Clin Oral Invest (2012) 16:1679–1684
DOI 10.1007/s00784-011-0658-0

ORIGINAL ARTICLE

Relation between insertion torque and bone–implant contact percentage: an artificial bone study

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Received: 22 February 2011 / Accepted: 8 December 2011 / Published online: 10 January 2012

Abstract
Objectives The purpose of this study was to determine the correlation between the peak insertion torque value (ITV) of a dental implant and the bone–implant contact percentage (BIC%).
Material and methods Dental implants were inserted into specimens comprising a 2-mm-thick artificial cortical shell representing cortical bone and artificial foam bone representing cancellous bone with four densities (groups 1 to 4—0.32, 0.20, 0.16, and 0.12 g/cm^3). Each specimen with an inserted implant was subjected to micro-computed tomography (micro-CT) scanning, from which the 3D BIC% values were calculated. Pearson's correlation coefficients (r) between the ITV and BIC% were calculated.
Results The ITVs in groups 1 to 4 were 56.2±4.6 (mean±standard deviation), 45.6±0.9, 43.3±4.3, and 38.5±3.4 N cm, respectively, and the corresponding BIC% values were 41.5±0.5%, 39.0±1.0%, 30.8±1.1%, and 26.2±1.6%. Pearson's correlation coefficient between the ITV and BIC% was r=0.797 (P<0.0001).
Conclusion The initial implant stability, quantified as the ITV, was strongly positively correlated with the 3D BIC% obtained from micro-CT images.
Clinical relevance The ITV of a dental implant can be used to predict the initial BIC%; this information may provide the clinician with important information on the optimal loading time.

Keywords Initial implant stability · Insertion torque · Bone–implant contact · Micro-computed tomography

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Introduction

Implant stability is critical to the survival probability of a dental implant [1–7]. Implant stability can be divided into two stages: initial (or primary) stability and secondary stability [8]. The initial stability is a function of the mechanical stability immediately after inserting the implant into the bone, while the secondary stability is primarily affected by osseointegration, which is the bone ingrowth into the implant surface. Generally, a higher implant initial stability will result in more bone ingrowth, producing better osseointegration and a higher survival probability.

Despite the importance of the initial stability of a dental implant to osseointegration, there is still no method for directly measuring relative movement at the interface between the bone and implant. Indirect methods include the Periotest value and the resonance frequency [1, 9–15], which are the two most common methods in clinical applications, while the peak insertion torque value (ITV) has also often been used to quantify the initial stability [1, 8, 16–19]. A high ITV may indicate a mechanically stable implant [20].

The implant stability is theoretically affected by the bone–implant contact (BIC) area, with the structural stiffness being higher when a larger amount of bone is in contact with the implant, resulting in higher interfacial strength [16, 21]. In addition, Gedrange et al. [21] reported that the implant stability will increase with the amount of bone contact. However, Degidi et al. [16] and Nkenke et al. [17] indicated that there was no significant correlation between the ITV and BIC based on 17 dental implants retrieved from humans and three human cadaver jawbones. Moreover, Jun et al. [8] considered that the ITV was not a reliable parameter for predicting the BIC area.

Previous studies [8, 16, 17] that found no correlation between the ITV and BIC quantified BIC based on 2D histomorphometric evaluations. The use of one or only a few histological sections is very unlikely to accurately represent the entire 3D BIC between the implant and bone [20]. Therefore, the present study aimed to determine the relation between the 3D BIC percentage (BIC%), as measured using high-resolution micro-computed tomography (micro-CT) images, and the initial stability, as quantified by the ITV.

Materials and methods

Specimen preparation

Four cellular rigid polyurethane foam blocks (Sawbones, Vashon, WA, USA) representing cancellous bone with densities of 0.32 g/cm^3 (model 1522-12, group 1), 0.20 g/cm^3 (model 1522-1, group 2), 0.16 g/cm^3 (model 1522-10, group 3), and 0.12 g/cm^3 (model 1522-09, group 4) were attached to a 2-mm-thick synthetic cortical shell (model 3401-01) with a density of 1.64 g/cm^3 (Fig. 1). Artificial foam bone specimens with dimensions of $42\times20\times20$ mm^3 were prepared. Five specimens of each group were prepared for the measurements of implant stability and BIC%.

Measurement of peak insertion torque value

Pilot holes were drilled into each artificial foam bone specimen using a 3.2-mm-diameter drill, and a commercial dental implant (4 mm in diameter and 12 mm long; ATLAS Implant System, Cowell Medi, Busan, South Korea) was inserted according to the manufacturer's instructions. The peak ITV (in Newton per centimeter) was recorded for each specimen using a digital torque meter (TQ-8800, Lutron Electronic Enterprise, Taipei, Taiwan) (Fig. 2).

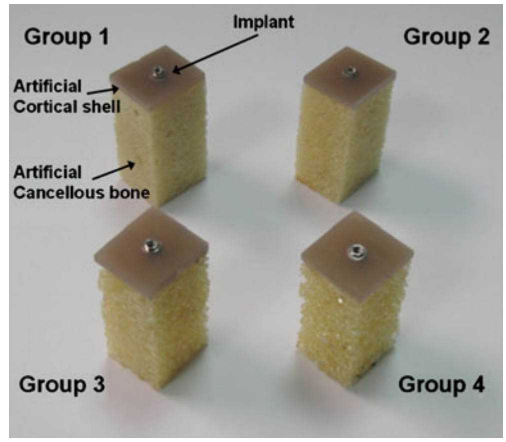

Fig. 1 Models of artificial foam bone with inserted implant as used in the experiments

Measurement of bone–implant contact percentage

The BIC% values were determined by using micro-CT (SkyScan-1076, Skyscan, Aartselaar, Belgium) to obtain 3D information about each specimen with an implant at a resolution of $17.2\times17.2\times17.2$ μm^3. The micro-CT images of each specimen with an implant were imported into professional medical imaging software (Mimics 10.0, Materialise, Leuven, Belgium) and then segmented using different thresholds for implant and bone (Fig. 3) [22]. The entire exterior surface area of the implant inside the specimen and the BIC area were then determined, with BIC% calculated as the area of the BIC region divided by the exterior surface area of the implant. In addition, the porosity was calculated in a region of approximately 4×

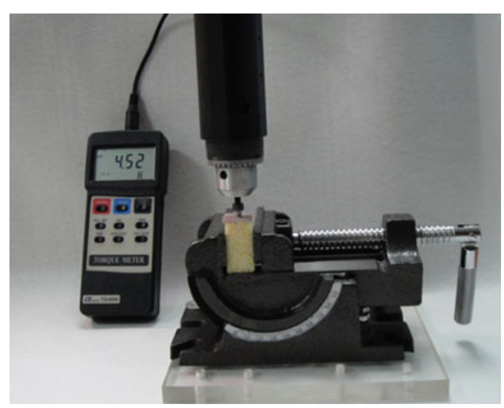

Fig. 2 Setup for measuring the peak ITV of the implants using a digital torque meter (Lutron TQ-8800)

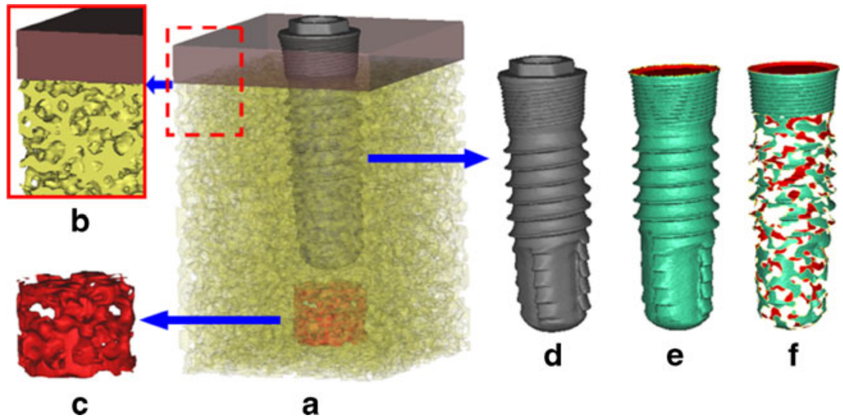

Fig. 3 *a* 3D model of the foam bone specimen with the inserted implant, *b* artificial cortical bone and cancellous bone (*closed view*), *c* cylinder region for the calculation of porosity, *d* 3D model of the implant, *e* exterior surface of the implant inside the artificial foam bone specimen, and *f* BIC region

3 mm^3 (diameter×height) away from where the implant was inserted in each artificial cancellous bone specimen.

Statistical analysis

The values of the ITV and BIC% of the implants and the porosities in the four groups of artificial foam bones were summarized as mean±SD (standard deviation) values, with differences between them tested using one-way analysis of variance. Pearson's correlation coefficient (r) was used to evaluate whether there was a statistically significant correlation between the ITV and BIC%. The significance cutoff level was deemed to be $P<0.05$. All statistical analyses were performed with SAS software (version 9.1.2, SAS Institute, Cary, NC, USA).

Results

Porosity of the artificial foam bone specimen

The porosities of the artificial foam bone specimens of the four groups are listed in Table 1. The porosity was highest in group 4 (lowest density, 83.5±0.6%) and lowest in group 1 (highest density, 62.3±0.2%). The SD of the porosity value was less than 1% in all of the groups, and the highest coefficient of variation of the four groups was 1.21% (0.8/66.1). This small variation indicates that the porosity was very consistent across all of the artificial foam bone specimens.

Insertion torque

The ITVs of the implants in the four groups are also listed in Table 1. The mean value of the ITV in the four groups ranged between 38.5 and 56.2 N cm and was higher in the foam bone specimens that had a higher density. However, the difference between groups 2 (45.6±0.9 N cm) and 3 (43.3±4.3 N cm) was not statistically significant.

Bone–implant contact percentage

The mean BIC% value ranged from 26.2% to 41.5% (Table 1). The 3D BIC% was the highest and the lowest in groups 1 and 4, respectively. There was strong positive correlation between the ITV and BIC% ($r=0.797$, $P<0.0001$) (Fig. 4).

Discussion

The initial stability of a dental implant crucially affects its long-term performance. Determining the ITV of an implant represents a nondestructive clinical approach for measuring the implant stability. The findings of previous studies imply that the implant stability is affected by the BIC area. Therefore, although BIC% should theoretically be predicted by

Table 1 ITV and BIC% values of artificial jawbone specimens

Group number	Artificial cortical bone thickness (mm)	Artificial cancellous bone			ITV (N cm)	BIC% (%)
		Density (g/cm^3)	Elasticity (MPa)	Porosity (%)		
1	2	0.32	137	62.3±0.2	56.2±4.6	41.5±0.5
2	2	0.20	47.5	66.1±0.8	45.6±0.9	39.0±1.0
3	2	0.16	23	79.2±0.4	43.3±4.3	30.8±1.1
4	2	0.12	12.4	83.5±0.6	38.5±3.4	26.2±1.6

The porosities of the four specimen groups are also listed. The values of density and elasticity were obtained from the manufacturer

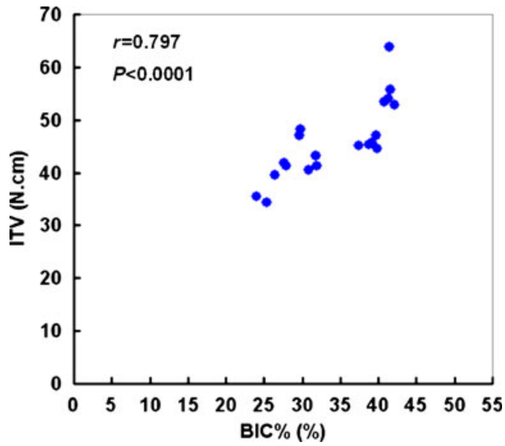

Fig. 4 Scattergraph illustrating the correlation between ITV and BIC%

the ITV, previous studies [8, 16, 17] found no significant correlation between the ITV and BIC. This might be due to the BIC being calculated in 2D histological analyses, since a single 2D histological section does not represent the entire 3D BIC around the implant [20]. The present study therefore used micro-CT to measure the 3D BIC% and correlated this with the ITV and found that Pearson's correlation coefficient (at r=0.797) was much higher than in the previous studies.

This study found that the ITVs were statistically related to the quality of artificial bone. The ITVs of the implants were in the range 38.5–56.0 Ncm, and even the upper value was markedly lower than the peak ITV that could break the surrounding bone (70 Ncm) [23]. These values are similar to those found by Rabel et al. [7]; they reported that the peak ITVs necessary to insert the implant into the bone ranged from 5 to 50 Ncm.

The initial stability of the implant is produced by the contact condition between the implant surface and the surrounding bone [7], and it is reasonable to assume that stiffer surrounding bone and a higher BIC% will result in a higher implant stability [21]. Trisi et al. [18] reported that an increased peak ITV could indicate reduced implant micromotion. In addition, a higher ITV probably reflects stronger primary fixation [24]. Moreover, Ottoni et al. [25] indicated that the ITV was associated with the probability of implant loss, which can decrease by 20% for every 9.8-N cm increase in the ITV. Moreover, Akca et al. [26] demonstrated that the ITV is the most sensitive implant stability quotient (obtained from the resonance frequency) for revealing biomechanical properties at the bone–implant interface. Therefore, based on this literature, the peak ITV should be suitable for evaluating the implant stability.

The range of elasticity values of the artificial cancellous bone used in this study was based on the work of Misch et al. [27]. We measured the porosity of each specimen in the lower part of the artificial cancellous bone, and not in the region where the implant was inserted, which made it unnecessary to calculate the relations between the porosity and both the ITV and BIC. However, the experimental results indicated that the porosity of each group was very consistent, with the SD being much less than the mean value. Previous studies [1, 2, 18, 28–30] found that the initial stability was greatly affected by the host bone quality and quantity. This is one of the reasons for using artificial foam bone rather than cadaver bone in this study, which focused on the relation between the ITV and BIC% in bone of different qualities.

Nkenke et al. [17] evaluated the relation between the ITV and BIC% in 48 stepped cylinder screw implants placed in two maxillary and two mandibular bones that were obtained from three human cadaver jawbones. They found no correlations between the ITV and BIC (P=0.277 and P=0.808 on the palatal and buccal sides). Also, Jun et al. [8] found no correlation (r=0.077, P=0.618) between ITV and BIC% measurements in 48 implants inserted into three maxillary and three mandibular bones obtained from three human cadaver jawbones. However, Jun et al. [8] focused on the relation between the initial stability (using the ITV, Periotest value, and resonance frequency) and the histomorphometry (BIC%) of implants inserted into extraction sockets, and not edentulous cadaver bone. In addition, they only calculated BIC% by measuring the contact length between the implant and bone divided by the implant length on the palatal and buccal sides. In addition, Degidi et al. [16] found no statistically significant correlation between the ITV and BIC% (P<0.892) based on 17 human-retrieved dental implants.

The finding of no correlation between the ITV and BIC% in previous studies is inconsistent with the present study finding a strongly positively correlation (r=0.797). The main reason for this discrepancy could be the use of 2D histological analysis by the previous studies to measure BIC% or BIC, since the 2D BIC% measured from a single histological section might not accurately represent the 3D BIC around the implant [20]. The present study calculated the entire 3D BIC% based on micro-CT images. The 3D BIC% should be more representative than the 2D BIC%, and this is supported by the coefficient of variation being much smaller for the 3D BIC% (obtained from the micro-CT approach) than for the 2D BIC% (obtained from histological analysis) [31]. The use of the micro-CT approach—as in this study—is supported by Jun et al. [8] stating in their "Discussion" section that "Additional research is needed to compare initial stability parameters and a 3D measurement of bone-to-implant contact." In addition, artificial foam bone specimens rather than animal bone were used in the present study. The consistency of foam bone specimens and the absence of osseointegration in the implants could mean that the measured values correspond to the initial stability of implants. This means that the ITV of an implant only depended on the BIC. The results indicated that the ITV was strongly positively correlated with 3D BIC%.

Some limitations of this study should be considered. First, the porosity of the artificial foam bones was very consistent, which might have artificially reduced the experimental error. The artificial foam bone specimens did not fully represent the real human jawbone. However, the ASTM F-1839 standard states that artificial foam bone is "…an ideal material for comparative testing of bones screws and other medical devices and instruments" [32]. The experiments performed in this study should be repeated with human cadaver bone specimens in order to confirm the obtained results. Second, the effect of cortical bone thickness on the initial stability was not evaluated in this study since it focused on evaluating the BIC behavior in cancellous bone. Moreover, the interfacial condition between the implant and cortical bone was not a total-contact one. Third, only a single type of implant was used in this study, and so the effect of different implant and thread shapes should be investigation in future studies. In addition, the initial stability of implants was only evaluated based on the ITV in the present study. Other methods for measuring the initial stability of an implant, such as the Periotest value and resonance frequency, should be applied in the future.

Conclusion

The experimental results obtained in this study indicate that the ITV decreases as the density/elasticity of the specimen increases as well as when the porosity of the specimen decreases. The initial implant stability, quantified as the ITV, was strongly positively correlated (r=0.797, P<0.0001) with the 3D BIC%, as measured from micro-CT images.

Acknowledgments This research was supported by China Medical University, Taiwan (grant number CMU 99-COL-43).

Conflict of interest None of the authors of this study has any financial and personal relationships with other people or organizations that could have inappropriately influenced this study.

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