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RESEARCH ARTICLE OPEN ACCESS

Evaluation of implant stability using resonance frequency analysis in two functional implant zones

Estephan MF[1]

[1]*Department of Physiology, College of Medicine, Al-Nahrain University, Baghdad, Iraq.*

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Abstract
Objective: The study aimed to compare implant stability between sinus and ischemic zones at three time points via resonance frequency analysis.
Methods: 37 dental implants were placed in 14 patients aged between 30 and 60 years. These implants were predominantly placed in regions of the mouth with sinus cavities and ischemic areas. Six implants were excluded from the study because they failed early, or the patients did not follow the treatment plan. That left 31 implants to be studied. The analysis assessed how stable the implants were using a special test on the day of surgery and then again at 8 weeks and 12 weeks afterwards.
Results: Implant stability slightly dropped at 8 weeks after surgery. By 12 weeks, stability had increased significantly, showing that the implants were becoming more securely attached to the bone.
The size of the implants did not vary much between the sinus and ischemic areas. Although primary stability was lower in the sinus zone compared to the ischemic zone, the difference was not significant ($p = 0.103$). Implant stability was significantly higher in the ischemia zone at 8 and 12 weeks after surgery ($p=0.0004$ and <0.0001, respectively). At 8 and 12 weeks, implants in ischemic areas were significantly more stable than those in sinus areas.
Conclusion: Where the implant is placed in the mouth can affect how well it bonds with the bone. In the early healing stages, areas with poor blood supply (ischemic zones) might actually provide better conditions for implant stability.

Keywords: Implant stability; Ischemic zone; Resonance frequency analysis; Sinus zone

Plain Summary English
Implant stability slightly dropped at 8 weeks after surgery, but this wasn't a big enough change to be considered significant. By 12 weeks, stability had increased significantly, showing that the implants were becoming more securely attached to the bone. In this study, the distribution of implant dimensions between sinus and ischemic dental implants did not differ significantly. The sinus zone displayed lower primary stability than the ischemic zone, although this difference was not statistically significant. At 8- and 12 weeks post-surgery, the ischemic zone group demonstrated considerably higher implant stability. When comparing primary stability to 8 weeks, 8 to 12 weeks, or primary stability to 12 weeks, no statistically significant changes were observed in the implant stability quotient (ISQ) values between the sinus and ischemic zones. A limited sample size, gender imbalance, and uncontrolled variables may impair the reliability and application of this study's results.

Correspondence:
Estephan May F
Department of Physiology, College of Medicine
Al-Nahrain University, Baghdad
Iraq.
mayfadheel@nahrainuniv.edu.iq

Background

Dental implants are extremely important in oral rehabilitation; not only do they restore function, but they also mimic the natural look of teeth. The process of osseointegration causes dental implants to be successful, where the bone grows and fuses with the implant (1). To ensure this process is going well, it is crucial to evaluate the implant's stability during healing. Stability isn't just a basic requirement; the implant needs to work precisely. There are two types of implant stability:

Primary stability occurs immediately after the implant is placed. It is the initial grip the bone has on the implant (2).

Secondary stability develops later, as new bone grows surrounding the implant and strengthens the connection (3).

Primary stability is inspected on the day of surgery, and secondary stability is usually evaluated around 12 weeks later. Checking stability at 8 weeks is an indicator of how healing is going (4). There is a challenging period called the 'stability dip'. Throughout this interval, the initial grip from the bone weakens before the new bone has fully formed. This may contribute to the implant being unstable and raise the risk of failure (5). The severity of this dip relies on the bone quality in the area (6). For example, the back part of the upper jaw (posterior maxilla) has weaker bone and heals more slowly, becoming more vulnerable. To measure implant stability, dentists often use digital tools like Resonance Frequency Analysis (RFA) and damping capacity assessment (DCA) (7). RFA is more reliable than older methods and gives real-time data (8, 9, 10). The prevalent RFA device is called Osstell. It is non-invasive and works by sending signals to a small part attached to the implant and assessing how the implant responds. The result is an ISQ score (Implant Stability Quotient) from 1 to 100:

Below 60 = low stability

60–69 = moderate stability

70+ = excellent stability (9).

Researchers have used RFA in numerous studies comparing implant stability in various regions of the mouth, but comprehensive, long-term data are limited. This study aimed to address the gap and used RFA to compare implant stability in two areas of the mouth:

Sinus zone: the back upper jaw near the sinus. This area is challenging for implants as the bone is thin and weak (11).

Ischemic zone: the lower back jaw, which has a limited blood supply and is affected by things like age and bone loss. Thorough imaging and careful planning are vital for implants in this area (11, 12).

As both areas are challenging for implants, the study aimed to better understand how stability develops in each one.

Materials and Methods

This study utilised a retrospective analysis of data collected at the Dental Implant Section, Department of Oral and Maxillofacial Surgery, College of Dentistry, University of Baghdad. The data were collected from patients who underwent implant-supported prosthetic rehabilitation for the replacement of missing teeth. The sample size incorporated 14 healthy, eligible patients (aged 30 to 60 years) who were recruited due to the delayed dental implant (DI) placement protocol in the maxilla or mandible. The patients underwent a total of 37 DI installations in the sinus (n = 20) and ischemic (n = 17) zones. Six implants were excluded from the analysis due to early failure, non-compliance, or lack of follow-up. The remaining thirty-one DIs were then considered with sinus (n=16) and ischemic (n=15). The dental implant utilised was Roxolid, characterised by a bone-level tapered SLActive surface. It is manufactured by Institute Straumann AG in Switzerland (BLT). Applicants were systemically healthy adults with a partly edentulous maxilla or mandible who needed delayed implant placement. All selected patients had appropriate vertical and horizontal alveolar ridge dimensions, as well as a six-month healing interval following tooth extraction. Exclusion criteria encompassed both systemic and local issues that could hinder healing. Local factors included acute or chronic infections, pathological conditions at the intended implant site, insufficient interdental space, aggressive periodontitis, and parafunctional habits such as bruxism or teeth clenching.

A preoperative cone-beam computed tomography (CBCT) scan (KaVo OP 3D PRO, Germany) was performed using the following parameters: 90 kV, 9.2 mA, an exposure period of 8.1 seconds, 13 × 15 cm of field of view, and 0.5 mm slice thickness. A CBCT scan was used to measure the height and width of the bone at the site of the designated implant. The On-Demand software helped take these measurements using its built-in measuring tool.

After the implant was placed, its stability was checked at three different times: during the surgery (primary stability), then again at 8 weeks and then 12 weeks after surgery (secondary stability). To measure how stable the implant an Osstell ISQ device (Osstell, Gothenburg, Sweden). was used, which works by checking how much the implant vibrates. To avoid bias in results, the same researcher took all the measurements.

Both buccolingual and mesiodistal stability evaluations were performed to guarantee a thorough assessment of implant stability (9). The implant stability was represented by the mean of these values, which was recorded as the ISQ.

Statistical analysis

Statistical analysis was performed using GraphPad Prism version 6 for Windows (GraphPad Software, La Jolla, CA, USA). For numerical variables, descriptive analysis included calculating the mean, standard deviation (SD), and median; for categorical variables, it included calculating frequencies and percentages. The Shapiro–Wilk normality test was employed to evaluate the normality of the continuous variables' distributions. The unpaired t-test was one of the inferential statistics used to determine whether two independent groups differed in normally distributed data, and the Mann-Whitney test was used to determine whether two independent groups differed in non-normally distributed data. More than two dependent groups with non-normally distributed data were analysed using the Friedman test and Dunn's multiple comparisons test. For categorical variables, the groups were tested for differences using the chi-square and Fisher's exact tests. Differences were considered statistically significant at $p < 0.05$, highly significant at $p < 0.01$, and not statistically significant at $p > 0.05$.

Results

The sample size comprised 14 healthy, eligible patients (aged 30 to 60 years) selected from the protocol for delayed DI placement in the sinus and ischemic zones. The patients received a total of 37 DIs, with 20 installed in the sinus zone and 17 in the ischemic zone. A total of 31 DIs were analysed following the exclusion of 6 implants (2 lost to follow-up, 3 not followed up, and 1 that failed early). Stability was measured at the time of surgery (1st measurement), 8 weeks post-surgery (2nd measurement), and 12 weeks post-surgery (3rd measurement). Table 1 illustrates the dimensional specifications of the dental implants included in the study, with the 4.1 mm diameter and 10 mm length configuration representing the most frequently utilised implant type.

Table 1: Dental implant dimensions of the whole sample

Implant dimensions	Number	%
Width/ mm		
3.3	5	16.1
4.1	26	83.9
Length/ mm		
8	5	16.1
10	19	61.3
12	7	22.6

Stability changes of the whole sample

Figure 1 and Table 2 present the ISQ values indicating implant stability across the study period, measured at three time points: baseline (primary stability), 8 weeks, and 12 weeks postoperatively. Figure 1 shows how the ISQ values changed over time. There was a small drop at 8 weeks after surgery, but a noticeable increase by 12 weeks. This pattern indicates that the implant became more stable as time went on. Table 2 indicates that, although there is a minor decrease in ISQ between primary stability and the 8-week mark, this variance is not statistically significant ($p = 0.0927$). Conversely, statistically significant differences were observed between the stability at 8 weeks and stability at 12 weeks ($P < 0.0001$), as well as between primary stability and stability at 12 weeks ($P = 0.006$) (Table 2).

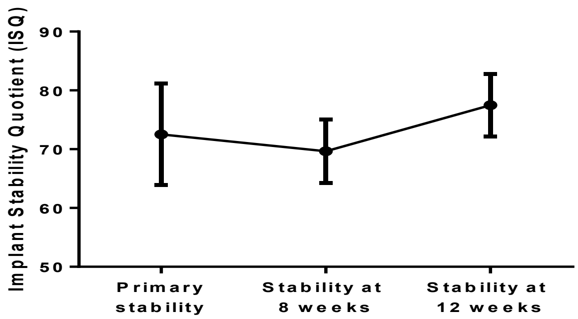

Figure 1: Scatter plot showing the stability changes of the whole sample

Table 2: Stability changes of the whole sample

Implant stability/ ISQ	Mean	SD	Median	P value
Primary stability	72.53	8.637	74.00	= 0.0927
Stability at 8 weeks	69.65	5.368	70.00	
Stability at 12 weeks (secondary stability)	77.48	5.289	78.00	< 0.0001*

* Friedman test. Dunn's multiple comparisons test
Primary stability vs. Stability at 8 weeks (p= 0.0927), Primary stability vs. Stability at 12 weeks (p= 0.006)
ISQ: Implant stability quotient

Differences between the two zones
Table 3 demonstrates that the distribution of dental implants based on implant dimensions did not vary significantly between the sinus and ischemic groups.

Table 3: Distribution of dental implants by width and length across the two groups

Implant dimensions	Sinus zone (n=16)	Ischemic zone (n=15)	P value
Width/ mm			
3.3	4	1	0.333 *
4.1	12	14	
Length/ mm			
8	2	3	
10	9	10	0.471 †
12	5	2	

† Chi-square, * Fisher's exact test

Changes in implant stability during the study period of the two groups are summarised in Table 4 and Figure 2. Concerning primary stability, the sinus zone group demonstrated lower stability when compared to the ischemic zone, as indicated in Table 4 and Figure 2; however, this difference did not reach statistical significance. Conversely, at 8 and 12 weeks postoperatively, implant stability was observed to be significantly higher in the ischemic zone group. Variations in ISQ values between primary stability and the 8-week measurement, between the 8- and 12-week measurements, and between primary stability and the 12-week measurement (which represents secondary stability) were not statistically significant, as shown in Table 4.

Table 4: Comparative analysis of implant stability between sinus and ischemic groups

Implant stability / ISQ	Sinus zone	Ischemic zone	P value
Primary stability			
Mean (SD)	69.63 (10.33)	75.63 (5.06)	0.103*
Median	71.75	77.50	
Stability at 8 weeks			
Mean (SD)	66.75 (3.90)	72.73 (5.06)	0.0004*

Median	68.25	72.50	
Stability at 12 weeks (secondary stability)			
Mean (SD) Median	74.00 (4.56) 73.50	81.20 (3.01) 82.50	< 0.0001*
Primary stability vs stability at 8 weeks			
Mean (SD) Median	2.88 (11.2) 4.50	2.90 (7.51) 3.50	0.994†
Stability at 8 weeks vs 12 weeks			
Mean (SD) Median	-7.25 (5.04) -8.50	-8.47 (3.82) -7.00	0.457†
Primary stability vs stability at 12 weeks (secondary stability)			
Mean (SD) Median	-4.38 (11.83) -1.75	-5.57 (5.69) -5.00	0.726†

* Mann Whitney test, † Unpaired t test, SD; Standard Deviation, ISQ; Implant stability quotient

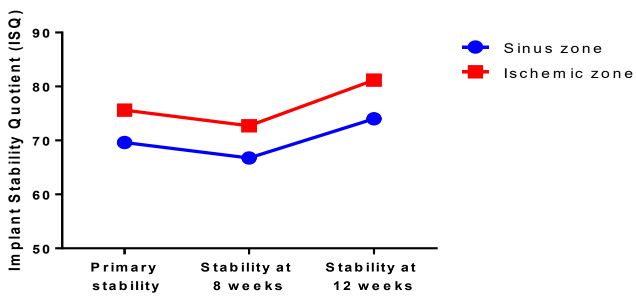

Figure 2: Scatter plot depicting variations in implant stability between the sinus and ischemic zones

Discussion

The success of a dental implant depends on achieving and maintaining stability (13). Maximising implant stability at placement is crucial because it sets the stage for secondary stability later. In this study, implant stability decreased slightly, not enough to be statistically significant, by the eighth week after surgery. By week twelve, stability had significantly increased to a level that demonstrated secondary stability. This increase occurs because of the body's natural healing process of osseointegration (14). Bone healing is a transition—stability can go up and down over time, and initial decreases usually recuperate, especially by the twelve-week point. Lee and colleagues detected this same trend (15). Other studies using resonance frequency analysis (RFA) followed 44 implants in 30 patients, divided between the maxilla and mandible. They measured ISQ values immediately after placement and again at 8, 16, and 24 weeks. The mean ISQ dropped to its lowest at week eight (69.5), then gradually increased to 76.8 by week twenty-four (16). In 2020, researchers found a substantial decline in mean implant stability after 8 weeks post-placement. Compared to baseline data, in 2020, another team reported a marked decrease in implant stability after eight weeks, but ISQ values either rose or stayed stable after twenty-four weeks. That study involved 15 adults aged 18 to 60, all meeting clinical and radiological criteria. Both flapped and flapless patients received delayed SLActive implants, with stability measured using Osstell (17). Implant size, both length and width, showed no significant differences between the sinus and ischemic zones. There was no observed link between implant dimensions and stability, likely because similar-sized implants were used in both regions (4.1 mm wide by 10 mm long), and the sample size was limited. Selva et al. (2018) also revealed no statistical correlation between implant length and stability when using RFA (18), while Shiffler's group revealed that length might be applicable in real-life situations (19).

Upon comparison of implant locations—explicitly in the sinus area versus areas with decreased blood flow (ischaemic zones)—the sinus group started with marginally lower stability, but the variance wasn't significant. At both 8 and 12 weeks, the ischemic zone group illustrated a pronounced improvement in stability than the sinus group. This is probably attributed to disparities in the structure of the bone in those areas. The primary mechanical stabilisation was analogous in both areas, but the ischemic zone usually consists of denser bone, for instance, cortical bone or bone with a strong blood supply, which exhibits a tendency to afford better implant retention (20). Regions with denser bone typically exhibit higher RFA values (ISQ or DI) subsequent to implant placement. Conversely, the sinus region often contains softer, more porous bone and might necessitate sinus augmentation procedures, which potentially cause a reduction in primary stability (21). Implants placed here show lower RFA values at baseline due to softer bone and reduced mechanical anchorage (22). In the first eight weeks, RFA values in the ischemic zone remain stable or decrease only slightly, but remain higher than those in the sinus zone. In the sinus zone, early bone remodelling and slower osseointegration can keep RFA values low (11). After twelve weeks, ISQ increases more in ischemic conditions, likely because of superior bone quality, healing, and implant surface characteristics (23, 24). In 2016, Shifler et al. demonstrated that the implant's position in the mouth also plays a role. Implants placed in the mandible were more stable than those in the maxilla, with higher ISQ values both at placement and during follow-up (19). Also, Takahiro Takekawa et al. found a considerable difference between the maxilla and mandible of the implantation site. This investigation was conducted on 81 implants located in the posterior region. Implant stability was assessed using RFA both at the time of placement and three months postoperatively (25). Research findings by Ibraheem, N.S., and S.S. Al-Adili revealed that implant stability is affected by anatomical location, particularly by comparing the maxilla and mandible, in addition to anterior versus posterior regions. Importantly, implants placed in the mandible and posterior areas showed significantly higher stability ISQ values than those in other regions (16). Additionally, in the comparison of implant stability between sinus and ischemic zones across multiple time points, no significantly different ISQ values were identified between primary stability and 8 weeks, between 8 and 12 weeks, or between primary stability and 12 weeks. This absence of significance indicates that while RFA is a valuable tool for evaluating implant stability, it does not appear to be sensitive enough to note subtle variations in bone quality across anatomically challenging sites (26, 27). Or this may be attributed to a small sample size.

Conclusion

The findings indicate that different areas where the implant is placed might affect how well the implant bonds with the bone, with the ischemic zone likely providing better conditions for stability during the early healing stages. Further research is needed.

List of Abbreviations

CBCT: Cone-Beam Computed Tomography
DI: Dental implant
DIs: Dental implants
ISQ: Implant stability quotient
RFA: Resonance frequency analysis
T1: Time of placement
T2: Time of placement during follow-up

Declaration

Ethics approval and consent to participate

The University of Baghdad College of Dentistry's Research Ethics Committee approved a retrospective data analysis based on this study (Ref. No. 037118). The study was conducted in conformity with the principles specified in the Declaration of Helsinki (2013). An informed consent form was signed by each patient before they were involved.

Consent for publication

Availability of data and materials

The data and materials supporting the findings of this study are available from the corresponding author upon reasonable request.

Competing interests

The author claims no conflicts.

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None

Author's contributions

The author did the searching, Planning, analysing, writing up and reviewing.

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