Original Article

Predictive values of resonance frequency analysis as a diagnostic tool in palatal implant loss

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ABSTRACT

Objectives: To determine the diagnostic value of resonance frequency analysis (RFA) in predicting palatal implant (PI) loss**.**

Materials and Methods: RFA values of 32 patients (study center at Mainz and Dresden) were evaluated in a prospective randomized controlled trial addressing clinical performance of two loading concepts on PI (Orthosystem, Straumann, Basel, Switzerland). Group 1: conventional loading after a 12-week healing period vs group 2: immediate loading within one week after insertion. Stability was assessed by RFA after surgical insertion (T1), one week (T2), and 12 weeks (T3) later.

Results: All 32 PI were clinically stable after surgical insertion; 14 PI were loaded conventionally and 18 immediately. One implant in group 1 was lost 6 weeks after insertion. One drop-out was registered in group 2. One false positive and three false negative implant stability quotients (ISQ) were observed. ISQ values of clinically stable PI in group 1 were 67.2 (SD $\pm$ 9.5) at T1, 62.3 (SD $\pm$ 11.7) at T2, and 68.2 (SD $\pm$ 5.5) at T3. Group 2 showed 67.1 (SD $\pm$ 11.7) at T1, 65.4 (SD $\pm$ 10.4) at T2, and 72.3 (SD $\pm$ 5.6) at T3. Differences between groups were not statistically significant for starting time ($P = .88$) and change from T1 to T2: 0.08 but were significant from T1 to T3: $P = .04$; (regression analysis).

Conclusions: RFA had no sensitivity for prediction of stability. General decrease after primary stability and increase with secondary stability gives support for specificity. Within the limits of the study, only the diagnostic value of RFA identifying stable palatal implants could be confirmed. (*Angle Orthod.* 2019;89:721–726.)

KEY WORDS: Resonance frequency analysis; Palatal implant

INTRODUCTION

Osseointegration is currently regarded as the most important prerequisite for successful clinical application of endosseous implants.[1–3] Implant stability is a crucial parameter for the prognosis of an implant and resistance to loading forces, especially when early or immediate loading is desired. It is widely accepted that high primary stability immediately after surgical insertion allows immediate loading of endosseous implants.[4–13]

Traditionally, clinicians have associated a low degree of bone density or limited bone resistance during tactile assessment when drilling with low primary stability. However, some studies showed that the intraoperative assessment in this setting was not always reliable.[14] Therefore, it would be highly desirable to find measuring instruments that permit an objective, quantitative assessment of primary stability.

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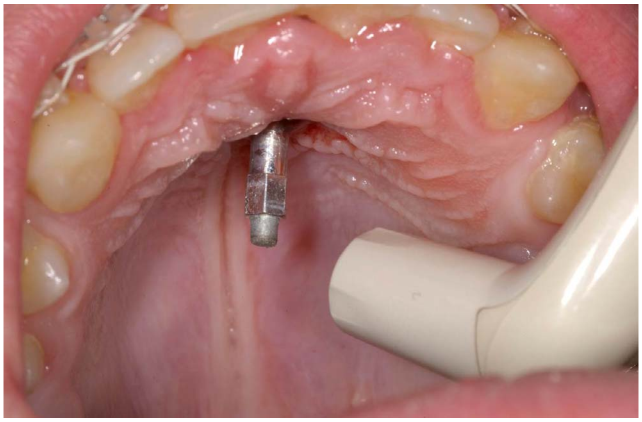

Figure 1. Measurement procedure for resonance frequency analysis.

Reliable and valid measurement of primary stability is crucial for implant success.

Resonance frequency analysis was introduced by Meredith almost 20 years ago. It is a noninvasive method that claims to accomplish objective measurement of primary implant stability as well as monitoring of implant stability over time.[6,8,11,15–18] Following the introduction of this method, a number of studies[7,14,16,19–23] have addressed the clinical value of resonance frequency analysis regarding the prediction of implant loss. However, due to the inhomogeneity of these studies, the currently available scientific data remained inconsistent.

Since palatal implants (PI) are uniform in length, diameter, and implant site, and are inserted according to a highly standardized protocol, patients with PI represent an ideal homogeneous cohort to investigate the clinical value of resonance frequency analysis as a diagnostic tool to predict implant failure.

MATERIALS AND METHODS

Ethical Review Committee approval from the institutional review board of Mainz, Germany (Ref. No: 837.210.06 (5308) and Dresden, Germany (EK274122066) was granted to conduct this study.

PI were inserted in the course of orthodontic treatment in 32 patients aged between 12 and 63 years (five males and 27 females). The patients were treated at the study centers of Dresden and Mainz and were participating in a prospective randomized controlled multicenter study with the aim of analyzing the clinical performance of two loading concepts on second-generation PI (Orthosystem, Straumann, Basel, Switzerland).

Inclusion criteria for the study were: orthodontic indication for skeletal anchorage, adequate bone quantity for a PI in the lateral cephalogram, good oral hygiene, normal wound healing capacity, and written informed consent. Exclusion criteria were cleft patients or syndromes associated with craniofacial anomalies, patients with immunodeficiency, diseases requiring prolonged steroid usage, previous radiation therapy or chemotherapy, patients with metabolic bone diseases or uncontrolled endocrine disorders, alcohol or drug abuse, and pregnancy. The complete study protocol was published at the time of the initiation of the RCT.[17]

PI of the second generation (sand-blasted and acid-etched surface (SLA; Straumann) of 4.1×4.2 mm were used. The implants were inserted in or close to the midline of the anterior palate by three experienced surgeons. Location was decided after probing and inspection of the suture region after removing the gingiva with the punch.

Surgical insertion was performed under local anesthesia, at the level of the first premolars, perpendicular to the bone surface. The implant site was prepared using the specific ortho instruments. Stability was measured by resonance frequency analysis, using an Osstell Mentor (Integration Diagnostics AB, Gothenburg, Sweden), immediately after surgical insertion. After confirmation of primary stability, the implants were randomized at a 1:1 ratio at an independent institute of biometry (KKS Mainz, Germany), using a computerized random numbers generator. According to randomization, the implants were either subjected to loading within 1 week or after a healing period of 12 weeks.

Implant stability was assessed by measurement of resonance frequency analysis using the Osstell Mentor device (Figure 1). A prefabricated implant specific transducer was screwed on palatal implants (Smartpeg Type 9, Integration Diagnostics, 4–6 Ncm). According to the principle of a tuning fork, the implant stability quotient (ISQ) values are, largely, a function of the stiffness (N/m) at the interface between the bone and the implant. The stiffer the implant/bone system, the higher is the frequency (kHz). The nondimensional ISQ scale ranges from 1 to 100. High ISQ values are indicative of high stability of the implant.

At every time point of investigation, four measurements were taken from each implant and were averaged. Measurements were performed at the following time points: immediately after insertion (T1), after 1 week (T2), and after 12 weeks (T3). For the measurements at the time of functional loading, the respective supraconstructions were removed from the implant. All measurements were performed by the same investigator in each center.

At the time of this analysis (3 months after surgical insertion), a palatal implant was rated successful (a) prior to preparation of the cast, in the absence of clinically detectable implant mobility before and (b) during orthodontic treatment indirectly by absence of undesirable movement of orthodontic supra structures.

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Figure 2. Direct loading at palatal implant.

Implants in patients of group 1 (conventional loading protocol) were cast after about 10 weeks with alginate when the osseointegration period had been concluded and the implant was found to be clinically stable; they were then subjected to functional loading after 12 weeks. Implants in patients of group 2 (early loading protocol) were cast immediately and subjected to functional loading within the first week after insertion.

Depending on the type of malocclusion, a customized palatal suprastructure was prepared on the work model for both groups. Direct force systems were applied between the anchorage implant and the teeth that were to remain mobile (eg, distal jet appliance, Figure 2). Indirect forms of anchorage were used for rigid connection between the anchorage implant and the teeth (eg, conventional or modified transpalatal arch) (Figure 3). The forces ranged between 1 and 5 N including increasing and declining after activation. Force magnitudes were measured chairside during insertion of the force systems using a spring balance (Correx, Haag-Streit, Köniz, Switzerland).

Figure 3. Indirect loading at palatal implant.

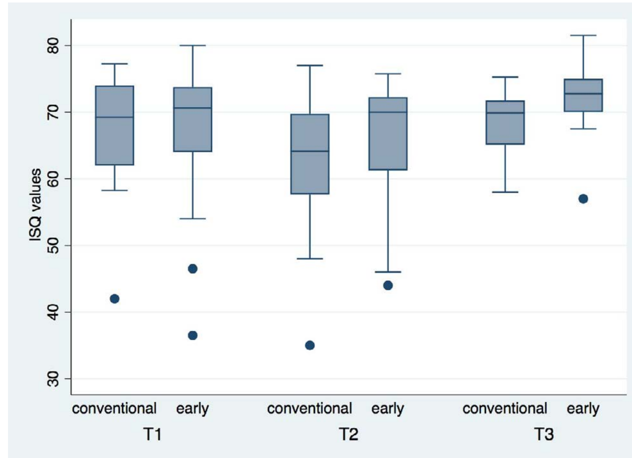

Figure 4. Changes in implant stability quotient (ISQ) values between the groups that were subjected to conventional (a) and (b) early loading after insertion (T1), after 1 week (T2) and 12 weeks (T3).

Statistical Analysis

Evaluation was performed based on absolute and relative frequencies. Calculations were performed using SPSS for Windows, version 18 (SPSS Inc., Chicago, IL) and Stata Version 15 (StataCorp, College Station, TX).

Mean changes in ISQ values within a group at the various time points were calculated using *t*-tests for paired data (Figure 4).

A linear regression analysis was used to analyze the changes in resonance frequency analysis (RFA) values and the influence of the variable "group," "age," "gender," and "vertical bone height" against the baseline values (Table 1, Figure 5). Adjustments were made according to the baseline value and center.

RESULTS

All palatal implants (32/32) were clinically stable at the time of insertion and were therefore eligible for randomization. Fourteen patients (group 1) were randomized for conventional implant loading after 12 weeks whereas 18 patients (group 2) were randomized to early functional loading within the first week. One case of local hemorrhage was noted in a patient from group 1.

One drop-out was registered in the immediate loading group. The reason was nonadherence to all control appointments. Thus, the implant could not be loaded within the first 7 days. However, this implant was stable at the last visit.

One implant in group 1 (conventional loading) was lost within 6 weeks after surgical insertion. Initial RFA values at the time of surgery (T1) were 67.2 (mean; SD ± 9.5) in group 1 (conventional loading) and 67.1 (mean; SD ± 11.7) in group 2 (early loading). Within 1

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Table 1. Results of the Linear Regression Analysis for the Variables at Time Points T1 and the Change From T1 to T2 and T3, Respectively[a]

	T1		ΔT2-T1		ΔT3-T1	
Variable	95% CI	*P* Value	95% CI	*P* Value	95% CI	*P* Value
Group	−051 [−7.6, 6.6]	.88	4.9 [−0,5, 11.6]	.06	4.35 [0.3, 8.4]	.037
Age	0.08 [−0.2, 0.3]	.59	0.20 [−0.07, 0.5]	.15	0.0001 [−0.2, 0.2]	.99
Gender	−1.17 [−10.6, 8.3]	.81	3.00 [−4.4, 10.4]	.41	2.05 [−3.5, 7.6]	.45
Center	−17.03 [−24.4, −9.6]	≤.0001	−3.76 [−12.7, 5.2]	.39	−5.86 [−12.1, 0.3]	.06
Vertical bone height	−1.08 [−33, 1.2]	.33	−0.69 [−2.6, 1.2]	.46	−0.89.08 [−1.1, −0.6]	.77

[a] Regression coefficient with 95% confidence interval [CI] and *P* value. Δ adjusted for baseline value.

week (T2), the values in the two groups had dropped to 62.3 (SD ± 11.7; group 1) and 65.4 (SD ± 10.4, group 2), respectively. After 12 weeks (T3), the values reached 68.2 (SD ± 5.5; group 1) and 72.3 (SD ± 5.6, group 2). The mean change (T2 vs T1) in ISQ was 4.9 units ($P = .06$; *t*-test) in group 1 and 1.7 units ($P = .05$; *t*-test) in group 2.

Linear regression analysis showed different RFA values between the centers at timepoint T1 ($P < .0001$, Table1). Afterward, only the influence of the variable "group" was observed on the change of RFA values ($P = .04$, ΔT3-T1, Table 1). Adjustments were made according to the baseline value when analyzing the changes.

In the case of implant loss, initial ISQ was 74 (T1) and first week ISQ was 65.3 (T2) and, thus, well within the normal range of the measurements.

DISCUSSION

The prognostic value of resonance frequency analysis with respect to early and late implant loss was unclear in the previously published literature. The investigations were based on various implant types, designs, and surfaces, as well as different anatomical insertion sites, and, thus, yielded contradictory results. Some studies supported the clinical value of resonance frequency analysis,[15,16,19,23] whereas others did not.[11,12,21,22,24]

In this study, 32 patients were included at two study centers with a single implant design, a precisely defined anatomical insertion site, bone quality, and a uniformly standardized surgical insertion protocol. Only the loading protocol, the intensity of orthodontic force, and the surgeons were variable. Patients were randomly assigned to the two loading groups (early vs conventional loading). Thus, it was possible to eliminate or adjust the typical confounding factors.

The changes in RFA values were largely similar in both loading groups. Following an initial decline, the values increased until time point T3 (after 12 weeks) and showed similar or higher ISQ values than at the time of implant insertion. Interestingly, the ISQ values (T1 mean: 74.00; T2 mean: 65.25) in one patient who suffered implant loss 6 weeks after insertion were in the upper range of those with long-term clinically stable implants.

A "loss" in RFA of nearly eight units at time point T2 might, at first sight, be noteworthy. However, similar changes were found in another seven patients without implant loss. Furthermore, one patient (group: immediate loading) had especially low RFA values at the time of surgery (ISQ 37 [Figure 4]) and, subsequently, the values remained markedly below those of the other palatal implants. This implant was early loaded indirectly with a transpalatal bar, and it remained stable. Therefore, in this highly standardized setting of palatal implants, the RFA method was not suitable to predict an implant loss or implant survival.

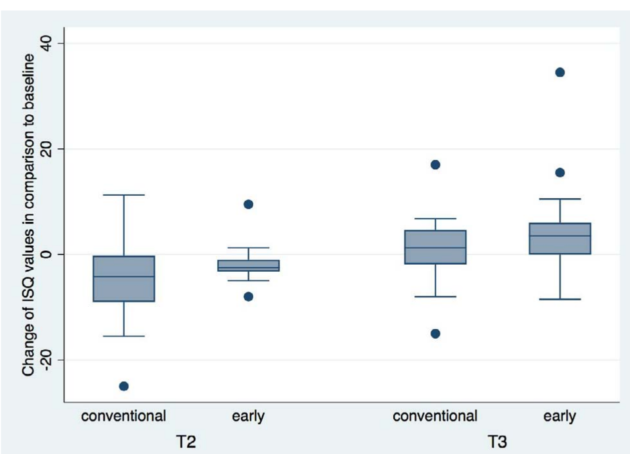

Figure 5. Δ changes in implant stability quotient (ISQ) values between the groups that were subjected to conventional and early loading after 1 week (T2) and 12 weeks (T3). The two groups showed no significant differences in implant stability at T2 ($P = .07$), but at T3 ($P = .04$) when adjusting for other covariates (baseline T1).

The results confirmed the findings of Crismani et al.[24] on 20 early loaded palatal implants over a period of 12 weeks. They described two implant losses at 9 and 11 days after insertion and under functional loading, with ISQ values of 66. The remaining implants, with similar low ISQ values as in the current investigation, remained stable. Accordingly, this also held true for palatal implants that were functionally loaded after 12 weeks. On the other hand, Huwiler et al.[22] found an

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increase of mean ISQ values one week after insertion of 24 dental implants followed by a decrease at 2 to 4 weeks. In the present study, the ISQ decreased in the patient with the implant failure after the first week more than average and this could have continued in weeks 2 to 4. In contrast to dental implants, tongue habits could interfere with the healing process of a palatal implant. Additionally, failure may potentially occur due to a certain quantity of connective tissue in the median suture and insufficient interdigitating.[25–28]

This study had the same limitation as that of Crismani et al.,[24] namely that palatal implant losses were very rare. Therefore, the rather "high" ISQ value of the single lost implant might be just a random finding (false positive). On the other hand, none of the three implants with initial ISQ values below 60 failed, rendering a major predictive effect unlikely as well (false negative).

The indirect early loading of the implant in the patient with the very low ISQ[17] at the beginning could have had a stabilization effect. Yamaguchi et al.[29] showed, with three-dimensional finite element analysis, that osseointegration could be achieved by rigid connection and reduction of micro movements.

The evaluation of the RFA as a diagnostic device able to discriminate between clinically stable and unstable implants requires the determination of a cut-off value.[12] It is the value that distinguishes between mobile and stable and is an expression of the sensitivity of the measurement. In contrast, the specificity of measurement is the probability to correctly identify clinical stability. Considering the one false positive result and three false negative results as well as tongue habit effects and potentially connective tissue in the median suture, a cut-off value cannot be determined, ie, RFA has not the sensitivity for the prediction of stability. But the general decrease after primary stability and increase with secondary stability in both groups gives support for the specificity of the RFA. In agreement with Huwiler et al,[22] RFA represents a specific but not a sensitive biomechanical test to reveal implant stability.

Therefore, within the limits of the study, the results could confirm the diagnostic value of resonance frequency analysis for correctly identifying stable PI so far.

CONCLUSIONS

- Resonance frequency analysis has no sensitivity for the prediction of palatal implant stability.
- The general decrease after primary stability and increase with secondary stability in both groups with early and conventional loading gives support for the specificity of RFA.
- Within the limits of the study, the results could confirm only the diagnostic value of RFA for correctly identifying stable palatal implants so far.

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