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The Applicability of Resonance Frequency Analysis (RFA) in Evaluation Implant Stability*

SUMMARY

The most important prerequisite for successful osseointegration is achievement and maintenance of implant stability. Recent clinical findings have demonstrated that only implants with high primary stability can be subjected to immediate loading protocol with predictable result. The purpose of this in vivo study was: (1) to determine the changes in implant stability after 6 months of functional loading by using RFA; (2) to evaluate implant stability of 4 implant systems utilizing different techniques for preparing surface roughness; and (3) to compare the results of RFA measurements with histomorphometrical data.

2 mongrel dogs were edentulated bilaterally in the mandibular and maxillary premolar areas. After 3 months, implants were placed in a pattern, 4 different implants per quadrant (n=32): (1) Mk III (RP), TiUnite, Nobel Biocare, Sweden D-3.75, L-10; (2) ITI-Screw, ITI TPS, Straumann, Switzerland D-4.1, L-10; (3) 3I-Osseotite, Implant Innovation, USA D-3.75, L-10; and (4) XiVE, Cell-Plus, Friadent, Germany D-3.4, L-11. Implants were subjected to immediate loading with 4 unit gold cast bridges (3-5days post implantation). Resonance Frequency Analysis - RFA, (Osstell^{tm}, Integration Diagnostics, Sävedalen, Sweden) was used for measurement of implant stability after insertion, as ISQ surgical, and 6 months later, as ISQ prosthetic. Histomorphometrical evaluation - BIC%, the percentage of implant to bone contacts were quantified in the defined zone of interest (total peri-implant area) by computer assisted histomorphometry.

In this experimental setting, all evaluated surfaces achieved a good bone-to-implant contact and implant stability. The study demonstrated no statistically significant difference in implant stability and amount of bone-to-implant contact between implant systems utilizing different techniques for preparing surface roughness. Decrease or increase of ISQ values were not always correspondent to histomorphometrical data.

Key Words: Implant, stability; Resonance Frequency Analysis; Histomorphometry

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Introduction

Immediate loading is considered to be the most innovative technique in contemporary implant dentistry. Recent clinical and experimental findings have demonstrated that implants can be subjected to immediate loading protocol with predictable results, if certain preconditions are fulfilled, such as implant stability and high bone density[1]. It is generally accepted that the most important pre-requisite for successful osseointegration is achievement and maintenance of implant stability. Primary stability occurs at the time of implant placement and is related to the level of primary bone contact, site preparation technique, and implant selection. Implant design and surface characteristics claim to be important factors for implant stability and time-reduced healing period as immediate or early treatment protocol[2]. Implants having high primary stability can be immediately loaded after surgical treatment with temporary or final prosthetic restoration.

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From the perspective of clinical reality, clinicians need a routine method to determine if implants have been successfully osseointegrated to be safe to load them. Meredith et al[9] presented a resonance frequency analysis (RFA) as repeatable, non-invasive diagnostic procedure for clinical assessment of implant stability and osseointegration[3].

The purpose of this *in vivo* study was:

1. To determine the changes in implant stability after 6 months of functional loading by using RFA;
2. To evaluate implant stability of 4 implant systems utilizing different techniques for preparing surface roughness;
3. To compare the results of RFA measurements with histomorphometrical data.

Material

In experimental study, 4 different types of commercially available implants were evaluated:

- **Mk III (RP), TiUnite**, Nobel Biocare, Sweden D-3.75, L-10;
- **ITI-Screw**, **ITI TPS**, Straumann, Switzerland D-4.1, L-10;
- **3I-Osseotite**, Implant Innovation, USA D-3.75, L-10 i
- **XiVE, Cell-Plus**, Friadent, Germany D-3.4, L-11.

The following implant systems were chosen due to their widely use in implant dentistry and their typical surface processing and roughness pattern.

TiUnite- and TPS- surface are presenting additive surface treatment, while for Osseotite and XiVE implants ablative surface treatment is used. TiUnite is prepared with electrochemical anodic oxygenation to generate 50 to 100μm thick porous Ti-oxide layer on implant surface[4]. The TPS surface is classical titan plasma sprayed surface processed by melting titanium powder in high temperature to cover the implant with a 3-dimensional roughness. The double etching with HCl-acid generates the micro-structured Osseotite surface with 1 to 2 μm large pits. The surface is very homogenous by the high temperature etching process[5]. The XiVE CELL-plus surface is a bi-modular surface done by sandblasting with 250 to 500 μm large grid, followed by a high temperature acid etching (H_2SO_4, HCl, HF).

Methods

o **Resonance Frequency Analysis - *RFA,*** (Osstell^{tm}, Integration Diagnostics, Sävedalen, Sweden) was used for measurement of implant stability after insertion, as *ISQ surgical*, and 6 months later, as *ISQ prosthetic*. ISQ value is Implant Stability Quotient, scaled from 1 to 100; the higher ISQ reflects that implant is more stable.

o **Histomorphometrical evaluation - *BIC%*,** the percentage of implant to bone contacts were quantified in the defined zone of interest (total peri-implant area) by computer assisted histomorphometry.

o **Statistical analysis:** t-test, Mann Whitney U-test, Kruskal Wallis test, Pearson correlation test.

Experimental design

- 2 mongrel dogs were edentulated bilaterally in the mandibular and maxillary premolar areas;
- After 3 months, implants were placed in a pattern, 4 different implants per quadrant (n=32);
- Resonance Frequency Analysis (RFA) was performed after implant placement as *ISQ surgical*;
- Implants were subjected to immediate loading with 4 unit gold cast bridges (3-5days post implantation);
- 4-step intra-vital fluorochrome labelling:
  1 week post-implantation - ***Oxytetracycline*** 15 mg/kg BM,
  3 weeks post-implantation - ***Xylenol orange*** 90 mg/kg BM,
  12 weeks post-implantation - ***Alizarin red komplexon*** 30 mg/kg BM,
  14 weeks post-implantation - ***Calcein green*** 15 mg/kg BM;
- 6 months post implantation animals were sacrificed respectively and RFA measurements for *ISQ prosthetic* were done. Then, implants were removed with surrounding tissues *via* block sections after perfusion fixation with neutralized Schaffer's formalin-ethanol solution, and the specimens were embedded into PMMA (Technovit®7200, Heraeus Kulzer, Germany). The samples were cut parallel to the longitudinal axis of the implant in an oro-vestibular direction. By the „sawing and grinding"-technique (Donath, 1988), they were prepared to a thickness of 100 μm (Exakt Apparatebau GmbH, Germany).
- Undecalcified, surface stained ground sections 100 μm thick and corresponding microradiographs (MRG) were prepared and digitally scanned. After defining 3 different contrast qualities (**Bone-Implant-Background**), they were digitally coloured and the percentage of implant to bone contact (BIC%) could be calculated. Degree of bone-implant contact and the area of bone occupying the lingual and buccal side of the implants were measured.

Results

After the loading period of 6 months, from the clinical point of view, all bridges were in function and all implants occurred as well osseointegrated. The ISQ values

showed an increase in average, between surgery and recall. The mean value for *ISQ surgery* for all implants was 70.38±5.75 and for *ISQ prosthetic* 79.63±8.63. When summarizing the ISQ values, it was noted that resonance frequency was significantly higher for mandibular implants. In the mandible, the mean value was 72.25±5.64 for *ISQ surgical* and 84.81±2.97 for *ISQ prosthetic*; in the maxilla, the following values could be determined *ISQ surgical* 68.50±5.38 and *ISQ prosthetic* was 74.44±9.36. While the standard deviation of the values in the mandible was reduced between surgery and recall, the standard deviation for the maxilla increased. At the time of surgery, the highest mean value was determined for the **XiVE** system with 74.38±4.57. At the time after 6 months of clinical function (*ISQ prosthetic*), the highest value was found 80.88±7.90 for the **Osseotite** system.

The differences between ISQ surgery and recall were determined. In the mandible, an increase of the ISQ value was always observed. In the maxilla, the ISQ value decreased for the **TiUnite**, **ITI TPS** and **XiVE** system, even if the implants showed clinical signs of successful osseointegration after 6 months of loading. The box-plots show the spreading of the values. The variation of *ISQ prosthetic* was lowest in mandible for the **TiUnite** and for the **ITI TPS** in maxilla. The highest variation for *ISQ surgical* was determined for the **Osseotite** system in the mandible, and for **ITI TPS** in the maxilla.

The histomorphometrical data revealed the highest values for **XiVE** with 65.03±7.68, followed by **Osseotite** 64.17±13.90 and 61.71±26.75 for **ITI TPS**, and the lowest value for **TiUnite** with 51.53±29.83. Greater bone to implant contact was achieved for implants in mandible 67.29±10.15, and lower for maxilla 53.93±27.04.

Table 1. ISQ values

Statistical parameters		Mean value (X)	Mediana (Med)	Standard deviation (SD)	Minimum (Min)	Maximum (Max)	CI95%
ISQ surgical		70,38	69,00	5,75	59	81	68,30-72,45
ISQs	Mandible	72,25	72,50	5,64	62	81	69,25-75,25
	Maxilla	68,50	69,00	5,38	59	77	65,63-71,37
ISQs	Osseotite	67,25	69,00	5,87	59	74	62,34-72,16
	TiUnite	71,38	69,50	4,90	66	81	67,28-75,47
	TPS	68,50	68,00	5,68	62	77	63,75-73,25
	XiVE	74,38	74,50	4,57	68	80	70,56-78,19
ISQ prosthetical		79,63	82,00	8,63	58	92	76,51-82,74
ISQp	Mandible	84,81	85,00	2,97	81	92	83,23-86,40
	Maxilla	74,44	77,50	9,36	58	86	69,45-79,42
ISQp	Osseotite	80,88	81,50	7,90	65	92	74,27-87,48
	TiUnite	79,00	82,50	9,52	62	88	71,04-86,96
	TPS	78,88	84,50	10,88	58	88	69,78-87,97
	XiVE	79,75	81,50	7,44	63	86	73,53-85,97
ISQ difference		9,25	10,00	8,98	-10	27	6,01-12,49
ISQp - ISQs	Mandible	12,56	12,00	6,79	2	27	8,94-16,18
	Maxilla	5,94	5,00	9,86	-10	23	0,68-11,19
	Osseotite	13,63	12,00	8,37	2	27	6,63-20,62
	TiUnite	7,63	8,50	8,75	-7	18	0,31-14,94
	TPS	10,38	12,00	11,71	-10	24	0,59-20,16
	XiVE	5,38	6,50	5,50	-5	12	0,78-9,97

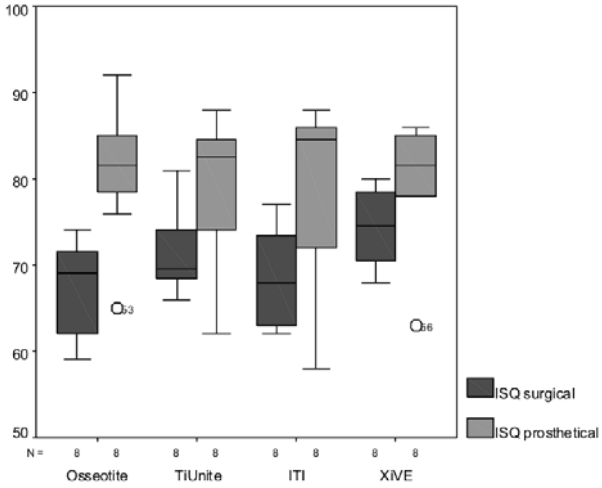

Figure 1. ISQ values

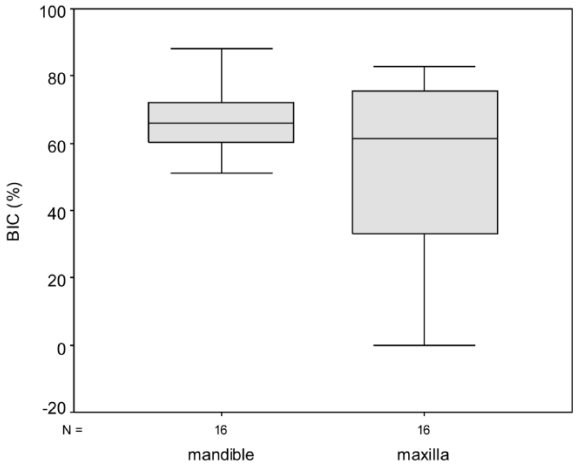

Figure 4. BIC values between implants in mandible and maxilla

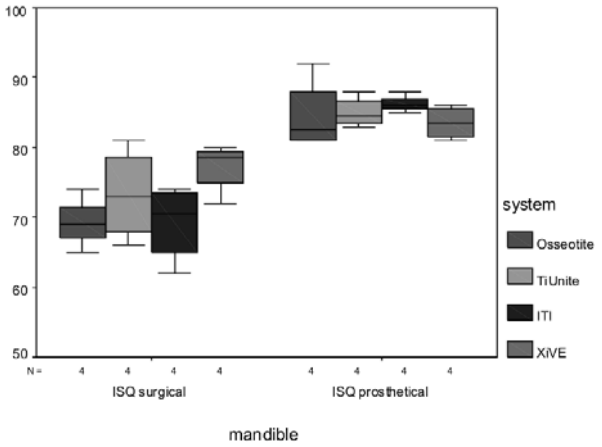

Figure 2. ISQ values in mandible

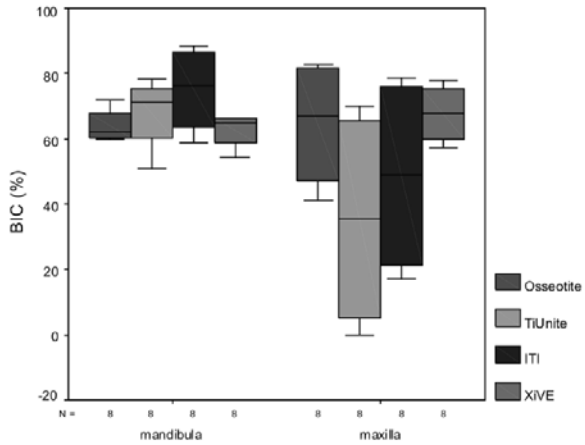

Figure 5. BIC values between different implant systems

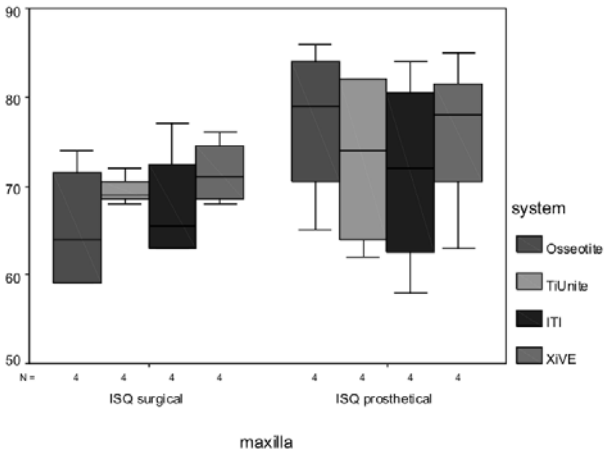

Figure 3. ISQ values in maxilla

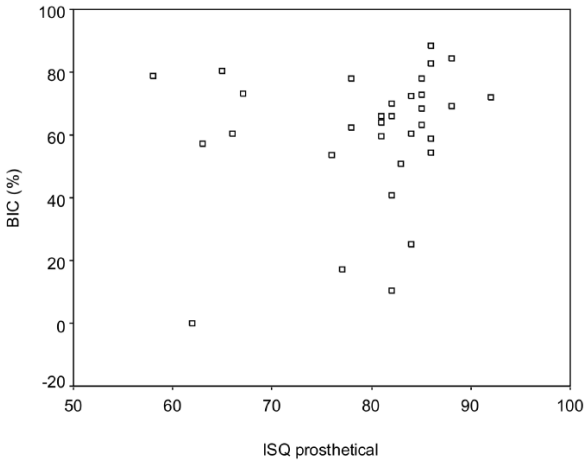

Figure 6. Correlation between BIC- and ISQ- values

Table 2. BIC values

Statistical parameters		Mean value (X)	Mediana (Med)	Standard deviation (SD)	Minimum (Min)	Maksimum (Max)	$CI_{95\%}$
BIC%		60.61	65.10	21.21	0.00	88.32	52.96-68.25
BIC%	Mandible	67.29	66.17	10.15	50.99	88.32	69.25-75.25
	Maxilla	53.93	61.49	27.04	0.00	82.78	39.52-68.34
BIC%	Osseotite	64.17	62.23	13.90	40.94	82.78	52.55-75.79
	TiUnite	51.53	64.96	29.85	0.00	78.13	26.57-76.48
	TPS	61.71	70.62	26.75	17.23	88.32	39.34-84.08
	XiVE	65.03	64.72	7.68	54.26	77.82	58.60-71.45

Discussion

RFA is becoming established as additional diagnostic tool for evaluating stiffness at the implant/bone interface. RFA method provides a possibility for clinical measurements of implant stability and monitoring of the implant response to occlusal loading. Implants with falling stability due to premature or overload situation can be detected and rescued before failure[6]. It has been recommended that ISQ of 60-65 reflects a lower limit for performing immediate loading and that RFA value below 40 ISQ units most likely represents a failed implant[7].

Still, this technique is under development and evaluation, and no absolute clinical guidelines can be given at this stage. However, the data and experience so far point to that the technique is more sensitive than other clinical methods and it should be used to support or confirm decisions based on other factors. Meredith suggested that RFA values can contribute to individualisation of implant therapy and guide the clinician regarding surgical procedure (one- vs. two-stage), timing of prosthodontic treatment (immediate, early or delayed loading protocol), duration of healing period, and type of prosthetic construction[3,6].

Generally, higher values of ISQ can be observed in solid bone, such as the mandible. In the maxilla, the ISQ levels are usually lower corresponding to the predominant bone quality[8]. This was confirmed with our results, because the differentiation of the stability patterns showed that overall stability level was higher for mandibular implants. ISQ values increased for all mandibular implants under loading conditions, while maxillary implants exhibited partially decrease of stability. The comparison of ISQ readings of various surface types demonstrated no significant difference between implant systems. The histomorphometrical quantification of bone to implant contact also showed a trend for better results in favour of the mandible. The results of both methods indicated that all implants reached a similar amount of bone to implant contact and stability over time. It has to be taken into consideration that study was performed with limited number of animals and implants, but trends are visible.

Many authors used RFA and histomorphometrical method to evaluate implant stability[9-12]. In some animal studies, TiUnite and Osseotite implant surfaces were analyzed, and TiUnite resulted in significantly higher BIC and ISQ values, but implants were not loaded and measurements were done after 6-10 weeks of healing[13,14]. Sennerby and Miyamoto[15] concluded that TiUnite implant showed a more rapid increase of stability compared to the SLA surface, possibly as combined effect of the surface, design and preparation features. Considering results reported from clinical immediate-loading studies, the difference in surface texturing of the implants did not significantly influenced implant stability[16,17]. Others suggested that surface modification and design features are less important for determining implant stability in dense bone. In soft bone, initial implant stability can be improved by implant design, as well as by preparation technique[18].

Conclusions

1. In this experimental setting, all evaluated surfaces achieved a good bone-to-implant contact and implant stability.
   - Increase of ISQ values for all implants in the mandible during prosthetic loading with 4 unit bridges;
   - Partially decrease of ISQ values for maxillary implants after 6 months functional loading.
2. The study demonstrated no statistically significant difference in implant stability and amount of bone-to-implant contact between implant systems utilizing different techniques for preparing surface roughness.
3. Decrease or increase of ISQ values were not always correspondent to histomorphometrical data. In this study no significant correlation was found between RFA- and histomorphometrical- results (ISQp / BIC, performed by the Pearson Test: R=0.182, p=0.318).

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