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The utility of resonance frequency analysis related to decision-making in immediately loaded dental implants: a systematic review

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Background: Research into immediate-loading protocols has shown encouraging results. The evaluation of an immediate-loading technique would require a quantitative method for the measurement of implant stability. Resonance frequency analysis (RFA) is emerging as a non-invasive tool for the clinician to assess primary stability of the newly placed implant. Nonetheless, so far, little evidence is available in the literature and no gold standard for the evaluation of implant stability exists that could be used for comparison.

Objective: To evaluate the evidence available in the literature regarding resonance frequency analysis for the determination of primary stability with regard to its utility in decision-making in immediate-loading protocols.

Materials and methods: An initial electronic database search (PubMed) was performed to identify articles related to resonance frequency analysis published or accepted for publication from 1996 to April 2007. Next, a manual search was performed throughout the most relevant journals that specialise in implant dentistry. Finally, an additional search was made through the references of the selected articles. The selection of articles, extraction of data, and assessment of validity were made independently by two reviewers.

Results: A total of 37 articles were selected for data extraction. Data regarding advantages and limitations of RFA and factors influencing primary stability was extracted from each paper. No randomised controlled trials were found in the literature; thus, all study designs were accepted. Due to the heterogeneous methodology, a meta-analysis could not be performed.

Conclusions: RFA may help the clinician to choose among various loading protocols and to selectively monitor implants during the healing phase. However, the biological parameters that may be represented by the implant stability quotient value are still not fully understood. There is a lack of consistency in the evidence analysed, thus drawing attention to the need for more methodologically acceptable studies.

■ Introduction

Research into immediate-loading protocols has shown encouraging results. The challenge continues due to increased patient/clinician expectations to shorten the treatment time[1,2]. Subsequently, the clinician needs reliable and objective guidelines to choose among the various loading protocols[3].

Primary stability is achieved at the time of implant placement and is associated with bone density, length, width and type of implant, and drilling technique[4]. The primary stability obtained after implant placement is considered a relevant factor for the prognosis of the implant[5] and has been identified as a prerequisite to achieve osseointegration[3,6]. This would suggest that high primary stability makes immediate loading more predictable[3].

In the past, objective measurements of primary stability have been proposed by several methods, including the Periotest (Siemens Gulden, Bensheim, Germany). However, their lack of resolution, poor sensitivity and susceptibility to operator variables have been criticised[7-10]. The evaluation of the possibility of loading an implant immediately would require a quantitative method for the measurement of implant primary stability[2]. With this aim, resonance frequency analysis (RFA) is emerging as a valuable tool for the clinician to determine the feasibility of a particular implant by providing a non-invasive method for assessing the stability of the newly placed implant. RFA requires placement of an electronic transducer onto the implant head or prosthetic abutment with a retaining screw and a low voltage current, not detectable by the patient, is discharged through the transducer. Resistance of the implant to vibration is registered in a small computer device[11]. The technique is now commercially available (Osstell™, Integration Diagnostics, Savedalen, Sweden), and an alternative to describe implant stability has been introduced: implant stability quotient (ISQ). ISQ is recorded as a number between 1 and 100, 100 representing the highest degree of stability[5]. Transducers are designed for specific implant types and calibrated by the manufacturer[12].

Although some authors assume RFA is an evidence-based method[10,13,14], no information on a documented normative range of ISQ values can be found in the literature[5,15,16]. Regarding this lack of information, the aim of this systematic review is to evaluate the evidence available in the literature on the use of resonance frequency analysis measurements to assess primary implant stability for immediate loading of dental implants.

■ Materials and methods

The article selection was carried out independently by two reviewers (AV and PD).

■ Search strategy

1. First, an electronic database search (PubMed) was made to identify articles related to RFA, published or accepted for publication, from 1996 to April 2007. The free text search included the keywords: 'resonance frequency analysis', 'dental implants', 'ISQ' and 'Osstell'. The articles were searched for and retrieved by means of the program EndNote (Version 8, ISI ResearchSoft 2001, Berkeley, CA; http://www.endnote.com), which was also used for the elaboration of the final list.
2. Next, a complementary manual search of the same time period was made of the following journals: *Journal of Clinical Periodontology*, *Clinical Oral Implants Research*, *Journal of Periodontology*, *International Journal of Periodontics and Restorative Dentistry*, and *International Journal of Oral and Maxillofacial Implants*.
3. Finally, a search was made throughout the bibliographies of the most relevant papers selected.

As inclusion criteria, it was a requisite that articles presented valuable information on resonance frequency analysis for the measurement of implant primary stability. All study types were considered, due to the absence of randomised clinical trials. The populations (subjects) were patients receiving dental implants (in immediate-loading protocols or not) or animals in which dental implants were placed to evaluate resonance frequency analysis.

The initial search returned 163 articles. In the first phase, two reviewers (AV and PD) evaluated the possible inclusion of the articles, studying the information found in titles and abstracts. The discrepancies were resolved by discussion. Articles of potential interest were searched for, to evaluate the complete text. In the second phase, two reviewers (AV and PD) individually evaluated the entire text of 55 pre-selected articles. A total of 55 articles were identified by the reviewers for data extraction. The data collection indicated that 37 of the 55 studies could be analysed. These 37 articles were stratified into groups: human, animal or *in vitro* studies. The publications were recent, dating from 1996 to 2007 (Table 1).

The following data were extracted from each selected article: author and year, study design, size, number of implants placed, number of failed implants, type of patient (animal/human), use of RFA (number of times), loading protocol (conventional/early/immediate), jaw (maxilla/mandible/both), edentulism (partial/total), and ISQ values (mean and standard deviation). The review also attempted to determine the time of follow-up after implant placement. The classification of loading protocols is taken from a recent study[17].

Results and discussion

After a preliminary evaluation of the selected articles, considerable heterogeneity was found in the study methodology, characteristics of the included patients, type of treatments provided, outcome variables registered and results. Thus, it was not possible to make a quantitative synthesis of the data and the consequent meta-analysis. We have therefore attempted to tabulate the data from a descriptive point of view.

Bone biology

It has been observed that the bone-implant interface transitions through an adaptation phase of decreased stability and back to a more stable configuration in a 60-day period[1,4,5,15,18]. This adaptation process is

Author	Size	Type	Number of implants (manufacturer)	RFA measurements per patient	Loading	Location	Edentulism	Follow-up
Al Nawas[15]	16 beagle dogs	Animal	160 (Brånemark and ITI)	3	8 weeks	Maxilla and mandible	Partial	nd
Balshi[19]	51 patients	Human	344 (Brånemark)	4	Same day	Maxilla and mandible	Partial	nd
Balleri[5]	14 patients	Human	45 (Brånemark)	1	nd	Maxilla and mandible	Partial	nd
Barewal[4]	20 patients	Human	27 (ITI SLA)	9	nd	Maxilla and mandible	Partial	2.5 months
Becker[11]	52 patients	Human	73 (Brånemark)	2	5.6 months ± 2.1	Maxilla and mandible	Partial	12 months
Bischof[7]	36 patients	Human	106 (ITI SLA)	8	IL: at 2 days	Maxilla and mandible	Partial	12 months
Boronat[24]	37 patients	Human	133 (Defcon)	1	No loading	Maxilla and mandible	Partial	nd
Cannizzaro[32]	33 patients	Human	202 (Brånemark)	2	IL: max. 24 hr	Maxilla	Total	12 months
Cornelini[20]	30 patients	Human	30 (ITI)	2	IL: at 24 hr	Mandible	Partial	12 months
Cornelini[39]	20 patients	Human	40 (ITI SLA)	2	IL	Mandible	Partial	12 months
Da Cunha[2]	12 patients	Human	24 (Brånemark)	1	Max. 30 hours	Maxilla	Partial	nd
De Smet[29]	10 guinea pigs	Animal	20 (Astra)	7	7 days	Tibiae	na	na
Ersanli[12]	31 patients	Human	122 (ITI and others)	4	3–6 months	Maxilla and mandible	Partial	12 months
Farzad[23]	34 patients	Human	105 (Brånemark, 1 lost)	1	3–6 months	Mandible	Partial	3.9 years (mean)
Friberg[6]	9 patients	Human	61 (Brånemark, 2 lost)	3	6–8 months	Maxilla	Total	20 months
Gedrange[25]	14 cadavers	Human	14 (ITI Ortho)	1	No loading	Palate	Total	nd
Crismani[21]	20 patients	Human	20 ITI Ortho, 2 lost)	14	1 week	Palate	nd	3 months
Glauser[1]	23 patients	Human	81 (Brånemark, 9 failed)	5	Same day–11 days	Maxilla and mandible	Total/partial	12 months
Huwiler[16]	13 patients	Human	24 (ITI SLA)	9	No loading	Maxilla and mandible	Partial	3 months
Meredith[10]	18 patients	Human	108 (Brånemark)	2	Conventional	Maxilla	Partial	60 months
Meredith[13]	10 rabbits	Animal	20 (Brånemark)	3	No loading	Tibiae	na	na
Nedir[3]	18 + 18 patients	Human	106 (ITI SLA)	8	IL: 63 days, DL: 43 days	Maxilla and mandible	Partial	12 months
Ostman[35]	20 + 20 patients	Human	123 + 120 (Tiunite, Brånemark)	2	IL: max. 12 hr	Maxilla	Total	12 months minim.
Sennerby[28]	4 beagle dogs	Animal	24 (ITI SLA)	9	No loading	Mandible	Partial	nd
Sjostrom[40]	29 + 10 patients	Human	222 +75 (Brånemark)	3	No loading	Maxilla	Partial	6 months
Veltri[31]	9 patients	Human	55 (Brånemark)	4	No loading	Maxilla	Total	nd
Zix[38]	35 patients	Human	120 (ITI)	3	Unloaded/ min. 3 months	Maxilla	nd	nd

IL: immediate-loading protocol; DL: delayed-loading protocol; na: not applicable; nd: not disclosed

Table 1 Studies that analyse RFA (resonance frequency analysis) results obtained *in vivo*. Four articles were carried out in animals and 23 in patients receiving dental implants. Note that *in vitro* articles (10 articles) are excluded from this table.

modulated by bone type and implant location[19]. Bone-resorptive processes yield to bone appositional processes during early healing phases. In spaces between the implant surfaces and the pristine bone, blood clot formation results in the organisation of an early granulation tissue after 4 days. This tissue leads to an osteocoating of the implant surfaces, thereby giving way to the processes developing biological stability[16].

It may be speculated that the decrease in ISQ values after 1 week may be due to the loss of mechanical stability identified during the early phase of healing. Conversely, the process of osseointegration documented by contact-osteogenesis in animal studies after 2 to 4 weeks may be reflected in slightly increased ISQ values during the latter phase of the healing process, after 4 weeks[20]. Another article remarks that the mean ISQ value dropped significantly after 2 and 3 weeks post-surgery when compared with the value obtained immediately after placing the implant[21]. This data suggest that ISQ values reflect the typical course of bone healing.

Primary stability

There are four determinant parameters for achieving primary stability: implant geometry, surgical procedure, site preparation and bone quality of the recipient site[2,22]. Current literature suggests a decisive influence of bone quality on implant stability[2,7]. However, some authors have found that implants, over time, will reach a similar stability (measured in ISQ units), irrespective of the bone density present at implant placement[23].

Some studies suggest that immediate loading protocols can be suitable for soft bone, including the posterior maxilla[19]. However, immediate loading should require a higher primary stability than conventional loading[3] in order to obtain osseointegration. Indeed, immediately loaded implants are submitted, during the healing phase, to higher stress than implants that are left to heal for 3 months.

According to different authors, there is greater primary stability in the mandible than in the maxilla[4,5,24]. Most maxillary implants presented ISQ measurements lower than 60, versus measurements higher than 60 in the case of the mandible[3]. Short implants reach similar stability values over time as do long implants and little differences in implant stability are seen between those in posterior and those in anterior regions after the bone-healing process[5].

Implant mobility, loss of osseointegration and failure

Failing implants show a continuous decrease in stability until failure. Some authors suggest resonance frequency analysis is sensitive enough to identify failing implants before complete loss[25] and that substantial increase or decrease in implant stability could be detected with this method that otherwise could not be clinically perceived. In another study on one-stage implants in edentulous mandibles monitored over time[6], the patients who displayed loss of implant stability showed dramatic declines in ISQ values, from 2 to 6 weeks after implant placement. More recent longitudinal studies on immediate loading of implants[1] postulated a continuous decrease of ISQ values until loss of implant stability was clinically evident, suggesting that low RFA levels after 1 and 2 months seem to indicate an increased risk for future failures. Other authors[16] consider that RFA represents a specific, but not a sensitive biomechanical test to reveal implant stability, and no predictive value for future loss of stability can be attributed to it.

Uses and limitations of RFA

It has been postulated that resonance frequency should reflect the bone anchorage of the implant and hence may be useful in documenting clinical implant stability[10,13,14]. RFA may be used as a predictor of implant success for immediately loaded implants[19]. Owing to its reproducibility and robustness, this novel technique has recently replaced previous techniques for monitoring implant stability[8,9]. Although the use of resonance frequency analysis to quantify ISQs increases continuously, a recent clinical study emphasised that it is not clear yet what RFA exactly measures and that it does not provide a measure of implant osseointegration[7]. On the other hand, some authors suggested that RFA is a useful tool in analysing the degree of osseointegration[6,7,14,26-28]. Some describe RFA as a non-invasive, reliable and objective method which would allow clinicians to measure the primary stability of implants at the time of placement and to measure implant stability during the various stages of healing[6,10,13,20,29,30]. Although extrapolated to represent a quantitative assessment for implant stability in clinical use, it is not clear yet what RFA exactly measures[16].

When measuring the resonance frequency it has to be taken into account that the transducer orientation influences the measurement. It seems therefore advisable to standardise the orientation[31]. Besides, it is important to know that the repeatability of the technique has been demonstrated[3,14,32]. Due to the absence of a documented normative range of ISQ values, it is obvious that multiple assessments of RFA represent a more reliable documentation of homeostasis and implant stability than a single determination of the ISQ value[16].

The RFA device displays a graphic to ensure the measurement is valid. The presence of a single peak of resonance in the graphic displayed was not found to be indicative of a stable implant as said by the manufacturer[3], and so values given by the RFA device must always be interpreted in combination with the Bode diagram (a plot of the amplitude of the received signal against the frequency). The frequency corresponding with the highest peak in this plot is chosen as the resonance frequency by the Osstell™ system. Then, this resonance frequency is translated into ISQ units[33,34].

ISQ reference values

It would be desirable to identify a normative range of values representing implant stability and to correlate it with histological analysis of the bone–implant interface. The results observed in a recent study[16] indicate that such a normative range appeared between ISQ values of 55 and 74 at the time of implant placement, considering those values represented homeostasis and implant stability. However, no correlations could be demonstrated between the ISQ values and the bone density. This means that ISQ values obtained at the time of implant placement do not reflect the nature of the bone/implant interface and hence, the degree of mechanical anchorage. Rather, a range of values appeared to reflect primary stability. Primary stability may not only be influenced by bone volumetric density, but also by the thickness and density of the cortical layer of the alveolar bone crest. Nevertheless, various ranges have been demonstrated for maxillary and mandibular bone[4,5,7,11,19,35,36]. In these studies, ISQ values were found to correlate with the classification of bone characteristics[37]. The results of the cited study could not confirm such correlations, but are in agreement with another study that failed to confirm such relationships[16,38].

Different authors have suggested ISQ reference threshold values necessary for immediate loading of implants. These results show a high variability (Table 2). While one author[19] suggests an ISQ above 60 at implant placement for immediate loading, another[3] advises a minimum ISQ of 54, reducing this minimum value to 49 in the case of conventional loading. Some authors[39] take an ISQ value of 62 as the minimum prerequisite for immediate loading, while others[19] have a 97% success rate immediately loading implants with ISQ values between 47 and 59.

Author	N1	N2	Implant manufacturer	Mean ISQ value after placement (SD)	Survival rate (follow-up, months)
Balshi[19]	51	276	Brånemark	70.35 (0.51)	98.5% (3)
Bischof[7]	36	63	ITI	57.2 (7.0)	98.4% (12)
Cannizzaro[32]	33	202	Zimmer	68.9 (2.05)	99% (12)
Cornelini[20]	30	30	ITI	70.6 (5.8) Minimum: ISQ 61	96.7% (12)
Cornelini[39]	20	40	ITI	72.0 (5.7) Minimum: ISQ 62	97.5% (12)
da Cunha[2]	12	24	Branemark	nd	Not available
Glauser[1]	23	81	Branemark	68	88.8% (12)
Nedir[3]	18	63	ITI	nd	98.4% (12)
Ostman[35]	20	123	Branemark	62.9 (4.9)	99.2% (12)

N1 = number of patients; N2 = number of implants placed; nd: not disclosed

Table 2 Studies on immediately loaded implants included in the review. Note that the survival rates in most cases are comparable to those found in conventional loading protocols. Also note the high variability between mean ISQ values found after implant placement.

Research into normal ISQ values for a stable osseointegrated implant has also been performed. An ISQ value above 47 has been considered as a stable implant[3], while other authors[16] suggest that ISQ values between 57 and 70 can be described as stable. Finally, another author[7] found ISQ values between 57 and 82 (with a mean of 69 at 1 year of loading) for implants successfully osseointegrated.

Conclusions

Implications for clinical practice

Resonance frequency analysis may orient the practitioner to choose among various loading protocols and to selectively monitor implants during the healing phase.

It is necessary to develop ISQ predictor ranges, which may provide the clinician with a reference for effective immediately loaded implantation given different clinical situations.

A decrease in ISQ values for implants with low values at placement should alert the clinician to submit these implants to a tighter follow-up schedule.

However, it should be taken into account that reduction of implant stability during the first 12 weeks of the healing process should be considered as a common event resulting from bone healing.

Implications for research

The variability of results and study designs suggest a lack of consistency, supported by the heterogeneous data and evidence analysed.

There is a need for more methodologically homogeneous studies in order to analyse the data, not only qualitatively, but also in a quantitative way. It is necessary to provide a comprehensive definition of the variables to ease the combination of data in future systematic reviews.

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