Resonance Frequency Analysis Measurements of Implants at Placement Surgery

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Purpose: The knowledge of what levels of primary stability can be obtained in different jawbone regions and of what factors influence primary stability is limited. The objective of this study was to evaluate primary stability by resonance frequency analysis (RFA) measurements of implants placed according to a surgical protocol that aimed for high primary stability. The aim was also to correlate RFA measurements with factors related to the surgical technique, the patient, and implant design. **Materials and Methods:** A total of 905 Brånemark dental implants used in 267 consecutive patients were measured with RFA at the time of placement surgery. **Results:** A mean ISQ value of 67.4 (SD 8.6) was obtained for all implants. Univariate analyses with the implant or patient as unit showed higher ISQ values in men compared with women, in mandibles compared with maxillae, in posterior compared with anterior sites, and for wide-platform implants in comparison with regular/narrow-platform implants. There was a correlation between bone quality and primary stability, with lower ISQ values obtained for implants placed in softer bone. A lower stability was seen with increased implant length. A stepwise multiple regression analysis using the patient as unit showed that jaw type and gender had independent effects on primary stability. **Conclusion:** The results suggest that factors related to bone density and implant diameter/length may affect the level of primary implant stability. Furthermore, greater stability was observed in male than in female patients. High primary implant stability was achieved in all jaw regions, although the use of thinner drills and/or tapered implants cannot fully compensate for the effect of soft bone. The research design does not permit conclusions regarding long-term treatment outcome with implants.
Int J Prosthodont 2006;19:77–83.

Maintenance of implant stability is an obvious requirement for long-term success with osseointegrated implant-supported dentures. Meta-analyses of clinical follow-up studies of totally and partially edentulous patients treated with implants have shown that an implant survival rate of about 93% to 95% can be expected over a 5-year period.[1,2] High failure rates have been reported to occur in grafted bone and in irradiated patients,[3,4] reflecting the importance of the healing capacity of the bone bed. Studies also show higher failure rates in soft bone and for short implants, which indicate that a certain degree of implant stability is required for successful integration and function during loading.[5,6] Therefore, the use of surgical techniques and implant designs to improve primary implant stability may be desirable, such as the use of thinner drills and/or wider implants.[7–9]

The degree of primary stability after implant placement is dependent on factors related to the properties of the bone, the design of the implant, and the surgical technique used. Secondary implant stability is dependent on tissue response to the surgery and the implant material. In cases of successful healing, bone is formed toward and at the implant surface, which creates a strong interlock between the bone and implant surface. Stability can be defined as the implant's capacity to withstand loading in the axial, lateral, and rotational directions. Thus, implant stability can be mea-

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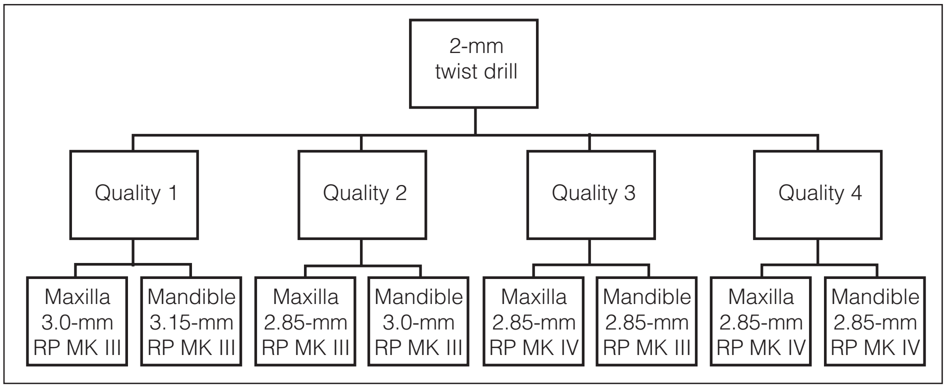

Fig 1 Flowchart showing choice of final drill diameter and implant type in the different bone qualities in the mandible and the maxilla.

sured in different directions. The clinical perception of implant stability is often related to rotational resistance when placing the implant[10,11] or when applying removal torque.[12] The latter is also commonly used as a technique to measure implant stability in experimental studies.[13] Resonance frequency analysis (RFA) is a technique for implant stability measurements that has been used extensively in experimental and clinical research.[14–21] The technique measures the resonance frequency (RF) of a transducer attached to the implant. The RF is mainly determined by the stiffness of the bone-implant system and the distance from the transducer to the first bone contact.[15] The technique can thereby be used to measure variations in implant stability as well as detect small changes in the marginal bone level.[14,16,21] RFA measures the stability of the implant when applying a lateral force, which is clinically relevant considering that most implants are subjected to bending forces. Measurements were originally given in Hz, but since the instrument became commercially available, measurements have been given in ISQ (implant stability quotient) units, as also used in recent clinical studies.

The objective of this study was to evaluate primary implant stability using RFA measurements and to correlate obtained RFA values with patient-, surgery-, and implant-related factors.

Materials and Methods

Patients and Implants

RFA measurements in 267 consecutive patients (141 women, 126 men, mean age 65.2 years) treated with implant-supported fixed prostheses at one clinic were used for statistical analyses.

All implants (n = 905) were from 1 manufacturer (Nobel Biocare). In total, 479 implants were placed in mandibles and 426 were placed in maxillae. Seventy-five percent of the mandibular implants were placed in posterior regions. The corresponding figure for maxillary implants was 49%. The implants had either a machined (n = 120) or an oxidized (TiUnite, n = 785) surface and were parallel-walled (MK III, n = 734) or tapered (MK IV, n = 171). Implant lengths varied from 7 to 18 mm (Table 1) and had diameters of 3.3 mm (narrow-platform [NP], n = 46), 3.75 and 4 mm (Regular Platform [RP] MKIII and RP MK IV, n = 808), and 5.0 mm (wide-platform [WP], n = 51) were utilized. The mixture of machined and oxidized implants reflects the change from one implant surface to another over time. Thus, machined implants were placed early in the study period, while only oxidized implants were used by the end of the study period.

Implant Surgery

Implants were placed according to a modified surgical protocol. The general principles are shown in Fig 1. Depending on bone density as judged by the surgeon, final drill diameters of 2.7 or 2.85 mm were used for NP implants; 2.7, 2.85, or 3 mm for RP implants; and 3.85 or 4.3 mm for WP implants. The implant heads were generally not totally submerged into the bone. NP implants were used in narrow ridges. WP implants were used to provide a wider platform for molar replacements.

Bone quality and bone quantity according to the index proposed by Lekholm and Zarb[22] were registered after surgery. Bone quality was assessed based on the resistance of the bone during drilling and implant placement (Table 2).

Table 1 Implant Designs and Lengths

Implant length (mm)	MK III TiUnite	MK III* machined	MK IV TiUnite	MK IV machined	Total
7	9	4	0	0	13
8.5	29	0	0	2	31
10	67	12	0	7	86
11.5	45	2	5	2	54
13	92	16	10	10	128
15	253	34	42	13	342
18	158	13	75	5	251
Total	653	81	132	39	905

*Includes standard implants.

Table 2 Bone Quality and Quantity and Distribution Within Male and Female Patients

	No. of implants (n = 905)	Distribution (%)	
		Male	Female
Bone quality			
1	16	3	1
2	194	22	22
3	517	60	55
4	178	16	23
Bone quantity			
A	14	1	2
B	352	48	31
C	427	44	50
D	112	7	17
E	0		

RFA Measurements

RFA measurements were performed immediately following implant placement using an Osstell instrument (Integration Diagnostics). The transducer was attached to the implant perpendicular to the alveolar crest with a screwdriver, using about 10 Ncm of torque. Care was taken to make sure that no tissue was trapped between the implant head and the transducer. The measurement was momentarily shown as a frequency/amplitude plot and an ISQ value. If the plot showed 1 clear peak, the measurement was accepted and the ISQ value was noted. If the plot indicated an erroneous measurement, the transducer was removed, the implant site was cleaned, and a new measurement was made. Different transducers were used for the different platforms.

Statistics

The difference in distributions was tested by a chi-square test. The influence of each separate parameter on implant stability was analyzed by a Pearson correlation (quantitative variables) or Student *t* test (binary variables). Furthermore, a stepwise multiple regression analysis was performed to identify independent determinants of implant stability. When a patient is included more than once in the regression analysis, no bias of the beta coefficient is introduced; however, the dependency will imply an underestimation of the variances of the coefficients. Therefore, the *P* values for the relationships and the *P* values and confidence intervals for differences were adjusted to the individual level by multiplying the variances with nimpl/npat (nimpl = number of implants and npat = the number of patients). By using the adjusted variances a conservative method was chosen. The interaction effect gender × bone quality was investigated as possible covariate in the multivariate regression analysis. *P* values (2-sided) ≤ .05 were considered statistically significant.

Results

The mean primary stability for all implants was 67.4 ISQ (SD 8.6). Of all 905 implants, 582 (64.3%) showed an ISQ value of 65 or higher and 761 (84.1%) implants showed an ISQ of 60 or higher (Fig 2).

The results from univariate and multivariate analyses are presented in Tables 3 and 4. The univariate

Table 3 Univariate Analysis of Primary Implant Stability (ISQ)

			Implant-based (n = 905)				Individual-based (n = 267)	
			Difference		Correlation			
Variable	n	Mean (SD)	95% CI	*P* value	*r*	*P* value	95% CI	*P* value
Age	905				-0.03	> .30		> .30
Gender								
Female	486	66.5 (8.8)	0.9 to 3.1	< .001			1.3 to 5.3	.04
Male	419	68.5 (8.4)						
Jaw type								
Maxilla	426	63.0 (7.6)	-9.4 to -7.4	< .001			-10.2 to -6.6	< .0001
Mandible	479	71.4 (7.5)						
Location								
Anterior	338	65.2 (7.7)	-4.7 to -2.4	< .001			-5.7 to -1.5	< .001
Posterior	567	68.7 (8.9)	-					
Bone quality	905				-0.24	< .001		< .001
Bone quantity	905				-0.05	.12		.25
Platform								
NP-RP	854	67.1 (8.4)	-8.5 to -3.7	< .001			-10.5 to -1.6	.007
WP	51	73.1 (9.8)						
Implant type								
MK III	734	67.8 (8.7)	0.4 to 3.3	.01			-0.8 to 4.5	.16
MK IV	171	65.9 (8.2)						
Implant length	905				-0.15	< .001		< .001

SD = standard deviation; CI = confidence interval.

Table 4 Stepwise Multivariate Regression Analysis of Primary Implant Stability (ISQ)

	Implant-based (n = 905)			Individual-based (n = 267)	
	Coefficient	(SE)	*P* value	(SE)	*P* value
Jaw type (maxilla, mandible)	7.4	(0.5)	< .001	(0.9)	< .001
Gender	-1.9	(0.5)	< .001	(0.9)	.04
Bone quality	-1.2	(0.4)	.002	(0.7)	.10
Anterior/posterior	1.3	(0.5)	.016	(1.0)	.10
Platform (NP-RP, WP)	2.6	(1.1)	.017	(2.0)	.20

SE = standard error.

analyses, with the implant or patient as unit, revealed significant differences when comparing different parameters: Male patients showed higher ISQ values than females: 68.5 (SD 8.4) versus 66.5 (SD 8.8, $P <$ 0.04). Mandibular implants with ISQ 71.4 (SD 7.5) were more stable than maxillary ones with ISQ 63.0 (SD 7.6, $P <$ .001; Fig 3). Implants placed in posterior regions were more stable than those placed in anterior sites, 68.7 (SD 8.5) versus 65.2 (SD 7.7, $P <$ .001). WP implants showed a mean ISQ of 73.1 (SD 9.8) and were more stable than RP or NP implants, which had a mean ISQ of 67.1 (SD 8.4, $P <$ .007; Fig 4). There was a correlation between bone quality and primary stability, with lower ISQ values in softer bone ($r =$ -0.24, $P <$ .001; Fig 5). Lower stability was seen with increased implant length ($r =$ -0.15, $P <$ .001; Fig 6).

A stepwise multiple regression analysis using the implant as unit showed that jaw type, platform, bone quality, position (anterior versus posterior), and gender were determinants of primary stability. The studied variables explained 27% of the variability in primary stability (Adjusted $R^2 = 0.27$). Based on the patient as unit, jaw type and gender were independent determinants of primary stability.

The 2 groups of male and female patients had different bone quality distributions ($P =$ .028). Analyses showed that the interaction effect gender × bone quality did not have a significant effect on primary stability. More female patients also had bone with less volume than did the group of male patients (Table 2; $P <$ .001). However, the univariate analyses showed no relationship between bone quantity and primary stability (Table 3; NS).

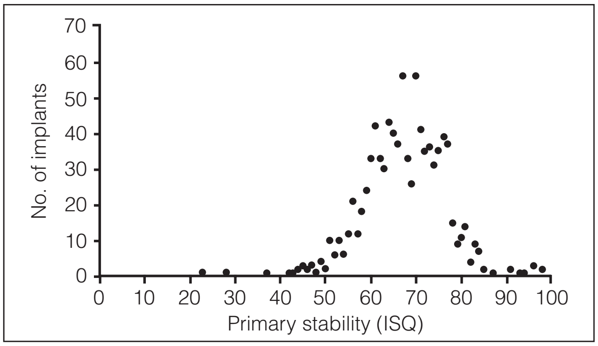

Fig 2 Frequency distribution plot of all measurements.

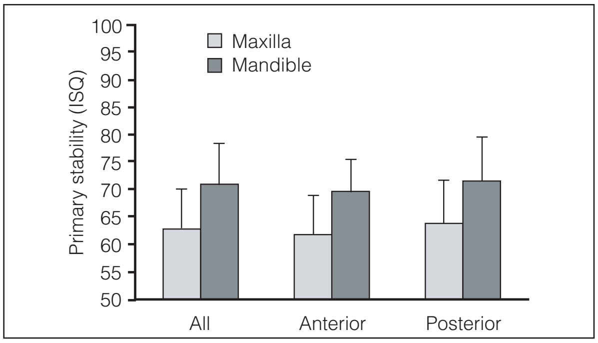

Fig 3 Mean values of primary stability in the mandible and in the maxilla for all implants and for anterior and posterior regions. Mandibular implants were statistically more stable than maxillary implants (see Table 3).

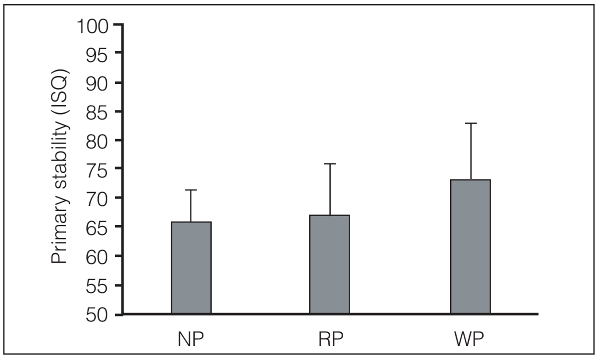

Fig 4 Primary stability with implant diameter. (NP = narrow platform, 3.3 mm; RP = regular platform, 3.75 mm; WP = wide platform, 5.0 mm). WP implants were statistically more stable than NP and RP implants (see Table 3).

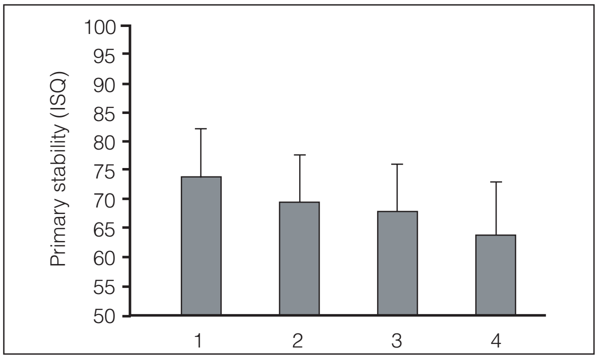

Fig 5 Primary stability with bone quality according to the index proposed by Lekholm and Zarb.[44] There was a statistically significant decrease of stability with softer bone (see Table 3).

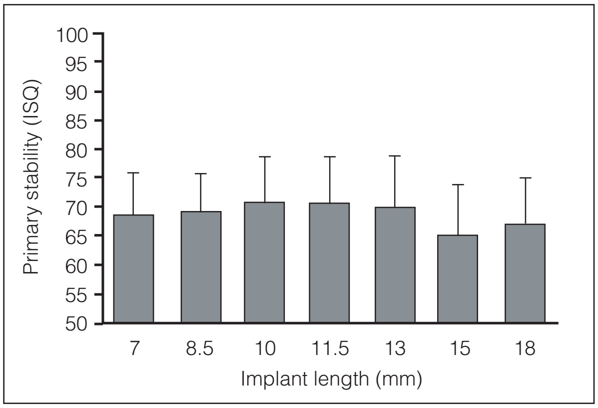

Fig 6 Primary stability with implant length. There was a statistically significant decrease of stability with implant length (see Table 3).

Discussion

The present study on 905 implants in 267 consecutive patients showed that factors related to the biomechanical properties of the bone and the implant design mainly influenced the ISQ values obtained from RFA measurement. Although a control group was not used, it can be anticipated that the use of an adapted surgical technique resulted in high primary stability in all jawbone regions. However, the use of thinner drills and/or tapered implants could not fully overshadow the effect of bone density, as indicated by the correlation between bone quality and stability. Interestingly, lower implant stability was seen for women than for men, in spite of a similar distribution of all parameters within the genders. The result from the present study indicated a difference in bone density between women and men, which, however, could not be subjectively discriminated using the Lekholm and Zarb index[22] and, therefore, may not be clinically relevant. For instance, according to the knowledge of the present authors, no clinical follow-up studies on dental implants have reported differences in implant failure rates in male and female patients.[6]

Decreasing implant stability was seen with decreasing bone quality, which is in line with the findings of Friberg et al,[23] who demonstrated a correlation between bone density, as assessed by cutting torque measurements when placing implants, and RFA measurements. This is most likely explained by the presence/absence of cortical bone, which is 10 to 20 times stiffer than trabecular bone. Differences between mandibular and maxillary implants can also be explained in terms of bone density, since maxillary bone is often softer owing to lesser extents of cortical bone.[24,25] In the present study, implant stability was higher in posterior than in anterior regions, in spite of the fact that implant placement generally is regarded as more challenging in posterior regions because of the anticipated more frequent presence of soft bone quality. Our results can be explained in part by the fact that all wide implants in the study, which showed higher ISQ values than RP/NP implants, were placed in posterior regions.

With regard to implant design, it was evident that wide implants were more stable than narrower ones. This may be attributed to the fact that wider implants engage more of the buccal/lingual cortical bone walls, both because of the width per se and because of the surface enlargement factor.[26] Previous studies have shown that primary implant stability can be improved by using a tapered implant design.[8,19] In the present study, when all implants were included in the analysis and not adjusted to the individual level, the tapered MK IV implants were less stable than the parallel-walled MK III implants. This is explained by the fact that tapered implants were only used in compromised, quality 4 bone, and that a reduced drill diameter (ie, 2.85 mm instead of 3.00 mm) was used when placing most of the MK III implants. The use of a tapered implant or reduced drill diameter will most likely create a similar increased stability as a result of lateral compression of the bone when placing the implant.[7] Nevertheless, it is likely that if implants had been placed in quality 4 bone without adapting the surgical technique, implant stability would have certainly been lower. It can also be speculated that implants with a more pronounced taper than the MK IV design, such as the Replace Select implant, may be used to further improve primary stability in quality 4 bone.

One intriguing finding was that implant stability decreased with increased implant length, a finding that corresponds with the results of Balleri et al.[18] This may have to do with the manufacturing of the implants and the nature of the RFA technique. To minimize friction heat when placing long implants, the diameter is slightly reduced in the coronal direction (F. Engman, personal communication, 2004). Friberg et al[17] measured bone density in the marginal, middle, and apical parts of implant sites in the maxilla. Subsequent RFA measurements showed a correlation between implant stability and the density of the marginal bone, but not at other parts of the implant site. The authors concluded that marginal bone properties were main determinants of RFA measurements. The lower stability for the long implants may therefore be explained by the reduced diameter in the marginal bone. It is also possible that the longer drilling time for placement of long implants resulted in overpreparation of the implant site.

Clinical studies have demonstrated the possibility of using immediate/early loading protocols for all indications. However, in comparison with 2-stage procedures, it seems that higher implant failure rates can be expected in partially edentulous jaws, especially in the posterior maxilla.[27] Further analysis of follow-up studies indicates that soft bone and immediate occlusal loading are some of the risk factors,[27–29] which implies that relative overload is a major cause of implant failure. The RFA technique may therefore be a useful tool to identify implants with a sufficient degree of stability and to monitor the clinical performance of the implants during loading. Glauser et al[20] measured the stability of 81 immediately loaded implants over a 1-year period. Nine implants were lost, and RFA measurements showed a statistically lower stability for failing implants after 1 and 2 months, compared with the implants that remained successful. Their results showed that the risk of failure increased with decreased ISQ value, as measured after 1 month of loading. Sennerby and Meredith[7] observed that a primary stability of around 65 ISQ in 20 patients did not result in any changes of stability with time and proposed this as a safe level for immediate loading. In the present material, about 65% of all implants showed ISQ values of 65 or above. If an ISQ of 60 was considered as a lower limit, about 85% of all implants could have been considered for immediate loading. However, clinical prospective studies are needed to verify this hypothesis.

It is concluded that high primary stability can be achieved in all jaw regions when using an adapted surgical protocol. However, the use of thinner drills and/or tapered implants cannot fully compensate for the effect of soft bone. Factors related to bone density and implant diameter/length may affect the level of primary implant stability. Furthermore, greater stability is observed in male than in female patients. It is conceded that the research design employed precludes reaching relevant conclusions regarding clinical treatment outcomes.

Acknowledgment

The statistical consultant for this study was Gunnar Ekeroth at Statistiska Konsultbyrån, Göteborg, Sweden.

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