

Article

Assessment of Implant Stability Using ISQ, Periotest, and CBCT in a Split-Mouth Pilot Study

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Abstract

This split-mouth pilot study evaluated implant stability using resonance frequency analysis (ISQ), Periotest measurements (PTV), and CBCT imaging as a supportive descriptive modality. Twenty patients requiring implant placement in the anterior maxilla underwent bilateral augmentation with deproteinized bovine bone mineral, with an adjunctive polynucleotide–hyaluronic acid complex applied at one site and the contralateral site serving as control. Implants were placed after a standardized 6-month healing period. Implant stability was recorded at placement and during follow-up. Test sites showed slightly higher ISQ values and more negative PTV values at placement, followed by progressive stabilization in both groups during healing. Parallel trends of increasing ISQ and decreasing PTV values were observed over time. CBCT was used exclusively for intra-patient comparative and morphologic assessment. Within the limitations of this pilot design, implant stability measurements should be interpreted as functional indicators of the implant–bone complex during early healing. The combined use of ISQ and Periotest measurements may support longitudinal monitoring of implant stability in routine clinical practice. Further studies with larger cohorts and extended follow-up are warranted.

Keywords: implant stability assessment; resonance frequency analysis (ISQ); Periotest; cone-beam computed tomography; split-mouth model

1. Introduction

Dental implants are widely recognized as a predictable long-term solution for restoring oral function and aesthetics, with reported survival rates consistently exceeding 90–95% [1,2]. Long-term implant success depends on the achievement of primary mechanical stability at placement and the subsequent development of secondary biological stability through bone remodeling and maturation [3,4]. Secondary stability is of particular importance in augmented sites, where bone quality and biological healing conditions differ from those of native bone.

Guided bone regeneration (GBR) is an established and widely applied approach for the management of horizontal and vertical alveolar deficiencies, especially in the anterior maxilla. Xenogeneic grafting using deproteinized bovine bone mineral (Bio-Oss) in combination with collagen membranes (Bio-Gide) represents one of the most extensively validated GBR strategies, supported by substantial evidence demonstrating osteoconductivity, dimensional stability, and predictable clinical integration [5,6]. Nevertheless, bone



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maturation in grafted sites is generally slower than in native bone, which may influence implant stability during early and intermediate healing phases [7,8]. Delayed mineralization and prolonged graft remodeling have been repeatedly described in xenograft-augmented sites and may affect the biomechanical environment at the implant–bone interface during early osseointegration [9]. Consequently, the identification of adjunctive materials that may support regenerative consolidation in such settings remains of clinical interest.

Hyaluronic acid (HA) has been increasingly investigated as an adjunct in regenerative procedures due to its involvement in tissue repair processes. Preclinical and clinical studies suggest an association between HA application and early bone healing as well as soft-tissue outcomes; however, its clinical relevance for implant stability following GBR procedures remains insufficiently explored [10–13]. Regenfast[®], a polynucleotide-based hyaluronic acid complex, has been introduced as a bioactive adjunct intended to support regenerative healing. To date, however, clinical data addressing its association with implant stability in GBR-augmented sites are lacking.

Implant stability is a dynamic parameter that evolves throughout the healing period, reflecting the transition from primary mechanical fixation to secondary biological anchorage. Resonance frequency analysis (RFA), expressed as the implant stability quotient (ISQ), is widely used to longitudinally monitor this process and has been shown to reflect changes in the stiffness of the implant–bone complex and peri-implant bone remodeling [14,15]. Clinical investigations have demonstrated that ISQ values may transiently decrease during early healing due to bone resorption before increasing as newly formed bone matures around the implant [16]. In regenerated or grafted bone, this stability pattern may differ from native sites because of delayed mineralization, altered bone density, and ongoing graft remodeling, underscoring the importance of longitudinal stability assessment in augmented regions.

In addition to RFA, implant stability may be evaluated using the Periotest device, which measures damping characteristics at the implant–tissue interface. Periotest values (PTVs) have been applied to assess implant stability in both native and regenerated bone and provide complementary functional information based on different physical principles compared with ISQ measurements [17–19]. The combined use of ISQ and PTV may therefore offer a broader functional assessment of implant stability, particularly in grafted bone where tissue composition differs from native conditions.

Despite the growing interest in HA-based biomaterials, no clinical study has specifically evaluated whether adjunctive application of Regenfast in GBR procedures involving Bio-Oss is associated with differences in early or intermediate implant stability. Given the pilot and exploratory nature of the present investigation, the study was not designed to test causal effects but to explore potential associations and temporal trends in implant stability parameters following different GBR protocols.

Accordingly, the aim of this pilot split-mouth clinical study was to descriptively assess implant stability parameters in the anterior maxilla following augmentation with Bio-Oss with or without a polynucleotide-based hyaluronic acid adjunct, using serial ISQ and Periotest measurements.

2. Materials and Methods

Study Design

This clinical pilot study was designed as a split-mouth, intraindividual comparison to descriptively assess implant stability parameters following guided bone regeneration (GBR) procedures with or without the adjunctive use of Regenfast[®].

The study was not designed or powered to establish causal relationships or long-term clinical outcomes but to provide descriptive, hypothesis-generating data on early implant stability.

The study was conducted in the anterior maxilla, a region considered clinically demanding due to its aesthetic requirements and specific biological characteristics of the alveolar bone. Implants were placed in the anterior maxilla, including the incisor and canine regions, in all enrolled patients. The split-mouth design was selected to minimize interindividual variability and to enhance the sensitivity of detecting differences in implant stability between the two regenerative approaches.

Participants

A total of 20 systemically healthy patients requiring tooth extraction and subsequent implant-supported rehabilitation in the anterior maxilla were consecutively enrolled in this pilot study. Inclusion criteria comprised adequate oral hygiene, absence of systemic diseases or medical therapies known to affect bone metabolism, and a clinical indication for guided bone regeneration (GBR) prior to implant placement in the anterior maxilla.

Patients were excluded if they presented with uncontrolled systemic conditions, active periodontal disease, a history of radiotherapy in the head and neck region, or other known risk factors that could adversely influence bone healing or implant stability, such as uncontrolled diabetes mellitus, immunosuppressive therapy, or metabolic bone disorders. These criteria were applied to ensure a clinically homogeneous study population and to minimize confounding factors related to bone regeneration and implant stability.

All participants provided written informed consent prior to enrollment, and the study was conducted in accordance with ethical principles for clinical research.

Surgical Protocol and Augmentation

Tooth extractions and augmentation procedures were performed using an atraumatic surgical approach in order to minimize surgical trauma and to ensure comparable healing conditions. Following tooth extraction, alveolar ridge augmentation was carried out using a standardized GBR protocol. At control sites, a deproteinized bovine bone mineral (Bio-Oss®, Geistlich Pharma, Switzerland) was applied and covered with a resorbable collagen membrane (Bio-Gide®, Geistlich Pharma, Switzerland) to stabilize the graft and prevent soft tissue ingrowth.

At test sites, the same xenogeneic bone substitute was combined with Regenfast® (a polynucleotide–hyaluronic acid complex) prior to membrane placement. All surgical procedures were performed by the same experienced operator following a standardized clinical protocol. A standardized healing period was allowed prior to implant placement to enable consolidation of the augmented sites.

Implant Placement

Following completion of the healing phase, dental implants (Ankylos®, Dentsply Sirona, Germany) of identical dimensions (3.5 mm diameter and 9.5 mm length) were placed according to the manufacturer's recommended protocol. Implant placement was performed with elevation of a full-thickness mucoperiosteal flap, without additional augmentation procedures at the time of implantation. Implants were placed after a healing period of 6 months, which was identical for all patients and confirmed by clinical and radiographic evaluation prior to implant placement.

Implant Stability Assessment (ISQ and PTV)

Implant stability was assessed using resonance frequency analysis (RFA) and Periotest measurements. ISQ values were obtained using an Osstell device (Osstell AB, Gothenburg, Sweden), with measurements performed in the buccopalatal and mesiodistal directions. The mean value of the measurements was used for analysis.

Periotest values (PTVs) were recorded using the Periotest M device (Siemens AG, Bensheim, Germany). For each implant, three consecutive measurements were performed, and the mean value was calculated. All stability measurements were conducted by the same examiner.

Measurements were performed at the following time points:

- T0—immediately after implant placement
- T1—4 weeks after implant placement
- T2—8 weeks after implant placement
- T3—12 weeks after implant placement

ISQ and Periotest values were interpreted strictly as functional measures of implant stability and implant–bone interface behavior, and not as direct indicators of bone quality or bone density.

ISQ and Periotest measurements were considered complementary functional assessments based on different physical principles and were not directly compared or interpreted as equivalent measures.

CBCT Evaluation

Cone-beam computed tomography (CBCT) was used as an adjunctive radiological method to evaluate morphological characteristics of regenerated bone in augmented areas. CBCT analysis was not defined as a primary study outcome but served as a supportive, semi-quantitative method for comparing bone conditions between test and control sites.

Standardized regions of interest (ROI) were defined within the augmented areas, avoiding metal artifacts from implants and adjacent anatomical structures. Within each ROI, relative grayscale values were analyzed as pseudo-densitometric indicators for in-traindividual comparison of regenerated bone.

CBCT-based pseudo-densitometric analysis was used solely for relative, within-patient comparison and descriptive illustration of local bone conditions. Absolute Hounsfield units were not interpreted, and no quantitative conclusions regarding bone density or biological causality were drawn.

Statistical Analysis

Statistical analysis was performed using descriptive methods due to the pilot nature of the study. Implant stability values (ISQ and PTV) were summarized using means, standard deviations, and ranges at each time point. Changes in stability over time were evaluated descriptively to identify trends in early and intermediate healing. No inferential statistical testing was performed, as the study was not powered to detect statistically significant differences between groups. Accordingly, the results are intended to inform future study design rather than to support definitive comparative conclusions.

Ethical Approval

The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the Primary Health Care Center of Osijek-Baranja County, Osijek, Croatia (approval date: 5 December 2024). All participants provided written informed consent prior to inclusion in the study.

3. Results

3.1. Study Population

Demographic and clinical characteristics of the study population are summarized in Table 1.

Table 1. Demographic and clinical characteristics of the study population.

Variable	Value
Number of patients	20
Sex (Male/Female)	8/12
Age (years), mean (range)	39.4 (18–59)
Number of implants	40
Implant location	Anterior maxilla
Study design	Split-mouth

Twenty patients were included in this split-mouth pilot study. Each patient received two implants in the anterior maxilla, resulting in a total of 40 implants. Within each patient, one site served as the test site (Bio-Oss combined with a polynucleotide–hyaluronic acid complex), while the contralateral site served as the control (Bio-Oss alone). Implant placement and follow-up proceeded without intraoperative or postoperative complications.

3.2. Implant Stability Assessed by Resonance Frequency Analysis (ISQ)

Mean implant stability quotient (ISQ) values for test and control sites at all observation time points (T0–T3) are presented in Table 2.

Table 2. Descriptive implant stability quotient (ISQ) measurements at defined time points.

Time Point	Test (Bio-Oss + Regenfast®)	Control (Bio-Oss)
T0 (implant placement)	70.61 ± 2.20	69.50 ± 3.81
T1 (4 weeks)	72.61 ± 2.56	71.27 ± 1.91
T2 (8 weeks)	74.06 ± 2.25	74.98 ± 2.49
T3 (12 weeks)	75.59 ± 1.63	75.32 ± 2.25

Values are presented as mean ± standard deviation (SD). T0, immediately after implant placement; T1, 4 weeks; T2, 8 weeks; T3, 12 weeks. Values are reported descriptively due to the exploratory pilot design.

Measurements were obtained from 40 implants placed in 20 patients using a split-mouth design. Each patient contributed one test site and one control site. Values represent descriptive ISQ measurements recorded at each time point for test and control implants.

3.3. Implant Stability Assessed by Periotest Measurements (PTVs)

Periotest values (PTVs) for test and control sites across all observation time points (T0–T3) are shown in Table 3.

Table 3. Descriptive Periotest (PTV) measurements at defined time points.

Time Point	Test (Bio-Oss + Regenfast®)	Control (Bio-Oss)
T0 (implant placement)	−3.36 ± 1.13	−2.45 ± 1.12
T1 (4 weeks)	−4.11 ± 1.00	−3.71 ± 0.72
T2 (8 weeks)	−4.15 ± 0.85	−3.80 ± 0.80
T3 (12 weeks)	−4.41 ± 0.45	−4.53 ± 0.94

Values are presented as mean ± standard deviation (SD). More negative values indicate higher implant stability.

3.4. CBCT Evaluation

CBCT was used as a supportive radiological method to descriptively assess morphological characteristics of regenerated bone in augmented sites. Relative grayscale values within standardized regions of interest were analyzed for intraindividual comparison between test and control sites. CBCT findings were used exclusively for descriptive purposes and were not considered a primary outcome measure.

4. Discussion

The growing interest in biologically active adjuncts in guided bone regeneration (GBR), particularly in the esthetic zone, has led to increased investigation of hyaluronic acid (HA)– and polynucleotide (PN)–based formulations in clinical settings. The present study primarily contributes to the practical integration and interpretation of complementary implant stability assessment tools within a controlled clinical model, rather than to definitive evaluation of regenerative outcomes. In this context, previous literature has predominantly focused on early healing phenomena rather than on long-term structural or mechanical outcomes. Within this framework, the present split-mouth pilot study descriptively explored whether adjunctive use of a PN–HA complex (Regenfast®) in combination with deproteinized bovine bone mineral (DBBM) was associated with differences in early and

intermediate implant stability compared with DBBM alone. Any observed differences should be interpreted cautiously, as they reflect descriptive trends within a pilot design rather than evidence of direct biological or mechanical effects.

One of the main observations was that implants placed in sites augmented with DBBM plus Regenfast exhibited slightly higher ISQ values and more negative PTV values at the time of implant placement (T0), followed by progressive stabilization in both groups during the healing period. These findings require careful interpretation. Primary implant stability at placement is predominantly governed by mechanical factors such as cortical bone engagement, implant macrodesign, and surgical technique [3,4]. Consequently, the differences observed at T0 cannot be interpreted as a direct biological effect of the HA/PN preparation. Rather, they may be related to differences in local biomechanical conditions at the time of implant placement, including graft particle cohesion, viscoelastic properties of the augmented site, or stabilization of the peri-implant microenvironment during osteotomy preparation.

Previous clinical investigations assessing implant stability in regenerated or grafted bone have shown that ISQ and PTV values often follow a delayed but progressive stabilization pattern. Early measurements are strongly influenced by local graft characteristics and surgical conditions rather than by newly formed bone. Studies evaluating implant stability in GBR-treated and sinus-augmented sites, together with methodological analyses of implant stability assessment, have reported greater variability at placement followed by stabilization of stability values over time, supporting the interpretation that early differences primarily reflect biomechanical rather than biological factors (Vallecillo-Rivas et al. [20–22]). The stabilization pattern observed in the present study is consistent with these reports.

Recent clinical investigations have emphasized that implant stability values obtained in regenerated bone should be interpreted primarily as functional descriptors of the implant–bone complex rather than as direct surrogates of bone quality or osseointegration. Küchler et al. [23] reported that stability values in augmented sites, assessed by resonance frequency analysis, can change substantially during early healing, supporting longitudinal monitoring rather than relying on isolated time-point comparisons. In addition, Shim et al. [24] demonstrated that different stability devices (e.g., ISQ via RFA versus Periotest values) operate on distinct measurement principles and may yield non-identical readings across follow-up, reinforcing the need for cautious, context-dependent interpretation—particularly in exploratory studies with limited sample size.

Evidence from previous clinical studies suggests that HA-based adjuncts may exert their most relevant effects during the early phases of tissue repair rather than producing sustained long-term structural differences. Alcântara et al. [12] demonstrated accelerated early bone formation following local HA application after tooth extraction, with diminishing intergroup differences over time. A similar temporal pattern has been described in ridge preservation and augmentation studies, where early advantages associated with HA use tend to attenuate during subsequent healing [11,13]. Although these studies did not directly assess implant stability, improved early tissue organization and ridge morphology may indirectly influence the biomechanical conditions encountered during initial osseointegration. Within the limitations of the present pilot study and the relatively short observation period, the findings do not support definitive clinical recommendations regarding adjunctive PN–HA use. While early healing dynamics may influence initial stability conditions, further studies with larger samples and extended follow-up are required to determine whether adjunctive use provides clinically meaningful long-term benefits.

From a biological standpoint, experimental studies have described roles of hyaluronic acid in tissue repair processes; however, the clinical relevance of these mechanisms for implant stability remains uncertain. Systematic reviews have emphasized substantial

heterogeneity in HA formulations, concentrations, application protocols, and outcome measures, limiting direct comparability between studies and precluding definitive conclusions [10,11,25]. Moreover, several controlled clinical and experimental investigations have reported neutral or inconsistent effects of HA on bone regeneration, suggesting that potential benefits are context-dependent rather than universal [26–28]. These findings underscore the need for caution when interpreting HA-related effects beyond early healing phases.

In the present study, implant stability was assessed using both resonance frequency analysis (ISQ) and percussive testing (PTV), which were deliberately treated as complementary rather than interchangeable methods. Accordingly, ISQ and Periotest values were interpreted strictly as relative, trend-based indicators reflecting functional behavior of the implant–bone complex, consistent with their applied use and known methodological limitations. ISQ is commonly interpreted as reflecting the stiffness of the implant–bone complex, whereas PTV provides information related to damping characteristics and micromobility under dynamic loading [17–19]. Absolute values of ISQ and PTV were not directly compared; instead, both methods were used to describe relative temporal trends in stability. Methodological studies have highlighted important limitations of each technique, supporting interpretation of ISQ and PTV as relative, longitudinal indicators rather than absolute measures of osseointegration [21,29]. In this context, parallel trends of increasing ISQ and decreasing PTV values observed in both groups are consistent with progressive biomechanical consolidation over time. The parallel trends observed in ISQ and Periotest measurements suggest that these complementary diagnostic methods may be useful for longitudinal monitoring of implant stability during the early phases of osseointegration. Their combined use can provide clinicians with practical, non-invasive tools for assessing implant stability over time in routine clinical settings.

CBCT-derived pseudo-densitometric analysis was incorporated as a supportive and descriptive tool. Within this applied framework, CBCT was intentionally not employed as a quantitative surrogate for bone regeneration, but rather as a supportive imaging modality providing spatial and contextual information relevant to the interpretation of stability measurements. In line with current methodological recommendations, CBCT was used exclusively for relative intra-patient comparisons and morphologic illustration rather than as a quantitative assessment of bone density, given its limited specificity for detecting thin buccal bone and for quantifying true mineral density [30]. Within these limitations, CBCT findings provided morphologic and spatial context that supported the interpretation of implant stability trends, rather than serving as a quantitative indicator of bone regeneration.

An additional aspect relevant to interpretation is careful case selection. Immediate implant placement was performed exclusively in clinically suitable extraction sites without facial recession or extended buccal defects, thereby avoiding morphologic situations associated with a high risk of esthetic failure. Recent conceptual frameworks have emphasized that the vertical and lateral extent of buccal dehiscence and the presence of facial soft-tissue support critically determine regenerative potential and esthetic risk in immediate implant placement, underscoring the importance of strict morphologic selection criteria in compromised sockets [31].

Several limitations of the present study must be acknowledged. More broadly, osseointegration outcomes are influenced by a range of clinical and surgical factors that can only be partially controlled in pilot clinical designs, which further supports cautious interpretation of stability metrics in small exploratory studies [16]. The pilot design and limited sample size restrict statistical power and generalizability, and the study was not intended to establish causal relationships. Although the split-mouth design minimizes inter-individual variability, local differences in bone morphology and cortical thickness may still influence primary stability. Furthermore, ISQ and PTV do not directly quan-

tify bone-to-implant contact, and the absence of histological validation precludes direct assessment of regenerated tissue quality.

Within these limitations, the findings suggest that adjunctive use of a PN–HA complex in GBR procedures may be associated with differences in early implant stability metrics, likely reflecting variations in local healing conditions during implant placement rather than direct biomechanical effects. These observations should be regarded as hypothesis-generating and warrant further investigation in larger, well-designed clinical studies. Future investigations should include larger patient cohorts, extended follow-up periods, and inferential statistical analyses to better clarify the relationship between regenerative conditions and implant stability outcomes.

Accordingly, the present results are primarily informative for the applied interpretation of implant stability measurements in exploratory clinical models.

5. Conclusions

Within the limitations of this split-mouth pilot clinical study, implant stability in the anterior maxilla following augmentation with Bio-Oss, with or without adjunctive polynucleotide-based hyaluronic acid, demonstrated comparable patterns of stabilization during the early healing period. Differences in ISQ and PTV values were observed at implant placement between the two protocols, while stability parameters converged during subsequent healing. The combined use of ISQ and Periotest measurements provided complementary functional assessment of implant stability, and CBCT served as a supportive descriptive tool. Further studies with larger cohorts may help to further explore these observations.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available from the corresponding author upon reasonable request.

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