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A COMPARATIVE ANALYSIS OF THE PRIMARY AND SECONDARY STABILITY OF IMMEDIATE, EARLY AND DELAYED PLACED IMPLANTS IN THE MAXILLARY ANTERIOR REGION USING RESONANCE FREQUENCY ANALYSIS: AN IN VIVO STUDY

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ABSTRACT

Background: Implant stability is a critical determinant of successful osseointegration and longterm prognosis of dental implants. The timing of implant placement, namely immediate, early, and delayed placement, may significantly influence primary and secondary stability outcomes, particularly in the maxillary anterior region where esthetic and functional demands are high.
Aim: To evaluate and compare the primary and secondary stability of immediate, early, and delayed placed implants in the maxillary anterior region using resonance frequency analysis (RFA).
Materials and Methods: A prospective comparative in vivo study was conducted on 90 patients requiring implant placement in the maxillary anterior region. Patients were equally divided into three groups (n=30 each): Group A (immediate implant placement), Group B (early implant placement), and Group C (delayed implant placement). Implant stability was assessed using the Osstell Mentor device by recording Implant Stability Quotient (ISQ) values immediately after implant placement (baseline) and after six months. Intergroup and intragroup comparisons were performed using one-way ANOVA and paired t-test. A p-value <0.05 was considered statistically significant.
Results: Delayed implants demonstrated significantly greater primary stability (76.20 ± 6.90) compared with early (64.67 ± 5.52) and immediate implants (62.37 ± 4.13) ($p<0.001$). Similarly, secondary stability at six months was significantly higher in delayed implants (89.87 ± 6.69), followed by early (75.83 ± 5.93) and immediate implants (73.03 ± 3.85) ($p<0.001$). Significant intragroup increases in ISQ values were observed in all groups over the six-month period ($p<0.001$).
Conclusion: Delayed implant placement demonstrated superior primary and secondary stability compared with immediate and early placement protocols. However, all three implant placement modalities achieved successful osseointegration and clinically acceptable implant stability outcomes.

KEYWORDS (alphabetical order): Dental implants; Delayed implant placement; Early implant placement; Implant Stability Quotient (ISQ); Immediate implant placement; Maxillary anterior region; Resonance frequency analysis (RFA).

INTRODUCTION

Dental implants have revolutionized contemporary prosthodontic rehabilitation and are currently regarded as one of the most predictable treatment modalities for replacing missing teeth [1]. Implant-supported restorations offer substantial advantages over conventional removable and fixed prostheses by improving aesthetics, function, phonetics, preservation of alveolar bone, and overall patient satisfaction [2]. The success of implant therapy relies primarily on the establishment and maintenance of osseointegration, a direct structural and functional connection between living bone and the surface of a load-bearing implant [3]. Since the pioneering work of Brånemark and colleagues, implant dentistry has undergone significant evolution in terms of implant design, surgical techniques, and loading protocols, thereby expanding the range of treatment options available to clinicians [4].

Among all regions of the oral cavity, rehabilitation of the maxillary anterior region presents a unique challenge because of its high aesthetic demands and complex anatomical considerations [5]. The anterior maxilla is commonly referred to as the "esthetic zone," where treatment outcomes are critically dependent on hard and soft tissue preservation, emergence profile, gingival architecture, and long-term implant stability [5]. In addition to esthetic requirements, the quality and quantity of available bone in the maxillary anterior region frequently influence treatment planning and implant prognosis.

Due to the relatively thin facial cortical plate and lower bone density often encountered in this region, obtaining predictable implant stability may become challenging [6].
Traditionally, implant placement was performed several months following tooth extraction to permit complete healing of the extraction socket and maturation of surrounding bone tissues [6]. This protocol, commonly referred to as delayed implant placement, was considered the standard treatment approach because it provided mature bone and adequate soft tissue healing, thereby enhancing implant stability [7]. However, the principal limitation of delayed placement is the prolonged treatment duration accompanied by progressive alveolar ridge resorption occurring during the healing period. Studies have demonstrated that significant horizontal and vertical dimensional changes occur following tooth extraction, potentially complicating future implant placement and necessitating additional grafting procedures [8-10].
To address these limitations, alternative timing protocols such as immediate and early implant placement have been introduced. Immediate implant placement refers to insertion of the implant directly into the extraction socket immediately following tooth removal, whereas early implant placement generally involves implant insertion after initial soft tissue healing, usually within four to eight weeks after extraction [11]. Both approaches aim to reduce treatment time and preserve alveolar architecture while simultaneously improving patient comfort and satisfaction [11].
Immediate implant placement offers several advantages, including reduction in the number of surgical interventions, shortened overall treatment duration, preservation of alveolar bone dimensions, and enhanced soft tissue esthetics [11]. Furthermore, placement of implants immediately after extraction can potentially utilize the existing socket anatomy to achieve an ideal prosthetic position. Despite these benefits, immediate placement is technically demanding and associated with challenges such as residual gaps between implant and socket walls, insufficient primary stability, and possible soft tissue complications [12].
Early implant placement serves as an intermediate approach that combines advantages of immediate and delayed protocols [12]. Healing of soft tissues before implant placement allows reduction of active inflammatory processes and improved flap adaptation while minimizing extensive bone remodeling associated with delayed healing [12]. However, because bone maturation remains incomplete during this stage, achieving ideal primary stability may still present clinical challenges [13].
Delayed implant placement continues to remain a widely accepted treatment protocol owing to the availability of mature bone and well-healed soft tissue architecture at the time of surgery [13]. This approach generally permits greater mechanical anchorage and favorable surgical access. Nevertheless, the requirement for prolonged healing periods, multiple surgical procedures, and increased risk of ridge resorption are notable disadvantages associated with this protocol [13].
Regardless of the timing protocol selected, implant stability remains one of the most important determinants of successful osseointegration and long-term implant survival. Implant stability is generally categorized into primary and secondary stability [14]. Primary stability refers to the mechanical engagement of the implant with surrounding cortical and trabecular bone immediately following placement. It is influenced by several factors including bone quality, implant design, surgical technique, and implant geometry [14]. Secondary stability develops subsequently through biological processes of bone remodeling and new bone formation at the implant–bone interface. The transition from primary to secondary stability represents a critical phase during healing and significantly influences loading protocols and treatment outcomes [14].
Several methods have been proposed for evaluating implant stability, including insertion torque analysis, reverse torque testing, percussion methods, radiographic evaluation, and resonance frequency analysis [13]. Among these techniques, resonance frequency analysis (RFA) has emerged as a reliable, non-invasive, reproducible, and objective method for assessing implant stability. Introduced by Meredith and coworkers in 1996, RFA determines the stiffness of the implant–bone interface by measuring resonance frequency and expressing it as an Implant Stability Quotient (ISQ) value ranging from 1 to 100. Higher ISQ values indicate greater implant stability and improved osseointegration potential [15].
The use of RFA has gained increasing popularity because it enables clinicians to monitor changes in implant stability over time without disturbing the healing process [10]. It can provide valuable information regarding the progression from primary to secondary stability and aid in clinical decision-making regarding implant loading and prognosis. Particularly in regions such as the maxillary anterior area where bone characteristics may compromise stability, quantitative assessment through RFA becomes clinically significant [11].
Although numerous studies have investigated immediate, early, and delayed implant placement protocols individually, limited evidence exists regarding direct comparison of primary and secondary stability among these three modalities within the maxillary anterior region using resonance frequency analysis [12]. Furthermore, most available studies focus on survival rates and esthetic outcomes rather than evaluating dynamic changes in implant stability over time [13].
Therefore, the present in vivo study was designed to comparatively analyze the primary and secondary stability of immediate, early, and delayed placed implants in the maxillary anterior region using resonance frequency analysis. The findings of this study may provide clinicians with evidence-based guidance regarding the optimal timing of implant placement and contribute to improved treatment planning, predictability, and long-term implant success.

MATERIALS AND METHOD

Study Design and Study Setting

The present study was designed as a prospective comparative in vivo clinical study conducted to evaluate and compare the primary and secondary stability of immediate, early, and delayed placed implants in the maxillary anterior region using resonance frequency analysis (RFA). The study was carried out in the Department of Prosthodontics and Crown & Bridge, Sardar Patel Post Graduate Institute of Dental and Medical Sciences, Lucknow. The study protocol was approved by the

Institutional Research Advisory Council and Institutional Ethical Committee before commencement of the study. The research was conducted according to the ethical principles outlined in the Declaration of Helsinki for biomedical research involving human subjects.

Sample Size Calculation

The sample size estimation was performed according to the formula proposed by Charan and Biswas for pilot and experimental studies. Based on an anticipated standard deviation of 9.68, mean difference of 6.15, 80% study power, and 5% level of significance, the minimum sample size calculated was approximately 28 subjects per group. To compensate for possible attrition or loss to follow-up, an additional 10% was incorporated into the sample size calculation, and the final sample size was rounded to 30 subjects in each study group. Therefore, a total of 90 participants were included in the study.

Study Population and Group Allocation

Ninety patients requiring implant rehabilitation in the maxillary anterior region and satisfying the inclusion criteria were recruited into the study after obtaining written informed consent. The participants were divided into three equal groups consisting of 30 patients each according to the timing of implant placement:

Group A: Immediate implant placement (implant placement immediately after extraction)

Group B: Early implant placement (implant placement after 4–8 weeks of extraction)

Group C: Delayed implant placement (implant placement after a minimum healing period of three months following extraction)

Allocation of participants into the study groups was performed according to the clinical indication and timing protocol for implant placement.

Inclusion Criteria: participants fulfilling the following criteria were included in the study

Participants fulfilling the study eligibility criteria were selected for inclusion in the present investigation. Individuals aged more than 21 years and less than 60 years requiring implant placement in the maxillary anterior region were considered eligible. Only patients presenting with Sagittal Root Position (SRP) Class I and II, according to the classification proposed by Kan et al., were included in the study. Participants were required to be in good general systemic health without any medical conditions capable of adversely affecting bone metabolism or wound healing. Furthermore, patients willing to participate in the study, capable of adhering to the treatment and follow-up protocol, and providing written informed consent were recruited for participation.

Exclusion Criteria: participants presenting with any of the following conditions were excluded:

Patients presenting with conditions that could potentially influence implant healing, osseointegration, or study outcomes were excluded from the investigation. Subjects with an immunocompromised status, including individuals with HIV infection or those who had undergone chemotherapy within the previous five years, were excluded. Pregnant and lactating women were not considered for participation. Patients with chronic smoking habits, poor oral hygiene practices, psychological or psychiatric disorders, and systemic diseases constituting contraindications for implant surgery were also excluded. Individuals exhibiting parafunctional habits such as bruxism, absence of posterior occlusal support, or active infection around failing teeth or previously placed implants were not included in the study. Additionally, cases requiring Guided Bone Regeneration (GBR) procedures were excluded to maintain uniformity in treatment conditions and minimize confounding variables affecting implant stability

Preoperative Evaluation

All patients underwent detailed clinical and radiographic examination before surgical intervention. Radiographic evaluation included cone beam computed tomography (CBCT) and intraoral periapical radiography/radiovisiography (RVG) for assessment of bone dimensions, bone density, root morphology, anatomical structures, and implant planning.

Routine laboratory investigations were performed to ensure suitability for surgical treatment and included complete haemogram, bleeding time, clotting time, prothrombin time (INR), blood glucose levels (HbA1c), hepatitis B surface antigen (HBsAg), enzyme-linked immunosorbent assay (ELISA) for HIV, serum calcium levels, vitamin D3 levels, and lipid profile. Following comprehensive clinical and radiographic evaluation, the decision regarding immediate, early, or delayed implant placement was made.

Surgical Procedure

All implant placements were performed under strict aseptic conditions following standardized surgical protocols. Local anesthesia was administered using 2% lignocaine hydrochloride containing 1:80,000 adrenaline.

For immediate implant placement, atraumatic extraction was performed with minimal elevation of mucoperiosteal flaps. Implant dimensions were determined using preoperative CBCT analysis. Osteotomy preparation was initiated using a pilot drill followed by sequential drilling according to the manufacturer's recommendations. Engagement of palatal bone was ensured to obtain adequate primary stability and maintain proper prosthetic orientation. Osteotomy preparation extended at least 3 mm beyond the apex of the extracted tooth to achieve optimal implant anchorage. The implant was positioned approximately 2 mm apical to the cemento-enamel junction of adjacent teeth.

For early implant placement, the same surgical protocol was followed after a soft tissue healing period of 4–8 weeks post extraction.

Delayed implant placement was performed after a healing period of three months following extraction. Full-thickness mucoperiosteal flap elevation was carried out using releasing incisions to expose the alveolar crest. Sequential osteotomy preparation was performed under continuous irrigation with cold sterile saline solution to avoid thermal injury. Paralleling pins and radiographic verification were used to assess implant angulation and positioning. The implant was placed at an equicrestal level and primary closure was achieved using 3–0 sutures after placement of the cover screw.

Resonance Frequency Analysis

Implant stability assessment was performed using resonance frequency analysis with the Osstell Mentor device. Measurements were obtained immediately after implant placement (baseline) to evaluate primary stability and repeated six months postoperatively to assess secondary stability.

For each measurement, a SmartPeg transducer **(figure 1)** was attached to the implant using approximately 4–6 Ncm torque. The probe of the Osstell device was positioned at approximately 90° relative to the SmartPeg without direct contact. Measurements were obtained in both mesiodistal and buccolingual directions. Four readings were recorded for each implant and the average value was considered for analysis.

The resonance frequency values were expressed as Implant Stability Quotient (ISQ) values ranging from 1 to 100, where higher values indicated greater implant stability and more favorable osseointegration. Postoperative examination at six months included assessment of mobility, periimplant inflammation, gingival margin position, attachment level, gingival width, and radiographic evaluation for peri-implant radiolucency.

Figure 1: Smart peg placement

Outcome Measures

The primary outcome measure was the change in Implant Stability Quotient (ISQ) values between baseline and six months in immediate, early, and delayed implant groups.

The secondary outcome measure was comparison of ISQ values among the three groups at baseline and six months.

Intragroup analysis was performed between baseline and six-month ISQ values within each group, while intergroup analysis was carried out among all three implant placement protocols.

Statistical Analysis

Data obtained from the study were entered into Microsoft Excel and analyzed using Statistical Package for Social Sciences (SPSS) version 21.0. Continuous variables were expressed as mean ± standard deviation, while categorical variables were represented as frequencies and percentages.

Intergroup comparison among the three study groups was performed using one-way analysis of variance (ANOVA) followed by post hoc analysis wherever appropriate. Chi-square test was used for categorical variables. Paired Student's t-test was used for intragroup comparison of baseline and six-month values. A p-value less than 0.05 was considered statistically significant, $p<0.01$ highly significant, and $p<0.001$ very highly significant.

RESULT

The present prospective comparative in vivo study was conducted to evaluate and compare the primary and secondary stability of immediate, early, and delayed placed implants in the maxillary anterior region using resonance frequency analysis (RFA). A total of 90 patients requiring implant placement in the maxillary anterior region were screened according to the predefined inclusion and exclusion criteria and enrolled following informed consent. The participants were equally distributed into three study groups: Group A (immediate placement), Group B (early placement), and Group C (delayed placement), with 30 subjects in each group.

Distribution of Study Population

The study population consisted of ninety patients, equally distributed among the three treatment groups. Each group represented 33.3% of the total study sample, ensuring balanced allocation among immediate, early, and delayed implant placement protocols **(table 1)**.

Table 1: Group-wise Distribution of Study Population

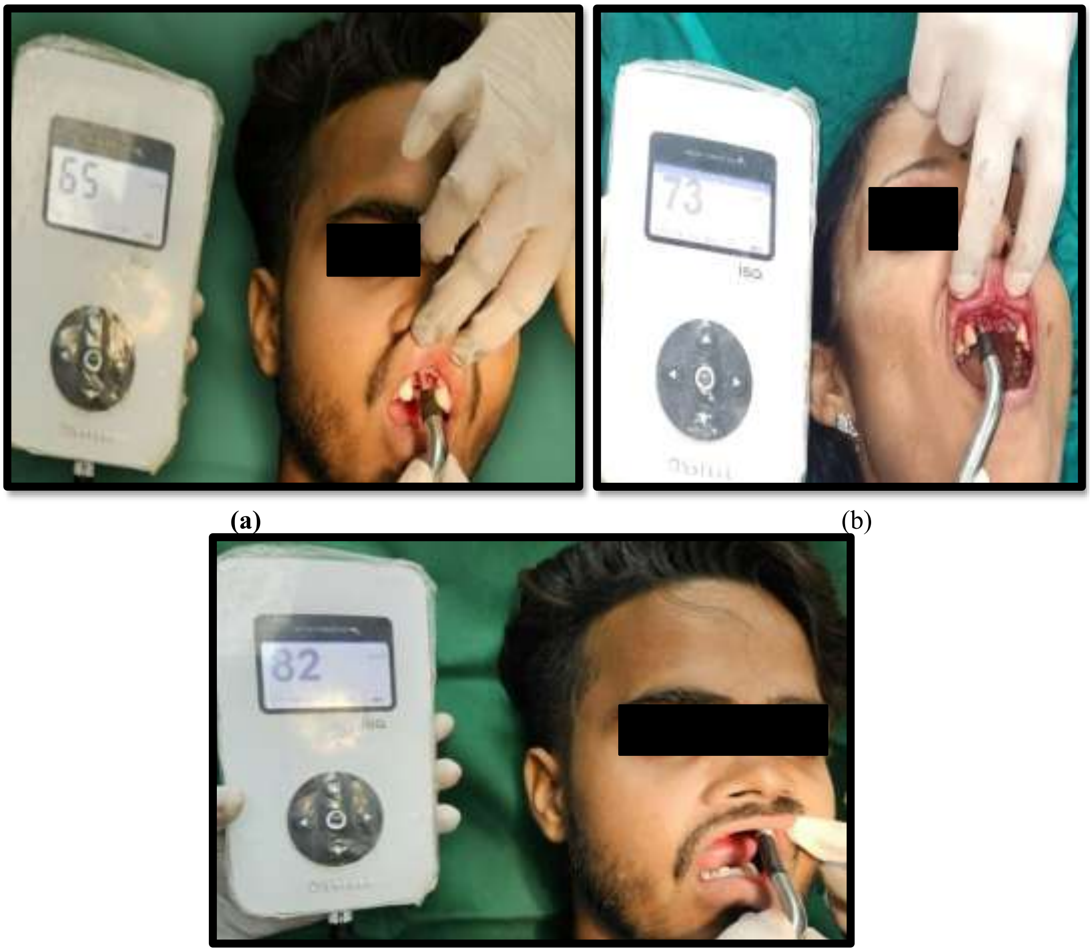
Group	Description	Number of Patients	Percentage
Group A	Immediately placed implants	30	33.3
Group B	Early placed implants	30	33.3
Group C	Delayed placed implants	30	33.3
Total		**90**	**100**

Intergroup Comparison of Primary Stability (Baseline ISQ)

The baseline implant stability quotient (ISQ), representing primary implant stability, demonstrated significant differences among the three groups. The delayed implant group exhibited the highest primary stability with a mean ISQ value of **76.20 ± 6.90**, followed by the early implant group with **64.67 ± 5.52**, while the immediate implant group demonstrated the lowest value (**62.37 ± 4.13**). Overall mean primary stability among all participants was **67.74 ± 8.25**. Statistical analysis showed a highly significant intergroup difference (**F=51.951; p<0.001**; **table 2, 2.1)**.

Group C demonstrated significantly greater primary stability compared to Groups A and B, whereas Groups A and B did not differ significantly **(figure 2 (a) – (c)**.

Figure 2: ISQ readings in (a) early; (b) immediate and (c) delayed placed implants at baseline



(a) (b)

(c)

Table 2: Intergroup Comparison of Primary Stability (ISQ)

Group	N	Minimum	Maximum	Mean	SD
Group A	30	56	71	62.37	4.13
Group B	30	54	79	64.67	5.52
Group C	30	63	90	76.20	6.90
Total	90	54	90	67.74	8.25

ANOVA: F=51.951; p<0.001 (Highly Significant)

Table 2.1: Pairwise Comparison of Primary Stability

Comparison	Mean Difference	SE	p-value
Group A vs Group B	2.300	1.454	0.259

Group A vs Group C	13.833	1.454	<0.001
Group B vs Group C	11.533	1.454	<0.001

Intergroup Comparison of Secondary Stability at Six Months
At six months, all groups exhibited improvement in ISQ values, reflecting progression of osseointegration and secondary implant stability. Delayed implants demonstrated the highest secondary stability (**89.87 ± 6.69**), followed by early implants (**75.83 ± 5.93**) and immediate implants (**73.03 ± 3.85**). Statistical analysis showed highly significant differences among the groups (**F=77.310; p<0.001; table 3, 3.1**).
Group C demonstrated significantly higher secondary stability than Groups A and B, while Groups A and B remained statistically comparable **(figure 3 (a) – (c)**.

Figure 3: ISQ readings in (a) early; (b) immediate and (c) delayed placed implants at six months

(a) **(b)**

(c)

Table 3: Intergroup Comparison of Secondary Stability (ISQ at Six Months)

Group	N	Minimum	Maximum	Mean	SD
Group A	30	67	82	73.03	3.85
Group B	30	67	95	75.83	5.93
Group C	30	77	99	89.87	6.69
Total	90	67	99	79.58	9.26

ANOVA: F=77.310; p<0.001 (Highly Significant)

Table 3.1: Pairwise Comparison of Secondary Stability

Comparison	Mean Difference	SE	p-value
Group A vs Group B	2.800	1.451	0.259
Group A vs Group C	16.833	1.451	<0.001
Group B vs Group C	14.033	1.451	<0.001

Intragroup Comparison of ISQ Changes Between Baseline and Six Months

A statistically significant increase in ISQ values from baseline to six months was observed in all three groups. Delayed implants demonstrated the greatest increase in implant stability (**13.667 ± 4.528**) with a percentage increase of **17.94%**, followed by early implants (**17.27%**) and immediate implants (**17.10%**). Paired t-test analysis showed highly significant improvement in all groups (**p<0.001**); **table 4**.

Overall, the results indicate that delayed implant placement demonstrated superior primary and secondary implant stability compared with immediate and early placement protocols. Although all three groups showed significant improvement in ISQ values over the six-month healing period, delayed placement produced the greatest enhancement in implant stability and osseointegration.

Table 4: Intragroup Change in ISQ Values from Baseline to Six Months

Group	Mean Change	SD	Percentage Change	t-value	p-value
Group A	10.667	3.133	17.10	18.647	<0.001
Group B	11.167	4.434	17.27	13.794	<0.001
Group C	13.667	4.528	17.94	16.530	<0.001

DISCUSSION

The present prospective comparative in vivo study evaluated and compared the primary and secondary stability of immediate, early, and delayed implant placement protocols in the maxillary anterior region using resonance frequency analysis (RFA). Implant stability is considered a key determinant of successful osseointegration and long-term implant survival because it reflects both the mechanical engagement of the implant with surrounding bone and the subsequent biologic process of bone remodeling. The findings of the present study demonstrated significant differences in implant stability among the three placement protocols, with delayed implant placement exhibiting superior primary and secondary stability compared with immediate and early placement modalities. These findings contribute important evidence regarding the influence of timing of implant placement on implant stability and clinical outcomes in the esthetic zone. The discussion is based on the study design and results presented in the uploaded manuscript and thesis.

The demographic variables including age and gender showed no statistically significant differences among the study groups. Such homogeneity among the groups is important because age-related alterations in bone metabolism and gender-related variations in bone density can potentially influence implant stability and osseointegration. Since no significant differences were observed, demographic characteristics were unlikely to have influenced the observed outcomes, thereby strengthening the internal validity of the study.

The present study revealed that delayed implants exhibited significantly greater primary stability at baseline (76.20 ± 6.90) compared with early implants (64.67 ± 5.52) and immediate implants (62.37 ± 4.13). Primary stability is predominantly determined by bone quality and quantity, cortical bone engagement, implant geometry, and surgical technique. Delayed placement is performed after complete healing of extraction sockets, thereby allowing mature bone formation and improved cortical support around the implant site. The presence of mature trabecular architecture and complete bone remodeling may explain the higher initial mechanical engagement observed in delayed implant placement.

The findings of the present study are consistent with observations by Lioubavina-Hack et al. [10], who emphasized that primary implant stability is a prerequisite for successful osseointegration and reported that inadequate primary stability could lead to fibrous encapsulation rather than osseous integration. Similarly, Molly et al. [11] reported a strong association between bone density and primary implant stability and suggested that higher-density bone contributes to increased implant anchorage. Coutant et al. [16] also demonstrated a significant relationship between bone density and resonance frequency measurements, supporting the concept that dense bone provides greater implant stability.

The lower primary stability observed in immediate implants in the present study may be attributed to the morphological characteristics of fresh extraction sockets. Immediate implant placement frequently presents challenges because the implant often occupies a position within a socket that is larger than the implant diameter, resulting in residual peri-implant gaps. In addition, buccal cortical plates in the anterior maxilla are generally thin and susceptible to resorption. Becker et al. [6] similarly reported that implants placed immediately into extraction sockets often demonstrate lower initial stability values because of limited bone-to-implant contact. Gunter Schultes et al. [17] also suggested that early crestal bone remodeling around immediately placed implants may adversely affect implant integration.

The results further demonstrated that secondary stability after six months was significantly higher in delayed implants (89.87 ± 6.69) compared with early (75.83 ± 5.93) and immediate implants (73.03 ± 3.85). Secondary stability reflects biological stability resulting from bone healing and new bone formation at the implant–bone interface. The significant increase in ISQ values over time observed in all three groups indicates successful progression of osseointegration irrespective of implant placement timing.

The increase in secondary stability observed in the present study agrees with findings by Alberto et al., [18] who reported that satisfactory primary stability facilitates the development of biological stability during healing. Similarly, Bajaj et al. [19] observed progressive increases in secondary stability during healing irrespective of loading protocol, suggesting that implant stability improves as bone remodeling proceeds. Satwalekar et al. [13] further emphasized that resonance frequency analysis is an effective clinical tool for monitoring changes in implant stability throughout healing periods.

The greater increase in ISQ values observed in delayed implants may be explained by favorable biologic conditions existing before implant placement. Since delayed implants are inserted into mature healed bone, remodeling processes primarily involve reinforcement and maturation around an already stable implant. Conversely, immediate implants

undergo simultaneous socket healing and implant osseointegration, making biologic events more complex and potentially less predictable.
The intragroup analysis demonstrated statistically significant improvement in implant stability from baseline to six months in all three groups. Immediate implants showed a mean increase of 10.67 ISQ units, early implants demonstrated an increase of 11.17 units, and delayed implants showed the highest increase of 13.67 units. These findings suggest that although initial stability differs among implant placement protocols, successful osseointegration occurs in all groups. Similar findings were reported by Sergio Alexandre et al., [20] who observed that implants placed in healed sites and fresh extraction sockets demonstrated comparable patterns of increasing stability over time, although healed sites consistently exhibited superior ISQ values.
Interestingly, although delayed implants showed significantly greater stability values, immediate and early placement protocols still achieved clinically acceptable ISQ values after six months. This observation aligns with findings of Katsoulis et al. [21] and Soydan et al. [22], who reported comparable long-term survival rates between immediate and early implant placement techniques. Therefore, while delayed placement may provide superior mechanical and biologic stability, immediate and early protocols remain clinically acceptable alternatives under favorable conditions and with appropriate case selection.
The findings of the present study may have important clinical implications. Delayed implant placement may be advantageous in situations where maximum implant stability is desired, particularly in patients with compromised bone quality or in cases where immediate loading is anticipated. However, delayed placement requires prolonged treatment time and may be associated with post-extraction alveolar bone loss. Immediate and early placement protocols, although associated with lower initial stability, offer several advantages including reduced treatment duration, fewer surgical interventions, and better preservation of hard and soft tissue architecture. Therefore, clinicians should balance stability outcomes against esthetic demands and patient expectations during treatment planning.

Limitations of the Study: despite the significant findings, certain limitations should be acknowledged:
1. The follow-up period was limited to six months and did not evaluate long-term implant survival and peri-implant bone changes.
2. The study was confined to the maxillary anterior region, limiting generalization to posterior regions where bone characteristics differ.
3. Bone density was not quantitatively measured and categorized using objective scales.
4. Variations in implant dimensions and patient-specific biological factors may have influenced stability outcomes.
5. Histological assessment of bone–implant contact was not possible because of ethical constraints.
6. The study assessed implant stability using only resonance frequency analysis without correlating findings with insertion torque values or other stability parameters.

Future Recommendations: future investigations should focus on:
1. Conducting multicenter studies with larger sample sizes to improve external validity.
2. Extending follow-up duration to assess long-term implant survival and marginal bone changes.
3. Evaluating the effect of bone density and bone quality quantitatively on implant stability.
4. Comparing different implant designs, surface characteristics, and diameters.
5. Correlating resonance frequency analysis with insertion torque measurements and radiographic bone density assessments.
6. Evaluating esthetic outcomes and patient-reported outcome measures in addition to implant stability.
7. Investigating the influence of immediate loading protocols on primary and secondary implant stability.

CONCLUSION
Within the limitations of the present in vivo study, delayed implant placement in the maxillary anterior region demonstrated significantly greater primary and secondary implant stability compared with immediate and early implant placement protocols as assessed by resonance frequency analysis. Delayed implants exhibited the highest baseline and six-month ISQ values, indicating superior mechanical engagement and more favorable osseointegration. However, all three implant placement protocols showed a statistically significant increase in implant stability over the six-month healing period, confirming successful progression from primary to secondary stability.
Although delayed placement provided superior stability outcomes, immediate and early implant placement protocols also achieved clinically acceptable ISQ values and predictable osseointegration. Therefore, while delayed implant placement may be preferred when maximum implant stability is required, immediate and early implant placement remain reliable treatment alternatives when appropriate case selection, careful surgical planning, and favorable clinical conditions are present. Resonance frequency analysis proved to be a reliable, objective, and noninvasive method for monitoring implant stability and evaluating treatment outcomes.

REFERENCES
1. Sennerby L, Meredith N. Implant stability measurements using resonance frequency analysis: biological and biomechanical aspects and clinical implications. Periodontol 2000.
2. 2008;47(1):51–66.

3. Meredith N. Assessment of implant stability as a prognostic determinant. Int J Prosthodont. 1998;11(5):491–501.
4. Buser D, Chen ST, Weber HP, Belser UC. Early implant placement following single-tooth extraction in the esthetic zone: biologic rationale and surgical procedures. Int J Periodontics Restorative Dent. 2008;28(5):441–51.
5. Schropp L, Isidor F. Timing of implant placement relative to tooth extraction. J Oral
6. Rehabil. 2008;35(Suppl 1):33–43.
7. Esposito M, Grusovin MG, Polyzos IP, Felice P, Worthington HV. Timing of implant placement after tooth extraction: immediate, immediate-delayed or delayed implants? A
8. Cochrane systematic review. Eur J Oral Implantol. 2010;3(3):189–205.
9. Becker W, Sennerby L, Bedrossian E, Becker BE, Lucchini JP. Implant stability measurements for implants placed at the time of extraction: a cohort prospective clinical trial. J Periodontol. 2005;76(3):391–7.
10. Kan JY, Roe P, Rungcharassaeng K, Patel RD, Waki T, Lozada JL, et al. Classification of sagittal root position in relation to the anterior maxillary osseous housing for immediate implant placement. Int J Oral Maxillofac Implants. 2011;26(4):873–6.
11. Huang HM, Chiu CL, Yeh CY, Lee SY. Factors influencing resonance frequency of dental implants. J Oral Rehabil. 2003;30(10):982–9.
12. Bischof M, Nedir R, Szmukler-Moncler S, Bernard JP, Samson J. Implant stability measurement of delayed and immediately loaded implants during healing. Clin Oral Implants Res. 2004;15(5):529–39.
13. Lioubavina-Hack N, Lang NP, Karring T. Significance of primary stability for osseointegration of dental implants. Clin Oral Implants Res. 2006;17(3):244–50.
14. Molly L. Bone density and primary stability in implant therapy. Clin Oral Implants Res. 2006;17(Suppl 2):124–35.
15. Han J, Lulic M, Lang NP. Factors influencing resonance frequency analysis assessed by
16. Osstell Mentor during implant tissue integration: II. Implant-related factors. Clin Oral Implants Res. 2010;21(6):605–11.
17. Satwalekar P, Nalla S, Reddy R, Chowdary SG. Clinical evaluation of osseointegration using resonance frequency analysis. J Indian Prosthodont Soc. 2015;15(3):192–9.
18. Mello CC, Lemos CAA, Verri FR, dos Santos DM, Goiato MC, Pellizzer EP. Immediate implant placement into fresh extraction sockets versus delayed implants into healed sockets: a systematic review and meta-analysis. Int J Oral Maxillofac Surg. 2017;46(9):1162–77.
19. Baltayan S, Pi-Anfruns J, Aghaloo T, Moy PK. The predictive value of resonance frequency analysis measurements in the surgical placement and restoration of dental implants. J Oral Maxillofac Surg. 2016;74(6):1145–52.
20. Coutant JC, Seguela V, Hauret L, Caix P, Ella B. Correlation between primary implant stability and bone density using computerized tomography and resonance frequency analysis in fresh cadavers. Clin Implant Dent Relat Res. 2014;16(2):255–65.
21. Schultes G, Gaggl A. Histologic evaluation of immediate versus delayed placement of implants after tooth extraction. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2011;112(2):e1–11.
22. Alberto M, Ravidà A, Wang HL, Helms JA, Brunski JB. Relationship between primary and secondary implant stability: a biologic and biomechanical perspective. J Oral Implantol. 2019;45(4):313–20.
23. Bajaj G, Gupta S, Chaturvedi TP, Dhanraj M. Evaluation and comparison of primary and secondary implant stability in immediate and early loaded implants using resonance frequency analysis. J Indian Prosthodont Soc. 2017;17(2):145–51.
24. Alexandre S, da Silva R, Rodrigues JA, Faverani LP, Okamoto R. Stability of implants placed in fresh extraction sockets versus healed alveolar sockets: a comparative clinical study. Clin Implant Dent Relat Res. 2016;18(6):1086–93.
25. Katsoulis J, Brunner A, Mericske-Stern R. Maintenance of implant-supported restorations and comparison of immediate and early implant placement protocols. Clin Oral Implants
26. Res. 2012;23(2):203–9.
27. Soydan SS, Cubuk S, Oguz Y, Uckan S. Are success and survival rates of early implant placement higher than immediate implant placement? Int J Oral Maxillofac Surg.
28. 2013;42(4):511–5.