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Investigation of Initial Implant Stability with Different Dental Implant Designs. A Pilot Study in Pig Ribs Using Resonance Frequency Analysis

Linish Vidyasagar, Girts Salms, Peteris Apse, Uldis Teibe

SUMMARY

Primary implant stability appears to be a prerequisite for successful bone integration of dental implants. A quantitative method of assessing osseointegration becomes essential for serving as a baseline and to be able to follow the measurement with time. A recently developed apparatus (Osstell; Integration Diagnostics AB, Sweden) uses resonance frequency (i.e. tuning fork principle) to determine implant stability. The use of resonance frequency analysis may provide an objective approach to measuring initial implant stability by being able to detect changes in micromotion that could be associated with increase or decrease in degree of osseointegration. Primary implant stability has been reported to be influenced by the bone quality and quantity, the implant geometry, and the site preparation technique. The purpose of the study is to test implant stability in relation to implant design (thread geometry and crest module) using Resonance Frequency Analysis (RFA). The stabilities of 5 implant designs were tested after insertion into pig ribs. It was observed that the pig rib demonstrated type1/ 2 bone density. Following implant placement, the corresponding transducer for each implant design was attached perpendicular to the long axis of the pig rib and implant stabilities assessed using resonance frequency analysis. Different implant designs achieved a similar primary stability in the pig ribs. It may be concluded that design features aimed at improving primary stability are less important in dense bone.

Key words: dental implant, stability, pig rib, resonance frequency.

INTRODUCTION

Dental implants have become a significant aspect of tooth replacement in prosthodontic reatment [1, 2, 3]. These studies, however, have been based on a two-stage submerged surgical protocol, allowing a 3-6 months bone healing period [1]. Thus within a treatment time frame, implant-supported prostheses may take up to 7-8 months to complete which, from the patient' perspective, may be unsatisfactory.

Consequently, there is a trend towards a one-stage non-submerged surgical procedure along with an early/ immediate loading protocol. This is a deviation from the initial criteria of delayed loading established by Brånemark et al [1].

The Brånemark protocol [1] favored a prolonged healing period, to promote bone growth around the dental implant. Furthermore, it was suggested that premature loading of the implant, soon after the first-stage surgery, would create 'micromotion', which could lead to fibrous tissue formation around the implant, and the subsequent implant loss [4, 5, 6].

Although micromotion has been implicated as a factor in fibrous tissue formation around an implant [7, 8, 9, 10], it has been reported that bone growth may also be stimulated by low frequency micromotion [11, 12]. It now appears that only ''excessive'' micromotion during healing phase can cause failure of osseointegration [13, 14, 15]. Their findings suggest that, a range of micromotion exists, that is tolerable, is in the order of 50-150 μm [15], and may vary according to implant design and implant surface topography [16].

Although evidence based information is available for late- loading implant protocol, there appears to be no clear criteria for the application of immediate or early loading of dental implants. An important aspect for success of early/ immediately loading dental implants may be the primary implant stability in bone at the time of implant placement. The traditional clinical methods for evaluating bone-implant relationship include radiographic evaluation [17], tapping the implant with a metallic instrument and assessing the emitted sound [18], stability measurement with the Periotest instrument [19], and reverse torque application [20]. However, these methods are rather subjective and do not give a linear definition of the level of implant stability.

A recently developed apparatus (Osstell; Integration Diagnostics AB, Sweden) uses resonance frequency (i.e. tuning fork principle) to determine implant stability. The wave feed back is interpreted as a numerical value that is linearly related to the degree of micromotion of the implant. This device may be able to detect changes in micromotion that could be associated with increase or decrease in degree of osseointegration [21]. The use of Resonance Frequency Analysis (RFA) may provide a possibility to individualize implant treatment with regards to healing periods, detecting failing implants, type of prosthetic construction, and if one- or two-staged procedures should be used [22]. Previous studies using RFA have reported resonance frequency in hertz as a parameter to describe implant stability

In a review [23], primary implant stability has been reported to be influenced by the bone quality and quantity, the implant geometry, and the site preparation technique. The purpose of the study is to test using Resonance Frequency Analysis (RFA) implant stability in relation to implant design (thread geometry and crest module).

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Table 1. Description of implants used in the study.

Implant System	Description	Diameter (mm)	Length (mm)	Number of implants	Label
Ankylos Implant system (Friadent, Mannheim, Germany)	Type 'A'	3.5	11	10	A
Astra Tech Implant system (Astra Tech, Mölndal, Sweden)	Microthread	4	11	10	B
Astra Tech Implant system (Astra Tech, Mölndal, Sweden)	Regular thread	4	11	10	C
BioHorizons Implant system (Maestro, Biohorizons Implant Systems, Birmingham, AL , North America)	D2 thread configuration	4	12	10	D
Biohorizons Implant system (Maestro, Biohorizons Implant Systems, Birmingham, AL , North America)	D3 thread configuration	4	12	10	E

MATERIALS & METHODS

The study was conducted at the ARK private dental clinic (Skanstes iela 13, Riga, Latvia). The pig ribs used in the study were obtained from a retail meat market.

Five different implant designs were chosen for the study (Table 1, Figure 1).

The Ankylos implant system (Label A) incorporates the concept of transferring load to the bone through an asymmetric thread profile that continually increases in the depth of thread transfers towards the apex of the implant.

The Astra Tech implant (Label C) incorporates microthreads on the crest module region of the implant, the idea being to optimize the load transfer from the implant to the surrounding bone, thus intending to preserve the marginal bone. This new design is tested for primary stability along with their conventional regular threaded design (Label B).

With the Biohorizon implant system (Labels D and E), the manufacturer alters the thread pitch and depth of the square thread ultimately aiming to obtain a similar microstrain in all bone densities [24].

The initial stabilities of the 5 implant designs were tested after insertion into ethanol treated [25] pig ribs (Figure 2). Although calf ribs have been used as the standard in previous studies, owing to limited access of calf ribs with appropriate dimensions, pig ribs were selected as the reference for this study. The 5 different implant geometries were labeled A, B, C, D, E respectively (Table 1, Figure 1). One implant of each geometry/design was placed according to the manufacturer's instructions in a pig rib (5 implants in a 60 mm pig rib). The implants were placed a minimum of 10 mm from each end of the rib and 8 mm from center of one implant to the other. The bone density of the ribs were assessed by surgeon by drilling a particular sequence of drills at the end of each rib, and classified as soft, medium, or dense. (equivalent to Type I/ II (medium-dense), and Type III/ IV (soft) of Lekholm and Zarb classification [26]; Table 2). Following implant placement, the corresponding transducer for each implant design was attached perpendicular to the long axis of the pig rib and secured with a torque of 10 Ncm as per manufacturer instructions (Osstell, Integration Diagnostics AB, Göteborgsvägen, Sweden) (Figure 3). The RFA values were then obtained using Osstell (Integration Diagnostics AB, Göteborgsvägen, Sweden). The data was analyzed for statistical significance between independent samples using analysis of variance, and statistical significance established at P = 0.05.

Table 2. Bone quality classification proposed by Lekholm and Zarb (1985).

Type 1	Homogenous compact bone
Type 2	Thick layer of compact bone surrounding a core of dense trabecular bone
Type 3	Thin layer of cortical bone surrounding a core of dense trabecular bone
Type 4	Thin layer of cortical bone surrounding a core of low-density trabecular bone

RESULTS

In all, 50 implants were placed in 10 pig ribs. The statistical analysis did not reveal differences in RFA readings between the various implant systems (Table 3). The diameters and lengths of the various implant systems are described in Table 1. However, when the variables of diameters and lengths were not accounted for in the statistical analysis, BioHorizons D3 implant demonstrated higher average implant stability (82.6) among the implant systems measured (Table 4). The averages of other implant systems in the descending order include Biohorizons D2 implant (81.3), Astra Tech Fixture Microthread (80.7), Astra Tech Fixture (77.4) and Ankylos implant (70.9).

DISCUSSION

Primary implant stability is considered to play a fundamental role in successful osseointegration [27, 28]. Friberg et al [28] reported an implant failure rate of 32% for those implants that showed inadequate initial stability. Ivanoff et al [29] in a rabbit study investigated the influence of primary stability on osseointegration by placing titanium implants so that some were primarily stable, some showed rotational mobility, and some were totally mobile. They found that although all the implants osseointegrated, on removal, demonstrated significantly less bone around those implants with initial total mobility. Thus it appears that high primary stability reduces the risk of micromotion and adverse tissue responses such as fibrous tissue formation at the bone-implant interface during healing and loading. Primary implant stability is now generally accepted as an essential

Table 3. Analysis of variance taking variables of implant diameter and implant lengths into account *(df = degree of freedom; MS = Variance; F = Fisher's ratio; P= Statistical significance; F crit = Critical value of Fisher's ratio).*

Implant labels	A	B	C	D	E
1	65	81	74	71	78
2	73	85	72	77	74
3	60	72	59	75	78
4	69	74	71	82	80
5	68	79	85	84	86
6	71	82	80	79	79
7	68	69	61	72	79
8	75	93	89	97	94
9	79	90	93	92	94
10	81	82	90	84	84
Implant labels	**A**	**B**	**C**	**D**	**E**
1	1,58	1,84	1,68	1,48	1,63
2	1,77	1,93	1,64	1,60	1,54
3	1,45	1,64	1,34	1,56	1,63
4	1,67	1,68	1,61	1,71	1,67
5	1,65	1,80	1,93	1,75	1,79
6	1,72	1,86	1,82	1,65	1,65
7	1,65	1,57	1,39	1,50	1,65
8	1,82	2,11	2,02	2,02	1,96
9	1,92	2,05	2,11	1,92	1,96
10	1,96	1,86	2,05	1,75	1,75

Anova: Single Factor
SUMMARY

Groups	Count	Sum	Average	Variance
A	10	17,18788	1,718788	0,023697
B	10	18,34091	1,834091	0,02985
C	10	17,59091	1,759091	0,074059
D	10	16,9375	1,69375	0,030483
E	10	17,20833	1,720833	0,02037

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0,120329	4	0,030082	0,842835	0,505446	2,578737
Within Groups	1,606132	45	0,035692			
Total	1,726462	49				

$p<0,05$

criterion for obtaining osseointegration. By means of RFA, initial implant stability can be quantitatively assessed and followed with time as a function of implant's stiffness in bone. Initial implant stability is suggested to be influenced by the bone quality and quantity, the implant design and the surgical technique used. As bone quality and quantity are set factors, primary implant stability may be influenced by the implant design and surgical technique.

The RFA did not reveal statistically significant differences between the different implant designs. This may be explained by the dense bone quality in the pig bone measured. The surgeon's assessment of bone density in general was medium-dense bone (equivalent to Type 1/ 2 of Lekholm and Zarb classification; Table 2). It is known from previous research in cadaver bone that differences between different implant designs are more pronounced in Type 4 bone [30]. The authors compared 5 different implant designs in a human cadaver model and found no major differences in Type 2 bone, while significant differences in primary stability were observed in low density bone. Similar results were reported by Rompen et al [31], where the initial stability between 2 different designs was compared in the dog mandible using RFA. The authors concluded that the benefits of using the Mk IV implant (Nobel Biocare AB, Gothenburg AB, Sweden) were not detected in dense bone. Glauser et al [32] in a clinical study inserted various Brånemark System implant designs in bone assessed as quality 3. Mk IV implants exhibited significantly higher insertion torques and resonance frequencies than Mk II and Mk III implants. It may therefore be speculated that different implant designs may result in improved primary stability and survival in soft bone by achieving and maintaining good stability during the remodeling of the trabecular network to more dense bone.

Table 4: Analysis of variance not taking the different diameters and lengths into account.
Anova: Single Factor
SUMMARY

Groups	Count	Sum	Average	Variance
A	10	709	70,9	40,32222
B	10	807	80,7	57,78889
C	10	774	77,4	143,3778
D	10	813	81,3	70,23333
E	10	826	82,6	46,93333

ANOVA

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	884,28	4	221,07	3,081926	0,02514	2,578737
Within Groups	3227,9	45	71,73111			
Total	4112,18	49				

When the implant diameters and lengths were not corrected for in the statistical analysis, the D3 Biohorizon implant exhibited higher average implant stability than other implant designs measured. In comparison with the Ankylos and Astra Tech implants (Labels A, B, C), the D 3 Biohorizon implant was wider and longer, thus plausibly suggesting a role of implant diameter and implant length in attaining initial stability. However, as reported in the pilot study by Bailleri et al [33], a comparison of implant stability readings failed to demonstrate a direct relationship between implant length and primary stability. Their results indicated that a short implant could be as stable as a long one. It may be that the differences observed in this study between the D3 Biohorizon (Label E) and Ankylos (Label A) implant systems, were more related to different implant diameters. Glauser et al [32] in a clinical study, compared insertion torque at various site depths when placing Mk IV (Nobel Biocare AB, Gothenburg AB, Sweden) in Type 3 bone. They found implants inserted in 3 mm diameter sites to demonstrate significantly higher torque values. It has been suggested that incorporating wider diameter implants may increase the bone-metal contact area by connection to the cortical bone envelope [34].

However, this may not justify the differences observed between D2 and the D3 implant designs (Labels D and E), both implants being of identical lengths and diameters. The surgeon designated a slightly lesser bone density for 2 of the 10 ribs used in the study, which may explain the difference in results between D3 and D2 Biohorizon (Labels E and D) and between D3 and Astra Tech implants (Labels E and B, C).

CONCLUSION

It was observed that the different implant designs achieved a similar primary stability in the pig ribs that were of a type 1-2 bone quality, as measured by RFA. It may be concluded that design features aimed at improving primary stability are less important in dense bone.

Further comparative studies may be necessary to evaluate the influence of different implant diameters and different implant designs in softer bone qualities.

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