The relationship between resonance frequency analysis (RFA) and lateral displacement of dental implants: an in vitro study

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SUMMARY This in vitro investigation was conducted to study the relationship between resonance frequency analysis (RFA) and lateral displacement measurements of dental implants. A total of 30 implant sites were prepared in nine fresh bovine bone specimens. The bone density around each preparation was determined by using cone beam computed tomography (CBCT) and imaging software. Dental implants were then inserted during continuous registration of insertion torque. RFA measurements were performed in perpendicular and parallel to the long axis of the specimens. The bone blocks were embedded in plaster and fixated in a specially designed rig for displacement measurements. A lateral force of 25 N was applied via an abutment perpendicular and parallel to each implant and the displacement measured in μm. In addition, a flex constant (μm N⁻¹) was calculated for each measurement. There was a significant inverse correlation between RFA and lateral implant displacement (μm) measurements and between RFA measurements and the flex constant in both perpendicular and parallel directions in bone (P ≤ 0.001). Moreover, both RFA and displacement measurements correlated with bone density (P ≤ 0.001). It is concluded that RFA measurements reflect the micromobility of dental implants, which in turn is determined by the bone density at the implant site.

KEYWORDS: primary implant stability, resonance frequency analysis, displacement, in vitro study, bone density

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Introduction

Extensive micromotion during healing and functional loading is one likely reason for implant failure as this may result in non-physiological conditions for bone formation and remodelling (1). This implies disturbed early bone healing at newly placed implants and bone resorption and fibrous tissue formation at successfully integrated implants when loading commences. It can be speculated that the risk of failure increases with increasing intensity and/or amplitude of micromotions, which in turn is determined by the magnitude of loading and the properties of the supporting bone. This notion is supported by clinical observations that implant failure is more common in low-density bone sites (2). Thus, clinical measurements of implant micromotion would be one way to identify implants at risk of failure. Resonance frequency analysis (RFA) represents a technique for non-invasive assessments of implant stability at any stage of treatment or follow-up (3). The technique has been demonstrated to evaluate implant stability as a function of interface...
stiffness (4). Experimental and clinical studies have shown bone density to be a predominant determinant of primary stability after implant placement as assessed with RFA, which further supports the findings of Meredith and co-workers. For instance, studies have shown RFA to correlate with insertion torque measurements (5–9), with clinical assessments of bone density (10–14) and with bone density measurements in CTs using Hounsfield units (7, 9, 15–17). As the test is based on that microscopic lateral forces are applied to the implant through a vibrating transducer, the RFA technique has been proposed to reflect the micromotion or displacement of the implant in bone when applying a lateral load (4). In fact, in a recent in vitro investigation, Trisi and co-workers (18) placed implants in bone specimens of different densities and found a correlation between RFA and displacement measurements. Their findings suggest that RFA can be used to understand how an implant can be displaced in bone during loading. However, no objective assessments of bone density were made and their results may be valid only for the type of implant used in their study.

The purpose of this in vitro study was to investigate the relationship between objective bone density measurements, RFA and lateral displacement of Neoss implants in bone of known density.

Materials and methods

Experimental procedure

A total of 30 mono-cortical implant sites were prepared in nine fresh bovine bone specimens at 2000 rpm (Elcomed SA310™) during irrigation with saline using 2-2, 3-0 and 3-4 mm twist drills to a depth of 15 mm followed by a full countersink preparation (†). The specimens were then scanned with a cone beam computed tomography (CBCT) scanner at 105 kV and 8 mA using a 120 mm × 80 mm field of view (FOV) (WhiteFox‡). The images were processed in imaging software allowing for bone density assessments in Hounsfield units (HUs) (White Fox Imaging†). In brief, a virtual probe was placed at the drilled sites and HUs were measured in a 1 mm wide circular corridor 4 mm around the central long axis of the site (Fig. 1 a and b) (9).

A total of 30 dental implants (13 mm long/4 mm in diameter§) were inserted using a motor unit (Elcomed SA310™) set on 20 rpm and a maximal insertion torque of 80 Ncm. The implants were inserted until the head was flush with the surrounding bone level. The insertion torque was continuously registered and data saved on a memory card in the unit. This procedure resulted in a torque/time curve for each specimen and a mean insertion and a peak insertion torque value was used. If the implant stopped before reaching desired position, it was seated by hand with a wrench and the peak torque registered as >80 Ncm.

Resonance frequency analysis (RFA) measurements were carried out using an Osstell ISQ instrument and a SmartPeg (Type 18§) in implant stability quotient

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(ISQ) units (Ostell AB). The SmartPeg was attached to each implant with a torque of 4–6 Ncm. Measurements were performed in perpendicular and parallel to the long axis of the bone blocks.

A specially made rig consisting of a vice, a motorised force transducer, a digital micrometre gauge, and a computer was used for displacement measurements (Fig. 2). The bone blocks were stabilised in plaster for firm fixation in the vice. A custom-made abutment (Neoss Ltd), 12 mm high and 10 mm in diameter, was attached to each implant using 15 Ncm of torque prior to each measurement as recommended by the manufacturer. A lateral force of 25 N was applied for 2 s 10 mm above the abutment–implant junction and the displacement was measured in μm with the micrometre gauge placed on the opposite side of the abutment. Measurements were performed in perpendicular and parallel directions to the long axis of the bone block and continuously registered during the loading with the computer using a TRACERDAQ PRO software. To evaluate the rigidity of the vice and the deflection of the abutment, displacement tests were performed at 25 N on a metal beam fixed in the vice and on an implant embedded in plaster. No displacement of the metal beam could be measured, indicating complete rigidity of the system. A displacement of 20 μm was measured for the special abutment when connected to the implant in plaster. Thus, it can be anticipated that the deflection of the abutment cylinder was 20 μm or less.

Statistics

The Spearman’s correlation test was used to find possible correlations between the different parameters of the study. A statistically significant correlation was considered if $P \leq 0.05$.

Results

There was a linear relation between load and displacement (Fig. 3a and b). Unloading resulted in gradual repositioning of the implant to its initial position (Fig. 3a), except in three cases of low density where the loading test in perpendicular direction permanently deformed the site. Thus, a second test in parallel direction could not be performed in these three cases.

Fig. 2. Showing set-up for displacement measurements. A bone specimen with 4 implants is embedded in plaster and fixed in a vice (centre). A specially designed abutment has been connected to one implant. A motorised load transducer (left) was used to apply a 25 N load for 2 s. A micrometre gauge (right) was used to measure the displacement.

Fig. 3. (a) Load/displacement plot for an implant in dense bone showing a linear relationship. Curve shows return of the implant to its original position when unloaded. (b) Load/displacement plot for an implant placed in soft bone.

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sites. In spite of this, the load/displacement plot showed linearity up to the point of deformation. Regression analysis was applied to calculate the flex constant (\(\mu mN/C_0\)) for each site and test. The outcomes of all measurements are presented in Table 1.

Due to technical mishaps, data from 29 and 26 implant sites could be used for correlation analysis of ISQ and displacement measurements in perpendicular and parallel directions, respectively. Correlation analysis showed a significant inverse linear correlation between ISQ and displacement measurements (Fig. 4a and b) and between ISQ and the flex constant (Fig. 5a and b) in both perpendicular and parallel directions (\(P \leq 0.0001\)). Also, bone density in HUs correlated significantly with ISQ and inversely with displacement and flex constant measurements (\(P \leq 0.0001\)) (Fig. 6a–c).

**Discussion**

The results from the present *in vitro* investigation showed a statistically significant correlation between RFA and lateral implant displacement measurements in bovine bone specimens of various densities. Numerous experimental and clinical studies have shown the biomechanical properties, that is, stiffness/bone density at the implant site to be the predominant determinants of primary stability as measured with RFA (4). It was therefore logical to assume that lateral implant displacement/micromovements would be influenced by bone density in a similar way and thus correlate with ISQ units as measured with RFA. Moreover, the results corroborate with a recent *in vitro* study by Trisi and co-workers (18), which was the first to demonstrate a correlation between RFA and micromotion/displacement measurements. The findings from that and the present study suggest that RFA measurements can be used to assess the resistance to lateral loading also in the clinical setting. Thus, the lower the ISQ values, the higher the risk of extensive micromotions at the interface, which may be deleterious for implant healing and maintained stability. In fact, clinical studies have shown increased numbers of implant failures with decreased or low ISQ units (15, 19–21). The statistical analysis also showed a significant correlation between bone density (HUs) and RFA (ISQ) measurements, which is in line with a previous pilot study in patients where the same implant system and software as in present study were used (9). The results imply that the bone density probe may be used to estimate implant stability during pre-surgical planning in the utilised imaging software. The present research group has initiated a prospective clinical study to evaluate this.

![Correlation plot for ISQ and displacement measurements](image)

**Fig. 4.** (a) Correlation plot for ISQ and displacement measurements in perpendicular direction, \((\rho = –0.861, P \leq 0.0001)\) (b) Correlation between ISQ and displacement measurements in parallel direction, \((\rho = –0.887, P \leq 0.0001)\)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>(N)</th>
<th>Mean ± s.d.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone density (HU)</td>
<td>30</td>
<td>418 ± 348</td>
<td>–85–1079</td>
</tr>
<tr>
<td>Peak insertion torque (Ncm)</td>
<td>29</td>
<td>31.6 ± 28.7</td>
<td>7–80*</td>
</tr>
<tr>
<td>Mean insertion torque (Ncm)</td>
<td>29</td>
<td>13.2 ± 10.0</td>
<td>4.1–33.9</td>
</tr>
<tr>
<td>RFA perpendicular (ISQ)</td>
<td>29</td>
<td>65.7 ± 11.8</td>
<td>44–84</td>
</tr>
<tr>
<td>RFA parallel (ISQ)</td>
<td>29</td>
<td>69.0 ± 11.9</td>
<td>48–85</td>
</tr>
<tr>
<td>Displacement perpendicular ((\mu m))</td>
<td>29</td>
<td>471.5 ± 624</td>
<td>26–2334</td>
</tr>
<tr>
<td>Displacement parallel ((\mu m))</td>
<td>26</td>
<td>360.3 ± 573.3</td>
<td>22–2244</td>
</tr>
<tr>
<td>Flex constant perpendicular ((\mu mN^{-1}))</td>
<td>29</td>
<td>8.5 ± 8.3</td>
<td>1.0–24.4</td>
</tr>
<tr>
<td>Flex constant parallel ((\mu mN^{-1}))</td>
<td>26</td>
<td>4.3 ± 5.2</td>
<td>0.6–25.8</td>
</tr>
</tbody>
</table>

*Measurements above 80 Ncm could not be made but registered as 80 Ncm.

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The design of the present study was based on the work by Trisi et al. (18, 22) who used a similar experimental set-up. Varying lateral loads from 20 to 30 N have previously been used. The present study used 25 N for 2 s, which is the same load/time as used by Trisi et al. (18). Implants were only loaded once in perpendicular and parallel directions, which is different to Trisi et al. (18), who loaded implants with 25 N for five times. The reason for loading once was to diminish the risk of permanent deformation of the site and to be able to make a second test 90 degrees to the first one. In fact, three sites in soft bone showed such deformation after the first test and a second displacement test could not be made.

In this in vitro model, we observed a linear response to the lateral force in most specimens, because the implants were displaced and returned to their original positions when unloaded. However, in specimens with extraordinary soft bone, a non-linear relation was observed. This means that these sites were deformed and that both the implant and the supporting bone were displaced. From a methodological point of view this suggests that the lateral force used in the experiment was too high for the soft bone specimens. Consequently, if a lower lateral force had been used, the dispersion of the displacement data had probably been less. However, also in the soft bone specimens, there was linearity up to a certain force level and this is why a flex constant was calculated by regression analysis of the linear part of the force/displacement

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curve. Figure 5 a and b show less dispersion in soft bone with the exception of one extreme value, although the overall correlation is similar as in Fig. 4 a and b. It is possible that the use of polyurethane blocks with defined biomechanical properties would be one way to overcome the problems with biological bone specimens when investigating implant stability in soft bone in future investigations (23).

In the present study, a standard preparation procedure was used for the implants in all bone densities. Moreover, all implants were placed with the head in level with the surrounding bone. Thus, a pre-set desired insertion torque was not used and all implants needed different torques for seating. In a clinical setting, different drilling protocols had probably been used to assure firm stability in low-density bone and to ensure seating without excessive torque in dense bone. These issues need to be addressed in further experiments using displacement measurements. Also the influence of implant length and diameter would be interesting to study, because the influence of these factors on stability is not well understood (4).

In conclusion, the present in vitro experiment showed significant correlations between ISQ and displacement measurements in various bone densities. Moreover, the study also showed a correlation between bone density and ISQ and displacement measurements.

Acknowledgments

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References


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[Correction added on 28 January 2013, after first online publication: the flex constants N μm⁻¹ have been corrected to μm N⁻¹ throughout the article.]