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# Stability measurements of craniofacial implants by means of resonance frequency analysis. A clinical pilot study

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**Abstract**
Nineteen patients previously treated with 52 implants for anchorage of craniofacial prostheses were subjected to implant stability measurements by means of resonance frequency analysis (RFA), six months to 15 years after implant placement. The resonance frequency (RF) of a transducer attached to the implant abutment was measured by using a frequency response analyser, a personal computer (PC) and dedicated software. Statistically significant higher RF values were seen for implants in the temporal bone as compared to implants in the nose and periorbital regions. There was a positive correlation with time since implant placement for the period from six months up to seven years. It was concluded that the preliminary results suggest that implant stability increases with time and that implants in temporal bone are more stable than implants in the bone in the nose and periorbital regions, probably reflecting differences in bone density.

**Key words: Prostheses, cranial facial; Osseointegration**

## Introduction

Osseointegrated titanium implants are widely used for prosthetic rehabilitation of craniofacial defects and for anchorage of hearing aids (Tjellström and Jacobsson, 1992). The long-term results are in general good although patient groups and anatomical regions with high failure rates have been identified (Tjellström, 1989; Jacobsson *et al.*, 1992; Granström *et al.*, 1994; Roumanas *et al.*, 1994). Both early and late implant failures occur more often in patients who have received irradiation in the region where the implants are to be placed (Granström *et al.*, 1994). This is most likely due to an impaired vascularization and healing capacity of the bone and skin tissues as a result of the irradiation therapy (Jacobsson, 1985). However, Granström *et al.* (1994) showed that if irradiated patients were treated with hyperbaric oxygen (HBO) prior to, and after, implant surgery, the success rate was dramatically improved.

Implants placed in maxillary and periorbital bone have lower success rates than implants in the temporal bone (Granström *et al.*, 1993; Roumanas *et al.*, 1994), that may be explained by differences in bone quality and the possibility of achieving primary stability of the implants. It is possible that longer healing periods are needed in soft bone in order to gain implant stability as a result of bone healing and maturation. On the other hand, it is possible that short or no healing periods are needed in dense bone where good implant stability may be achieved at placement. In fact, a one-stage surgical and early loading (three months) approach, has successfully been used for implants in the temporal bone of adults (Tjellström and Granström, 1995). On the other hand, a two-stage procedure and long healing period (six months) was still advocated for children, due to thinner bone and softer character. Therefore, it would be valuable to be able to measure implant stability at the time of placement in order to decide the healing period on an individual basis. Moreover, such a technique could be used to check that sufficient stability has been achieved during healing and to monitor implant stability during function.

A novel non-invasive test method to measure implant stability, resonance frequency analysis (RFA) has been described by Meredith *et al.* (1996). With this technique the RF of a small transducer that is attached to the implant or abutment is measured. The RF value is determined by the stiffness of the bone-implant complex and by the distance from the transducer beam to the bone level. In a series of *in vitro* and *in vivo* investigations on intraoral implants the technique has been proven to be sensitive to monitor changes in implant stability (Meredith *et al.*, 1996; Meredith, 1997; Meredith *et*

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*al.*, 1997a; Meredith *et al.*, 1997b; Rasmusson *et al.*, 1997).

The purpose of the present clinical pilot study was to investigate the clinical feasibility of the RFA technique when used for stability measurements of extraoral implants. The aim was also to compare implant stability in temporal bone to that for implants in the nose and periorbital regions.

## Materials and methods

### *Patients*

Nineteen patients (10 males, nine females) previously treated with implants in conjunction with reconstruction of craniofacial defects were included in the study (Table I). The mean age was 46.2 years (range 23–80 years). A total of 52 4 mm long flange fixtures (Nobel Biocare AB, Gothenburg, Sweden) and standard abutments being 3 (n = 8), 4 (n = 43) or 5.5 mm (n = 1) had been placed in accordance with the guidelines given by Tjellström and Jacobsson (1992). Thirteen patients had received implants in the temporal bone for ear prostheses, five patients had implants in the periorbital region for eye prostheses and one patient was treated with implants for a nose prosthesis. All six patients treated with implants in the nose and periorbital regions had been subjected to irradiation prior to implant treatment. Two of these patients had also been treated with hyperbaric oxygen in conjunction with implant surgery.

TABLE I
PATIENT DATA AND RF-VALUES

| Patient number | Sex | Age | Region | Irradiation | HBO treatment | Time since replacement | Implant length | Abutment length | RF value |
|---|---|---|---|---|---|---|---|---|---|
| 1. | M | 27 | Temporal bone | No | No | 7.0 years | 4 | 4 | 7880 |
| | | | | | | | 4 | 4 | 8020 |
| 2. | M | 77 | Periorbital bone | Yes | Yes | 0.6 years | 4 | 3 | 7560* |
| | | | | | | | 4 | 3 | 6720* |
| | | | | | | | 4 | 3 | 6020* |
| | | | | | | | 4 | 3 | 6940* |
| 3. | F | 80 | Temporal bone | No | No | 8.2 years | 4 | 4 | 7900 |
| | | | | | | | 4 | 4 | 8180 |
| | | | | | | | 4 | 4 | 7440 |
| | | | | | | | 4 | 4 | 7990 |
| 4. | M | 54 | Nose | Yes | No | 0.5 years | 4 | 3 | 6500* |
| | | | | | | | 4 | 3 | 6540* |
| | | | | | | | 4 | 3 | 7750* |
| | | | | | | | 4 | 3 | 6420* |
| 5 | F | 35 | Temporal bone | No | No | 4.5 years | 4 | 5.5 | 7840* |
| | | | | | | | 4 | 4 | 6840 |
| | | | | | | | 4 | 4 | 7770 |
| | | | | | | | 4 | 4 | 7890 |
| | | | | | | | 4 | 4 | 7250 |
| 6. | M | 27 | Temporal bone | No | No | 3.8 years | 4 | 4 | 6850 |
| | | | | | | | 4 | 4 | 7890 |
| 7. | F | 37 | Temporal bone | No | No | 4.5 years | 4 | 4 | 7990 |
| | | | | | | | 4 | 4 | 7620 |
| 8. | M | 33 | Temporal bone | No | No | 12 years | 4 | 4 | 7990 |
| | | | | | | | 4 | 4 | 8080 |
| | | | | | | | 4 | 4 | 7890 |
| 9. | M | 56 | Periorbital bone | Yes | No | 5.5 years | 4 | 4 | 7280 |
| | | | | | | | 4 | 4 | 7460 |
| 10. | M | 76 | Periorbital bone | Yes | No | 13.5 years | 4 | 4 | 7330 |
| 11. | F | 50 | Periorbital bone | Yes | Yes | 8 years | 4 | 4 | 7670 |
| | | | | | | | 4 | 4 | 6490 |
| | | | | | | | 4 | 4 | 7130 |
| 12. | F | 43 | Temporal bone | No | No | 14.5 years | 4 | 4 | 7950 |
| | | | | | | | 4 | 4 | 7720 |
| 13. | F | 64 | Temporal bone | No | No | 15 years | 4 | 4 | 7340 |
| | | | | | | | 4 | 4 | 7250 |
| 14. | M | 23 | Temporal bone | No | No | 7.3 years | 4 | 4 | 8050 |
| | | | | | | | 4 | 4 | 8070 |
| 15. | F | 25 | Temporal bone | No | No | 7 years | 4 | 4 | 7840 |
| | | | | | | | 4 | 4 | 8050 |
| 16 | F | 31 | Temporal bone | No | No | 9 years | 4 | 4 | 8130 |
| | | | | | | | 4 | 4 | 8030 |
| 17. | M | 37 | Temporal bone | No | No | 5.8 years | 4 | 4 | 8060 |
| | | | | | | | 4 | 4 | 7290 |
| | | | | | | | 4 | 4 | 8030 |
| | | | | | | | 4 | 4 | 7340 |
| 18. | F | 49 | Temporal bone | No | No | 8.8 years | 4 | 4 | 7380 |
| | | | | | | | 4 | 4 | 7500 |
| | | | | | | | 4 | 4 | 6960 |
| | | | | | | | 4 | 4 | 7620 |
| 19. | M | 54 | Periorbital bone | Yes | No | 8 years | 4 | 4 | 6700 |
| | | | | | | | 4 | 4 | 7140 |

*Adjusted values because of different abutment lengths (see text)

*Stability measurements*

Implant stability measurements were performed on regular check-ups at different times after implant surgery (mean 7.5 ± 4.0 years, range six months to 15 years).

RFA according to Meredith (1997) and Meredith *et al.* (1997a,b) was utilized for implant stability measurements. In brief, the RFA technique comprised the use of a transducer, a frequency response analyser, a PC and dedicated software (Figure 1). The transducer had an offset cantilever beam onto which piezo electric elements had been attached on either face. During testing the beam was vibrated by exciting one of the elements with a sinusoidal signal of varying frequency, typically from five to 15 kHz. The second element measured the response of the beam. At the first flexural resonance of the beam there was a marked increase in amplitude which was detected as a peak on a plot of frequency against amplitude. RF is determined by the stiffness of the bone surrounding the implants and the distance from the transducer beam to the first bone contact (Meredith *et al.*, 1996). Since different abutment lengths were used, the RFA was calibrated using an implant embedded in plaster and 3 to 5.5 mm long abutments. Based on the calibration test, the RF values for implants with 3 and 5.5 long abutments were recalculated to be comparable with the measurements on implants with 4 mm abutments.

At the time for measurements, all bars or other attachments were unscrewed from the abutments whereafter the abutment screw was tightened. The transducer was attached to the abutment via a hand-tightened screw and the measurement was started from the PC software (Figure 2). The RF value was registered and used as a measurement of implant stability.

*Statistics*

The student T-test for unpaired observations and the Spearman Correlation test were used for statistical analysis.

## Results

The measurements were quick and easy to perform and about one minute was needed for attaching, measuring and removing the transducer for each implant. Some patients with temporal implants could hear the transducer beam ringing but without causing any discomfort.

Clear RF peaks were registered for all implants. The implants with low RF values showed in general a wider and less distinct peak as compared to implants with high RF values (Figure 3 and 4). Resonance frequencies ranging from 6020 to 8080

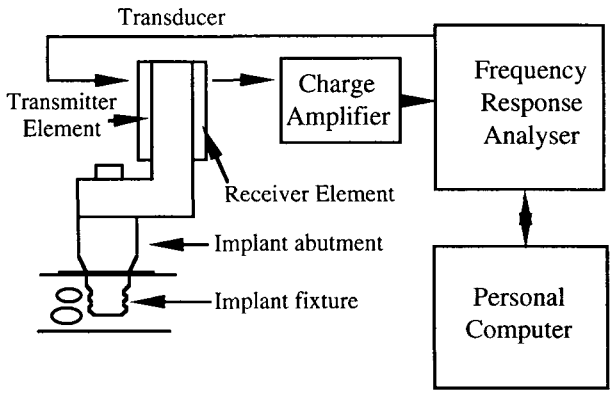


FIG. 1

Schematic of the instrumentation used to measure the resonance frequency of a cantilever beam attached to an implant.

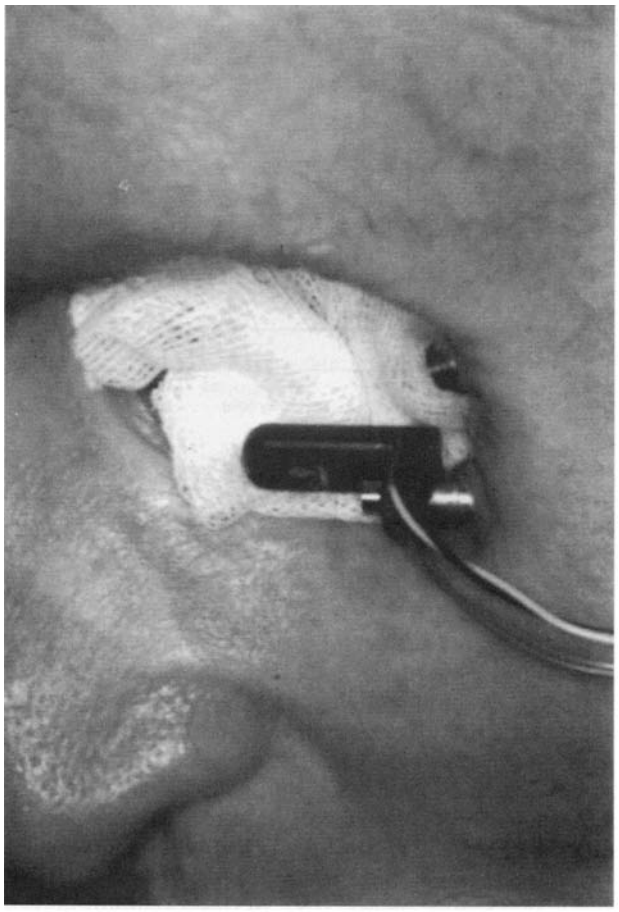

FIG. 2

Clinical photograph of the transducer attached to an implant in periorbital bone.

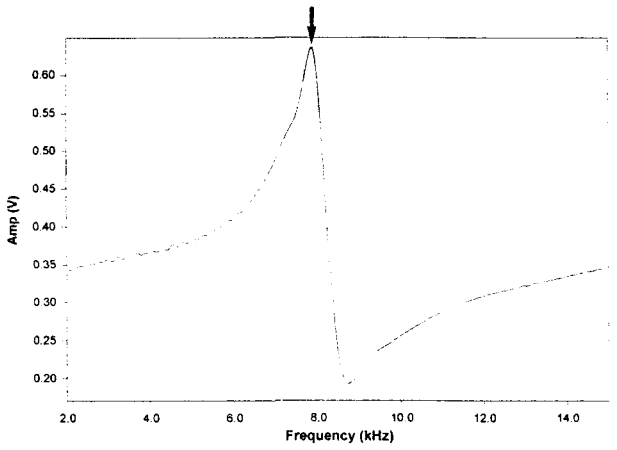


FIG. 3

Typical frequency-amplitude plot for an implant in temporal bone with a high RF (arrow).

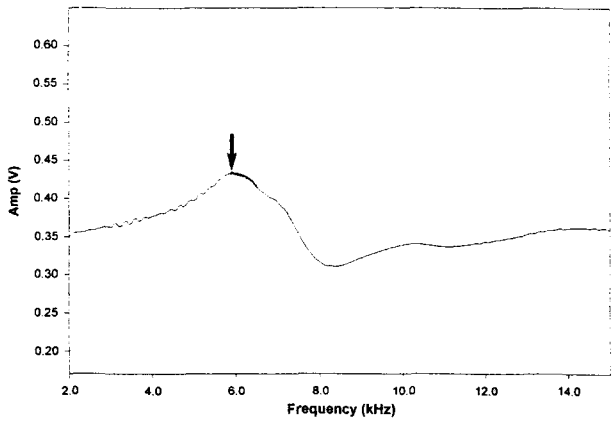


FIG. 4

Frequency-amplitude plot for an implant in periorbital bone with a low RF (arrow). Note the broad and less distinct peak as compared to Figure 3.

Hz were measured with a mean of 7491 ± 542 Hz based on all implants (Figure 5) and 7525 ± 417 based on patient means (Figure 6). In general, statistically significant higher RF values were registered for implants in temporal bone (implant mean 7720 ± 377 Hz, patient mean 7751 ± 277 Hz) as compared to the nose and periorbital regions (implant mean 6978 ± 512 Hz, patient mean 7056 ± 254 Hz) (Figure 7). There was a correlation between RF and time since implant placement for the first seven years ($r = 0.97, p<0.001$) (Figure 8) but not later (Figure 9).

In patient #6, one of two temporal implants that was affected by a soft tissue infection showed a marked lower RF (6850 Hz *vs* 7890 Hz) (Figure 10). Patient #17 had four implants in the temporal bone whereof two implants showed exposed flanges. These two implants had marked lower RF values as compared to the other two implants (7290 and 7340 Hz *vs* 8060 and 8030 Hz) (Figure 11).

## Discussion

The findings from the present investigation showed that RFA was a feasible method for measuring implant stability in the craniofacial region. There were no complaints of discomfort from the patients and the measurements were quick and easy to make. This limited study indicated a correlation between clinical observations and RF values: Two of the 19 patients had one implant with a severe skin reaction and two implants with exposure of the fixture flange. All these implants showed lower RF values, probably due to bone resorption, as compared to the unaffected implants in the same regions. Moreover, a higher implant stability was measured for implants placed in temporal bone as compared to the implants in the nose and periorbital regions, which most likely reflected differences in bone density. This may also explain the documented differences in survival rates (Jacobsson *et al.*, 1992; Tjellström, 1992; Granström *et al.*, 1993; Roumanas *et al.*, 1994). However, in the present study all patients treated with implants in the nose and periorbital regions had also received irradiation prior to implant therapy. Therefore, it is not possible to conclude if the differences were caused by irradiation or due to normal bone anatomy.

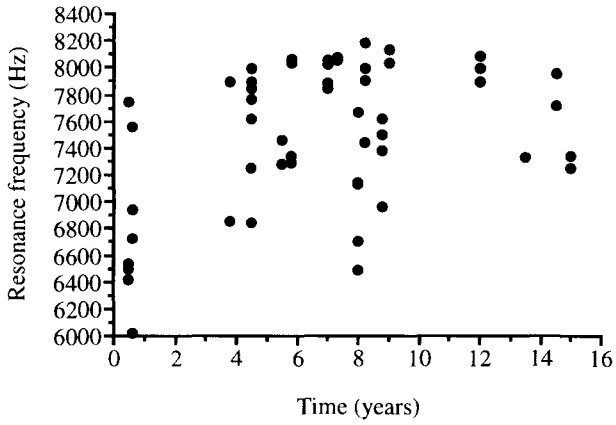


FIG. 5

Plot of all RF values against time since implant placement.

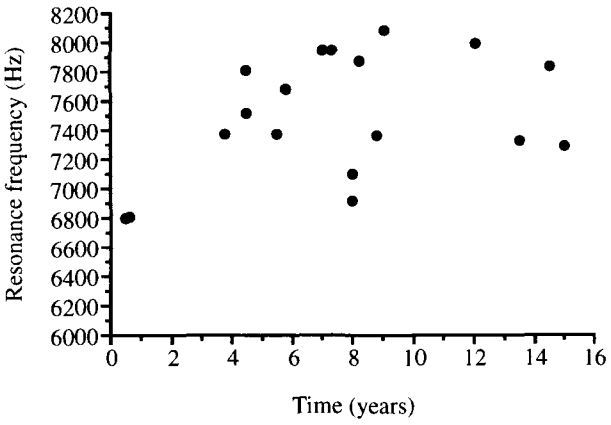


FIG. 6

Plot of patient mean RF against time since implant placement.

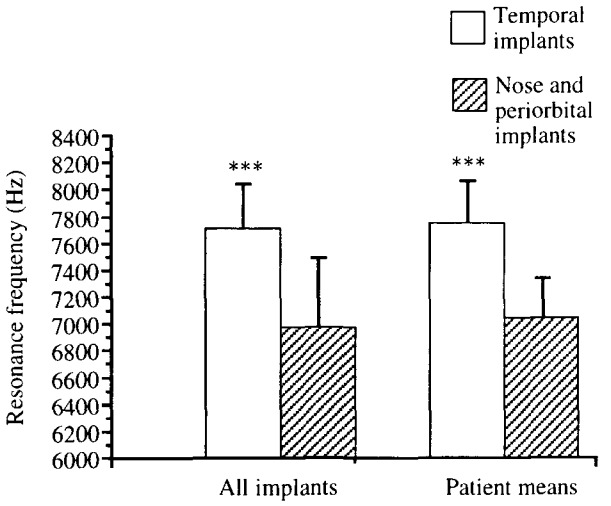


FIG. 7

Differences in resonance frequency for implants placed in temporal bone vs nose and periorbital bone.*** $p<0.001$.

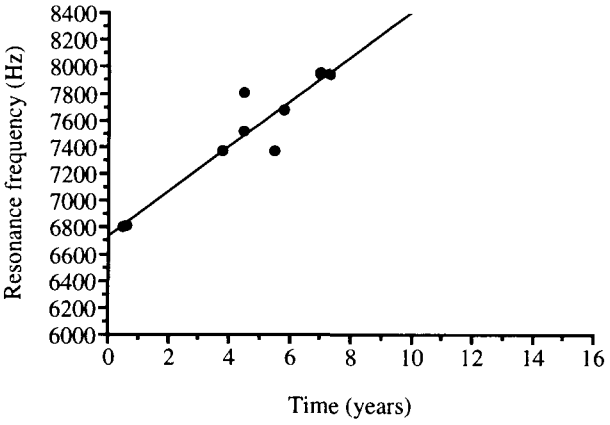


FIG. 8

Mean resonance frequency for patients with implants placed from 6 months up to 7.3 years ago. There is a statistically significant correlation between RF and time since placement ($p<0.001$, $r = 0.97$)

However, long-term clinical documentation shows higher failure rates in these regions also for non-irradiated patients (Tjellström and Jacobsson, 1992; Granström *et al.*, 1993). There seemed to be a correlation between RF and time since placement during the first seven years, which is in line with previous findings using the removal torque technique on clinical craniofacial implants (Yamanaka *et al.*, 1992).

The clinical manifestation of osseointegration is the absence of implant mobility (Albrektsson and Isidor, 1994). Clinically, it is possible to distinguish between a mobile, failed, and a stable implant but it has not until recently been possible to in a predictable way, discriminate between differences and changes in stability for stable implants. Radiography gives valuable information regarding marginal bone conditions around implants but has a number of limitations as a clinical method to assess implant stability. Sundén *et al.* (1995) concluded that the probability of predicting clinical implant instability from radiographs was low in populations with a low prevalence of implant mobility. Moreover, conventional radiography of craniofacial implants is

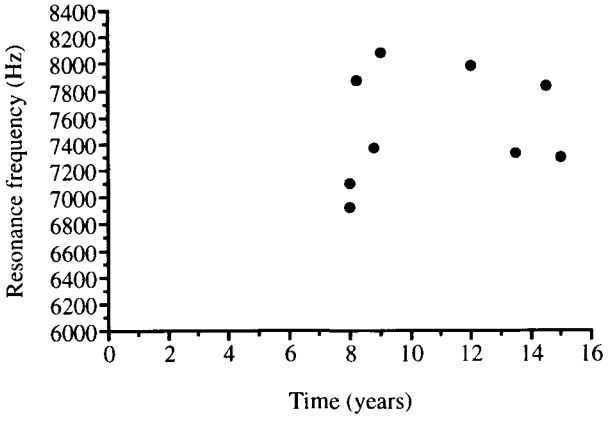


FIG. 9

Mean resonance frequency for patients with implants placed 8 years ago or more. There is no correlation with time.

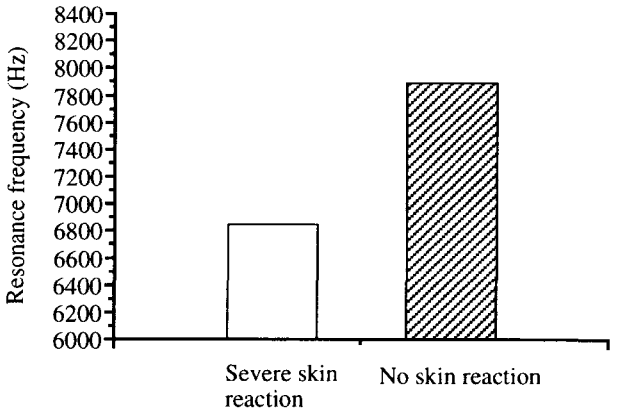


FIG. 10

Resonance frequency of one implant with severe skin reaction and one unaffected implant in temporal bone of one patient.

practically difficult to perform and tomographic techniques with less good resolution have to be used.

Percussion tests such as the Periotest® have been used to check implant stability (Teerlinck *et al.*, 1991; van Steenberghe *et al.*, 1993; Derhami *et al.*, 1995) but found to lack in sensitivity and to be influenced by a range of methodological factors when performing the test (Derhami *et al.*, 1995; Meredith *et al.*, 1998). Previous studies using the RFA technique have shown that the technique is sensitive to discriminate changes in bone stiffness around the implant (Meredith *et al.*, 1996; Meredith 1997; Meredith *et al.*, 1997a; Meredith *et al.*, 1997b; Rasmusson *et al.*, 1997). For instance, an increase in RF and implant stability from implant placement to abutment connection eight months later was observed for all except four implants in nine patients treated with 56 implants in their maxillae (Meredith *et al.*, 1997a). In that study, two of the implants with decreased RF values were found to be mobile in all directions and were removed. A third implant with a small decrease in RF showed slight rotational mobility at abutment connection. A fourth implant with unchanged RF value was clinically firm as were all the implants with increased RF values. The RF is also influenced by the effective implant length, i.e.

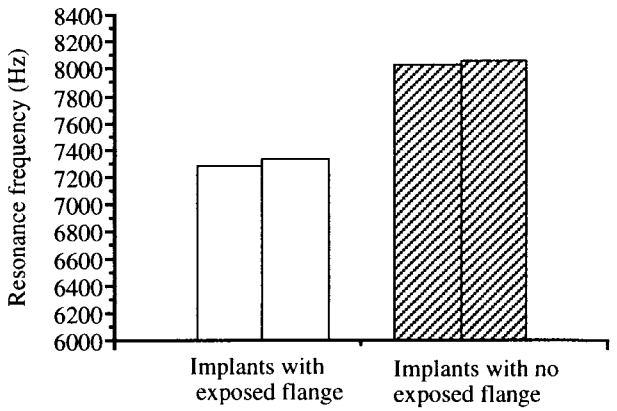


FIG. 11

Resonance frequency of temporal implants with and without exposed flanges in one patient.

the length of the abutment + the degree of marginal bone resorption. However, there is a linear relationship between RF and effective implant length which means that this can be accounted for (Meredith *et al.*, 1996; Meredith 1997; Meredith *et al.*, 1997a). In the present study, broader peaks were seen for implants with low RF values as compared to implants with high values which may reflect the damping properties of the different bone qualities. This may be one way to discriminate between changes in stiffness and changes due to marginal bone resorption.

Although, the RFA technique has been proven to be sensitive to measure changes in implant stability, it is presently not known if the technique can be used as a clinical instrument for predicting implant failure and success. Based on the clinical documentation on titanium implants, there is a correlation between soft bone quality/poor initial implant stability and implant failure (Friberg *et al.*, 1991; Jaffin and Berman, 1991; Jacobsson *et al.*, 1992; Tjellström and Jacobsson, 1992; Granström *et al.*, 1993; Roumanas *et al.*, 1994). Therefore, it may be speculated that a certain degree of implant stability is needed for successful long-term function for a certain load situation. It is concluded that RFA can be used to measure stability of craniofacial implants and that clinical longitudinal studies are needed in order to identify threshold levels for implant stability which will give high success rates.

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