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A biomechanical assessment of the relation between the oral implant stability at insertion and subjective bone quality assessment

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Abstract

Aim: The study was set to evaluate the validity of subjective jaw bone quality assessment.

Materials and Methods: A total of 298 patients (198 females, mean age 56.4) were treated with oral implants at the Periodontology Department at the University Hospital of KUL. A total of 761 TiUnite™ implants have been installed. Subjective bone quality assessment was performed on radiographs and by the surgeon's tactile sensation and was compared with torque measurements. In a subset of patients, implant stability was also assessed by implant stability quotient and/or periotest values.

Results: Subjective assessment of bone quality was related to the PTV, ISQ and placement torque [in the crestal, the second and the apical third (N cm)], respectively; in grade 1: −5.3, 73.3 (4.2, 9.6, 15.2), and grade 3 or 4: −1.6, 55 (3.3, 5.5, 8.4). For the surgeon's tactile sensation, a good correlation was noted for the presence of a thick cortex: −4.6, 70.3 (4.2, 9.7, 15.1), or a thin one: −0.3, 65.9 (3.6, 6.9, 10.1). For dense trabecular bone, the values were −2.8, 69.4 (4.4, 9.7,14.8), while for poor trabecular bone, the values were −1.7, 66.4 (3.6, 6.4, 9.8).

Conclusions: Subjective assessment of bone quality is related to PTV, ISQ and placement torque measurements at implant insertion.

Key words: biomechanics; bone quality; dental implants; insertion torque; oral implants; osseointegration; periotest; RFA

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Several clinical reports on the use of oral implants mention that poor bone quality, as assessed on pre-operative radiographs, lead to a less predictable outcome (Porter & von Fraunhofer 2005). While in well-mineralized bone with proper degrees of corticalization, like the symphyseal area a success rate of 99% was reported even after 15 years with Brånemark system® implants (Nobel Biocare, Gothenburg, Sweden) (Lindquist et al. 1996), in distal areas of the upper jaw it can be substantially lower (Adell et al. 1990, Nevins & Fiorellini 1998). It thus seems relevant to develop measurements of the bone quality, especially referring to its mineral density, as a determinant for the primary stability of endosseous implants. It has been indeed observed that too large micromovements during the healing period can disrupt the bone apposition process on the implant surface and rather lead to fibrous scare tissue formation (Szmukler-Moncler et al. 1998). The assessment of the primary stability at insertion may be another option to determine the prognosis or to decide whether early or even immediate loading can be performed. The alternative is to let the bone-to-implant interface heal for a few months before being exposed to the oral environment as described in the original P–I Brånemark protocol (Brånemark et al. 1985).

Conflict of interest and source of funding statement

The authors declare that they have no conflict of interest.

One available technique to determine the bone mineral content is to take biopsies of the jaws. This procedure is certainly reliable and safe but does not seem practical in a routine clinical situation.

The most popular current method of bone quality assessment is that developed by Lekholm & Zarb (1985), who introduced a scale of 1–4, based on both the radiographic assessment, and the sensation of resistance experienced by the surgeon when preparing the fixture site. The grading refers to individual experience, and furthermore, it provides only a rough mean value of the entire jaw. Johansson & Strid (1994) described a technique whereby bone quality as a function of density and hardness could be derived from the torque forces needed during the implant insertion. They postulated that the energy used in tapping the site, before or during implant placement, is a combination of the thread placement force from the tip of the instrument and the friction created as the remaining part of a tap or implant enters the site. It has been demonstrated in ex vivo human preparations that the cutting resistance during implant installation correlates well with the bone density as assessed by microradiography (Friberg et al. 1995)

The absence of fixture mobility either indicative of a good primary stability or after a while of an intimate bone-to-implant contact can be objectively determined by an electronic measuring system, the Periotest® (Siemens, AG, Bensheim, Germany) (Olivé & Aparicio 1990, Teerlinck et al. 1991, van Steenberghe & Quirynen 1993, van Steenberghe et al. 1995). This apparatus is widely used to assess implant outcome as can be seen from the hundreds of papers referring to it (http://www.periotest.de). The periotest values (PTV) reveals the increased stiffness of the implant–bone continuum over time (Tricio et al. 1995).

Implant stability can also be measured by resonance frequency analysis, normally referred to as implant stability quotient (ISQ) Meredith 1998. The in vivo experimental findings demonstrate that resonance frequency is related to implant stiffness in the surrounding tissues, which means a higher bone-to-implant contact percentage (Rasmusson et al. 1998). Clinically, the increase in implant stability has been measured using ISQ, and the increase in mobility was attributed to corticalization of the surrounding bone (Friberg et al. 1999a). The Osstell™ device (*Mentor*, Integration Diagnostics AB, Sävedalen, Sweden) has less documentation but also allows registration of minute changes in the rigidity of the bone-to-implant contact.

The aim of the study was to evaluate the validity of subjective jaw bone quality assessment by comparing it with an objective parameter: the torque force needed to install implants, besides the primary stability of these implants measured either by ISQ or PTV, or both, were also related to the subjective bone quality assessment when the measurement was available.

Materials and Methods

A total of 298 consecutive patient files (198 females) were analysed. They represent the total patient population treated by means of implants at the Department of Periodontology of the University Hospital of the Catholic University Leuven between November 2003 and June 2005. The mean age was 56.4 years (range: 18–86).

All patients have been provided with a total of 761 Mark III TiUnite™ implants (Brånemark system®, Nobel Biocare, Gothenburg, Sweden). At implant insertion, a minimal bone height of 7 mm had to be available. The classical surgical protocol with strict sterility measures as defined by Brånemark was used for all surgeries. Bone quality assessment was performed using the Lekholm & Zarb (1985) index. It consists of a scale of 1–4 (Fig. 1). A copy of this grading system is available. The score was given immediately after implant placement.

Tactile sensation was assessed as such for both the cortical bone and the trabecular part during high-speed drilling, as experienced by the surgeon when preparing the fixture site. For the latter, a scale, ranging from grade 1 (very thick cortex/dense trabecular bone) to grade 3/4 (thin or very thin cortex/poorly or very poorly mineralized trabecular bone), was introduced (Table 1). Indeed, the last two scores were grouped because a distinction is limited.

Besides, the bone quality was assessed objectively during implant insertion, by means of an electronic torque force measurement device, which is part of a controlled motor device. The latter measures the torque force while tapping or inserting the implant at a slow speed (OsseoCare™, Nobel Biocare, Gothenburg, Sweden). The OsseoCare™ motor was developed to insert the implant into the (pre-tapped) bone site with a well-controlled insertion torque of 20, 30, 40 or 50 N cm (Fig. 2a, b).

The software controls and registers the operation of the hand-piece micromotor, and monitors the torque delivered, as well as the number of turns performed. The software records the cutting torque resistance as mean values (N cm) at the crestal third, the middle third and the apical third of each implant insertion trajectory.

The rigidity of the implant–bone continuum was assessed by the resonance frequency analysis method (Osstell™ *Mentor*, Integration Diagnostics AB; Fig. 3a–c). These measurements were performed at implant insertion as well as just before the abutment insertion (after submerged healing). The RFA technique analyses the resonance frequency (range: 1100–10,000 Hz) of a peg (Smartpeg™, Integration Diagnostics AB), which can be attached to the fixture with the aid of a mount; 4–5 N cm of torque is enough. Subsequently, the probe is held

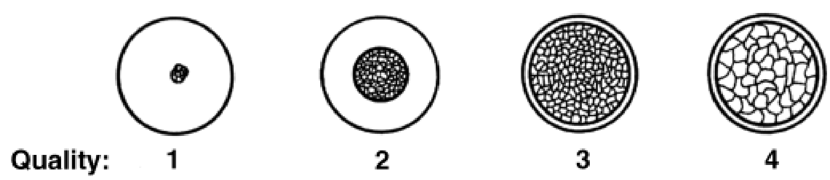

Fig. 1. Grading system for bone quality assessment (Lekholm & Zarb 1985).

Table 1. Tactile evaluation of the cortical and trabecular bone during surgery

	Grade 1	Grade 2	Grades 3, 4
Cortical bone	Thick	Moderate	(very) Thin
Trabecular bone	Dense	Moderate	(very) Poor

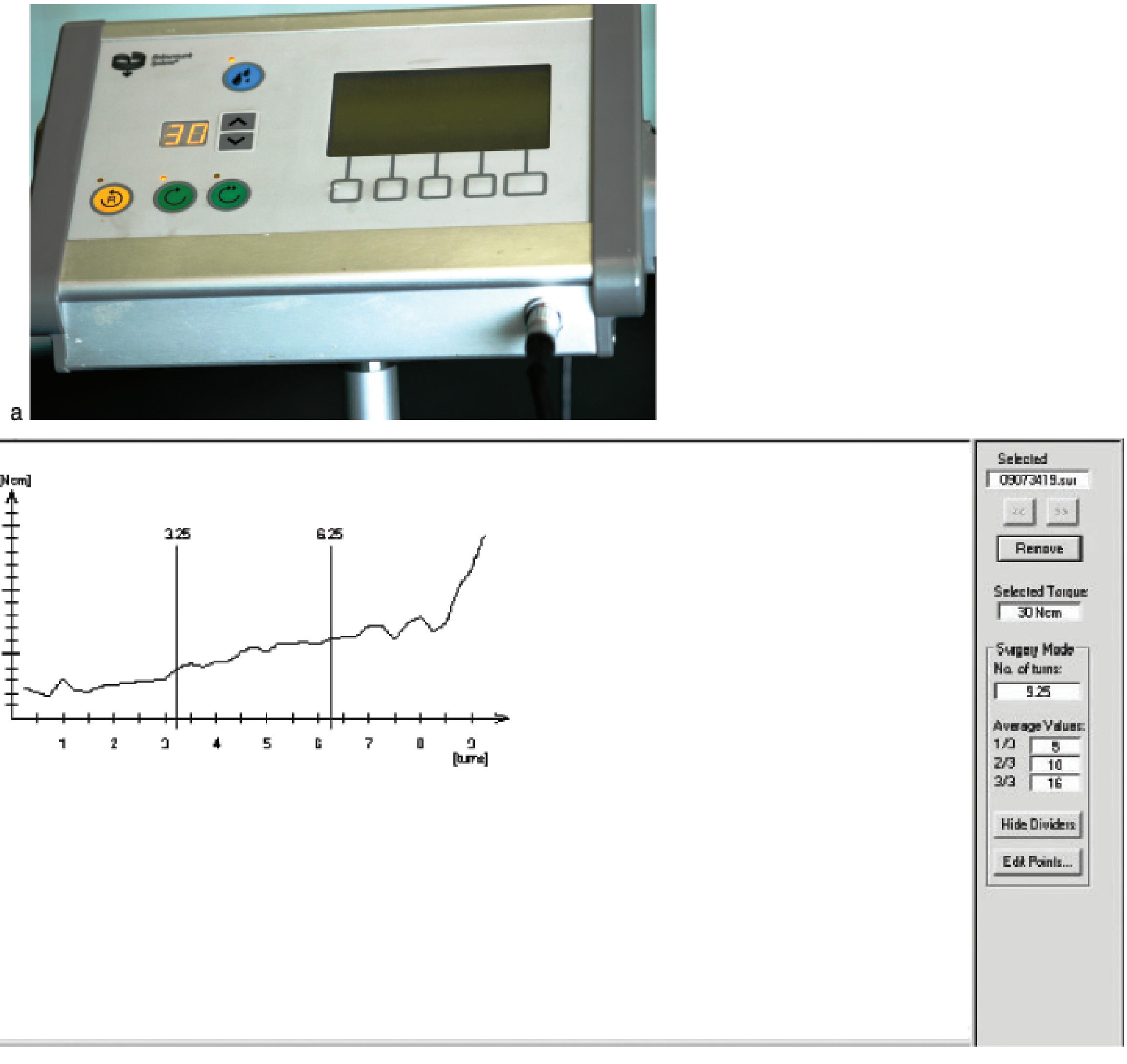

Fig. 2. (a) OsseoCare™ Unit. The screen shows a graph like (b). The OsseoCare™ software curve of the placement torque (N cm) in the first, second and third during implant placement.

close to the peg in a vestibular-oral and in a mesio-distal direction during the pulsing time. After the processing time, the ISQ value is presented on the display. The resonance frequency values are automatically converted into an arbitrary index called the ISQ. The ISQ, which runs from 1 to 100; the higher the ISQ, the more stable the implant. This index facilitates clinical evaluation (Meredith 1994, Meredith et al. 1996). The device was only available at implant placement for the last 141 patients. Unfortunately, because of technical problems encountered at the beginning, measurements could only be made on 71 patients provided with a total of 153 implants.

The rigidity of implant–bone continuum was also recorded by means of a Periotest® device (Siemens AG) after connecting a temporary abutment (Ceka®, Alphadent, nv, Antwerp, Belgium) 4 mm in length. Because of time pressure in the OR and/or patient-related factors, this procedure was only performed in a subgroup of 22 patients provided with a total of 44 implants. These PTV were also recorded at abutment surgery. This device measures the damping capacity of the implant–bone continuum. It consists of a hand-piece connected to a unit that analyses the braking time of the rod projected onto a surface (Tricio et al. 1995). The rod of the device is placed perpendicular to the abutment at a distance of 2 mm. Then, the rod is accelerated electromagnetically. When the rod hits the implant, it is decelerated. The faster the deceleration, the greater the implant stability in the bone tissue.

The values were only accepted when two consecutive measurements did not deviate more than one unit from each other. The arbitrary values can range from −8 (very stable) to +50 (extremely mobile) (Fig. 4).

Although not useful to assess the biomechanics of teeth, it appeared that the Periotest® was very useful for the assessment of implant stability (Olivé & Aparicio 1990, Teerlinck et al. 1991, van Steenberghe et al. 1995).

Statistical analysis

Data were statistically analysed by means of SAS® software version 9.1 for windows (SAS Institute, Cary, NC, USA). Pearson's correlation coefficients were calculated using PROC MIXED

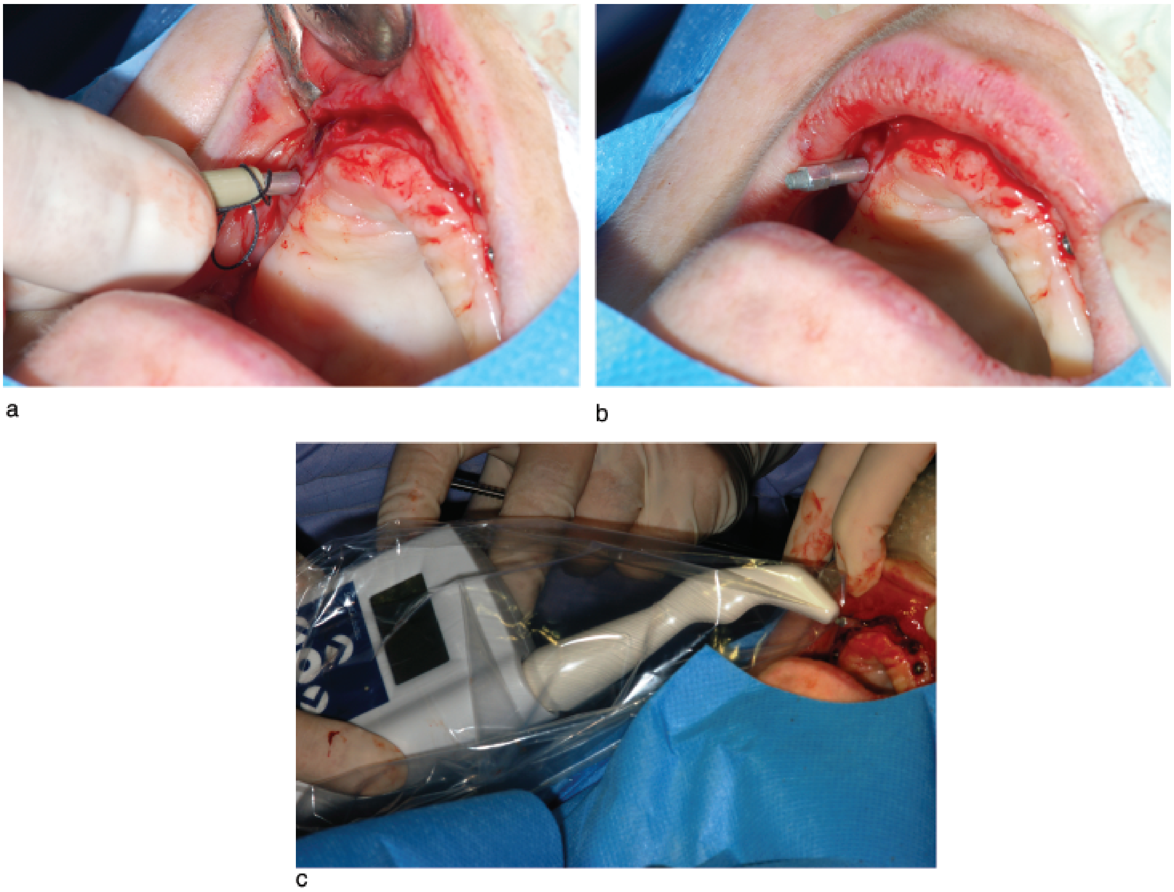

Fig. 3. (a, b) Fixation of the peg on the implant, (c) Osstell™ *Mentor;* stimulation and recording of the resonance frequency of the peg.

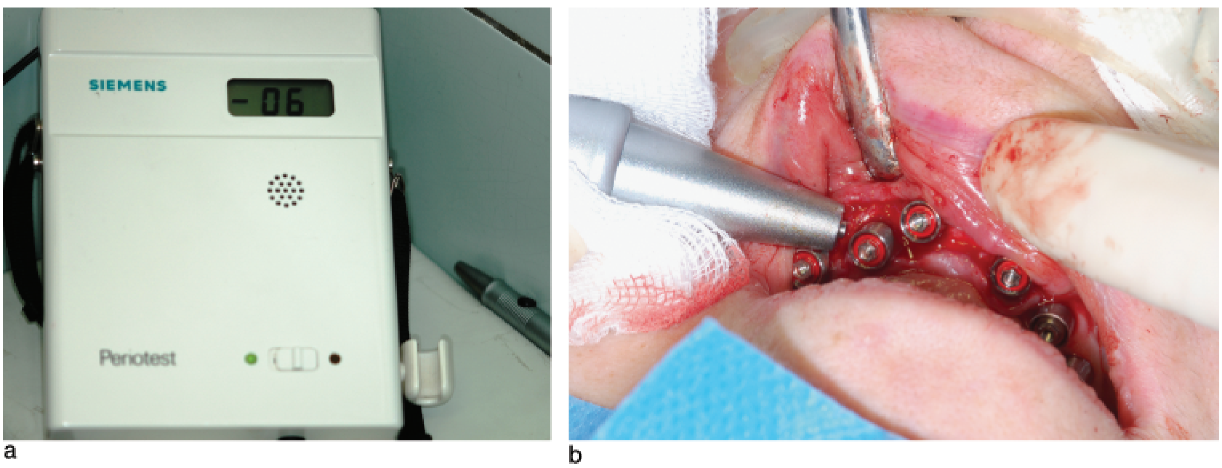

Fig. 4. (a) The Periotest® device with a digital display and the microphone for the artificial voice, (b) The rod hits the abutment after acceleration.

fitting a bivariate model. In order to assess mean differences statistically, a linear model was fitted in PROC MIXED with the corresponding response value, placement torque values in the crestal, middle and apical third separately, ISQ and PTV and covariates bone quality according to the Lekholm & Zarb (1985) index and bone quality as assessed by the surgeon's tactile sensation for the cortical and trabecular bone.

Multiple testing corrections by the Tukey's procedure for pair-wise differences when applicable were used.

The ISQ values at implant insertion were dichotomized (cutoff = 60). Based on these, a comparison for the placement torque measurements within each region separately was performed. The *p*-value was set to 0.05 to detect the level of significance.

Results

From a total of 761 implants, installed in the 298 patients, the placement torque

Table 2. Frequency distribution of 720 implants in the upper and lower jaws (UJ and LJ) and the corresponding placement torque measurements

Implant position	No. of implants	Crestal third (N cm)		Middle third (N cm)		Apical third (N cm)	
		Mean	SD	Mean	SD	Mean	SD
Lower anterior	157	4.52	2.87	10.15	5.66	15.69	6.96
Upper anterior	185	4.46	2.51	8.52	4.39	12.25	5.21
Lower posterior	177	4.05	2.24	9.41	5.50	14.64	6.30
Upper posterior	201	3.86	1.76	7.41	3.77	11.30	5.22
LJ	334	4.27	2.56	**9.76***	5.58	**15.13***	6.63
UJ	386	4.15	2.17	**7.95**	4.11	**11.75**	5.23
Total	720	4.21	2.36	8.79	4.93	13.32	6.15

*A significant difference was detected for placement torque measurement between upper and the lower jaw (p-values < 0.0001).

Table 3. Placement torque measurements *versus* bone quality assessment grades according to Lekholm & Zarb (1985)

	No. of implants	Crestal third (N cm)	Middle third (N cm)	Apical third (N cm)
Grade 1	109	4.22	9.58	15.21
Grade 2	322	4.67	10.03	14.85
Grade 3	241	3.76 *	* 7.41 *	* 11.39 *
Grade 4	47	3.28	5.49	8.38

A significant relationship was found between the Lekholm & Zarb index and the placement torque measurements (p < 0.0001).
*A significant difference was detected between the grades (p-value < 0.0001).

Table 4. Placement torque measurements related to the grades of bone quality assessment according to the surgeon's tactile sensation

	No. of implants	Crestal third (N cm)	Middle third (N cm)	Apical third (N cm)
Cortical bone				
Thick (grade 1)	323	4.22	9.70	15.06
Moderate (grade 2)	316	4.10	8.32 *	12.34 *
Very thin (grade 3/4)	66	3.58	6.85	10.06
Trabecular bone				
Dense (grade 1)	295	4.38	9.71	14.83
Moderate (grade 2)	331	4.24 *	8.60 *	12.92 *
Poor (grade 3/4)	87	3.62	6.39	9.84

Significant relationship was detected between the cortical bone grades and placement torque measurements in the middle and apical thirds (p-value < 0.0001), and between the trabecular bone and placement torque measurements in the crestal (p-value = 0.03), middle and apical thirds (p-value < 0.0001).
*Significant difference was detected between the grades (p-value < 0.0001).

Table 5. Frequency distribution of implants in the upper and lower jaws and the corresponding PTV and ISQ values at implant insertion and at abutment connection for the same implants

Mean	No. of implants	At implant insertion	At abutment connection
PTV			
UJ	11	− 1.00	− 3.27
LJ	6	− 5.00	− 3.50
Total	17	**− 2.41**	**− 3.35***
ISQ			
UJ	36	67.78	72.00
LJ	17	72.24	69.53
Total	53	**69.21**	**71.21***

*A significant difference was found between PTV values at implant insertion and at abutment connection (p-value < 0.05), and between ISQ values at implant insertion and at abutment connection as well (p-value < 0.0001).
PTV, periotest values; ISQ, implant stability quotient.

measurements in the crestal, the second and the apical third were recorded for 720 implants installed in 288 patients, and compared with implant position in the jaw. A significant difference was detected for placement torque measurement between anterior and posterior locations (p-value < 0.01). The missing data are due to inadvertent erasing of the Osseocare® data or due to technical problems with the machinery (Table 2).

For one implant, bone quality was not assessed because of the use of bone-filling material, and therefore the placement torque for 719 implants in 288 patients was measured and compared with the bone quality assessment according to the Lekholm & Zarb (1985) index. A significant relationship was detected between placement torque and the Lekholm & Zarb index (p-value < 0.0001) (Table 3).

The placement torque measurements of 705 implants were compared with the cortical bone thickness as assessed by the surgeon on the basis of his tactile grading. The very few missing data are related to for example placement of implant at the time of tooth extraction, the presence of filling material or accidentally deleted data.

For a total of 713 implants, the placement torque values were compared with the trabecular bone density as assessed by the surgeon on the basis of his tactile grading. Again, the very few missing data are related to factors as mentioned above (Table 4).

Comparisons were performed between ISQ measurements at implant insertion and at abutment connection for those implants (53) where both measurements were performed. The same was done for PTV (17) (Table 5).

To evaluate the relation between two objective assessments of bone quality, i.e. the insertion torque and ISQ measurements, a correlation was calculated on the part of the data for which these measurements were available. For a total of 136 implants the insertion torque as well as the ISQ values during surgery were measured (Fig. 5). The correlation coefficient between these two variables was calculated. The estimated correlation equals $\rho = 0.20$ (SE = 0.08). This coefficient is significantly different (p-value = 0.01). From the latter the placement torque measurement corresponding to ISQ < 60 was compared with the placement torque measurement $\geqslant 60$ (Table 6).

ISQ and PTV were also compared with the bone quality assessed according to the Lekholm & Zarb index. A

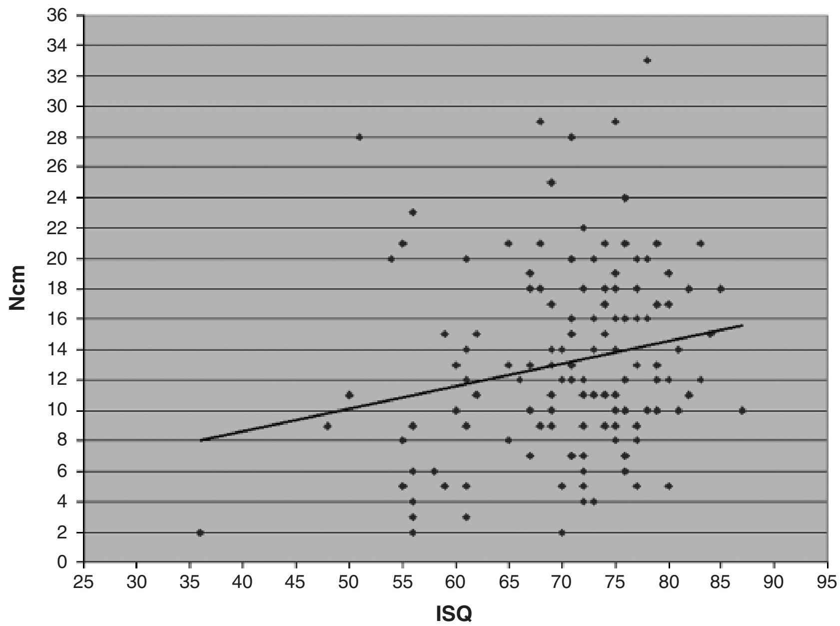

Fig. 5. Linear regression for placement torque at the apical third (N cm) and implant stability quotient (ISQ) values at implant insertion.

Table 6. The mean of placement torque measurements and corresponding ISQ values with a cut-off at 60 *(*p*-value = 0.05)

Torque measurements	Crestal third (N cm)	Middle third (N cm)	Apical third (N cm)
Correspondent to ISQ < 60	3.94	8.00	10.41 ⌉ *
Correspondent to ISQ ⩾ 60	4.34	9.13	13.52 ⌋

ISQ, implant stability quotient.

Table 7. ISQ of 146 implants compared with bone quality assessment according to Lekholm & Zarb index

	No. of implants	ISQ
Grade 1	14	73.29
Grade 2	65	69.61
Grade 3	64	70.15
Grade 4	3	55.00 *

*A significant difference was detected between the grades (*p*-value < 0.02).
ISQ, implant stability quotient.

Table 8. PTV values *versus* the grades of bone quality assessment according to Lekholm & Zarb for 44 implants

	No. of implants	PTV
Grade 1	7	− 5.29
Grade 2	19	− 3.74
Grade 3	18	− 1.61 *
Grade 4	0	/

*A significant difference was detected between the grades (*p*-value < 0.05).
PTV, periotest values.

significant relationship was detected (*p*-value = 0.01; Tables 7 and 8).

Furthermore, ISQ and PTV recorded at implant insertion were also compared with the bone quality assessed according to the surgeon's tactile sensation. A significant relationship was detected between ISQ, PTV and cortical bone grades (*p*-value = 0.02, < 0.0001, respectively), and between ISQ and trabecular bone grades (*p*-value = 0.01; Tables 9 and 10).

Discussion

Subjective assessments seem to have a limited value when trying to discriminate among bone qualities; the present data indicate that definitely for the extreme categories (1 and 4), the relationship with objective parameters is good. Especially today, where early or immediate loading of endosseous implants is being considered more and more, these biomechanical parameters may help the clinician to decide whether such deviation of the classical osseointegration protocol can be considered. Indeed, very large micromovements of endossesous implants can lead to fibrous encapsulation rather than bone apposition (Szmukler-Moncler et al. 1998), and this risk increases with a lower degree of bone density.

Although biomechanical assessments were only performed on a fraction of the patients for a variety of reasons, these data substantiate the main findings and provide new perspectives. The workload and the medical considerations or technical reasons sometimes led to the need to pursue only the patient treatment, and prevented data registration.

The insertion torque measurements were higher in the lower jaw, especially the symphyseal area, when compared with the upper jaw. The posterior region of the upper jaw has the lowest torque value, which is in agreement with a previous study (Friberg et al. 1999a). In the posterior maxilla, there is indeed frequently a (very) thin cortical bone combined with less dense trabecular bone (Jacobs 2003). Thus, clinicians generally observe a poor degree of bone mineralization on the radiographs and a limited bone resistance while drilling in this area (Friberg et al. 1995, 1999b).

Johansson et al. (2004) also found that cutting torque values correlated with the Lekholm & Zarb index of bone quality.

Homolka et al. (2002) found a significant correlation between bone mineral density measurements and the insertion torque measurements in cadaver mandibles.

A number of studies indicated that the failure rate is greater in the category of quality IV bone according to the Lekholm & Zarb (1985) classification (Engquist et al. 1988, Friberg et al. 1991, Jaffin & Berman 1991). Implant stiffness indeed means a higher bone-to-implant contact percentage (Rasmusson et al. 1998), which can explain the better prognosis.

In the literature, the ISQ readings obtained during the early phases of osseointegration revealed higher implant stability in the mandible compared with the maxilla (Ersanli et al. 2005). It is striking that this difference seems to decrease in the present study (see Table 5) during the osseointegration process. It may indicate that a better marrow content in the upper jaw may

Table 9. ISQ of 146 implants compared with bone quality assessment according to surgeon tactile sensation assessment

	No. of implants	ISQ	
Cortical bone			
Thick (grade 1)	64	70.27	*
Moderate (grade 2)	61	71.86	*
Thin/very thin (grade 3/4)	21	65.9	*
Trabecular bone			
Dense (grade 1)	71	69.42	
Moderate (grade 2)	52	72.53	
Poor/very poor (grade 3/4)	23	66.43	

*A significant difference between grades (p-value < 0.05).
ISQ, implant stability quotient.

Table 10. PTV values *versus* the grades of bone quality assessment according to the surgeon tactile sensation assessment for 44 implants

	No. of implants	PTV	
Cortical bone			
Thick (grade 1)	21	− 4.62	*
Moderate (grade 2)	13	− 2.83	*
Thin/very thin (grade 3/4)	10	− 0.30	*
Trabecular bone			
Dense (grade 1)	23	− 2.78	
Moderate (grade 2)	14	− 4.00	
Poor/very poor (grade 3/4)	7	− 1.71	

*A significant difference was detected between the grades (p-value < 0.0001).
PTV, periotest values.

speed up the bone apposition. Miyamoto et al. (2005) found a significant correlation between ISQ and the thickness of cortical bone. Nkenke et al. (2003), in a human cadaver study, found that RFA values did correlate with the surface of bone-to-implant contact, and with the height of the crestal cortical bone penetrated by the implants in the oral aspects of the implant sites. Ostman et al. (2006) found a significant correlation between bone quality and ISQ values, which is in accordance with the present study.

Friberg et al. (1999b) found a significant correlation between insertion torque and RFA measurements.

Previous reports indicate that the mean Periotest® values obtained for Brånemark system® implants placed in the maxilla were higher than for the mandible, indicating less rigidity (Olivé & Aparicio 1990, van Steenberghe et al. 1995). The same applies for ITI implants (Buser et al. 1990) and TPS (Salonen et al. 1993).

Bone quality assessment according to Lekholm & Zarb (1985) in the present study could be related to insertion torque measurements, ISQ and PTV.

Quirynen et al. (2005) observed that the PTV value of an implant was dominated by the cortical/crestal bone. This is illustrated by ''peri-apical lesions'' around implants where PTV values remain low, although much of the trabecular bone contact has disappeared. The Periotest® showed a correlation with the crestal cortical bone penetrated by the implants in the buccal aspect of the implant site. Previously, van Steenberghe et al. (1995) showed that the PTV values were lower for implants with a bicortical *versus* a monocortical contact.

Conclusions

The present clinical data illustrate that several objective measurement devices are available to assess bone-to-implant contact and primary or early stability. These measurements seem to be related to the categories of the Lekholm & Zarb index, which subjectively assesses bone quality on the basis of radiological aspects and the surgeon's tactile sensation.

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Clinical Relevance

Scientific rationale for the study: While clinicians mostly base their decision making on traditional opinions, the present paper offers objective parameters to determine a proper timing for the loading of oral implants: PTV, Resonance Frequency Analysis and insertion torque.

Principal findings: The present clinical data suggested that the subjective assessment of bone quality is related to PTV, ISQ and placement torque measurements at implant insertion.

Practical implications: The biomechanical assessments of implant primary stability and bone resistance during implant insertion may help the clinician to decide when early or immediate loading can be considered reasonable.