Can Resonance Frequency Analysis Predict Failure Risk of Immediately Loaded Implants?

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Purpose: Resonance frequency analysis (RFA) is used to measure oral implant stability. There is controversy with regard to its accuracy in predicting both implant stability and osseointegration. This systematic review and meta-analysis determined the prognostic accuracy of RFA in predicting implant failure following immediate loading protocols. ***Materials and Methods:*** MEDLINE, EMBASE, the Cochrane Oral Health Group's Trials Register, the United Kingdom National Research Register, the Australian New Zealand Clinical Trials Registry, the Database of Abstracts of Reviews of Effectiveness, and the Conference Proceedings Citations Index were searched to select studies that used RFA in assessing implant stability prior to immediate loading. The sensitivity, specificity, and accuracy of RFA in the selected studies were evaluated using a random effects model. The summary receiver operating characteristic was constructed to summarize the overall test performance. ***Results:*** Fifteen studies with 2,236 immediately loaded implants were identified. The sensitivity of RFA in predicting failure of immediately loaded implants was 0.38 (95% confidence interval [CI]: 0.22 to 0.56), the specificity was 0.73 (95% CI: 0.71 to 0.75), and the diagnostic odds ratio was 2.10 (95% CI: 0.79 to 5.57). The area under the curve was 0.54, suggesting a poor predictive and discriminative ability. ***Conclusion:*** RFA measurement at the time of implant placement is not sufficiently accurate to determine implant stability and osseointegration during immediate loading protocols. *Int J Prosthodont 2012;25:326–339.*

Traditional surgical protocols with oral implants empirically required a submerged healing period of 3 to 6 months prior to exposure and loading with prostheses.[1,2] Most recently, abbreviated loading protocols have been deemed necessary both commercially and professionally to circumvent this prolonged period of compromised esthetics and function. Therefore, early and immediate loading protocols have evolved to facilitate prosthodontic rehabilitation with a shorter healing period.

Implant stability is considered an indicator for and a measure of osseointegration[3,4] that can be defined at the primary and secondary level. Primary stability reflects the degree of mechanical interlocking between the implant and surrounding bone at the time of placement.[5,6] It is often related to the degree of bone compression and therefore can be influenced by bone quality and quantity, the surgical technique, and implant design and characteristics.[7] On the other hand, secondary stability is a biologically induced mechanism[8] involving complex processes of bone formation, maturation, and remodeling at the implant-bone interface.[9,10]

Over the past decade, outcomes of immediate loading protocols have been facilitated with the introduction of implants of altered surface characteristics and modification of surgical techniques. The rationale was to promote improved primary implant stability as a prerequisite for successful osseointegration.[11,12] Immediate loading has been thought to result in implant micromobility, leading to fibrous encapsulation instead of osseointegration.[13,14] A critical micromobility threshold of 100 μm was proposed thereafter, above which implant failure would ensue.[15,16] However, Ledermann[17,18] showed that the micromobility at the bone-implant interface remains below this critical threshold; hence, successful osseointegration of immediately loaded implants could be achieved, albeit specifically for mandibular implant overdentures.

Subsequently, several methods for the assessment of implant stability at different clinical time points have been described.[3,19] The percussion test, in which

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a stable implant would exhibit a high-pitched tone when tapped with a mouth mirror handle, was the original method used.[20] Another method was radiography, by which bone level changes around implants could be determined as a measure of successful osseointegration and therefore stability.[21] However, both methods are of limited value since they fail to objectively quantify implant stability. Other methods include the the direct evaluation of the bone-implant contact using electron microscopy,[22] removal torque analysis,[23,24] and pushout and pullout tests.[25] These methods are invasive, lack accuracy, and are impractical to use clinically. Alternative noninvasive quantitative methods such as the Periotest device (Siemens) and Osstell instrument (Integration Diagnostics) are now extensively used as surrogate measures for osseointegration, with claims of predicting optimum time for loading.[4,26]

The currently popular Osstell device uses resonance frequency analysis (RFA) in measuring implant stiffness as a determinant of implant stability.[3,27] This device is thought to be a more accurate and precise tool than the Periotest[28] and has progressively dominated implant research. Three versions of Osstell devices with different mechanisms of action are currently available commercially: the early electronic Osstell, the magnetic Osstell mentor, and the most recent Osstell ISQ. It has been suggested that the magnetic Osstell mentor is more reliable, with improved recording accuracy compared to the older electronic version.[19] On the other hand, Valderrama et al[29] compared the two devices and found a similar pattern of implant stability quotient (ISQ) values and moderate correlation between the two. The authors concluded that the use of both RFA devices was sensitive and required a learning curve.

Several factors specific to the surgical site, patient characteristics, or implant surface design were thought to influence RFA measurements. Extensive research has been done to determine the correlation between these factors and RFA measurements. However, the findings were highly variable. For example, several authors[30–34] showed that ISQ values correlated well with bone quality as defined by Lekholm and Zarb.[35] Others[36–38] demonstrated a weak correlation between bone quality and operator-perceived primary stability on one hand and ISQ values on the other. Lack of significant correlation between ISQ values and microcomputed tomographic analysis of bone volume density or trabecular connectivity was also observed.[8] RFA measurements also failed to correlate with the insertion torque[39–44] but correlated well with cortical bone thickness[45] and the cutting resistance at the time of implant placement.[46] Implant surface chemistry and finishing did not seem to influence ISQ values,[29,44,47] nor did the implant diameter.[30,47] In contrast, implant length was found to enhance the primary stability since longer implants provided more bone-implant contact area.[34,48–50]

Clinically, RFA could be more useful in monitoring implant stability over a period starting from the time of implant placement and extending throughout the healing phase. Use of repeated measurements at separate intervals following implant insertion is thought to determine the appropriate time of loading[51] and to predict early signs of clinical failure.[4] Although an ISQ value falling within the wide range of 57 and 74 has been considered normal during implant placement,[8,30,52] consensus regarding a normative ISQ range has not been established.[53,54] The controversy over the variable literature on RFA becomes compounded when it is applied to immediate loading protocols by clinicians. With these abbreviated loading protocols, the only RFA measurement taken prior to loading is the one recorded at the time of implant placement. Therefore, it is of imperative clinical significance to identify a safe ISQ threshold for planned immediate loading. This threshold could identify implants that are amenable to immediate loading and predict those at a high risk of failure. In an animal study, Al-Nawas et al[55] suggested that an ISQ threshold value of 65.5 at implant placement, with a sensitivity of 83% and specificity of 61%, may predict implant loss. Other clinical studies suggested that implants with ISQ values above 65 at the time of placement were suitable for immediate loading.[4,56–59] On the other hand, ISQ values of ≥ 42,[60] 60,[61–64] or 62[65] at implant placement have also been suggested as threshold values for immediate loading. These conflicting results across the different clinical studies using RFA have perplexed the profession with regard to the acceptable normative ISQ value for immediate loading.

The objective of this systematic review was to determine the prognostic accuracy of RFA measurements recorded at the time of implant placement in predicting osseointegration of immediately loaded implants.

Materials and Methods

Search Strategy

This systematic review was prepared in accordance with standard guidelines.[66–68] A comprehensive review methodology was performed by searching the following electronic databases up to January 2011: MEDLINE, EMBASE, the Cochrane Oral Health Group's Trials Register, the Cochrane Central Register of

Controlled Trials (CENTRAL), United Kingdom National Research Register, Australian New Zealand Clinical Trials Register, Database of Abstracts of Reviews of Effectiveness (DARE), and the Conference Proceedings Citation Index. The search terms included ("immediate loading" OR "immediate restoration") AND ("immediate functional loading" OR "immediate nonfunctional loading") AND ("oral implant" OR "dental implant" OR "implant-supported prostheses") AND ("implant stability quotient" OR "implant stability measurement") AND ("resonance frequency analysis" OR "resonance frequency method" OR "Osstell") AND ("survival rate" OR "success rate") AND ("sensitivity" OR "specificity") AND ("predictive value" OR "likelihood").

Manual searches were also conducted in the following journals for the past 5 years (up to January 2011): *Clinical Implant Dentistry & Related Research*, *Clinical Oral Implants Research*, *Implant Dentistry*, *International Journal of Oral & Maxillofacial Implants*, *International Journal of Periodontics & Restorative Dentistry*, *International Journal of Prosthodontics*, *Journal of Clinical Periodontology*, *Journal of Dental Research*, *Journal of Oral Implantology*, *Journal of Oral Rehabilitation*, *Journal of Periodontal Research*, *Journal of Periodontology*, *Journal of Prosthetic Dentistry*, *Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontology*, and *Quintessence International*. The search was also supplemented by searching the bibliographies of the selected articles, and relevant reviews were manually searched to identify further studies for inclusion. The authors attempted to contact corresponding authors to verify the extracted data or obtain missing data.

Study Selection

Studies in the English language were independently selected by the authors, with disagreements resolved by consensus. All human studies that used RFA at the time of implant placement to detect the stability of immediately loaded oral implants were included if they fulfilled the following inclusion criteria: population of healthy participants without any systemic disease, heavy smoking, or parafunctional habits; intervention consisting of immediate loading of at least 10 solid root-form titanium implants placed in nongrafted sites; mean follow-up period of at least 12 months; and clearly reported sensitivity and specificity of RFA or the presence of raw ISQ data that would allow the construction of 2 × 2 tables for assessment of diagnostic accuracy.

Immediate loading of implants was defined as restoring the implants within 48 hours of placement.[69] ISQ values recorded by both the electronic Osstell and magnetic Osstell Mentor were included in the analysis, since measurements obtained by both devices were correlated.[29] An ISQ value of 65 at surgery was selected as the threshold value for predicting the risk of implant failure.[4,56–59] The survival rate of the immediately loaded implants after a minimum follow-up period of 12 months was used as a surrogate reference standard. The positive reference standard was failure of an immediately loaded implant to osseointegrate.

Data Abstraction

The authors, who were unmasked to the journal of publication, used a specially designed data template to extract the following information: publication details (title, author[s], journal, year, volume, issue number, pages), type of study, patient details, number of immediately loaded implants, type of RFA device, ISQ measurements at the time of implant placement, bone quality, insertion torque, implant survival rate, and follow-up period. In the presence of other treatment groups, the data pertaining to the immediate loading group only were collected. The sensitivity, specificity, and positive and negative predictive values were calculated based on the ISQ threshold value of 65.[4,56–59]

Quality Assessment

The methodologic quality of the included studies was assessed based on a quality assessment tool adopted from Hayden et al.[70] The assessment tool included six domains that assessed the patient selection, study attrition, statistical analysis, measurements of the prognostic factor, outcome, and potential confounders. Each item was scored as yes (lack of bias), no (potential bias), or unclear (insufficient data).

Data Synthesis and Analysis

The meta-analysis was performed using Meta-DiSc software, version 1.4 (Clinical Biostatistics Unit, Ramón y Cajal Hospital).[71] For each study, the true-positive, false-positive, false-negative, and true-negative results were obtained directly from the published data or by contacting the corresponding authors. The sensitivity, specificity, positive likelihood ratio (LR+), negative likelihood ratio (LR–), and diagnostic odds ratio (DOR) were calculated from 2 × 2 contingency tables for the 65 ISQ threshold value. To avoid computational problems, 0.5 was added to each cell that contained a value of 0 in the 2 × 2 table.[72] The LRs are more reliable in measuring the discriminatory ability of diagnostic and prognostic tests since

they are less dependent on the prevalence rate. An LR+ of more than 10 and LR– of less than 0.1 indicate a satisfactory discriminatory diagnostic and prognostic performance. The overall pooled sensitivity, specificity, and LR estimates with 95% confidence intervals (CIs) were combined using meta-analytic methods for random effects.[73] Between-study heterogeneity was assessed visually using forest plots and statistically using the Cochran Q chi-square test, with a P value < .10 indicating a statistically significant degree of heterogeneity. The I^2 test quantified heterogeneity, with I^2 values of 25, 50, and 75 indicating low, moderate, and high heterogeneity, respectively. The potential causes of heterogeneity were explored using a meta-regression model that included the type of Osstell device, mean ISQ at baseline, and implant location and system.

The interaction between sensitivity and specificity was graphically presented using the summary receiver operating characteristic (SROC). The overall ability of RFA to predict the outcome was quantified using the area under the SROC curve. The area under the curve measures the overall capacity of the test to discriminate between participants with the disease and those without it. An area under the curve of 0.5 to 0.7 indicates poor accuracy, 0.7 to 0.9 is moderate, and 0.9 to 0.99 is very good; an area of 1.0 indicates perfect predictive ability.[74,75] The DOR is the ratio of the odds of positive test results in participants with failed implants compared with the odds of positive test results in those with implants that osseointegrated. The DOR allows the assessment of study characteristics (covariates) and is often constant, regardless of the diagnostic threshold, and ranges from 0 to infinity, with greater values indicating greater accuracy.[76] The funnel plot, which is constructed from the standard error and the estimated effect size ($\log_{DOR}$), was used to assess any potential for publication bias.

Results

The initial search identified 404 citations for reviewing. Of these, 374 were rejected after screening the abstracts. Following detailed assessment of the full text of the remaining 30 articles, a total of 15 studies,[30,38,42,60,61,63,77–85] all published in English, were included in the review. Fifteen studies were excluded from the review for the following reasons (Fig 1): 11 studies had insufficient information and data could not be obtained from corresponding authors,[31,59,65,85–93] 2 studies did not include immediately loaded implants,[94,95] 1 study had a mean follow-up period of less than 12 months,[96] and 1 study allowed smoking and local bone grafting procedures.[97]

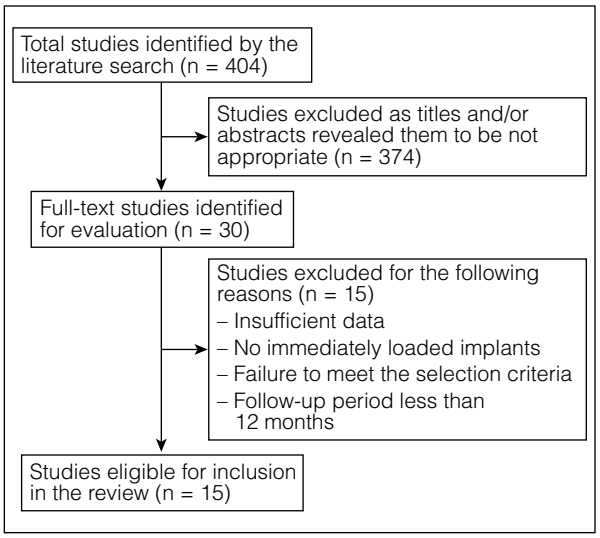


Fig 1 Flowchart of the search strategy.

Hand-searching failed to provide any additional studies. All together, the studies included 2,236 immediately loaded oral implants in both maxillary and mandibular sites. Contact with the corresponding authors of the selected studies provided more relevant data and confirmed eligibility of inclusion. The characteristics of the included studies are summarized in Table 1.

Description of Included Studies

All included studies had similar inclusion and exclusion criteria that involved recruiting participants with controlled periodontal health and adequate bone quantity and quality and excluding bruxers, heavy smokers, and those with systemic diseases or requiring augmentation procedures. Seven studies[42,61,77–79,82,83] used Brånemark implants with oxidized surfaces (TiUnite, Nobel Biocare), three studies[38,63,84] used microtextured surfaced implants (Dentsply Friadent), three studies[30,60,85] used Straumann implants with sandblasted and acid-etched surfaces (SLA; Straumann), and the remaining two studies used one-piece implants with a sandblasted, acid-etched surface (Neodent, Curitiba)[80] and cylindric implants with blasted surfaces (PrimaConnex, Keystone Dental).[81]

The implants included in the analysis were inserted with a torque value of ≥ 32 Ncm to restore partially dentate and edentulous arches. All but 3 studies[38,81,85] used the electronic Osstell device, with

Table 1 Characteristics of the Included Studies

	Study design	Country	No. of patients	Mean age (y)	No. of implants*	Implant system	Implant diameter (mm)
Bischof et al[30]	CCT	Switzerland	18	57.1	63	SLA ITI (Straumann)	4.1, 4.8
Calandriello and Tomatis[77]	Prospective	Italy	33	52.0	40	TiUnite Wide Platform MK III (Brånemark System, Nobel Biocare)	5
da Cunha et al[42]	Prospective	Brazil	12	35.0	24	Standard and TiUnite MK III (Brånemark System, Nobel Biocare)	3.75
Degidi et al[84]	Prospective	Italy	130	53.0	484	Microtextured XiVE (Dentsply Friadent)	3.0 to 5.5
Degidi et al[63]	Retrospective	Italy	321	49.5	423	Microtextured Frialit and XiVE plus (Dentsply Friadent)	3.0 to 6.5
Degidi et al[38]	Prospective	Italy	152	NS	514	Microtextured XiVE (Dentsply Friadent)	3.0 to 5.5
Fischer et al[78]	Prospective	Sweden	16	54.0	16	Oxidized tapered Replace Select TiUnite (Nobel Biocare)	4.3, 5.0
Güncü et al[79]	RCT	Turkey	12	41.1	12	MK III TiUnite (Brånemark System, Nobel Biocare)	4
Liddelow and Henry[83]	Prospective	Australia	35	68.0	32	Machined or oxidized Brånemark MK III (Nobel Biocare)	4
Melo et al[80]	Prospective	Brazil	11	66.0	44	GT (sandblasted and acid-etched surface; Neodent, Curitiba)	3.75 to 4.50
Nedir et al[60]	Prospective	Switzerland	18	57.1	63	SLA ITI (Straumann)	4.1, 4.8
Ostman et al[61]	Prospective	Sweden	20	73.0	123	Brånemark IV, III TiUnite, and Replace Select Tapered (Nobel Biocare)	NS
Pieri et al[81]	Prospective	Italy	22	66.7	103	Cylindric with bioabsorbable blasted surface (PrimaConnex, Keystone)	3.3, 4.0
Rao and Benzi[82]	Prospective	Italy	46	42.0	47	Oxidized, threaded, Replace Select Tapered TiUnite (Nobel Biocare)	4.3, 5.0, 6.0
Stoker and Wismeijer[85]	Prospective	The Netherlands	124	64.4	248	SLA ITI (Straumann)	3.3, 4.1

RFA = resonance frequency analysis; ISQ = implant stability quotient; CCT = controlled clinical trial; RCT = randomized controlled trial; SLA = sandblasted, large-grit, acid-etched; NS = not specified.
*Values given for immediately loaded implants only.

mean ISQ values ranging from 57.2[30] to 75.1[85] at surgery. Two classification systems[35,98] were used to describe bone density. A total of 24 failed implants were reported in 11 studies,[30,60,61,63,77–79,81,83–85] of which 6 were placed in low bone quality (type IV). An ISQ range of 53 to 78 was recorded for failed implants at placement. The immediately loaded implant survival rates ranged from 90.6%[83] to 100%[42,80,82] over a period of 12 to 72 months.

Quality of Included Studies

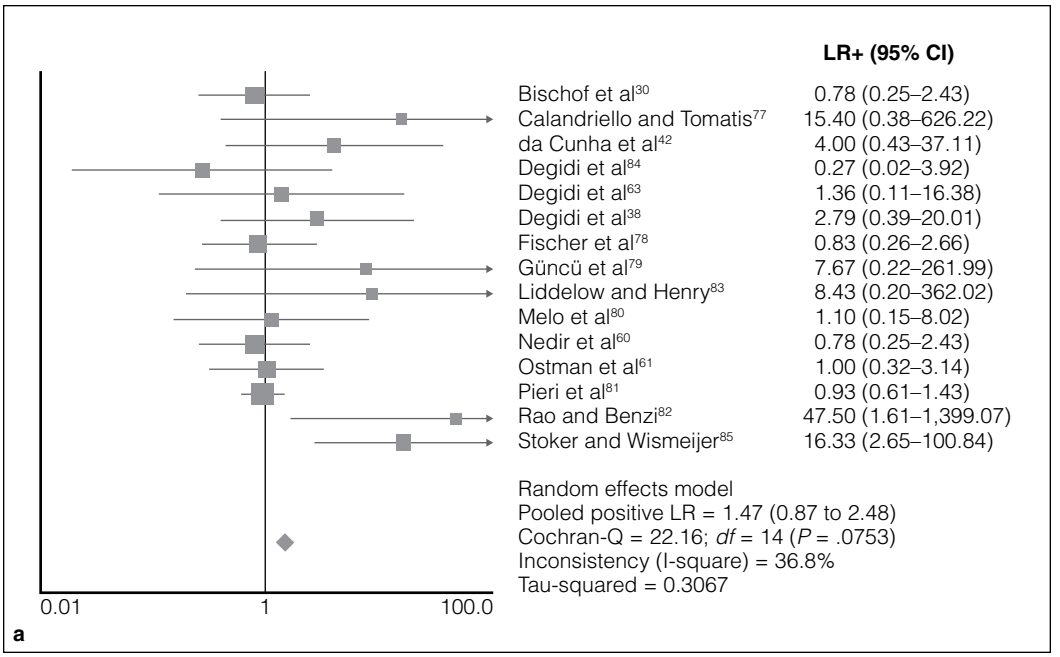
The methodologic quality of the studies was assessed according to the six-item list proposed by Hayden et al.[70] For the first item, the study population was represented by a clear definition of the inclusion and exclusion criteria in all but three studies.[30,60,85] The items related to follow-up period, prognostic factor, and outcome were adequately described by all selected studies except for 1,[38] which did not report a follow-up period, but relevant information was obtained from the author. With regard to accounting for confounding variables, a standardized technique for measurements was followed in each study, but none of the studies clearly stated that the decision to immediately load the implant was made blind to the RFA measurements at surgery, bone quality, or other potential confounders. Based on the published data, all but one study[60] scored "unclear" for the last item. However, further data were supplemented by contacting the corresponding authors. The results of the quality assessment are summarized in Table 2.

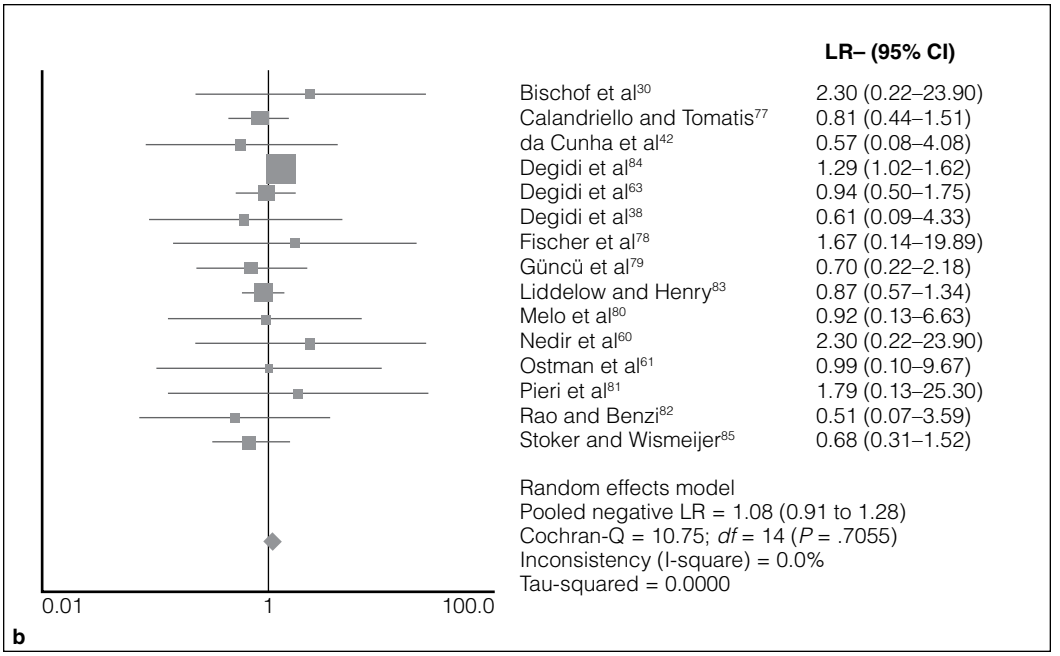
Implant length (mm)	Implant location	Insertion torque (Ncm)	Type of RFA unit	Mean ISQ (at surgery)*	Mean observation period (mo)	Implant survival (%)	Sensitivity (%)	Specificity (%)
8 to 13	Maxilla, mandible	NS	Electronic Osstell (transducer type L4F5)	57.2	12	98.4	66.7	14.5
8.5 to 18	Mandible	35	Electronic Osstell	> 70	60	95.0	20.0	98.7
13	Maxilla	20 to 43	Electronic Osstell	67.8	72	100.0	50.0	87.5
8 to 18	Maxilla, mandible	> 25	Electronic Osstell	NS	24	98.8	7.7	71.8
8 to 18	Maxilla, mandible	> 25	Electronic Osstell	NS	12	99.6	20.0	85.3
8 to 18	Maxilla, mandible	39.9	Magnetic Osstell Mentor	73.5	12	100.0	50.0	82.1
10 to 16	Maxilla	≥ 32	Electronic Osstell	63.3	12	93.8	66.7	20.0
11.5	Mandible	NS	Electronic Osstell	74.2	12	91.7	33.3	95.7
10 to 18	Mandible	> 45	Electronic Osstell	Machined surface: 72.25 Oxidized surface: 74.76	36	90.6	14.3	98.3
≥ 13	Mandible	NS	Electronic Osstell	64.1	12	100.0	50.0	54.5
8 to 13	Maxilla, mandible	35	Electronic Osstell	NS	12	98.4	66.7	14.5
10 to 18	Maxilla	≥ 30	Electronic Osstell	62.9	12	99.2	66.7	33.6
10 to 15	Maxilla	≥ 30	Magnetic Osstell Mentor	60.9	12	97.1	85.7	8.0
10, 13	Mandible	≥ 30	Electronic Osstell	71.9	12	100.0	50.0	98.9
10, 12, 14	Mandible	≥ 35	Magnetic Osstell Mentor	75.1	24	98.8	33.3	98.0

Table 2 Results of the Methodologic Quality Assessment

Item	Study population	Follow-up	Prognostic factor	Outcome	Confounding	Analysis
Bischof et al[30]	No	Yes	Yes	Yes	No	Unclear
Calandriello and Tomatis[77]	Yes	Yes	Yes	Yes	No	Unclear
da Cunha et al[42]	Yes	Yes	Yes	Yes	No	Unclear
Degidi et al[84]	Yes	Yes	Yes	Yes	No	Unclear
Degidi et al[63]	Yes	Yes	Yes	Yes	No	Unclear
Degidi et al[38]	Yes	No	Yes	Yes	No	Unclear
Fischer et al[78]	Yes	Yes	Yes	Yes	No	Unclear
Güncü et al[79]	Yes	Yes	Yes	Yes	No	Unclear
Liddelow and Henry[83]	Yes	Yes	Yes	Yes	No	Unclear
Melo et al[80]	Yes	Yes	Yes	Yes	No	Unclear
Nedir et al[60]	Unclear	Yes	Yes	Yes	No	Yes
Ostman et al[61]	Yes	Yes	Yes	Yes	No	Unclear
Pieri et al[81]	Yes	Yes	Yes	Yes	No	Unclear
Rao and Benzi[82]	Yes	Yes	Yes	Yes	No	Unclear
Stoker and Wismeijer[85]	Unclear	Yes	Yes	Yes	No	Unclear

Yes = lack of bias; no = potential bias; unclear = insufficient data.





Figs 2a and 2b Plots of **(a)** positive (LR+) and **(b)** negative (LR–) likelihood ratios of RFA in predicting failure risk.

Meta-analysis

At the proposed threshold value of 65 ISQ at baseline, all selected studies were included in the meta-analysis. The pooled sensitivity and specificity were relatively poor at 37.9% (95% CI: 21.6% to 56.4%) and 72.6% (95% CI: 70.7% to 74.5%), respectively. Consequently, the pooled LR+ and LR– were 1.47 (95% CI: 0.87 to 2.48, Fig 2a) and 1.08 (95% CI: 0.91 to 1.28, Fig 2b), respectively, indicating inadequate predictive information. The DOR was calculated at 2.10 (95% CI: 0.79 to 5.57, Fig 3) with insignificant heterogeneity (P = .32). The area under the curve was calculated as 0.54 (statistical error = 0.06, Fig 4),

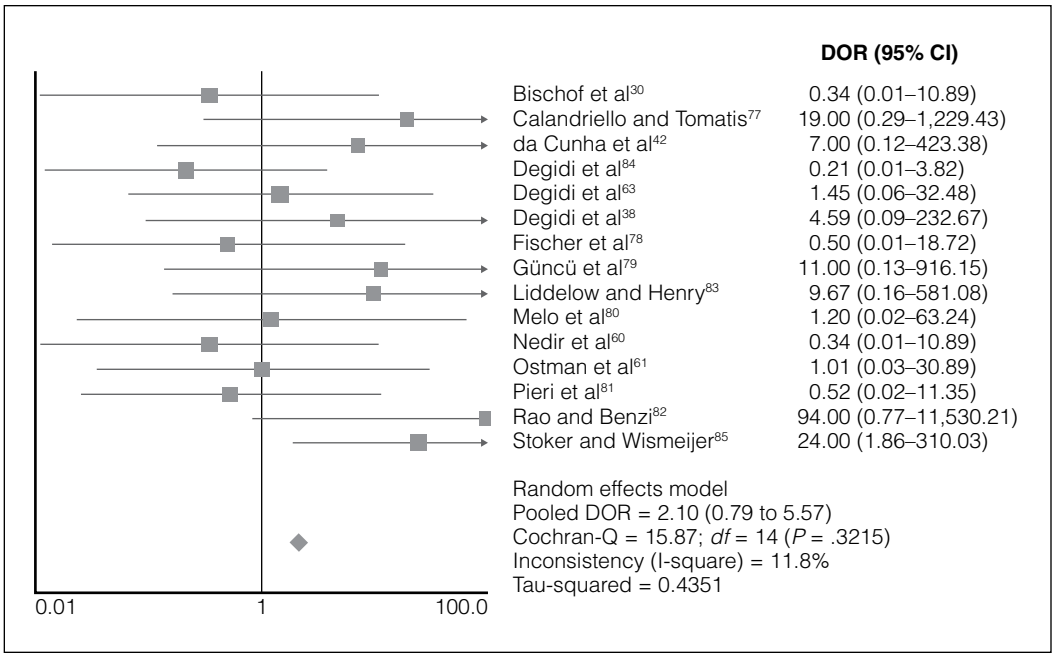


Fig 3 Diagnostic odds ratio of RFA analysis in predicting failure risk.

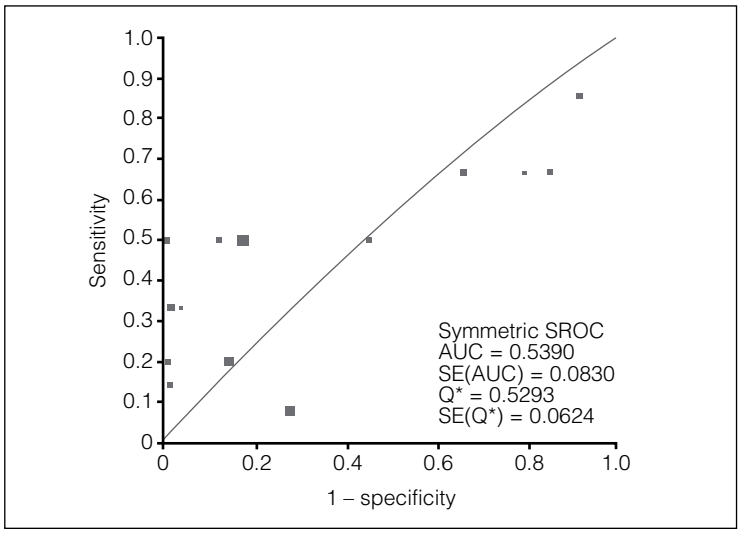


Fig 4 Summary receiver operating characteristic of RFA for predicting failure. AUC = area under the curve; SE = standard error; Q* = point of indifference where sensitivity meets specificity.

suggesting a poor performance of the initial RFA measurements in predicting implant failure after 1 year of immediate loading. The funnel graph showed no evidence of publication bias since the distribution of the included studies was moderately symmetric around the vertical line that represented the pooled $\log_{DOR}$ (Fig 5). Despite the limited number of studies, the meta-regression was conducted to assess the potential sources of heterogeneity. The type of Osstell unit, the mean ISQ at placement, and implant location or system did not significantly improve the performance of RFA (Table 3).

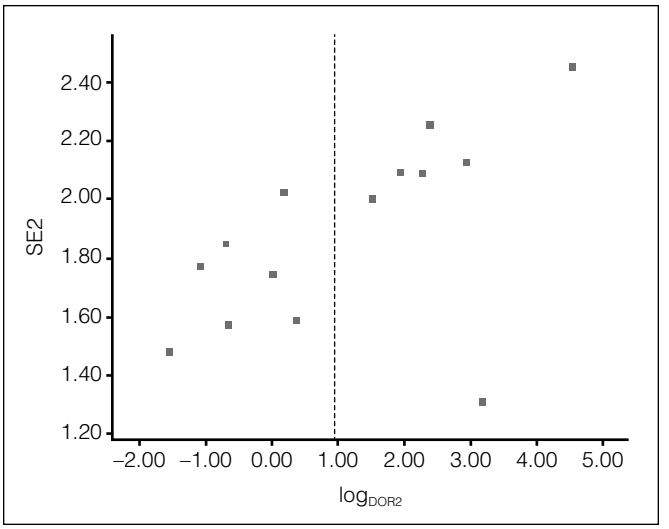


Fig 5 Funnel plot for assessment of publication bias.

Table 3 Weighted Meta-Regression of the Effects of Type of RFA Unit, Mean ISQ at Surgery, and Implant Location and System

Covariates	No. of studies	Coefficient	Relative DOR	*P*
Type of RFA unit	12	–1.30	0.27	.24
Mean ISQ at surgery ≥ 70	6	2.75	15.67	.06
Implant location (mandible or maxilla)	6	2.14	8.50	.12
Implant system	7	0.90	2.46	.38

RFA = resonance frequency analysis; ISQ = implant stability quotient; DOR = diagnostic odds ratio.

Discussion

A standardized approach[66–68] was followed in the preparation of this systematic review and meta-analysis to evaluate the best available evidence for the use of RFA as a predictor of implant failure in immediate loading conditions. Fifteen studies[30,38,42,60,61,63,77–85] with a total of 2,236 implants were included in the meta-analysis to provide an overall estimation of the sensitivity, specificity, and accuracy of RFA based on published and unpublished data obtained by request from the corresponding authors. The clinical outcome (implant survival vs failure) was considered to be the reference standard. An ISQ threshold of 65 was selected based on previous literature[4,56–59] and since it was the highest recommended threshold value in an attempt to minimize false positives and improve sensitivity. However, the results of the meta-analysis showed poor sensitivity, specificity, and accuracy of RFA, with an LR close to 1 indicating inadequate performance.

To investigate the potential sources of heterogeneity, a meta-regression model was generated with four covariates (type of the measuring unit, mean ISQ at baseline, and implant location and system). The overall performance of RFA was not significantly affected by any of the covariates studied. This is partly in accordance with previous literature[29] in which the patterns of RFA measurements recorded by the electronic and magnetic Osstell instruments were not significantly different. However, this review failed to show any influence of implant design or surface alterations on RFA performance despite the variability of the mean ISQ values reported for different implant systems. Mean ISQs of 68.1, 57.4, and 67.4 were recorded for Neoss,[99] Straumann,[30] and Brånemark implants,[32] respectively. It is worth noting that one of the covariates (mean ISQ at surgery) was closer to statistical significance (P = .06) than the others, which might highlight the need for an ISQ threshold level of > 70 to improve the accuracy of the test.

The authors propose that the reasons behind the limitations of RFA as a prognostic tool for immediate loading are not only related to different responses in various locations and implant systems, but also include the ambiguity about what biologic parameters are exactly measured by RFA. Huwiler et al[8] described an ISQ range of 57 to 74 as being normal

during implant placement but showed that RFA measurements failed to reflect the bone-implant interface and questioned the predictive capability of RFA. Despite improvements in hardware, it appears that RFA testing may merely indicate that the inserted implant is clinically stable at the time of measurement and therefore may provide a false sense of assurance for both clinicians and patients contemplating immediate implant restoration.

To overcome the low sensitivity of RFA at the time of implant placement, it has been suggested that RFA should be combined with clinical parameters, radiographic evaluation, and insertion torque analysis before implant loading. Otherwise, an additional healing period should be allowed. Moreover, monitoring ISQ during the first month of functional loading has shown to be more valuable since any decrease in ISQ value may indicate a tendency to fail. In this instance, the implant is unloaded until it regains its stability and reaches a safe ISQ level prior to definitive restoration.[82,100]

This systematic review and meta-analysis had several limitations. Despite the extensive literature on the use of RFA, only a small number of studies were included. This limited number is attributed to the strict inclusion criteria adopted and the difficulty in obtaining individual patient data from corresponding authors of otherwise eligible trials. Moreover, the review failed to identify any unpublished studies despite the extensive search strategy. Nevertheless, data obtained from unpublished literature are thought to be of low quality and may in themselves be sources of bias.[101] Finally, the search strategy was limited to studies in the English language, which may have introduced language bias, although it is acknowledged that non–English language trials tend to be of lower methodologic quality compared with those in English.[102] The present systematic review also has its merits, such as the use of strict inclusion criteria in an effort to minimize the heterogeneity, the acquisition of additional data from corresponding authors to include further studies, and the moderate quality of the selected studies. In addition, given the lack of a generally accepted ISQ threshold for immediate loading, this review is the first systematic review to use a threshold value to evaluate the accuracy of RFA in measuring primary stability and to determine the failure risk of implants subjected to immediate loading.

The use of RFA has been the subject of numerous systematic reviews.[19,64,100,103] Aparicio et al[64] reviewed the literature to investigate the validity and prognostic characteristics of RFA and the Periotest method. The authors acknowledged the advantages in determining both implant stability and failure of osseointegration but emphasized that single readings are not clinically beneficial for long-term evaluation of implant success. The authors recommended further prospective clinical studies to investigate the prognostic accuracy of RFA. Atsumi et al[19] summarized the current status of noninvasive methods of measuring implant stability. They questioned the reliability of RFA and called for longitudinal studies to establish ISQ thresholds for different implant lengths and locations as well as evaluate the diagnostic and prognostic value of the RFA units. Sennerby and Meredith[100] carried out a comprehensive review that discussed the development of RFA and the factors that may influence implant stability measurements. The authors suggested a safe ISQ threshold of 45 and 55 for Straumann and Brånemark systems, respectively, below which measures should be adopted to control stability. In addition, the authors highlighted the need for clinical guidelines on the use of RFA for measuring implant stability before loading. In a meta-analysis that included human, animal, and in vitro studies, Cehreli et al[103] attempted to correlate RFA to other methods of evaluating implant stability. The results showed an overall strong correlation only between cutting or insertion torque and RFA. However, none of the previously mentioned reviews discussed the prognostic value of RFA in immediate loading conditions.

This review, albeit specifically on immediate loading, questions whether RFA as a measuring unit of implant stability provides clinicians with a reliable ISQ value that can be used as an inclusion criterion for implant loading within the first 48 hours of placement. The authors showed that RFA reliability is indeed poor, and its measurements should be interpreted with caution. The findings further suggest that there are no clinically meaningful benefits of using RFA at surgery on the outcome of immediately loaded implants. The authors do concede that the RFA concept is part of the zeitgeist of searching for a precise diagnostic and prognostic tool for challenging implant situations. However, the inflated claims regarding the accuracy of RFA were mainly based on descriptive literature, and the informational cascade provided by previous correlational studies had simply developed RFA in another legacy of empiricism. In a pertinent commentary, Koka[104] issued a call for further evidence to prove whether RFA provided any additional diagnostic information than can be simply obtained by the tactile skills of an experienced surgeon. Yet again, it now appears that the external validation of the instrument identifies flaws in relation to immediate loading as well. Therefore, to establish an evidence-based practice with regard to the use of RFA, further outcomes based on longitudinal human

trials should be reported to validate its true short- and long-term diagnostic and prognostic capabilities.

Future planned studies evaluating the diagnostic and prognostic values of RFA are required to follow the guidelines of the Standards for the Reporting of Diagnostic Accuracy studies (STARD).[105] Subsequently, consensus among clinical guidelines for the assessment of implant stability should be established to determine threshold ISQ values for each implant system and in different locations. In addition, other noninvasive objective methods of measuring the long-term stability of immediately loaded implants need to be further investigated and developed.

Conclusion

RFA measurement at the time of implant placement is not sufficiently accurate to determine implant stability and osseointegration during immediate loading protocols.

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Literature Abstract

Surgical management of bisphosphonate-related osteonecrosis of the jaw in oncologic patients: A challenging problem

The aim of this study was to analyze a single-institution patient cohort suffering from bisphosphonate-related osteonecrosis of the jaw (BRONJ) in various stages as well as their type of treatment and clinical outcome. One hundred forty-two patients (95 women and 47 men) with BRONJ ranging in age from 38 to 94 years (median: 62 years) were treated. Various surgical modalities were carried out, and patients were followed long term to investigate any surgical complication or residual BRONJ. The mandible was affected in 58% of patients, and the maxilla was involved in 27% of patients; 15% of patients had involvement in both arches. Ninety-seven percent of patients received intravenous nitrogen-containing bisphosphonates. The duration of bisphosphonate treatment ranged from 5 to 130 months, with a mean of 37.1 months. Eighty-six percent of patients required surgical treatment of the necrotic bone areas under local or general anesthesia. Conservative treatment, consisting of chlorhexidine oral irrigation and antibiotic medications, was effective in only 14% of patients. Sixty-four percent of patients presented with large exposed necrotic bone areas and required a marginal bone resection and soft tissue closure. Six patients (5%) suffered from extensive necrosis, infection, or pathologic fracture of the mandible and required a segmental bone resection and immediate rigid fixation with titanium reconstruction plates using a submandibular approach. Twenty patients (16%) required a soft tissue closure procedure using a myofascial flap from the mylohyoid muscle. One patient required intraoral soft tissue reconstruction using a fascio-cutaneous vascularized graft from the upper lateral arm. Forty percent of treated patients suffered from refractory BRONJ and required additional surgical interventions. It can be clearly seen that a large percentage of patients with BRONJ have a high morbidity rate, and a significant percentage of patients suffer from refractory BRONJ despite having treatment. The authors rightly emphasized the need for optimized oral and dental health and regular monitoring of patients treated with bisphosphonates, and this notion has to be clearly communicated to these patients.

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