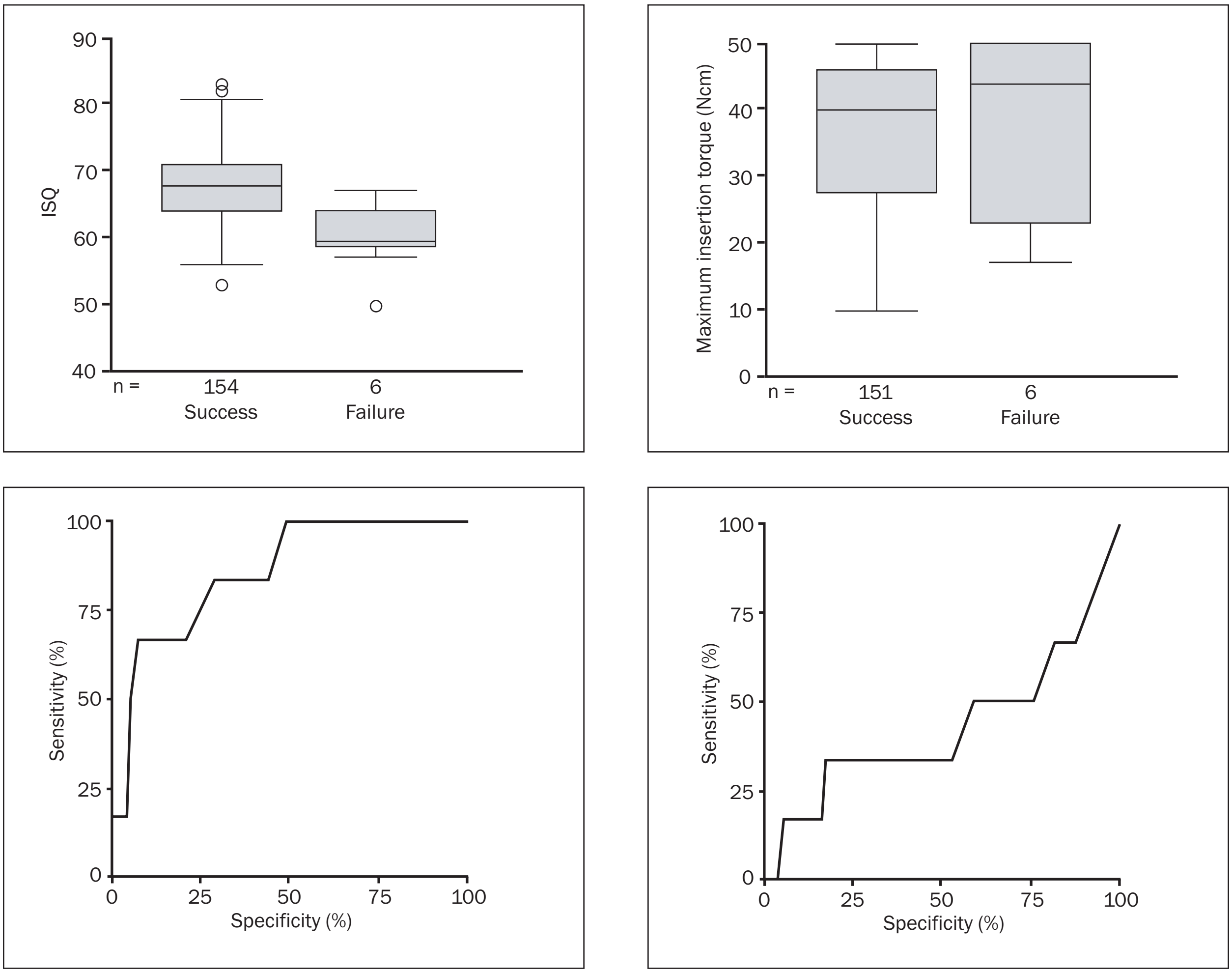

Fig 6 Box plots and ROC curve analysis of ISQ *(left)* and maximum torque *(right)* at insertion by occurrence of implant failure during the healing period.

loading for successful implants were compared with those of unsuccessful implants, no statistically significant difference is seen (*P* = .86).

DISCUSSION

The torque values at placement mainly reflect the macrostructure of the implants, with lower values for the non–self-tapping, cylindric implants and higher ones for the conical MkIV, which was placed using an "underdimensioned" drilling procedure. Similar data for the MkIV have been reported in human jawbone, which indicates the validity of the beagle model.[33] Correspondingly higher RFA values have been reported for the MkIV in human cadavers[33] but were not reproduced in the present study. An explanation might be the influence of different bone qualities on ISQ,[34] which has been demonstrated to level off in clinical long-term observation.[35] Despite correction for the Straumann implants for the height above the bone, ISQ values for Straumann implants were lower than those found for Brånemark implants at all time points, regardless of macro- or microstructure. The clinical relevance of the finding of lower ISQ values for the Straumann implants at placement is questionable, especially if data from other studies with similar "low" values for the Straumann implants are considered.[35] It should be noted that no gold standard for the evaluation of implant stability exists which can be used for comparison. With respect to the authors' broad clinical experience with a variety of implant systems, this difference seems to have been influenced more by the type of transducer than by the type of implant. On the other hand, the intraindividual longitudinal ISQ values reflect the typical course of bone healing, with a slight decrease of stability followed by a rise or plateau, as described by other investigators.[5,36–42]

For the prediction of implant loss during the unloaded healing period in this model, a relatively high ISQ threshold of 65.5 would have allowed a clinically useful conclusion. ISQ at placement appeared to be more predictive of implant loss than torque measurement. However, this may be related to the fact that 50 Ncm was used as a cutoff number for hand-torqued implants. Interestingly, this discriminative effect of ISQ was not observed at the loading phase. It should be noted that the time until prosthetic loading was 3 months. Implant mobility, an indicator of failure, was identified at this time. The low number of implant losses in the present beagle model stresses the importance of validation of these preliminary results in a larger, human trial, before clinical consequences can be drawn. Interestingly, another group[43] judged RFA to be an unreliable diagnostic tool with which to identify mobile implants but found that the same method could be reliably used to determine implant stability, with stable implants having an ISQ of at least 47. The biologic parameters reflected by the ISQ value are still not fully understood.[44]

In conclusion, caution must be used in judging implant systems on the basis of RFA and torque measurement.

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