"COMPARATIVE EVALUATION OF CRESTAL BONE LOSS AND BONE DENSITY CHANGES WITH EARLY AND DELAYED LOADING OF IMPLANTS FOR REHABILITATION OF SINGLE MISSING POSTERIOR MANDIBULAR TOOTH- *A SPLIT-MOUTH IN-VIVO STUDY*"

BY

REG. NO- IM0222006

Dissertation

Submitted to
KAHER, Belagavi, Karnataka
In partial fulfilment of the requirements for the degree of

MASTER OF DENTAL SURGERY

In

PROSTHODONTICS AND CROWN & BRIDGE

(BRANCH – I)

DEPARTMENT OF PROSTHODONTICS
AND CROWN & BRIDGE
KAHER's V.K. INSTITUTE OF DENTAL SCIENCES,
BELAGAVI, KARNATAKA.

2022 – 2025

KLE ACADEMY OF HIGHER EDUCATION AND RESEARCH
KLE V.K. INSTITUTE OF DENTAL SCIENCES,
BELAGAVI, KARNATAKA

Endorsement by the HOD, Principal/ Head of the Institution

This is to certify that this dissertation entitled **"Comparative evaluation of crestal bone loss and bone density changes with early and delayed loading of implants for rehabilitation of single missing posterior mandibular tooth- *A split-mouth in-vivo study*"**, is a bonafide research work done by **REG. NO- IM0222006.**

Head of Department

Dr. RAMESH NAYAKAR MDS
Professor & Head,
Department of Prosthodontics
and Crown & Bridge,
KAHER'S Vishwanath Katti Institute
of Dental Sciences, Belagavi.

Date: 16/04/25

Place: Belagavi

Professor and Head
Department of Prosthodontics
KLE V. K. Institute of Dental Sciences,
Belagavi

Principal

Dr. ALKA D. KALE MDS, PhD
Principal,
KAHER's Vishwanath Katti Institute of
Dental Sciences,
Belagavi.

PRINCIPAL
KLE V.K. Institute of Dental Sciences
Nehru Nagar, BELAGAVI-590010.

Date: 17/4/25

Place: Belagavi

PLAGIARISM ACCEPTED LETTER

Scientific Correspondence and Review Committee

KLE VK Institute of Dental Sciences

A Constituent Unit of KLE Academy of Higher Education and Research
(Deemed-to-be-University u/s 3 of the UGC Act, 1956)
Nehru Nagar, Belagavi - 590 010, Karnataka State

Accredited 'A+' Grade by NAAC (3rd Cycle) Placed in Category 'A' by MHRD (GoI)

☎: 0831-2470362 Web: http://www.kledental-bgm.edu.in
FAX: 0831-2470640 E-mail:principal@kledental-bgm.edu.in

Date : 15/4/2025 Serial No. : 405

PLAGIARISM CHECK REPORT

Name of the Applicant : **REG. NO- IM0222006**
UG / PG / Ph.D / Staff : PG
Batch & Year : 2022
Department : Prosthodontics.

The soft copy of Research Work / Manuscript by **REG. NO- IM0222006** .. entitled "Comparative evaluation of crestal bone loss & bone density changes with early & delayed loading of implants for rehabilitation of single missing posterior mandibular tooth - A split mouth in-vivo study.
under the guidance of . ...has been submitted for Anti-Plagiarism check to the Scientific Correspondence & Review Committee of KLE VK Institute of Dental Sciences using "Turn-it-in" software.

The scan has been carried out and the scanned output reveals a Similarity Index of ......6......%, which is **within / not within** the acceptable limits of 10% as per the UGC guidelines.

15/4/2025 15/4/25

Member Secretary
Scientific Correspondence and Review Committee
KLEVK Institute of Dental Sciences
KAHER-Belagavi

Chairman
Scientific Correspondence and Review Committee
KLEVK Institute of Dental Sciences
KAHER - Belagavi

BIOSTATISTICS CLEARANCE CERTIFICATE

KLE
VISHWANATH KATTI
INSTITUTE OF DENTAL SCIENCES
A Constituent college of
K.L.E. Academy of Higher Education and Research
J.N.M.C. Campus, Nehru Nagar Belagavi -590010 Karnataka, India.
Department of Prosthodontics and Crown & Bridge

BIOSTATISTICS CLEARANCE CERTIFICATE

This is to certify that the Biostatistics art of Dissertation/Research work of

REG. NO- IM0222006 **ıte student** under the guidance of

Department of Prosthodontics **and crown and bridge** entitled **"Comparative evaluation of crestal bone loss and bone density changes with early and delayed loading of implants for rehabilitation of single missing posterior mandibular tooth- A split-mouth in-vivo study"** has been done under my guidance and considered satisfactory.

Place: Belagavi

Date: 13. 03. 2024

Name and signature of Biostatistician

Dr. S. B. Javali. Ph.D.
Professor In Statistics
Department of Community Medicine
USM KLE International Medical Programme,
BELAGAVI-590010.

UNDERTAKING

I, **REG. NO- IM0222006,** a postgraduate student in the subject of **Prosthodontics and Crown and Bridge,** have completed research work on the topic **"COMPARATIVE EVALUATION OF CRESTAL BONE LOSS AND BONE DENSITY CHANGES WITH EARLY AND DELAYED LOADING OF IMPLANTS FOR REHABILITATION OF SINGLE MISSING POSTERIOR MANDIBULAR TOOTH- A *SPLIT-MOUTH IN-VIVO STUDY*",** from the year **2022-2025**.

I have been given to understand that any research work I undertake for the purpose of dissertation, oral presentation or publication during my study course shall be the property of the *KAHER's Vishwanath Katti Institute of Dental Sciences, Belagavi.* Hence, I hereby declare that the name of the Department Institute and University shall be mentioned in my publications. The authorship shall be according to the guideline informed to me.

Date:16-04-2025

Place: Belagavi. **REG. NO- IM0222006**

UNDERTAKING

I, **REG. NO- IM0222006,** hereby declare that the information and the data mentioned in my dissertation entitled **"COMPARATIVE EVALUATION OF CRESTAL BONE LOSS AND BONE DENSITY CHANGES WITH EARLY AND DELAYED LOADING OF IMPLANTS FOR REHABILITATION OF SINGLE MISSING POSTERIOR MANDIBULAR TOOTH- A *SPLIT-MOUTH IN-VIVO STUDY*",** belongs to me and is original. I am aware of the definition of plagiarism as detailed below:

- An act or instance of using or closely imitating the language and thoughts of another author without authorization and the representation of that author's work as one's own, as by not crediting the original author.
- A piece of writing or other work reflecting such unauthorized use or imitation.
- The deliberate or reckless representation of another's words, thoughts or ideas as one's own without attribution in connection with submission of academic work, whether graded or otherwise.

I hereby declare that the dissertation prepared by me is original one and does not involve plagiarism any here. In case at a later stage, it is found that I have indulged in plagiarism, then I am solely responsible for the same and the institution is at liberty to take any disciplinary action against me including cancellation of dissertation or any other penalties imposed by the university.

Date: 16-04-2025

Place: Belagavi. **REG. NO- IM0222006**

LIST OF ABBREVIATIONS USED IN THE STUDY

CBCT	Cone-Beam Computed Tomography
MBL	Marginal Bone Loss
ISQ	Implant Stability Quotient
RFA	Resonance Frequency Analysis
SLA	Sand blasted, Large grit, Acid-etched
PVS	Polyvinyl Siloxane
PMMA	Polymethylmethacrylate
PFM	Porcelain-Fused-to-Metal
ANOVA	Analysis of Variance
SD	Standard Deviation
AI	Artificial Intelligence
mm	Millimeter

ABSTRACT

STATEMENT OF PROBLEM

Tooth loss in the posterior mandible often necessitates implant-supported restorations. While early loading protocols can reduce treatment time and improve patient comfort, their impact on peri-implant crestal bone stability and bone density compared to conventional delayed loading remains unclear.

PURPOSE

To evaluate and compare the changes in peri-implant crestal bone level and bone density for rehabilitation of single missing posterior mandibular tooth with implants in split-mouth cases using early and delayed loading protocol.

METHODOLOGY

Nine patients with bilateral posterior mandibular edentulous sites received identical implant placement under standardized surgical conditions. In each patient, one site underwent early loading at 14 days with a provisional PMMA restoration, while the contralateral site followed a delayed loading protocol at three months. Cone-beam computed tomography (CBCT) scans were obtained at baseline (implant placement), 15 days, 3 months, 6 months, and 9 months post-loading. Crestal bone levels were measured at mesial, distal, buccal, and lingual aspects using the fifth thread pitch as a reference. Bone density (gray-scale values) was recorded at the crestal, middle, and apical thirds. Statistical analysis included repeated measures ANOVA for time effects, paired t-tests for intragroup changes, and independent t-tests for intergroup comparisons ($\alpha = 0.05$).

RESULTS

All 18 implants (100%) survived without biological or prosthetic complications. Both early and delayed loading groups exhibited significant reductions in mean total MBL from baseline to 9 months (early: 5.10 ± 0.43 mm to 4.80 ± 0.40 mm; delayed: 5.30 ± 0.47 mm to 4.82 ± 0.45 mm; $p < 0.001$). Independent comparisons at each time point revealed no statistically significant differences in MBL between protocols ($p > 0.05$). Volumetric bone density increased progressively in both groups at all thirds, with the most pronounced gains at the lingual crest; no intergroup differences were observed ($p > 0.05$).

CONCLUSION

When primary stability criteria (ISQ ≥ 60) are met, early loading of posterior mandibular implants produces peri-implant bone remodeling and density outcomes equivalent to those of delayed loading. Early loading may therefore be considered a reliable option in well-selected patients, offering reduced treatment time without compromising bone health.

KEYWORDS

Dental implants; early loading; delayed loading; marginal bone loss; bone density; cone-beam computed tomography; split-mouth study.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF GRAPHS

INTRODUCTION

- The field of modern dentistry focuses on restoring oral function, aesthetics, speech and overall oral health. Tooth loss that results from trauma, periodontal disease or caries, possesses tremendous potential in interfering with the quality of life. The use of dental implants as a prevalent mode of treatment for total or partial edentulism increases due to advantages like long-term success, reduced risk of complications in nearby teeth, increased alveolar bone preservation and increased patient comfort. Compared to traditional prosthetic alternatives such as fixed partial prosthesis and removal prosthesis, dental implants provide stability and function similar to natural teeth.[1]

- The application of the term "osseointegration" by Per-Ingvar Branemark has introduced a sea change in the history of implant dentistry as it offers bone-to-implant contact with no intervening soft tissue. The success of an implant varies with several factors, some of which include the surgical intervention, surface characteristics and loading conditions of the implant. Improvements in implant surface technology, including surface roughening and bioactive coatings, have improved osseointegration, resulting in higher success rates and reduced healing times.[2]

- The success of implant prostheses is influenced by surgical and prosthodontic protocols.[3,4] Implant loading refers to the application of forces on an implant following its placement. Based on timing, it is categorized as:

    - **Immediate Loading:** The implant is restored within one week of placement, allowing for immediate function and aesthetics.

- **Early Loading:** Functional loading occurs between 1 week and 2 months post-placement, providing a compromise between immediate and delayed approaches.
- **Delayed (Conventional) Loading:** The implant is restored after more than two months, ensuring full osseointegration before functional forces are applied.[5,6]

- Each protocol presents specific clinical considerations. While immediate and early loading reduce treatment duration, immediate loading outcomes can be affected by bone anatomy and ridge alterations after tooth extraction.[7,8] Also, achieving high primary stability is crucial for immediate loading, as inadequate stability can lead to micromovements and implant failure. Delayed loading allows complete osseointegration before functional forces are applied, potentially enhancing implant stability and long-term outcomes. This method is commonly used in cases of poor bone quality or lack of primary stability as it reduces the chances of implant failure.[9]

- Marginal bone loss (MBL) is a very significant determinant in the longevity of the implant and is affected by implant design, surgical technique, occlusal forces and loading protocols. MBL is more in the first-year post-placement because of bone remodeling and physiological adjustment. Bone loss of more than 1.5 mm in the first year and 0.2 mm each year thereafter is an indicator of implant failure. Some of the reasons for MBL are surgical trauma, incorrect position of the implant, occlusal overload, and peri-implantitis. Microgaps between the implant and prosthesis can also lead to bone resorption, and thus accurate restorative techniques are critical.[10,11]

- Changes in bone density also impact implant success. Bone remodeling after implant placement alters peri-implant bone quality. Early loading may accelerate bone density reduction due to functional stress before complete osseointegration. Conversely, delayed loading supports gradual bone maturation, leading to enhanced bone density and implant stability. Bone density is particularly important in implant success, as low-density bone (e.g., in the posterior maxilla) is more prone to resorption and implant instability. Research has indicated that changes in implant design, like increased diameters and tapered shape, can enhance primary stability in low-density bone and lower the risk of failure.[12,13]

- Studies have shown that earlier loading can result in greater marginal bone loss than delayed loading, especially in situations of insufficient primary stability or poor-quality bone.[4] However, advancements in implant surface technology have improved early osseointegration, reducing MBL even with early loading protocols. The use of platform-switching implants, which create a horizontal offset between the implant and abutment, has shown to reduce marginal bone loss and improve peri-implant tissue stability. In addition, guided bone regeneration (GBR) procedures, such as the application of bone grafts and barrier membranes, have been utilized to create improved bone quality and quantity prior implant placement.[14]

- There are few studies that evaluate the effect of early loading and delayed loading protocols on implant success, peri-implant bone stability, and prosthetic success. A systematic review reported both protocols with high survival rates (>95%), but early loading had more marginal bone loss during the first year.[5]

- Delayed loading is specifically advantageous in low bone density because it minimizes the likelihood of early failure of the implant. Certain reports indicate that primary stability is crucial to success, and high insertion torque (>35 Ncm) implants yield the same results under early and delayed loading. In contrast, excessive torque can lead to microfractures in the bone, negatively impacting osseointegration. Therefore, achieving an optimal balance between insertion torque and implant stability is essential for success.[2,6]

- Although research has extensively compared early and delayed loading, most studies have assessed these protocols in different patient groups. There is no standardized study evaluating both protocols within the same patient, making it difficult to control for individual variations in bone quality, healing potential, and occlusal load distribution. Also, few have investigated the role of implant geometry, surface conditioning and surgical habits on the effectiveness ofearly and delayed loading protocols.

- This split-mouth in vivo study aims to compare early loading and delayed loading protocols within the same patient, eliminating inter-patient variability. The study measured and compared peri-implant marginal bone loss and bone density changes, providing standardized data to determine the optimal loading approach for long-term implant success.

NEED FOR THE STUDY

The goal of modern-day dentistry is to restore the patient's oral cavity to normal form, function, comfort, aesthetics, speech and health by restoring carious teeth or replacing missing teeth.[1]

The success of dental implants depends on meticulous pre-operative treatment planning, appropriate surgical protocol, regular follow-up and eventful healing phase to achieve osseointegration.[2]

These implants are loaded to a large extent by three loading protocols, i.e., immediate loading (< 1 week), early loading (1 week - 2 months) and delayed or conventional loading (> 2 months).[3]

Delayed loading of dental implants after healing time possesses high biologic stability, but there's a drawback of extending treatment duration.[2]

Early or immediate loading protocols are used to minimize the time gap between prosthesis and implant loading, which makes the patient more comfortable. Although, immediate loading of the implant has been reported to have a higher failure rate.[3]

Earlier research has compared the effect of early and delayed loading protocols between two groups of patients; one group was administered early loading protocols and another group was administered delayed loading protocols.

There has not been a study comparing early and late loading outcomes in a group; thus not standardized.

The present split-mouth in vivo study is aimed at comparing the effect of early and delayed loading of dental implants on marginal bone level around peri-implants bone density changes in the same individual.

HYPOTHESIS:

NULL HYPOTHESIS

- There is no difference between peri-implant marginal bone level and bone density in early and delayed loading of implants.

RESEARCH HYPOTHESIS

- There is difference between peri-implant marginal bone level and bone density in early and delayed loading of implants.

AIM OF THE STUDY:

To evaluate and compare changes in peri-implant marginal bone level and bone density for rehabilitation of single missing posterior mandibular tooth with implants in split-mouth cases using early and delayed loading protocol.

OBJECTIVES:

- To evaluate changes in peri-implant marginal bone level for single posterior mandibular implant placed on either side of the posterior partially edentulous mandibular arches with early and delayed loading protocol using CBCT (Cone beam computed tomography)
- To evaluate bone density on gray-scale for single posterior mandibular implant placed on either side of the posterior partially edentulous mandibular arches with early and delayed loading protocol using CBCT.
- To evaluate and compare changes in peri-implant marginal bone level and bone density for single posterior mandibular implant in split-mouth cases using early and delayed loading protocol using CBCT.

REVIEW OF LITERATURE

1. Branemark et al. (1967) revolutionized implant dentistry by demonstrating the concept of osseointegration. The study investigated the long-term success of titanium implants in fully edentulous patients following 10-year follow-up. The machined titanium implants were loaded by two-stage surgery, with no interference, allowing healing prior to loading. Clinical and histological evaluations ensured sturdy bone integration with few complications, establishing titanium as one material that is biocompatible as an implant. This research formed the cornerstones of contemporary implantology, validating osseointegrated implant success and influencing developments in prosthetic rehabilitation.[15]

2. Adell et al. (1981) performed a 10-year prospective study of osseointegrated implants in edentulous patients. Their research involved continuous clinical monitoring, radiographic assessment, and patient satisfaction questionnaire to document the survival of the implants, marginal bone loss, and prosthetic stability. The findings provided standardized implant placement and loading protocols with long-term survival of over 90%.[16]

3. Branemark et al. (1985) elaborated on the concept of osseointegration, emphasizing its clinical applications in dentistry. This article discussed the osseointegration biological processes and application in prosthetic rehabilitation. Many clinical and experimental investigations evaluated titanium implant bone integration, including the factors of implant stability, healing, and long-term success. High survival rates with few complications at patient follow-up testified to titanium implant predictability and stability and to application of standardized surgical technique, e.g., two-stage placement procedure, to provide osseointegration.[17]

4. Albrektsson et al. (1986) assessed long-term implant success of dental implants and suggested standard criteria for implant success evaluation. The authors established five criteria for requirements of implant success: immobility of the implant, lack of peri-implant radiolucency, controlled marginal bone loss (≤1.5 mm at the first year and ≤0.2 mm/year), lack of pain or infection and a success rate of ≥85% at five years.These requirements provided a scientific approach to the assessment of implant longevity and function in clinical practice.[10]

5. Misch (1990) had addressed how bone density affects the success of the implant, highlighting its significance on treatment planning, surgical procedure, and loading regimen. Bone was grouped in the study into four density categories (D1–D4) with regard to implant stability, healing rates, and biomechanical performance. Results showed that more dense bone (D1, D2) offered more primary stability and more rapid osseointegration, with early loading potential. Conversely, more fragile bone types (D3, D4), common in the posterior maxilla, were correlated with higher rates of implant failure and necessitated altered surgical techniques. Techniques like wider implants, longer healing times and gradual loading were suggested to guarantee maximum success in low-density bone. In this work, a rational implant planning strategy was proposed, where clinicians could choose methods according to bone quality. The adjustment of bone density variation greatly enhanced the predictability of implant therapy and allowed maximum patient-specific treatment protocols.[18]

6. Jaffin et al. (1991) explained Branemark implant failure rates when there was type IV bone, the poorest quality bone that can be found in the posterior maxilla. Five-year follow-up compared implant survival among patients with different densities of bone. Results indicated that implants with type IV bone experienced considerably greater failure rates than denser types of bone, owing mostly to unfavorable primary stability and osseointegration retardation. The research emphasized the requirement for altered surgical procedures, such as longer healing times, tapered or wider implants and step-wise loading protocols to enhance success in compromised bone. These results have guided implant treatment planning by highlighting the significance of a preplacement bone density measurement. The research has offered important information on how to attain ideal implant result in difficult cases, leading experts to even better means of patient management with unsatisfactory bone quality.[19]

7. Esposito et al. (1998) examined biological causes of implant failure with a focus on establishing the criteria for success and risk factors. Overview of the study compared implant success and enumerated complications including infection, peri-implantitis and mobility of the implant. Peri-implantitis, failure of osseointegration, smoking and systemic illnesses (diabetes, osteoporosis, etc.) were identified by the study as major causes of implant failure. Inadequate primary stability, poor surgical ability and overloading occlusion were other causes of early failures. Results emphasized the importance of precise patient selection, correct surgical procedure and stringent postoperative management in order to enhance implant survival. Suggestions were made for better hygiene practices, frequent follow-up and alteration of surgical procedures to reduce risk factors. By emphasizing the multifactorial etiology of implant failures, the research made a significant contribution to the development of more advanced treatment and to reaffirming the significance of preventive treatments in implant dentistry.[20]

8. Cochran et al. (2004) developed consensus statements on loading protocols for endosseous dental implants, establishing standardized clinical guidelines. Expert panel discussion contrasted clinical and experimental evidence to establish optimal loading regimens and distinguish between immediate, early and conventional loading.

Results showed that immediate loading was feasible only if adequate primary stability is obtained, whereas early and conventional loading protocols were varied regarding bone quality and healing potential. The research suggested that clinicians evaluate implant stability with resonance frequency analysis (RFA) or torque testing prior to choosing loading options. These recommendations enhanced predictability in implant treatment, lowering the risks of failure due to premature loading. By offering an evidence-based protocol, the research optimized clinical decision-making and enabled more tailored treatment plans that optimize osseointegration and long-term survival of implants in different patient situations.[21]

9. Buser D et al. (2004) reviewed key aspects of implant therapy, focusing on biological and clinical factors influencing treatment success. A comprehensive literature review contrasted implant surface treatments, bone healing processes and loading protocols, and identified advances enhancing osseointegration and implant stability. The study centered primarily on the influence of implant shape, surface design and surgical technique on long-term success. Patient-specific treatment planning came out as a factor that significantly contributed to compromised bone condition cases according to the findings. The review reaffirmed evidence-based practice in implant therapy, giving practitioners new guidelines for achieving maximum results. By synthesizing research findings into clinical practice, the study contributed to optimizing implant procedures, enhancing patient care and implant durability. This activity formed the basis of current implantology as a reference text, directing optimal practices in surgical placement, prosthetic rehabilitation, and long-term maintenance.[22]

10. Esposito et al. (2007) conducted a Cochrane systematic review evaluating immediate, early and conventional loading of dental implants to determine their impact on long-term success. The research compared randomized controlled trials of implant survival rates with various loading protocols. Findings showed that all three loading protocols had high survival, and immediate and early loading needed optimal primary stability and precise occlusal management to succeed. Delayed loading remained the most predictable approach, especially in cases with compromised bone quality or limited primary stability. The research concluded that other loading protocols may indeed succeed but patient selection, surgical care and follow-up after implant placement were vital in an attempt at long-term implant stability. Through its evidence-based input to implant loading protocols, the study facilitated the fine-tuning of clinical guidelines such that clinicians enjoyed more freedom in planning treatment with outcomes that were reliable.[23]

11. Hammerle et al. (2008) carried out a prospective clinical trial that evaluated early loading in the anterior maxilla. The research solved the dilemma of reduced treatment time without compromising on esthetics and function. Patients who received their implants under an early loading protocol, typically at 4–6 weeks following implant placement, were monitored for one year. Clinical parameters such as implant survival rates, soft tissue outcomes and marginal bone levels were compared with those of conventional loading protocols. The results indicated that immediate loading had the same survival and peri-implant soft tissue success as long as primary stability was achieved at the time of implant placement. The study concluded that early loading in the esthetic zone may be a predictable option if accurate surgical procedures and correct case selection were ensured. This study favored the emerging trend towards reducing treatment time without compromising clinical results, improving patient satisfaction and efficiency of treatment.[24]

12. Sanz et al. (2009) carried out a randomized controlled trial to compare early loading versus conventional loading for single-tooth implants in the esthetic zone. The study evaluated whether a decrease in waiting time before loading the implant would preserve satisfactory esthetic and functional results. Patients were randomized into an early loading group, where implants were loaded approximately six weeks following placement, or a conventional loading group with delayed loading. Standard placement protocols for the implants and follow-up assessments were used for uniformity. Results showed that both groups had identical marginal bone stability and implant survival at the one-year follow-up. The conclusion of the study was that early loading is an acceptable option for the esthetic zone but depends on optimal primary stability.[25]

13. Vignoletti et al. (2010) examined the clinical results of early loading in the posterior mandible. The research included patients with 12-month follow-up and evaluated implant survival, marginal bone loss, and prosthetic complications. The study confirmed that early loaded mandibular posterior implants had excellent survival and reduced peri-implant bone remodeling, and this confirmed that early loading was not limited to the esthetic anterior region. Effective patient selection and adequate surgical procedures were stressed as key determinants of success. The study found that early loading in the posterior mandible could be performed safely if rigorous clinical criteria were utilized. These results helped broaden the indications of early loading outside of esthetic zones, confirming its application to functionally stressful posterior locations.[26]

14. Lang et al. (2011) conducted a five-year prospective study to assess the long-term stability of early loading protocols in the mandibular region. The study aimed to provide robust evidence regarding the predictability of early loading over an extended period. Early loading patients were loaded at about six weeks after implantation and their radiographic and clinical outcomes were measured at five years. Outcomes showed that early loading implants had survival and success percentages equal to those documented using conventional delayed loading. Furthermore, marginal bone levels also remained unaltered over time, also giving testament to early mandibular loading success long term. Early loading was confirmed by the study to be a reliable treatment option if primary implant stability is guaranteed. The results also validated the effectiveness of early loading in decreasing the treatment time without compromising satisfactory long-term clinical results.[27]

15. Schropp and Isidor (2012) conducted a systematic review to examine the biological rationale and clinical outcomes of early implant loading. The research explored the healing processes and biomechanical implications of early loading schedules, reviewing various clinical trials in which early loading and conventional loading schedules were compared. A key focus was the histological and radiographic evidence supporting early osseointegration. The findings suggested that early loading would be able to produce favorable osseointegration results, provided that enough initial stability had been achieved during implant placement. The research highlighted the role of accurate surgical techniques and patient parameters in influencing the success of early loading. The conclusion restated that early loading is a good treatment technique if biological and mechanical requirements are fulfilled. This review was strong evidence in favor of early loading as a reliable alternative and which increased the popularity of this protocol in the field of implant dentistry.[28]

16. Degidi et al. (2009) explored the effect of underpreparing implant osteotomies on primary stability in low-density bone, a crucial factor for successful osseointegration. Poor bone quality, especially type IV bone, is difficult to provide adequate implant stability, and further increases the likelihood of early failure. Comparisons of implant placement in type IV simulated bone and various amounts of osteotomy underpreparation were made in vitro to determine implant placement. Outcomes showed that a reduced osteotomy considerably enhanced primary stability through improved mechanical retention, offsetting the compromised bone density. The research stressed the need to alter surgical methods according to bone quality to improve implant success. By proving that underpreparation improves the stability of the implant in compromised bone, the current research presented sensible clinical findings, directing implantologists toward better treatment strategies for patients with low bone density and better long-term implant outcomes.[29]

17. Romanos et al. (2016) compared immediate and delayed loading in the posterior mandible in a split-mouth study with a follow-up period of up to 15 years. The posterior mandible is biomechanically difficult for immediate loading because of excessive occlusal forces. Long-term implant survival, marginal bone loss, and prosthetic failure were evaluated. The study findings indicated that the loading protocols were equally effective and marginally different if sufficient primary stability was not achieved at the time of implantation. The study concluded that immediate loading could be a viable option in load-bearing posterior sites if occlusal control could be well preserved. The findings justify the use of immediate loading as a constructive treatment modality that shortens total treatment time without affecting long-term success of the implants. By placing the significance of stability and occlusal factors at the forefront, this research helped in furthering loading protocols for implant dentistry.[30]

18. Esposito et al. (2016) conducted a systematic review and meta-analysis of immediate, early (6 weeks) and delayed (3 months) loading of single implants. Clinical and biological factors influencing implant loading decisions were examined to determine the most effective approach. Randomized controlled trials were compared to facilitate comparison between implant survival, marginal bone loss and prosthetic success rate following different loading protocols. The study reported that survival rates with-loaded implants, taking the condition of patients into account, revealed no significant differences. The study emphasized that the loading times be adjusted in relation to patient conditions to yield the best results. Bilateral immediate loading was revealed to be an effective option when primary stability was excellent, justifying the value of precise surgery and patient choice. Bilateral immediate loading was revealed to be an effective option when primary stability was excellent, justifying the value of precise surgery and patient choice.[31]

19. Cheng et al. (2020) systematically critically reviewed the efficacy of single-tooth implant immediate loading in the esthetic region where the patient's need for a shorter treatment time and esthetics outweighs. Clinical trials were analyzed on implant survival, esthetic success and biological complications to assess if immediate loading was feasible. Success was seen as identical between immediate loading and traditional methods when primary stability was achieved. Soft tissue adaptation was vital to long-term esthetic success, thereby justifying the importance of precise prosthetic planning. Immediate loading was a reliable treatment modality in the esthetic area when case choice, management of occlusion and dealing with soft tissues are taken into account. This study validated the increasing popularity of immediate loading as a good modality for minimizing treatment time with excellent functional and esthetic outcomes.[32]

20. Rojas-Rojas PD et al. (2024) discussed the success and survival rates of post-extraction implants that are immediately loaded, with an emphasis on improving patient experience as well as minimizing the length of treatment. Clinical trials of implant stability, bone remodelling and soft tissue integration were sought to determine the long-term survival of immediate loading. Results showed that successful immediate loading could be achieved with maintenance of primary stability and careful control of occlusal forces. The research laid emphasis on selection of the patient, surgical accuracy and appropriate loading protocols in the process of achieving successful outcomes. Immediate loading proved to be a highly predictable form of treatment, especially in situations where high primary stability could be attained at insertion. By illustrating the success criteria, this study helped to build further evidence in favor of immediate loading as a useful method in contemporary implant dentistry.[33]

21. Qian X et al. (2024) conducted a systematic review and meta-analysis of various implant placement and loading protocols for single anterior maxillary implants. Clinical trials with regard to outcomes of immediate, early and late loading were reviewed to ascertain the best method. Results indicated that where proper primary stability and prosthetic planning were guaranteed, immediate loading achieved similar success rates to conventional loading. The research emphasized that the immediate loading offers esthetic and functional benefits but requires careful case selection and occlusal treatment to minimize complications. By providing a comprehensive comparison of loading protocols, the study allowed clinical guidelines for implant placement in the anterior maxilla to be further developed and patient outcomes to be enhanced in esthetically demanding situations.[34]

22. Rohner D et al. (2024) conducted a 10-year follow-up evaluation of full-arch maxillary rehabilitation through immediate loading of implants. Effective and reliable edentulous maxilla rehabilitation was studied to estimate the long-term dependability of this method. Patients treated with full-arch, immediately loaded prostheses were followed for ten years for implant survival, bone stability, and prosthetic complications. Results were confirmed with high survival rates and low bone resorption, validating the long-term success of immediate loading. The study highlighted that good surgical skills, occlusal control and prosthetic considerations are crucial for successful outcomes. Immediate full-arch loading was a reliable and successful treatment option for edentulous patients, which provided functional and esthetic advantages, and minimized the total treatment time. This study provided good clinical evidence in favor of the use of immediate loading as an excellent approach to full-arch maxillary rehabilitation.[35]

23. Vouros et al. (2025) conducted a systematic review and meta-analysis comparing immediate, early and delayed implant loading protocols, focusing on long-term outcomes and clinical decision-making. Comparison of survival, marginal bone loss and prosthesis success randomized clinical trials was done to evaluate the validity of various loading modality. The survival between the three protocols was not significantly different, meaning that immediate and early loading could be effective alternative treatment options to delayed loading in right clinical conditions. The research insisted that patient-specific factors, occlusal factors and implant stability must be variables for loading considerations and not a fixed time period.

By reinforcing the variability of loading protocols dependent on the particular needs of individual patients, the research encouraged evidence-based clinical practice, enabling clinicians to have more predictable and successful treatment planning with high success rate implants.[36]

MATERIALS AND METHODOLOGY:

Table 1: Materials used in the study.

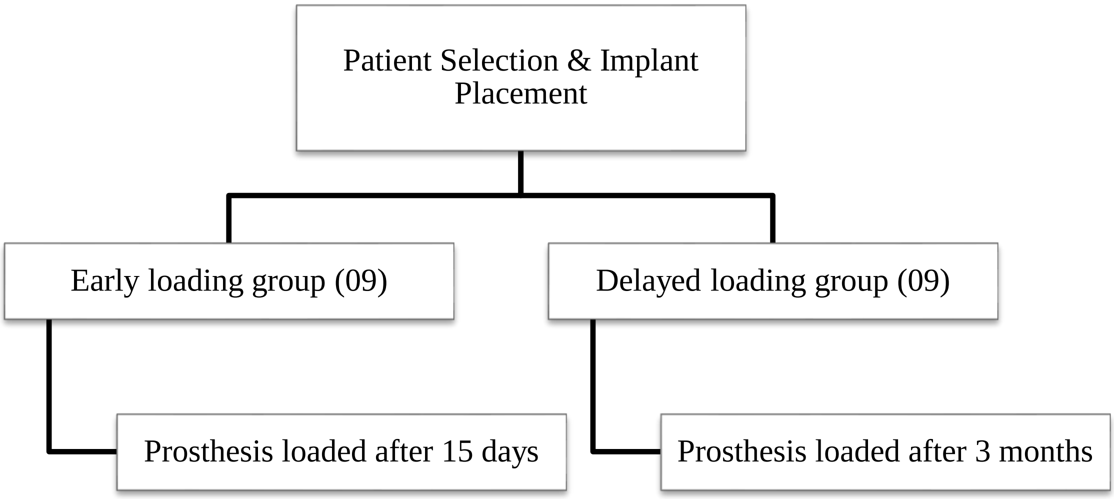
Sr no.	Material	Manufacturer
1	Endosseous root-form SLA dental implant	Pivot Implants, Punjab, India
2	Implant surgical kit with all accessories	Pivot Implants, Punjab, India
3	Local Anaesthesia	Lidayn®, New Delhi, India
4	Dentulous Perforated Plastic Impression trays	Cotisen
5	Light Body PVS Impression Material	3M ESPETM, Seefeld, Germany
6	Putty PVS Impression Material	3M ESPETM, Seefeld, Germany
7	Tray Adhesive	3M ESPE, USA
8	Pick up impression Coping	Pivot Implants, Punjab, India
9	Implant Analog	Pivot Implants, Punjab, India
10	Co-Cr Metal Alloy Pellets	Girobond NBS, Amann Girrbach, Germany
11	Veneering Ceramics	VITA VMK 95
12	Polymethylmethacrylate	GC Temperon, India
13	Auto Polymerizing Acrylic Resin	DPI India
14	Inlay Wax	Bego, Germany
15	Die Stone	Pearstone Die Stone Class IV
16	Die Lubricant	Picosilk-Renfert, Germany
17	Die Spacer	Die Master, Renfert
18	Phosphate Bonded Investment Material	Bego, Germany
19	Sprue Wax	Renfert Germany

Table 2: Armamentarium used in the study.

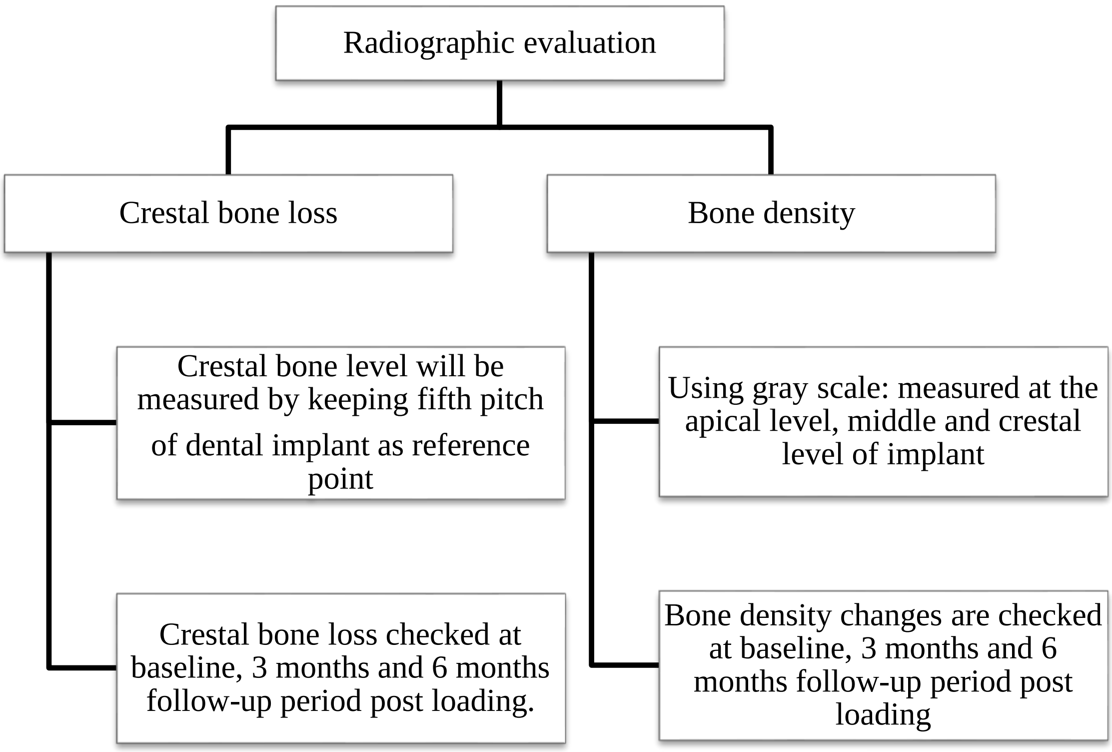
Sr No.	Armamentarium	Manufacturer
1	Mouth Mirror, Probe, Explorer, Tweezer, Kidney tray	G.D.C, India
2	CBCT machine	Dentsply Sirona, USA
3	PKT Instrument set	Visa Stainless Steel, Germany
4	Metal Casting Ring	Keystone Industries, Germany
5	Induction Casting Machine	Fornax, Bego
6	Automatic Mixer	Easy Mix-26090
7	Sandblasting Unit	Bego Duostar Z2-26115

METHODOLOGY:

Study methodology:



MBL and bone density analysis:



DETAILS OF THE PROCEDURES TO BE CONDUCTED DURING THE RESEARCH:

1. Surgical Procedure

Patient Selection and Preoperative Assessment

- Nine patients with bilateral missing posterior mandibular teeth were selected for the study following strict inclusion and exclusion criteria. (Figure 1 & 2)
- The inclusion criteria included patients between 20 and 65 years with good oral health, sufficient bone width (<3.5 mm) and height (≥10 mm) for the placement of implants and a natural dentition opposing them.
- Exclusion criteria included patients with systemic diseases, parafunctional habits, insufficient bone volume and a history of alcohol, drug dependency or smoking.
- Detailed medical and dental histories were obtained and written informed consent was signed by each participant.
- The selected edentulous sites were clinically assessed for buccolingual and mesiodistal width, soft tissue condition and occlusal relationships.
- CBCT was performed to evaluate the available bone, determine the optimal implant dimensions and assess anatomical structures such as the inferior alveolar nerve and mental foramen.

Implant Placement Protocol

- Surgical procedures were carried out under strict aseptic conditions under local anesthesia using 2% lignocaine with epinephrine 1:80,000.
- A mid-crestal incision was made at the location of choice for the implant, and a full-thickness mucoperiosteal flap was raised to expose the bone.
- Sequential osteotomy was performed using the sequence of drilling as recommended by the manufacturer (Pivot Implant surgical kit, Punjab, India) to achieve an osteotomy of appropriate depth and width.strict aseptic conditions under local anesthesia using 2% lignocaine with epinephrine 1:80,000.
- A mid-crestal incision was made at the desired implant site, followed by a full-thickness mucoperiosteal flap elevation to expose the underlying bone.
- Sequential osteotomy was performed using the manufacturer's recommended drilling sequence (Pivot Implant surgical kit, Punjab, India) to create an osteotomy of appropriate depth and width.
- Each implant (Pivot Implants) was placed in the prepared osteotomy site (Figure 3 & 4) following standard guidelines for insertion torque (≥35 Ncm).
- Implant position and angulation were confirmed radiographically using a periapical radiograph and CBCT scan.
- Primary stability was determined using resonance frequency analysis (RFA) and was selected for early loading with implants having an implant stability quotient (ISQ) ≥ 60.
- Surgical area was cleaned with sterile saline and healing abutment inserted in early loading group and implant being covered by a cover screw in delayed loading group.

- Soft tissue closure was performed using black braided silk sutures, ensuring minimal flap tension.
- Post-operative care instructions were provided, including medication (antibiotics and analgesics) and dietary restrictions.
- After 7 days, suture removal was done, ensuring uneventful healing of overlying soft tissues.

2. Prosthetic Procedure

Group 1 (Early Loading Protocol)

- After 14 days, a temporary prosthesis was fabricated using polymethylmethacrylate (PMMA) to minimize occlusal forces during early healing. (Figure 5)
- The temporary prosthesis was non-functionally loaded, ensuring passive fit and occlusal clearance. (Figure 6)
- Definitive prostheses were fabricated and placed after three months, following assessment of implant stability and peri-implant tissue health. (Figure :)

Group 2 (Delayed Loading Protocol)

- Implants in the delayed loading group were submerged under the soft tissue for three months of healing.
- Second-stage surgery was scheduled and executed after osseointegration had been confirmed radiographically and clinically with CBCT scanning and RFA analysis, respectively.
- Uncovering of the implant platform was carried out using the incisional technique, followed by the placement of healing abutments to allow soft tissue maturation.

- Following soft tissue maturation, an open-tray impression was recorded with PVS impression material and a final prosthesis was fabricated.
- A conventional porcelain-fused-to-metal (PFM) screw retained crown was fabricated and loaded. (Figure 7,8)

3. Interpretation and Data Analysis

Clinical and Radiographic Evaluation

- Patients were scheduled for follow-ups at baseline (immediately after implant placement), 15 days, and 3-, 6- and 9-months post-loading.

Table 3: Follow-up table

GROUP1/GROUP 2 Duration of loading	GROUP 1 (EARLY LOADING)	GROUP 2 (DELAYED LOADING)
15 days	✓	
3months	✓	✓
6months	✓	✓
9months		✓

- Standardized CBCT images were taken at all time points to evaluate peri-implant crestal bone levels and bone density.
- **Measurement of Crestal Bone Loss:** Crestal bone levels were measured on the buccal, lingual, mesial and distal based on the fifth pitch of the implant thread as reference point of the implant platform, as noted in Figures 9 & 10.
- **Bone Density Evaluation**: Gray-scale values were measured at the crestal, middle, and apical thirds of the implant using CBCT-based image analysis software and subsequent bone density was evaluated, as shown in Figure 11.

Soft tissue was evaluated with clinical parameters such as peri-implant probing depth and bleeding on probing at each follow-up check-up.

Peri-implant probing depth was measured with a calibrated periodontal probe with light force (approximately 0.25 N) at six implant locations (mesiobuccal, midbuccal, distobuccal, mesiolingual, midlingual, and distolingual).

Bleeding on probing was established by probing the peri-implant sulcus gently and observing whether any bleeding after probing occurred within a time span of 30 seconds.

These measurements were used to evaluate peri-implant health and any potential indication of inflammation or peri-implant disease over time.

Figure 1: Early loading group

Figure 2: Delayed loading group

Figure 3: Implant and healing abutment placed in early loading group

Figure 4: Implant placed in delayed loading group

Figure 5: Temporary prosthesis

Figure 6: Early non-functional loading of temporary prosthesis

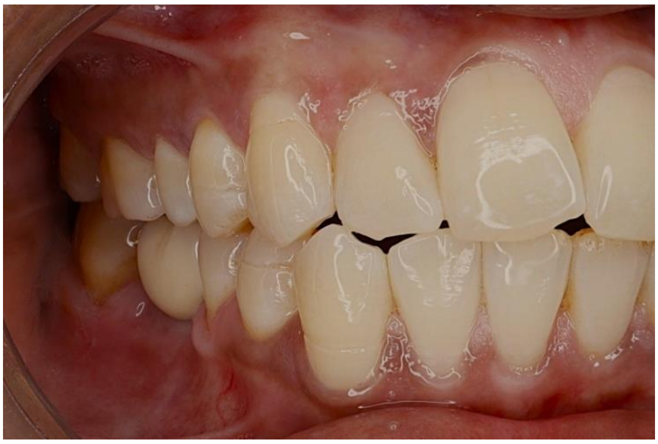


Figure 7: Definitive prosthesis placement in early loading group

Figure 8: Definitive prosthesis placement in delayed loading group

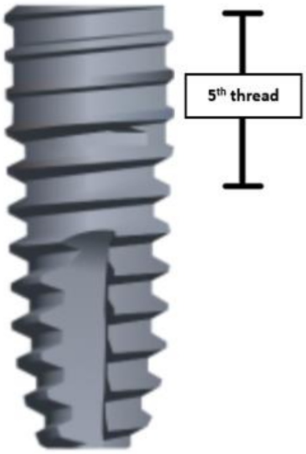


Figure 9: Standardized technique used for measuring MBL

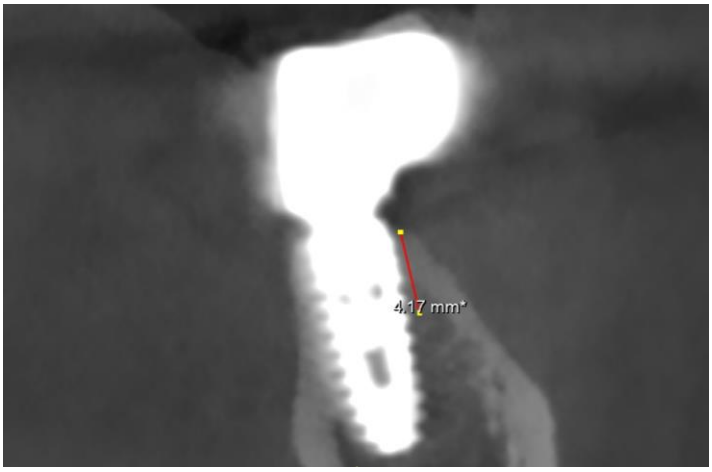


Figure 10: CBCT analysis for measuring MBL

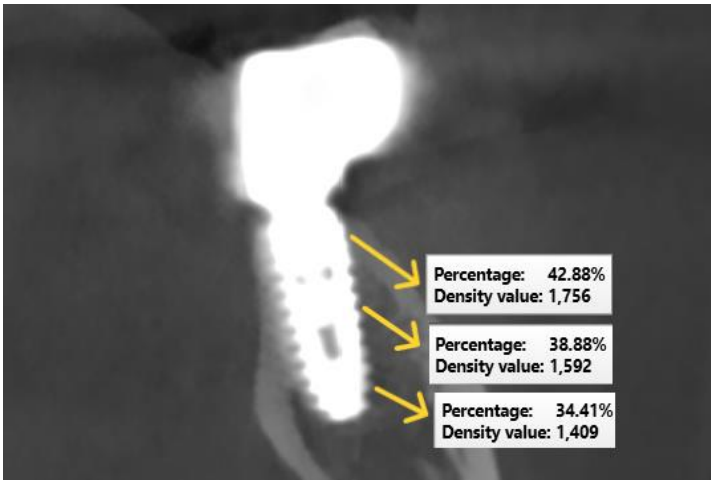


Figure 11: CBCT analysis for measuring density change

RESULTS

The collected data were systematically recorded at Baseline, 15 days, 3 months and 6 months in Microsoft Excel and subjected to statistical analysis.

The normality of the data was first assessed using the Shapiro-Wilk and Kolmogorov-Smirnov tests. Since the data conformed to normal distribution criteria, the continuous variables are presented as mean ± standard deviation (SD), while categorical variables are expressed as frequencies and percentages.

For intragroup comparisons—assessing changes over time in parameters such as marginal bone loss (MBL), Crestal bone density, Middle third bone density, and Apical third bone density—repeated measures ANOVA was performed. Where appropriate, pairwise comparisons between individual time points were further evaluated using paired t-tests.

For intergroup comparisons, differences between the Early Loading and Delayed Loading groups were analyzed using the student's unpaired (independent) t-test when the data were normally distributed. In cases where normality was not met, the Mann-Whitney U test was employed.

Additionally, sectional analyses for the mesial, distal, buccal, and lingual regions were conducted using one-way ANOVA, with Tukey's multiple posthoc tests applied to identify statistically significant differences among the sections.

All statistical tests were carried out at a significance level of 5% ($p \leq 0.05$).

1. MARGINAL BONE LOSS:

Table 4: Comparison of early group & delayed group with MBL scores at different treatment time points as whole, Mesial, Distal, Buccal, Lingual section by independent t-test

Section	Time-points	Early group		Delayed group		Effect size	t- value	p-value
		Mean.	S.D.	Mean.	S.D.			
Total (Average of Mesial, Distal, Buccal and Lingual Section)	Baseline	5.10	0.43	5.30	0.47	-0.44	-1.9516	0.0546
	15 days	5.03	0.42	5.14	0.44	-0.27	-1.1962	0.2353
	3months	4.92	0.41	4.98	0.43	-0.13	-0.5853	0.5601
	6 months	4.84	0.40	4.92	0.43	-0.18	-0.8193	0.4151
	9 months	4.80	0.40	4.82	0.45	-0.05	-0.2350	0.8148
Mesial	Baseline	5.42	0.30	5.49	0.35	-0.20	-0.4532	0.6558
	15 days	5.35	0.32	5.38	0.29	-0.10	-0.2289	0.8215
	3months	5.28	0.36	5.21	0.32	0.20	0.4521	0.6566
	6 months	5.18	0.31	5.11	0.25	0.25	0.5563	0.5849
	9 months	5.12	0.32	4.96	0.30	0.51	1.1507	0.2649
Distal	Baseline	5.28	0.30	5.45	0.56	-0.39	-0.8324	0.4161
	15 days	5.16	0.32	5.22	0.50	-0.14	-0.3042	0.7644
	3months	5.01	0.28	5.03	0.48	-0.05	-0.1128	0.9114
	6 months	4.98	0.32	5.03	0.44	-0.13	-0.2932	0.7727
	9 months	4.93	0.31	4.99	0.39	-0.17	-0.3795	0.7088
Buccal	Baseline	4.71	0.40	5.02	0.51	-0.67	-1.4930	0.1527
	15 days	4.65	0.38	4.86	0.45	-0.51	-1.1276	0.2743
	3months	4.58	0.36	4.71	0.38	-0.36	-0.7953	0.4368
	6 months	4.50	0.38	4.67	0.36	-0.46	-1.0239	0.3194
	9 months	4.46	0.44	4.63	0.44	-0.39	-0.8614	0.4003
Lingual	Baseline	5.00	0.37	5.25	0.33	-0.71	-1.5861	0.1301
	15 days	4.94	0.31	5.10	0.40	-0.45	-1.0000	0.3306
	3months	4.82	0.29	4.96	0.43	-0.38	-0.8439	0.4098
	6 months	4.71	0.21	4.86	0.53	-0.41	-0.8458	0.4088
	9 months	4.67	0.18	4.69	0.57	-0.05	-0.1049	0.9176

The above table shows the comparison of early group and delayed group with MBL scores at different treatment time points as a whole, i.e. mesial, distal, buccal and lingual section by independent t test.

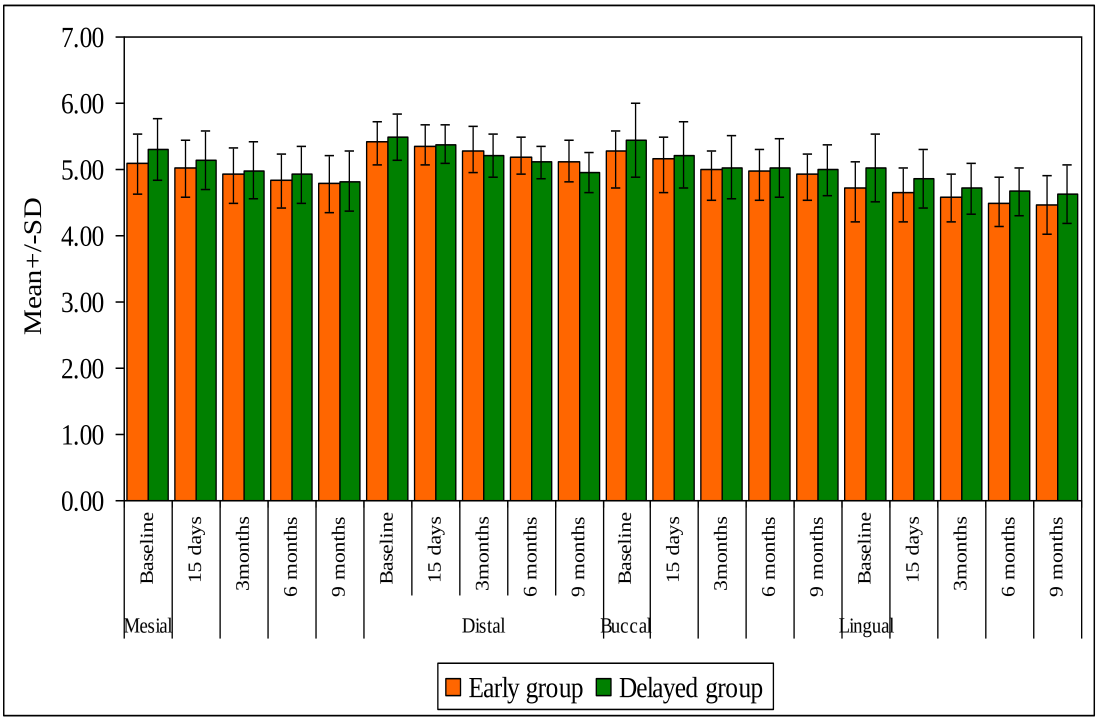
MBL decreased over time in both groups without significant differences (**p-value > 0.05**).

In **early loading group**, MBL reduced from **5.10 ± 0.43 mm** at baseline to **4.80 ± 0.40 mm** at 9 months. Mesial and distal sections showed declines from **5.42 ± 0.30 mm** to **5.12 ± 0.32 mm** and **5.28 ± 0.30 mm** to **4.93 ± 0.31 mm**, respectively. Buccal and lingual sections decreased from **4.71 ± 0.40 mm** to **4.46 ± 0.44 mm** and **5.00 ± 0.37 mm** to **4.67 ± 0.18 mm**.

In the **delayed loading group**, MBL declined from **5.30 ± 0.47 mm** to **4.82 ± 0.45 mm**. Mesial and distal sections reduced from **5.49 ± 0.35 mm** to **4.96 ± 0.30 mm** and **5.45 ± 0.56 mm** to **4.99 ± 0.39 mm**. Buccal and lingual sections dropped from **5.02 ± 0.51 mm** to **4.63 ± 0.44 mm** and **5.25 ± 0.33 mm** to **4.69 ± 0.57 mm**.

Although the delayed group had slightly higher MBL initially, both groups showed similar reductions, with negligible differences at 9 months.

Graph 1: Comparing the early group with delayed group along with MBL scores at different treatment time points in Mesial, Distal, Buccal, Lingual sections



Graphical representation comparing the early group with delayed group along with MBL scores at various treatment time points in Mesial, Distal, Buccal, Lingual sections.

In the **early loading group**, Crestal bone density increased across all sections over time. In the **mesial section**, it rose from **32.80 at baseline to 37.60 at 9 months**. In the **distal section**, it improved from **33.80 to 38.70**, in the **buccal section** from **43.30 to 44.70**, and in the **lingual section** from **43.80 to 51.60**.

In the **delayed loading group**, a similar trend was observed. Crestal bone density in the **mesial section** increased from **33.10 at baseline to 39.10 at 9 months**.

In the **distal section**, it changed from **37.10 to 37.70**, in the **buccal section** from **41.30 to 42.30**, and in the **lingual section** from **44.90 to 50.10**.

The differences between the 2 groups were **statistically insignificant (p-value> 0.05)** at all time points.

Table 5: Comparison of different treatment time points with MBL scores in 2 groups by paired t- test

Groups	Time-points	Mean.	S.D.	Mean Diff. from BL	t-value	p-value
Total	Baseline	5.20	0.46	-	-	-
	15 days	5.08	0.43	0.12	6.8052	0.0001*
	3months	4.95	0.42	0.25	8.9791	0.0001*
	6 months	4.88	0.41	0.32	9.7072	0.0001*
	9 months	4.81	0.43	0.40	11.1254	0.0001*
Early	Baseline	5.10	0.43	-	-	-
	15 days	5.03	0.42	0.08	6.0457	0.0001*
	3months	4.92	0.41	0.18	6.9509	0.0001*
	6 months	4.84	0.40	0.26	7.2339	0.0001*
	9 months	4.80	0.40	0.31	8.0444	0.0001*
Delayed	Baseline	5.30	0.47	-	-	-
	15 days	5.14	0.44	0.16	5.0979	0.0001*
	3months	4.98	0.43	0.32	6.8042	0.0001*
	6 months	4.92	0.43	0.38	7.0306	0.0001*
	9 months	4.82	0.45	0.48	8.4528	0.0001*

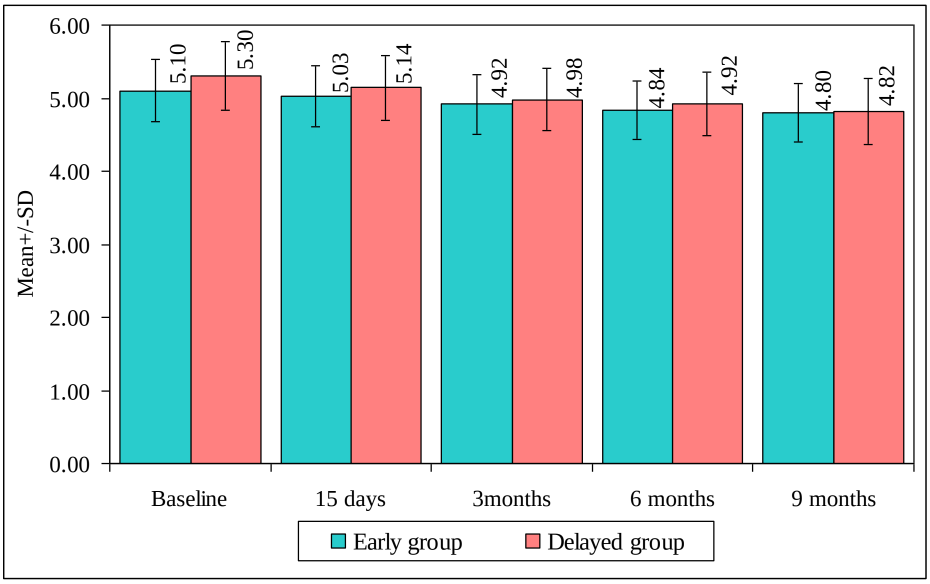
*p<0.05

The above table shows the comparison of different treatment time points with MBL scores in two groups by paired t test. Within each group revealed a reduction in MBL over time which was statistically noteworthy (**p- value < 0.05**).

In the **early loading group**, MBL decreased from **5.10 mm** at baseline to **5.03 mm** at 15 days, **4.92 mm** at 3 months, **4.84 mm** at 6 months, and **4.80 mm** at 9 months, with a consistent downward trend.

Similarly, in the **delayed loading group**, MBL reduced from **5.30 mm** at baseline to **5.14 mm** at 15 days, **4.98 mm** at 3 months, **4.92 mm** at 6 months, and **4.82 mm** at 9 months, indicating a uniform decrease over time.

Graph 2: Comparison of the early group and delayed group with MBL scores at varying time points of treatment as whole



Graphical representation of the comparison of early group and delayed group with MBL scores at different time points of treatment as whole.

The marginal bone loss (MBL) in the early loading group showed a consistent decrease over time. At baseline, the MBL was **5.10 mm**, which reduced to **5.03 mm** at 15 days, **4.92 mm** at 3 months, **4.84 mm** at 6 months, and **4.80 mm** at 9 months. The reduction in MBL over time indicates a stable bone adaptation process in the early loading protocol.

Similarly, delayed loading group also exhibited gradual decline in MBL. The baseline MBL was **5.30 mm**, which decreased to **5.14 mm** at 15 days, **4.98 mm** at 3 months, **4.92 mm** at 6 months, and **4.82 mm** at 9 months. The Delayed loading group followed a comparable trend to the early loading group, with slightly higher MBL values initially, which progressively stabilized over time.

The independent t-test analysis revealed statistically insignificant differences (**p- value** > **0.05**) between the 2 groups at any given time point. Although the early loading group consistently exhibited slightly lower MBL values than the delayed loading group, the differences remained clinically insignificant.

Table 6: Comparison of different sections in two groups with MBL scores at different treatment time points by one way ANOVA

Group	Time points	Mesial		Distal		Buccal		Lingual		F-value	P -value
		Mean.	S.D.	Mean.	S.D.	Mean	S.D.	Mean	S.D.		
Total	Baseline	5.45	0.32	5.36	0.44	4.87	0.47	5.12	0.36	8.4854	0.0001*
	15 days	5.36	0.30	5.19	0.41	4.76	0.42	5.02	0.36	9.5308	0.0001*
	3months	5.24	0.33	5.02	0.39	4.65	0.36	4.89	0.36	9.5981	0.0001*
	6 months	5.15	0.28	5.01	0.37	4.59	0.37	4.79	0.40	9.4651	0.0001*
	9 months	5.04	0.31	4.96	0.35	4.55	0.44	4.68	0.41	7.4445	0.0002*
Early	Baseline	5.42	0.30	5.28	0.30	4.71	0.40	5.00	0.37	8.3393	0.0002*
	15 days	5.35	0.32	5.16	0.32	4.65	0.38	4.94	0.31	8.0805	0.0003*
	3months	5.28	0.36	5.01	0.28	4.58	0.36	4.82	0.29	8.3161	0.0002*
	6 months	5.18	0.31	4.98	0.32	4.50	0.38	4.71	0.21	9.2808	0.0001*
	9 months	5.12	0.32	4.93	0.31	4.46	0.44	4.67	0.18	7.9027	0.0004*
Delayed	Baseline	5.49	0.35	5.45	0.56	5.02	0.51	5.25	0.33	2.2791	0.0960
	15 days	5.38	0.29	5.22	0.50	4.86	0.45	5.10	0.40	2.7110	0.0593
	3months	5.21	0.32	5.03	0.48	4.71	0.38	4.96	0.43	2.5967	0.0674
	6 months	5.11	0.25	5.03	0.44	4.67	0.36	4.86	0.53	2.2928	0.0945
	9 months	4.96	0.30	4.99	0.39	4.63	0.44	4.69	0.57	1.7539	0.1735

*p<0.05

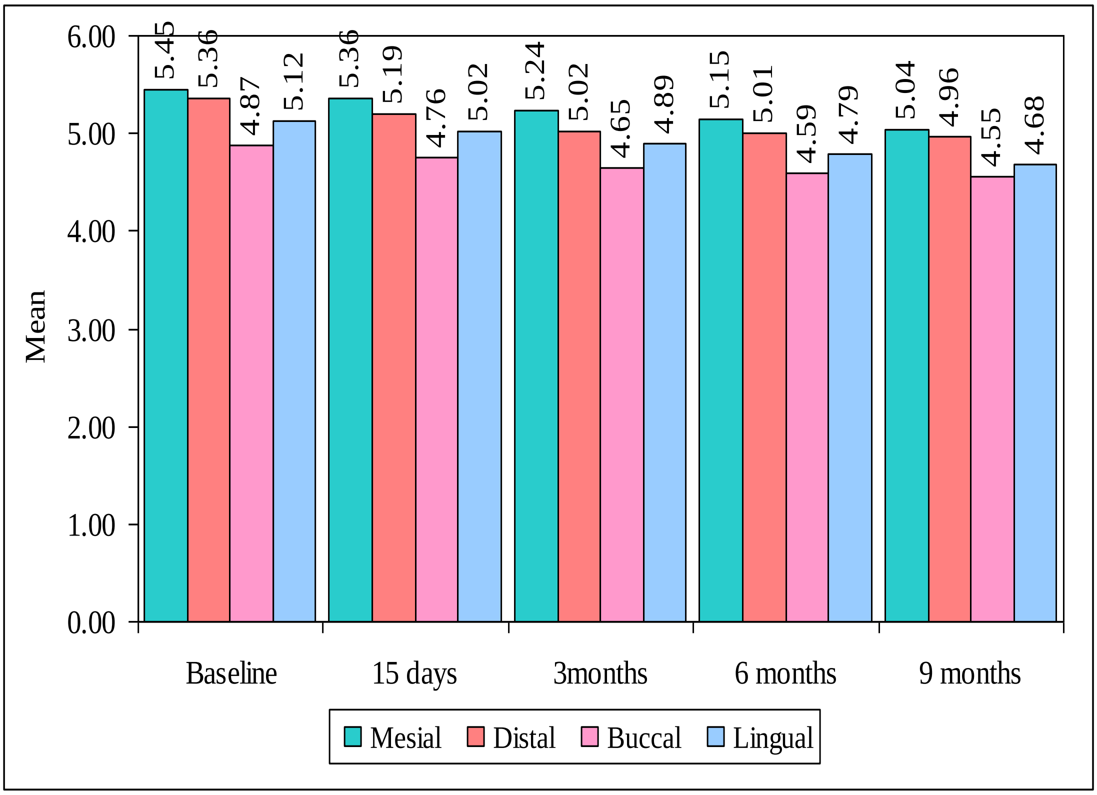
The above table shows the comparison of different sections in two groups with MBL scores at different treatment time points by one way ANOVA.

In the **early loading group**, MBL scores showed a significant reduction over time across sections. At **baseline**, the mesial section had the highest MBL, followed by the distal, lingual, and buccal sections. By **9 months**, all sections showed a decline in MBL, with the greatest reduction observed in the mesial section. However, **statistically insignificant differences** were found between sections at any given time point (*p-value* > 0.05).

In the **delayed loading group**, a similar trend was observed, with MBL scores decreasing in all sections over time. The **mesial and distal sections** showed slightly higher MBL values than the buccal and lingual sections at baseline, but differences between sections remained statistically in**significant** at all time points ($p > 0.05$).

Comparing the 2 groups, both **early and delayed loading** followed a **similar pattern of MBL reduction**, with no significant section-wise differences at any time point. While the early group showed slightly lower MBL values overall, the differences were not much statistically significant.

Graph 3: Comparison of different sections in two groups with MBL scores at different treatment time points as whole



Graphical representation of the comparison of different sections in two groups with MBL scores at different treatment time points as whole. MBL decreased over time in both groups across all sections, with statistically significant (**p- value < 0.05**) differences among mesial, distal, buccal, & lingual regions. At baseline, the mesial section had the highest MBL (**5.45 mm**), while the buccal section had the lowest (**4.87 mm**). By 9 months, MBL reduced to **5.04 mm** in the mesial section, **4.96 mm** in distal, **4.55 mm** in buccal, and **4.68 mm** in the lingual section (**p = 0.0001**). Although variations existed between sections, the differences between early and delayed loading groups did not remain statistically significant (**p > 0.05**).

Table-7: Pair wise comparison of different sections in two groups with MBL scores at different treatment time points by Tukeys multiple posthoc procedures

Group	Time points	Mesial vs Distal (p=)	Mesial v Buccal (p=)	Mesial vs Lingual (p=)	Distal vs Buccal (p=)	Distal vs Lingual (p=)	Buccal Vs Lingual (p=)
Total	Baseline	0.8970	0.0001*	0.0580	0.0010*	0.2520	0.1890
	15 days	0.4570	0.0001*	0.0240*	0.0020*	0.4830	0.1230
	3months	0.2090	0.0001*	0.0140*	0.0080*	0.6680	0.1490
	6 months	0.6050	0.0001*	0.0110*	0.0020*	0.2190	0.2970
	9 months	0.9110	0.0010*	0.0200*	0.0050*	0.1020	0.6790
Early	Baseline	0.8000	0.0001*	0.0460*	0.0040*	0.2810	0.2520
	15 days	0.5860	0.0001*	0.0440*	0.0080*	0.4640	0.2290
	3months	0.2610	0.0001*	0.0150*	0.0260*	0.5620	0.3610
	6 months	0.4820	0.0001*	0.0090*	0.0070*	0.2270	0.4400
	9 months	0.5660	0.0001*	0.0190*	0.0140*	0.2970	0.4830
Delayed	Baseline	0.9970	0.1110	0.6390	0.1640	0.7560	0.6690
	15 days	0.8270	0.0410*	0.4500	0.2360	0.9180	0.5790
	3months	0.7560	0.0440*	0.5220	0.3080	0.9800	0.5220
	6 months	0.9710	0.0920	0.5240	0.2160	0.7870	0.7260
	9 months	0.9990	0.3490	0.5230	0.2750	0.4320	0.9900

*$p<0.05$

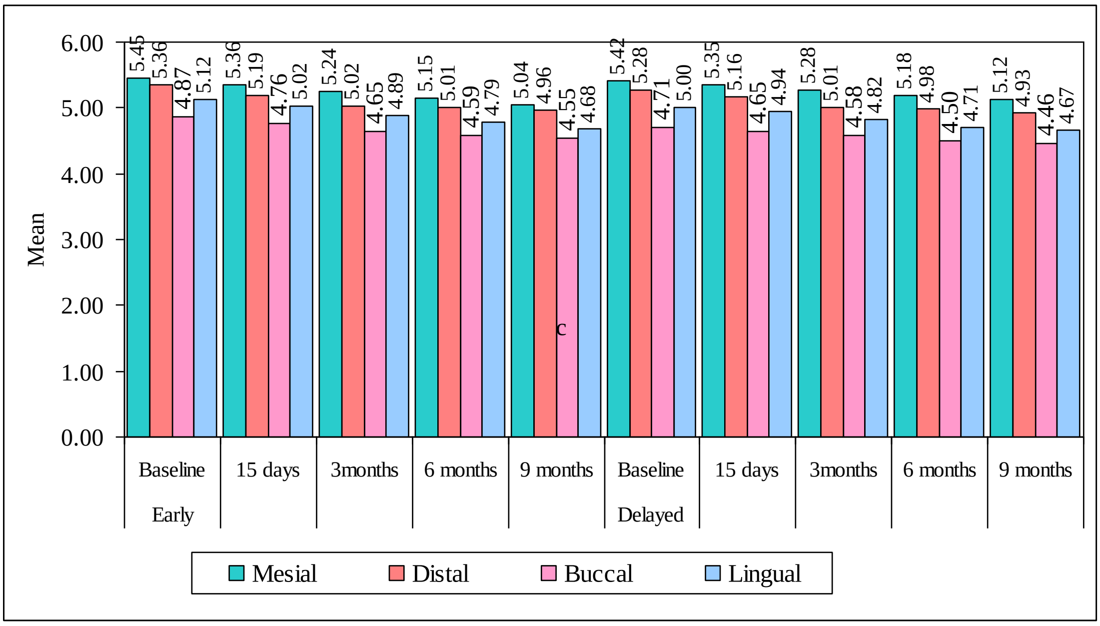
The table above compares different sections in two groups with MBL scores at different treatment time points by Tukeys multiple posthoc procedures.

In the **early loading group**, statistically insignificant pairwise differences were observed between sections at **baseline** (*p- value* > 0.05). However, at **9 months**, the **mesial section exhibited significantly higher MBL** compared to the **buccal section** (*p* < 0.05), indicating greater bone remodeling in the mesial region over time. Other section-wise comparisons did not show significant differences.

In the **delayed loading group**, **baseline MBL values** were comparable across all sections ($p > 0.05$). By **9 months**, the **mesial section showed significantly higher MBL compared to the lingual section** ($p < 0.05$), while other sections did not exhibit statistically significant differences.

Comparing **early and delayed groups**, **no significant differences** were noted between corresponding sections at **any time point** ($p > 0.05$), suggesting **similar patterns of bone remodeling** irrespective of the loading protocol.

Graph 4: Comparison of different sections in two groups with MBL scores at different treatment time points in early and delayed group



Graphical representation of the comparison of different sections in two groups with MBL scores at different treatment time points in early and delayed group.

In the **early loading group**, a gradual reduction in MBL was observed across all sections. At **baseline**, MBL values were similar across sections ($p > 0.05$). By **9 months**, the **mesial section exhibited the highest MBL**, while the **buccal and lingual sections showed relatively lower MBL values**, though the differences were **statistically insignificant** ($p > 0.05$).

In the **delayed loading group**, MBL also decreased over time. The **mesial section demonstrated significantly greater MBL** compared to the **lingual section** at **9 months** ($p < 0.05$), suggesting a difference in bone remodeling dynamics between these regions. However, **zero significant differences** were seen in MBL between the **distal & buccal sections** at any time point ($p > 0.05$).

When comparing **early and delayed loading groups**, **statistically insignificant differences** in MBL were seen between corresponding sections at any given time point (p -value> 0.05).

2. DENSITY CHANGE:

2.1. CRESTAL BONE DENSITY CHANGE:

Table 8: Comparison of early group and delayed group with Crestal bone density scores at different treatment time points as whole, Mesial, Distal, Buccal, Lingual section by independent t- test

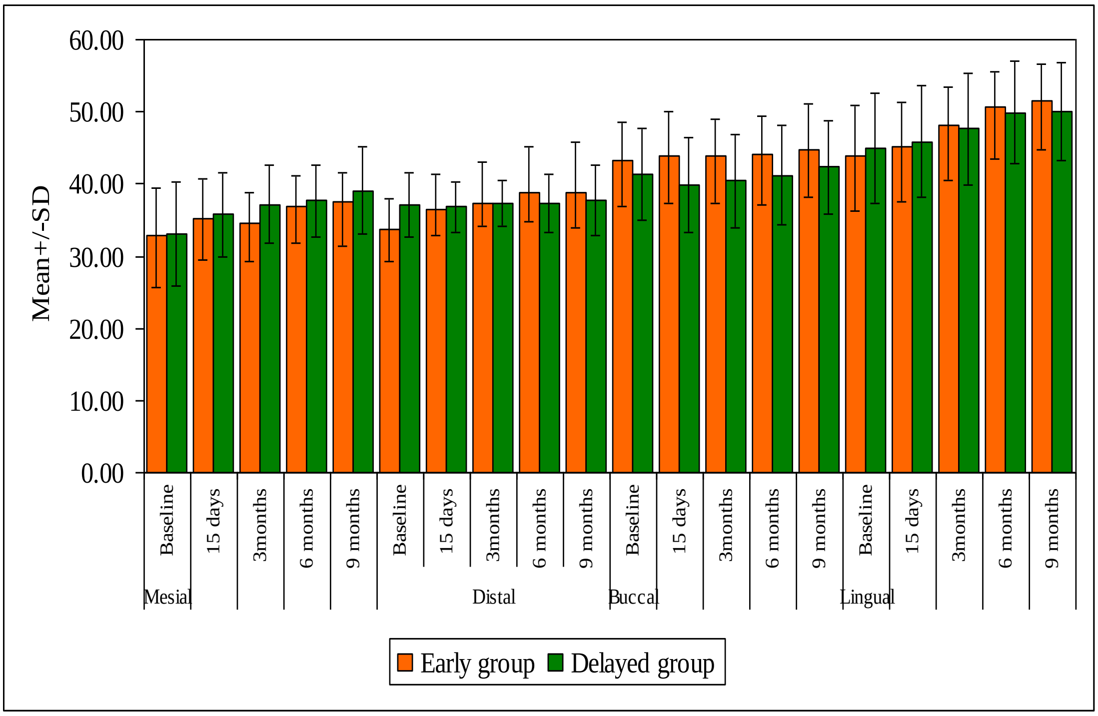
Samples	Time-points	Early group		Delayed group		Effect size	t- value	P -value
		Mean.	S.D.	Mean.	S.D.			
Total (Average of Mesial, Distal, Buccal and Lingual Section)	Baseline	38.43	7.69	39.10	7.72	-0.09	-0.3920	0.6961
	15 days	40.18	7.01	39.60	7.08	0.08	0.3648	0.7162
	3months	40.95	7.37	40.65	7.13	0.04	0.1851	0.8537
	6 months	42.58	7.44	41.53	7.66	0.14	0.6221	0.5357
	9 months	43.15	7.91	42.30	7.61	0.11	0.4898	0.6256
Mesial	Baseline	32.80	6.70	33.10	7.20	-0.04	-0.0965	0.9242
	15 days	35.30	5.42	35.80	5.85	-0.09	-0.1984	0.8450
	3months	34.50	4.38	37.20	5.31	-0.56	-1.2409	0.2306
	6 months	36.90	4.15	37.70	5.01	-0.17	-0.3888	0.7020
	9 months	37.60	4.01	39.10	6.12	-0.30	-0.6486	0.5248
Distal	Baseline	33.80	4.05	37.10	4.48	-0.77	-1.7273	0.1012
	15 days	36.40	4.86	36.80	3.58	-0.09	-0.2095	0.8364
	3months	37.30	5.77	37.40	3.20	-0.02	-0.0479	0.9623
	6 months	38.80	6.44	37.30	4.08	0.28	0.6218	0.5419
	9 months	38.70	7.13	37.70	4.85	0.17	0.3665	0.7183
Buccal	Baseline	43.30	5.21	41.30	6.40	0.34	0.7668	0.4531
	15 days	43.90	6.06	39.90	6.56	0.63	1.4164	0.1737
	3months	43.80	5.27	40.40	6.54	0.58	1.2810	0.2164
	6 months	44.00	5.50	41.20	6.83	0.45	1.0101	0.3258
	9 months	44.70	6.34	42.30	6.48	0.37	0.8369	0.4136
Lingual	Baseline	43.80	7.08	44.90	7.61	-0.15	-0.3346	0.7418
	15 days	45.10	6.23	45.90	7.65	-0.12	-0.2565	0.8005
	3months	48.20	5.14	47.60	7.78	0.09	0.2035	0.8410
	6 months	50.60	5.04	49.90	7.17	0.11	0.2526	0.8035
	9 months	51.60	5.04	50.10	6.76	0.25	0.5628	0.5805

The above table shows the comparison of the early group and delayed group with Crestal bone density scores at different treatment time points as whole, Mesial, Distal, Buccal, Lingual section by independent t test. In the **early loading group**, Crestal bone density increased over time in all sections. It rose from **38.43 at baseline to 43.15 at 9 months** overall. In the mesial section, it improved from **32.80 to 37.60**, in the distal section from **33.80 to 38.70**, in the buccal section from **43.30 to 44.70**, and in the lingual section from **43.80 to 51.60**.

In the **delayed loading group**, a similar trend was observed. Overall Crestal bone density increased from **39.10 at baseline to 42.30 at 9 months**. In the mesial section, it rose from **33.10 to 39.10**, in the distal section from **37.10 to 37.70**, in the buccal section from **41.30 to 42.30**, and in the lingual section from **44.90 to 50.10**.

The differences between the two selected groups remained **statistically insignificant (p- value > 0.05)** at all time points

Graph 5: Comparison of early group and delayed group with Crestal bone density scores at different treatment time points in Mesial, Distal, Buccal, Lingual sections



Graphical representation of the comparison of early group and delayed group with Crestal bone density scores at different treatment time points in Mesial, Distal, Buccal, Lingual sections. In the **early loading group**, Crestal bone density increased consistently across all sections. In the mesial section, it rose from **32.80 at baseline to 37.60 at 9 months**. In the distal section, it increased from **33.80 to 38.70**, in the buccal section from **43.30 to 44.70**, and in the lingual section from **43.80 to 51.60**.

In the **delayed loading group**, a similar pattern was observed. Crestal bone density improved in the mesial section from **33.10 at baseline to 39.10 at 9 months**. In the distal section, it changed from **37.10 to 37.70**, in the buccal section from **41.30 to 42.30**, and in the lingual section from **44.90 to 50.10**.

Although the early group showed slightly higher Crestal bone density values at most time points, the variations between the two groups were **statistically insignificant (p- value > 0.05)** across all sections.

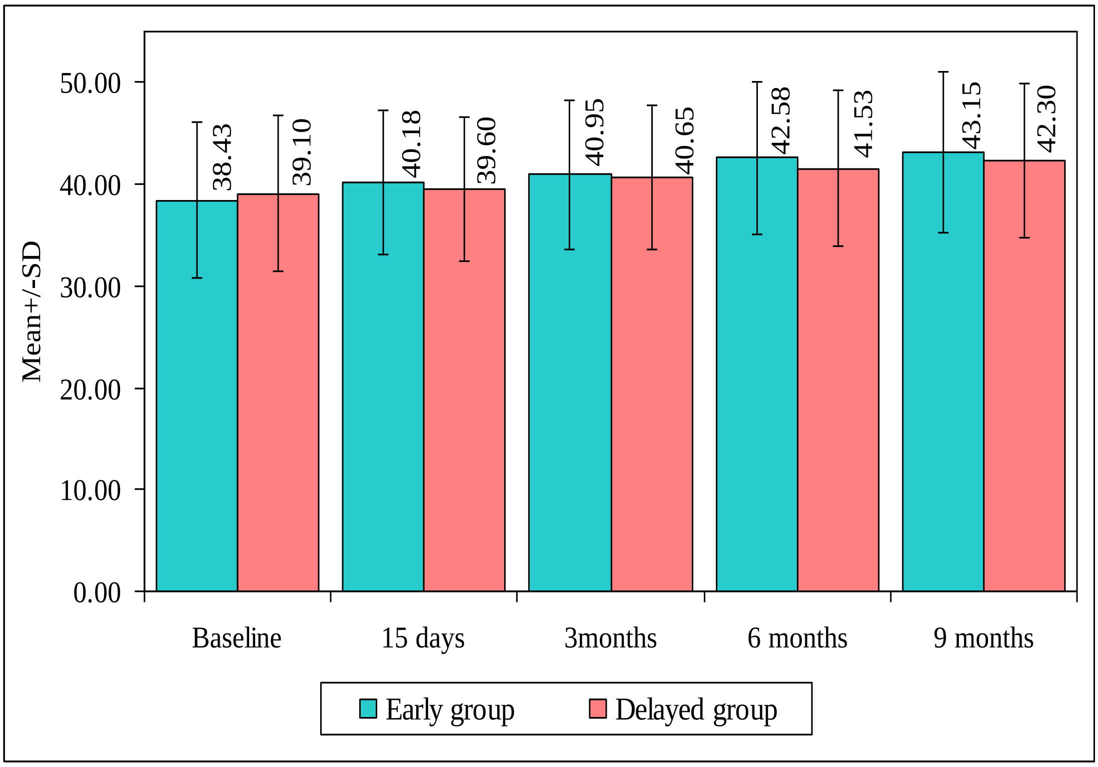
Table 9: Comparison of different treatment time points with Crestal bone density scores in 2 groups by paired t-test

Groups	Time- points	Mean	S.D.	Mean Diff. from BL	t-value	p-value
Total	Baseline	38.76	7.66	-	-	-
	15 days	39.89	7.01	-1.13	-2.8914	0.0050*
	3months	40.80	7.20	-2.04	-4.2379	0.0001*
	6 months	42.05	7.52	-3.29	-5.4162	0.0001*
	9 months	42.73	7.72	-3.96	-6.1183	0.0001*
Early	Baseline	38.43	7.69	-	-	-
	15 days	40.18	7.01	-1.75	-3.5388	0.0011*
	3months	40.95	7.37	-2.53	-4.2449	0.0001*
	6 months	42.58	7.44	-4.15	-5.1909	0.0001*
	9 months	43.15	7.91	-4.73	-5.8957	0.0001*
Delayed	Baseline	39.10	7.72	-	-	-
	15 days	39.60	7.08	-0.50	-0.8467	0.4023
	3months	40.65	7.13	-1.55	-2.0522	0.0469*
	6 months	41.53	7.66	-2.43	-2.6858	0.0106*
	9 months	42.30	7.61	-3.20	-3.1574	0.0031*

*$p<0.05$

The above table shows the comparison of different treatment time points with Crestal bone density scores in two groups by paired t-test. Crestal bone density showed a significant increase statistically (**p< 0.05**) over time in both groups. In the overall measurement, it increased from **38.76** at baseline to **42.73** at 9 months (**p = 0.0001**). In the early group, values rose from **38.43** at baseline to **43.15** at 9 months (**p = 0.0001**). In the delayed group, Crestal bone density increased from **39.10** at baseline to **42.30** at 9 months (**p = 0.0031**).

Graph 6: Comparison of early group and delayed group with Crestal bone density scores at different treatment time points as whole



Graphical representation of the comparison of early group and delayed group with Crestal bone density scores at different treatment time points as whole.

Crestal bone density scores increased progressively in both groups, with statistically insignificant differences (**p -value** > **0.05**) at any given time point.

In the **early loading group**, the mean Crestal bone density was **38.43** ± **7.69** at baseline, increasing to **40.18** ± **7.01** at 15 days, **40.95** ± **7.37** at 3 months, **42.58** ± **7.44** at 6 months, and **43.15** ± **7.91** at 9 months.

Similarly, in **delayed loading group**, baseline score was **39.10** ± **7.72**, rising to **39.60** ± **7.08** at 15 days, **40.65** ± **7.13** at 3 months, **41.53** ± **7.66** at 6 months, and **42.30** ± **7.61** at 9 months.

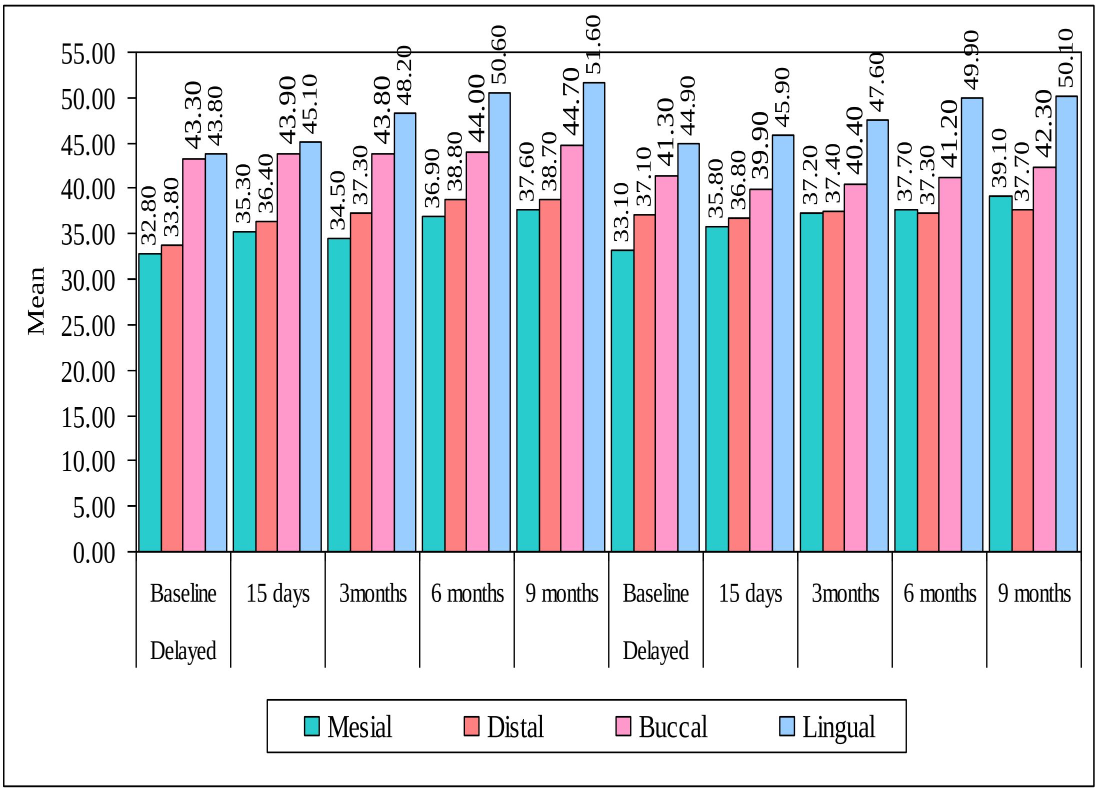
Table 10: Comparing different sections in 2 groups with Crestal bone density scores at different treatment time points by one way ANOVA

Group	Time points	Mesial		Distal		Buccal		Lingual		F-value	P -value
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.		
Total	Baseline	32.95	6.77	35.45	4.49	42.30	5.77	44.35	7.18	15.6514	0.0001*
	15 days	35.55	5.49	36.60	4.16	41.90	6.48	45.50	6.80	12.8058	0.0001*
	3months	35.85	4.93	37.35	4.55	42.10	6.03	47.90	6.42	19.2399	0.0001*
	6 months	37.30	4.50	38.05	5.31	42.60	6.20	50.25	6.04	22.9380	0.0001*
	9 months	38.35	5.09	38.20	5.96	43.50	6.36	50.85	5.85	20.8033	0.0001*
Early	Baseline	32.80	6.70	33.80	4.05	43.30	5.21	43.80	7.08	10.1712	0.0001*
	15 days	35.30	5.42	36.40	4.86	43.90	6.06	45.10	6.23	7.9025	0.0004*
	3months	34.50	4.38	37.30	5.77	43.80	5.27	48.20	5.14	14.4543	0.0001*
	6 months	36.90	4.15	38.80	6.44	44.00	5.50	50.60	5.04	13.1660	0.0001*
	9 months	37.60	4.01	38.70	7.13	44.70	6.34	51.60	5.04	12.5140	0.0001*
Delayed	Baseline	33.10	7.20	37.10	4.48	41.30	6.40	44.90	7.61	6.1281	0.0018*
	15 days	35.80	5.85	36.80	3.58	39.90	6.56	45.90	7.65	5.5701	0.0030*
	3months	37.20	5.31	37.40	3.20	40.40	6.54	47.60	7.78	6.6674	0.0011*
	6 months	37.70	5.01	37.30	4.08	41.20	6.83	49.90	7.17	9.7937	0.0001*
	9 months	39.10	6.12	37.70	4.85	42.30	6.48	50.10	6.76	8.2726	0.0003*

*p<0.05

The above table shows the comparison of different sections in two groups with Crestal bone density scores at different treatment time points by one-way ANOVA. Crestal bone density increased over time in the given 2 groups, with statistically significant (**p -value < 0.05**) differences among mesial, distal, buccal, and lingual sections. At baseline, the lowest Crestal bone density was observed in the mesial section (**32.95**), while the highest was in the lingual section (**44.35**). By 9 months, values increased to **38.35** in the mesial, **38.20** in the distal, **43.50** in the buccal, and **50.85** in the lingual section (**p = 0.0001**).

Graph 7: Comparison of different sections in two groups with Crestal bone density scores at different treatment time points in early and delayed group



Graphical representation of the comparison of different sections in two groups with Crestal bone density scores at different treatment time points in early and delayed group. In the early group, the mesial section rose from 33.80 to 39.00, distal from 34.30 to 44.30, buccal from 43.80 to 47.90, and lingual from 45.30 to 50.60 at 9 months. The delayed group showed a similar trend, with mesial increasing from 33.10 to 37.90, distal from 34.00 to 41.20, buccal from 37.90 to 47.40, and lingual from 47.50 to 50.00.

Both groups exhibited progressive bone remodeling, with early loading showing consistently higher Crestal bone density, especially in the lingual and distal sections. The delayed group's buccal section improved significantly, reducing the gap at 9 months.

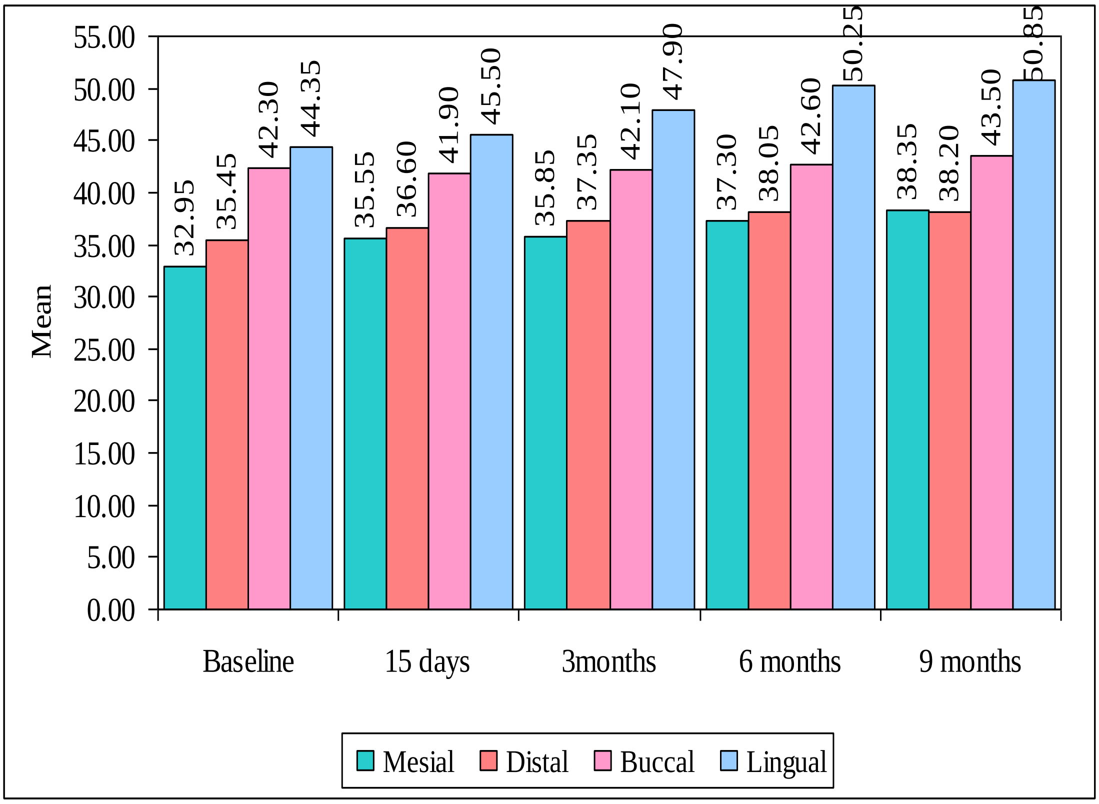
Table 11: Pair wise comparison of different sections in two groups with Crestal bone density scores at different treatment time points by Tukeys multiple posthoc procedures

Group	Time points	Mesial vs Distal (p=)	Mesial v Buccal (p=)	Mesial vs Lingual (p=)	Distal vs Buccal (p=)	Distal vs Lingual (p=)	Buccal Vs Lingual
Total	Baseline	0.5740	0.0001*	0.0001*	0.0040*	0.0001*	0.7170
	15 days	0.9410	0.0050*	0.0001*	0.0260*	0.0001*	0.2150
	3months	0.8270	0.0030*	0.0001*	0.0400*	0.0001*	0.0080*
	6 months	0.9740	0.0180*	0.0001*	0.0550	0.0001*	0.0001*
	9 months	1.0000	0.0330*	0.0001*	0.0270*	0.0001*	0.0010*
Early	Baseline	0.9810	0.0020*	0.0010*	0.0050*	0.0030*	0.9980
	15 days	0.9720	0.0090*	0.0020*	0.0270*	0.0080*	0.9640
	3months	0.6230	0.0020*	0.0001*	0.0380*	0.0001*	0.2440
	6 months	0.8560	0.0260*	0.0001*	0.1500	0.0001*	0.0430*
	9 months	0.9730	0.0430*	0.0001*	0.1100	0.0001*	0.0520
Delayed	Baseline	0.5260	0.0380*	0.0010*	0.4850	0.0530	0.6110
	15 days	0.9830	0.4450	0.0040*	0.6690	0.0100*	0.1420
	3months	1.0000	0.6290	0.0020*	0.6750	0.0030*	0.0490*
	6 months	0.9990	0.5540	0.0001*	0.4630	0.0001*	0.0120*
	9 months	0.9550	0.6470	0.0010*	0.3450	0.0001*	0.0340*

*$p<0.05$

The table above compares different sections in 2 groups with Crestal bone density scores at different treatment time points by Tukeys multiple posthoc procedures. Pairwise comparisons showed statistically significant (**p- value< 0.05**) differences in Crestal bone density between specific sections at different time points. The mesial section consistently had significantly lower Crestal bone density than the buccal and lingual sections (**p = 0.0001**). Differences between the mesial and distal sections were statistically insignificant (**p > 0.05**) at most time points. The buccal and lingual sections showed significantly higher density values compared to the mesial and distal sections (**p < 0.05**).

Graph 8: Comparison of different sections in two groups with Crestal bone density scores at different treatment time points as a whole



Graphical representation of the comparison of different sections in two groups with Crestal bone density scores at different treatment time points as a whole. Crestal bone density increased over time in both the groups, with statistically significant (**p** < **0.05**) differences among mesial, distal, buccal, and lingual sections. At baseline, the mesial section had the lowest Crestal bone density (**32.95**), while the lingual section had the highest (**44.35**). By 9 months, values increased to **38.35** in the mesial, **38.20** in the distal, **43.50** in the buccal, and **50.85** in the lingual section (**p = 0.0001**).

2.2. MIDDLE THIRD BONE DENSITY CHANGE:

Table 12: Comparison of early group and delayed group with Middle third bone density scores at different treatment time points as whole, Mesial, Distal, Buccal, Lingual section by independent t- test

Section	Time-points	Early group		Delayed group		Effect size	t -value	p -value
		Mean	S.D.	Mean	S.D.			
Total (Average of Mesial, Distal, Buccal and Lingual Section)	Baseline	40.35	8.41	40.80	9.14	-0.05	-0.2292	0.8193
	15 days	41.93	7.24	41.48	7.44	0.06	0.2741	0.7847
	3months	42.33	6.95	42.30	7.40	0.00	0.0156	0.9876
	6 months	43.30	7.66	43.20	6.53	0.01	0.0628	0.9501
	9 months	44.30	7.24	43.65	5.54	0.10	0.4506	0.6535
Mesial	Baseline	33.50	5.70	36.30	8.41	-0.40	-0.8717	0.3949
	15 days	35.30	2.87	36.20	7.24	-0.18	-0.3655	0.7190
	3months	35.50	3.17	37.30	7.47	-0.34	-0.7015	0.4920
	6 months	36.50	4.40	38.60	6.43	-0.39	-0.8519	0.4055
	9 months	36.30	2.26	39.90	4.38	-1.08	-2.3078	0.0331*
Distal	Baseline	34.40	4.25	37.70	7.02	-0.59	-1.2712	0.2198
	15 days	38.00	4.45	37.90	5.92	0.02	0.0427	0.9664
	3months	39.50	4.79	39.10	5.57	0.08	0.1722	0.8652
	6 months	39.40	5.85	40.30	5.85	-0.15	-0.3439	0.7349
	9 months	41.40	4.99	41.30	4.50	0.02	0.0471	0.9630
Buccal	Baseline	46.90	4.91	39.80	9.08	1.02	2.1756	0.0432*
	15 days	45.40	4.22	43.60	5.36	0.38	0.8344	0.4150
	3months	45.10	3.28	43.50	6.15	0.34	0.7258	0.4773
	6 months	45.20	3.43	44.30	3.37	0.26	0.5924	0.5609
	9 months	46.40	2.76	44.70	4.85	0.45	0.9630	0.3483
Lingual	Baseline	46.60	7.01	49.40	6.57	-0.41	-0.9216	0.3689
	15 days	49.00	6.82	48.20	4.85	0.14	0.3025	0.7658
	3months	49.20	6.61	49.30	4.16	-0.02	-0.0405	0.9682
	6 months	52.10	5.53	49.60	4.27	0.51	1.1316	0.2727
	9 months	53.10	4.28	48.70	4.35	1.02	2.2806	0.0350*

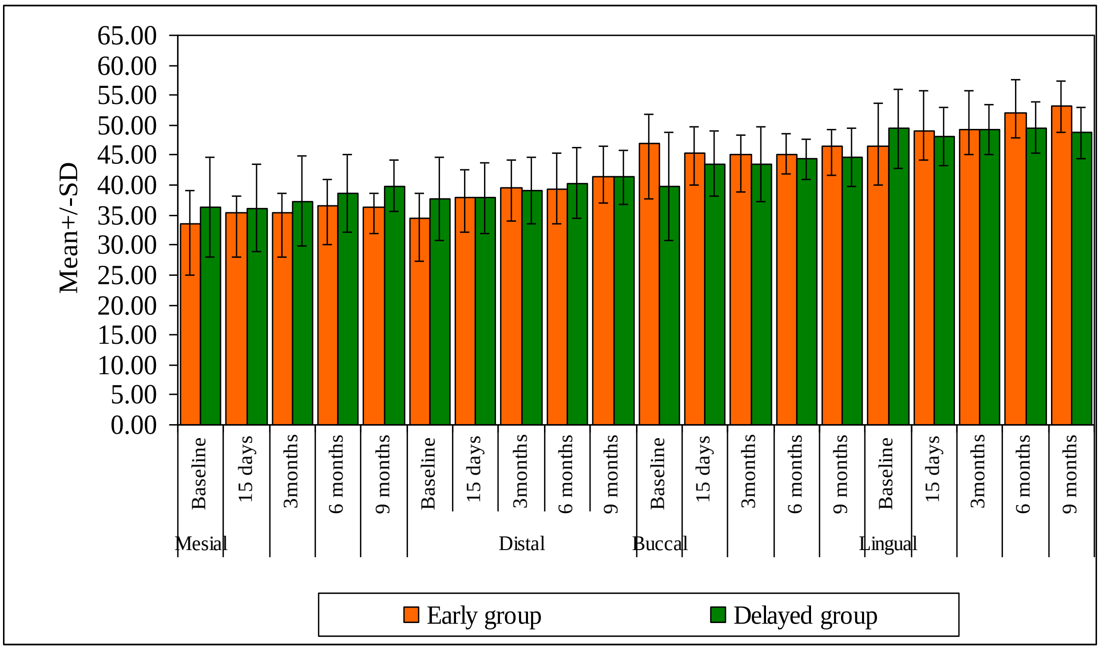
*p<0.05

The above table shows the comparison of early group and delayed group with Middle third bone density scores at different treatment time points as whole, Mesial, Distal, Buccal, Lingual section by independent t test. Middle third bone density increased over time in both groups.

In the **early group**, overall density rose from **40.35 to 44.30**. Mesial density increased from **33.50 to 36.30**, but was significantly lower than the delayed group at 9 months (**p = 0.0331**). Distal density increased from **34.40 to 41.40**, with no significant difference. Buccal density was significantly higher at baseline (**46.90 vs. 39.80**, **p = 0.0432**) and reached **46.40**. Lingual density increased from **46.60 to 53.10**, remaining significantly greater than the delayed group at 9 months (**p = 0.0350**).

In the **delayed group**, overall density increased from **40.80 to 43.65**. Mesial density rose from **36.30 to 39.90**, remaining significantly more than the early group at 9 months (**p = 0.0331**). Distal density increased from **37.70 to 41.30**, with no significant difference. Buccal density improved from **39.80 to 44.70**, narrowing the gap with the early group. Lingual density decreased slightly from **49.40 to 48.70**, making it significantly lower than the early group at 9 months (**p- value = 0.0350**).

Graph 9: Comparison of early group and delayed group with Middle third bone density scores at different treatment time points in Mesial, Distal, Buccal, Lingual sections



Graphical representation of the comparison of early group and delayed group with Middle third bone density scores at different treatment time points in Mesial, Distal, Buccal, Lingual sections.

In the **early group**, Middle third bone density increased across all sections. The **mesial** score rose from **33.50 to 36.30**, while the **distal** increased from **34.40 to 41.40**. The **buccal** section started higher at **46.90** (p = 0.0432) and reached **46.40** at 9 months. The **lingual** section showed a significant rise from **46.60 to 53.10** (p = 0.0350).

In the **delayed group**, Middle third bone density also improved. The **mesial** score increased from **36.30 to 39.90**, with a significant difference at 9 months (p = 0.0331). The **distal** section rose from **37.70 to 41.30** with no significant differences (p > 0.05). The **buccal** section started lower at **39.80** but reached **44.70** at 9 months. The **lingual** section slightly declined from **49.40 to 48.70**, showing a significant difference favoring the early group (p = 0.0350).

Table 13: Comparison of different treatment time points with Middle third bone density scores in two groups by paired t test

Groups	Time-points	Mean	S. D.	Mean Diff. from BL	t-value	p-value
Total	Baseline	40.58	8.73	-	-	-
	15 days	41.70	7.30	-1.13	-2.1623	0.0336*
	3months	42.31	7.13	-1.74	-2.6886	0.0087*
	6 months	43.25	7.07	-2.68	-3.5654	0.0006*
	9 months	43.98	6.42	-3.40	-4.3589	0.0001*
Early	Baseline	40.35	8.41	-	-	-
	15 days	41.93	7.24	-1.58	-2.5572	0.0146*
	3months	42.33	6.95	-1.98	-2.5873	0.0135*
	6 months	43.30	7.66	-2.95	-3.1097	0.0035*
	9 months	44.30	7.24	-3.95	-4.4058	0.0001*
Delayed	Baseline	40.80	9.14	-	-	-
	15 days	41.48	7.44	-0.68	-0.8028	0.4269
	3months	42.30	7.40	-1.50	-1.4260	0.1618
	6 months	43.20	6.53	-2.40	-2.0455	0.0476*
	9 months	43.65	5.54	-2.85	-2.2217	0.0322*

*p<0.05

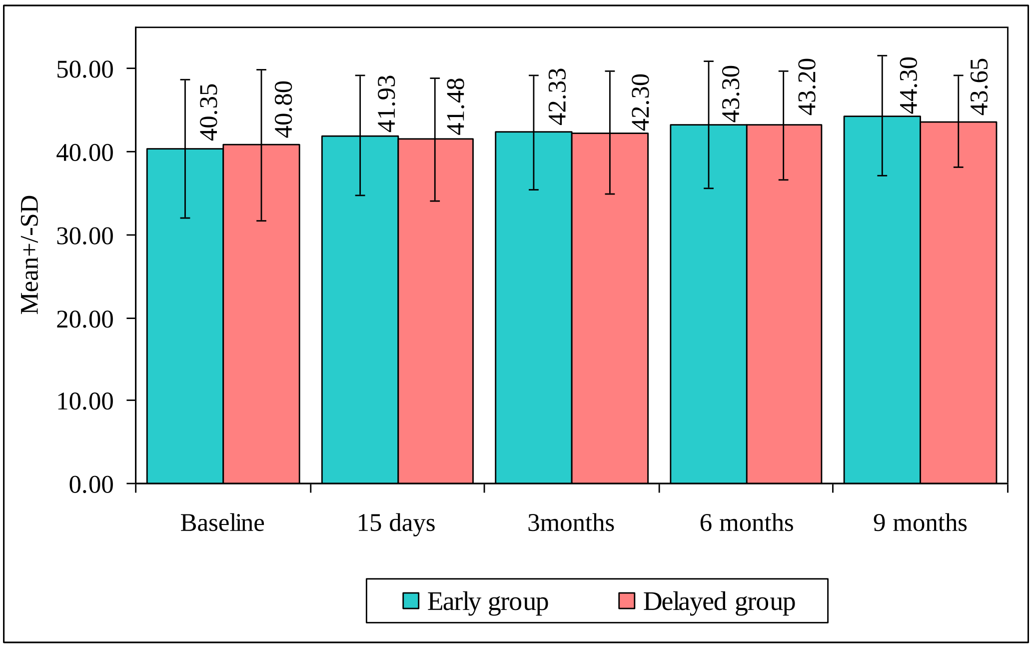
The above table shows the comparison of different treatment time points with Middle third bone density scores in two groups by paired t test.

In the **early loading group**, paired t-test analysis showed a significant increase in Middle third bone density scores over time. The **mesial** section increased from **33.50 at baseline to 36.30 at 9 months** ($p < 0.05$). The **distal** section rose from **34.40 to 41.40** ($p < 0.05$). The **buccal** section had a notable rise from **46.90 to 46.40** ($p > 0.05$), while the **lingual** section increased significantly from **46.60 to 53.10** ($p = 0.0350$).

In the **delayed loading group**, Middle third bone density also showed an overall increase. The **mesial** section improved from **36.30 to 39.90**, with a significant change ($p = 0.0331$). The **distal** section increased from **37.70 to 41.30** ($p > 0.05$). The **buccal** section rose from **39.80 to 44.70**, while the **lingual** section slightly decreased from **49.40 to 48.70**, showing a significant difference favoring of the early group (p = 0.0350).

Overall, both the groups exhibited a gradual increase in Middle third bone density scores over time, with significant changes in specific sections, particularly in the mesial and lingual regions. The early loading group showed more consistent improvements.

Graph 10: Comparison of early group and delayed group with Middle third bone density scores at different treatment time points as whole



Graphical representation of the comparison of early group and delayed group with Middle third bone density scores at different treatment time points as whole.

In the **early loading group**, Middle third bone density scores showed a gradual increase over time. The mean score was **40.35 at baseline**, rising to **41.93 at 15 days**, **42.33 at 3 months**, **43.30 at 6 months**, and **44.30 at 9 months**. The overall increase suggests progressive bone adaptation, but the changes were not statistically significant at any period of time ($p > 0.05$).

Similarly, **delayed loading group** exhibited a steady rise in Middle third bone density scores, starting from **40.80 at baseline** and increasing to **41.48 at 15 days**, **42.30 at 3 months**, **43.20 at 6 months**, and **43.65 at 9 months**. Like the early group, statistically insignificant ($p > 0.05$) changes were seen.

The **independent t- test** showed no statistically significant differences between the two groups at any given period of time ($p > 0.05$). Both groups demonstrated a similar trend of increasing Middle third bone density scores over time, with the early group showing a slightly higher final value at 9 months.

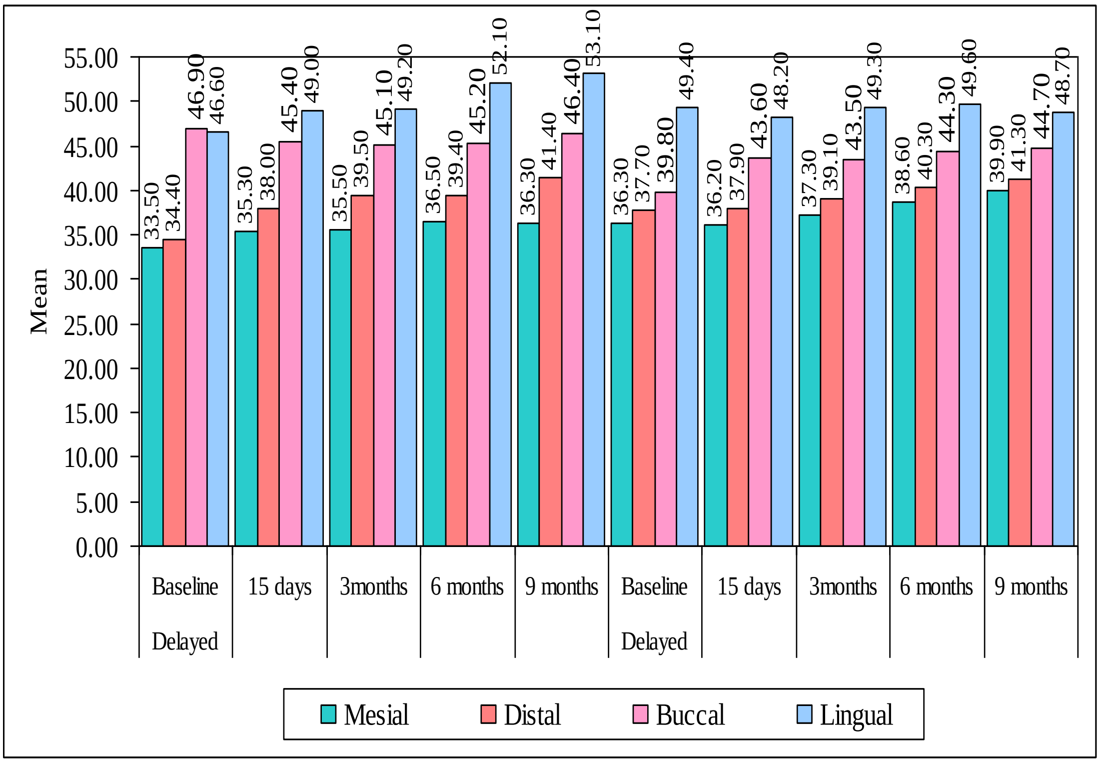
Table 14: Comparison of the different sections in 2 groups with Middle third bone density scores at different treatment time points by one way ANOVA

Group	Time points	Mesial		Distal		Buccal		Lingual		F-value	P-value
		Mean.	S.D.	Mean.	S.D.	Mean.	S.D.	Mean.	S.D.		
Total	Baseline	34.90	7.14	36.05	5.90	43.35	7.98	48.00	6.77	15.7783	0.0001*
	15 days	35.75	5.38	37.95	5.09	44.50	4.78	48.60	5.77	25.1869	0.0001*
	3months	36.40	5.66	39.30	5.06	44.30	4.87	49.25	5.38	23.2448	0.0001*
	6 months	37.55	5.47	39.85	5.71	44.75	3.34	50.85	4.98	28.1674	0.0001*
	9 months	38.10	3.86	41.35	4.63	45.55	3.94	50.90	4.77	32.8372	0.0001*
Early	Baseline	33.50	5.70	34.40	4.25	46.90	4.91	46.60	7.01	17.6941	0.0001*
	15 days	35.30	2.87	38.00	4.45	45.40	4.22	49.00	6.82	17.5452	0.0001*
	3months	35.50	3.17	39.50	4.79	45.10	3.28	49.20	6.61	16.6899	0.0001*
	6 months	36.50	4.40	39.40	5.85	45.20	3.43	52.10	5.53	19.8054	0.0001*
	9 months	36.30	2.26	41.40	4.99	46.40	2.76	53.10	4.28	36.7432	0.0001*
Delayed	Baseline	36.30	8.41	37.70	7.02	39.80	9.08	49.40	6.57	5.6911	0.0027*
	15 days	36.20	7.24	37.90	5.92	43.60	5.36	48.20	4.85	8.6285	0.0002*
	3months	37.30	7.47	39.10	5.57	43.50	6.15	49.30	4.16	8.0476	0.0003*
	6 months	38.60	6.43	40.30	5.85	44.30	3.37	49.60	4.27	9.0906	0.0001*
	9 months	39.90	4.38	41.30	4.50	44.70	4.85	48.70	4.35	7.5187	0.0005*

*p<0.05

The above table shows the comparison of different sections in two groups with Middle third bone density scores at different treatment time points by one way ANOVA. Middle third bone density increased over time in both the groups, with statistically significant (**p < 0.05**) differences among mesial, distal, buccal, and lingual sections. At baseline, the mesial section had the lowest density (**33.90**), while the lingual section had the highest (**48.00**). By 9 months, values increased to **38.10** in the mesial, **40.10** in the distal, **45.55** in the buccal, and **50.90** in the lingual section (**p = 0.0001**).

Graph 11: Comparison of different sections in two groups with Middle third bone density scores at different treatment time points in early and delayed group



Graphical representation of the comparison of different sections in two groups with Middle third bone density scores at different treatment time points in early and delayed group.

Middle third bone density scores increased over time in both early and delayed loading groups across all sections. In the early group, the mesial section increased from **33.50 to 36.30**, distal from **34.40 to 41.40**, buccal from **46.90 to 46.40**, and lingual from **46.60 to 53.10** at 9 months. The delayed group showed a similar trend, with mesial increasing from **36.30 to 39.90**, distal from **37.70 to 41.30**, buccal from **39.80 to 44.70**, and lingual decreasing slightly from **49.40 to 48.70.**

Both groups exhibited bone remodeling, with the early group showing a higher increase in lingual and distal sections. Significant differences at 9 months in the mesial ($p = 0.0331$) and lingual ($p = 0.0350$) sections favored early loading.

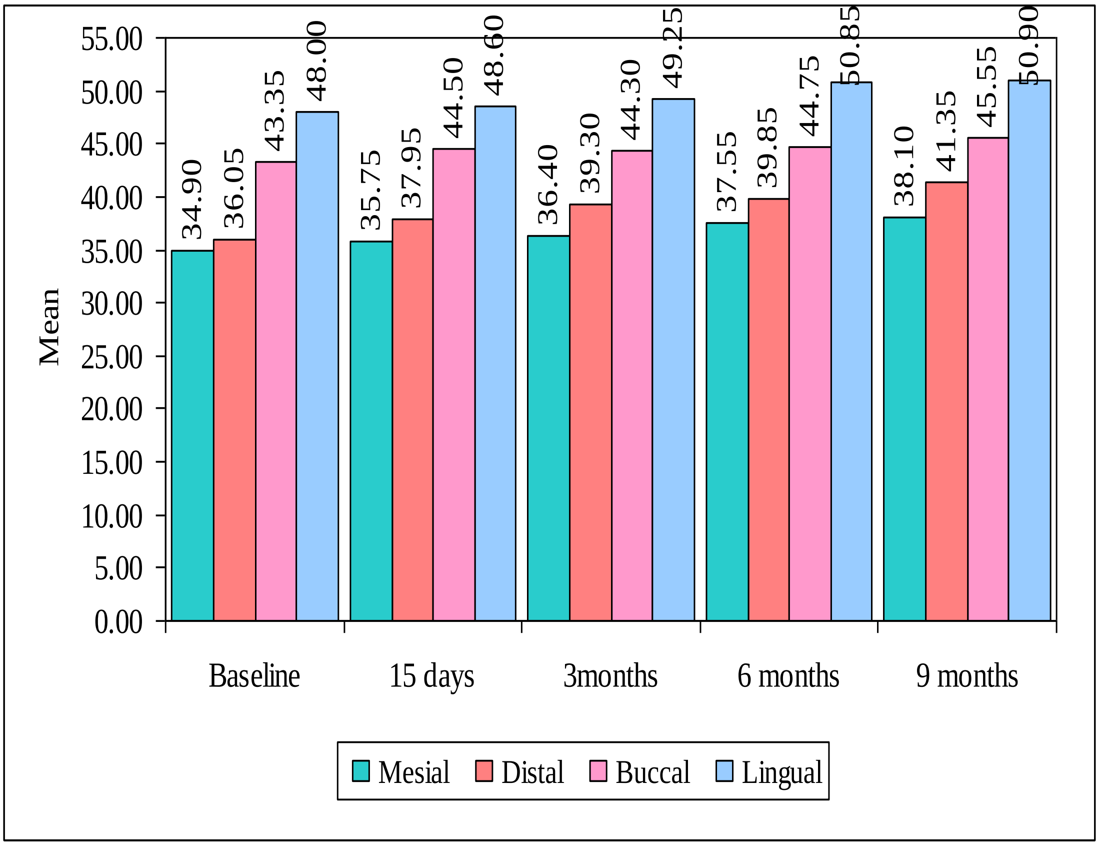
Table 15: Pair wise comparison of different sections in two groups with Middle third bone density scores at different treatment time points by Tukeys multiple posthoc procedures

Group	Time points	Mesial vs Distal (p=)	Mesial v Buccal (p=)	Mesial vs Lingual (p=)	Distal vs Buccal (p=)	Distal vs Lingual (p=)	Buccal Vs Lingual (p=)
Total	Baseline	0.9540	0.0010*	0.0001*	0.0080*	0.0001*	0.1610
	15 days	0.5530	0.0001*	0.0001*	0.0010*	0.0001*	0.0750
	3months	0.3070	0.0001*	0.0001*	0.0180*	0.0001*	0.0200*
	6 months	0.4630	0.0001*	0.0001*	0.0130*	0.0001*	0.0010*
	9 months	0.0900	0.0001*	0.0001*	0.0150*	0.0001*	0.0010*
Early	Baseline	0.9840	0.0001*	0.0001*	0.0001*	0.0001*	0.9990
	15 days	0.5960	0.0001*	0.0001*	0.0080*	0.0001*	0.3510
	3months	0.2410	0.0001*	0.0001*	0.0520	0.0001*	0.2220
	6 months	0.5540	0.0020*	0.0001*	0.0550	0.0001*	0.0170*
	9 months	0.0210	0.0001*	0.0001*	0.0250*	0.0001*	0.0020*
Delayed	Baseline	0.9780	0.7510	0.0030*	0.9320	0.0100*	0.0450*
	15 days	0.9170	0.0390*	0.0001*	0.1550	0.0020*	0.3180
	3months	0.9060	0.1110	0.0001*	0.3640	0.0030*	0.1490
	6 months	0.8800	0.0790	0.0001*	0.3170	0.0010*	0.1140
	9 months	0.9000	0.1010	0.0010*	0.3490	0.0040*	0.2160

*p< 0.05

The table above shows the pair wise comparison of different sections in two groups with Middle third bone density scores at different treatment time points by Tukeys multiple posthoc procedures. Pairwise comparisons showed statistically significant (**p< 0.05**) differences in Middle third bone density between specific sections at different time points. The mesial section consistently had significantly lower density than the buccal and lingual sections (**p = 0.0001**), while differences between the mesial and distal sections were statistically insignificant (**p > 0.05**) at most time points. The buccal and lingual sections had significantly higher density compared to the mesial and distal sections (**p < 0.05**).

Graph 12: Comparison of different sections in two groups with Middle third bone density scores at different treatment time points as a whole



Graphical representation of the comparison of different sections in two groups with Middle third bone density scores at different treatment time points as a whole. Middle third bone density increased over time in both groups, with statistically significant (**p < 0.05**) differences among mesial, distal, buccal, and lingual sections. At baseline, the mesial section had the lowest density (**33.90**), while the lingual section had the highest (**48.00**). By 9 months, values increased to **38.10** in the mesial, **40.10** in the distal, **45.55** in the buccal, and **50.90** in the lingual section (**p = 0.0001**).

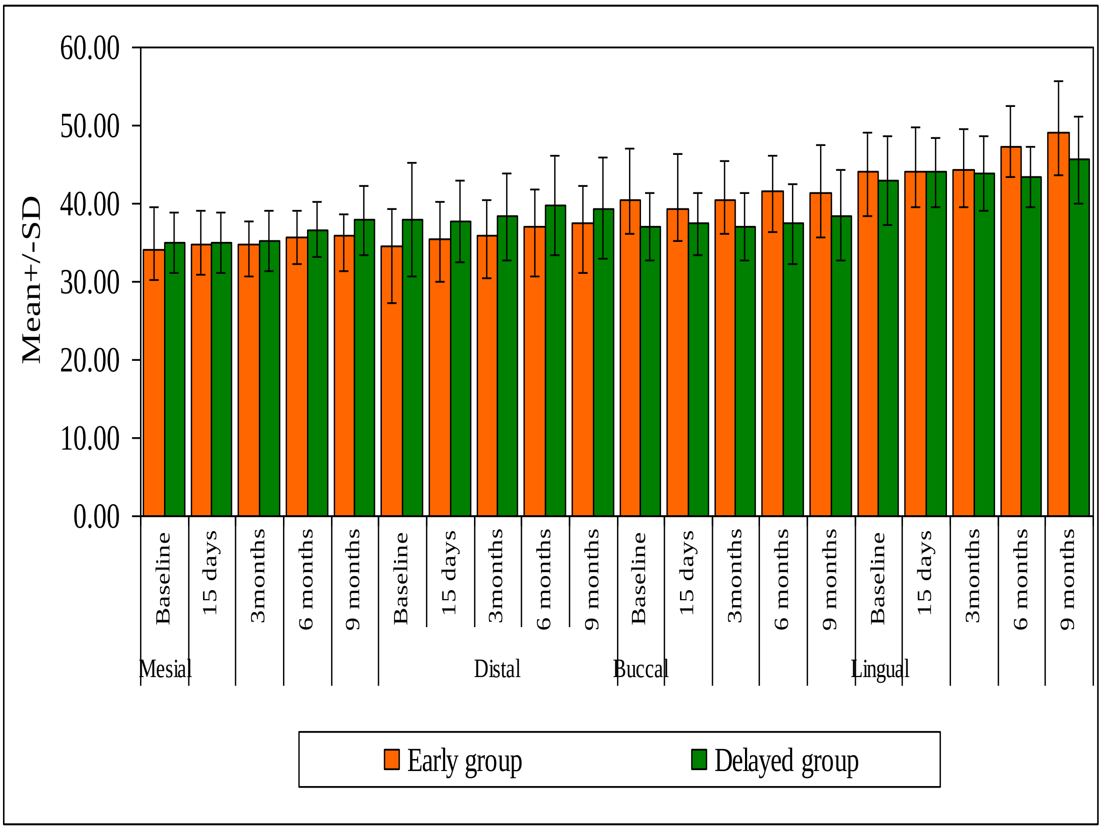
2.3. APICAL THIRD BONE DENSITY CHANGE:

Table 16: Comparison of early group and delayed group with Apical third bone density scores at different treatment time points as whole, Mesial, Distal, Buccal, Lingual section by independent t-test

Section	Time points	Early group		Delayed group		Effect size	t-value	p-value
		Mean	S.D.	Mean	S.D.			
Total (Average of Mesial, Distal, Buccal and Lingual Section)	Baseline	38.30	6.82	38.23	6.01	0.01	0.0522	0.9585
	15 days	38.43	6.46	38.53	5.45	-0.02	-0.0748	0.9405
	3months	38.85	5.82	38.63	5.58	0.04	0.1765	0.8603
	6 months	40.38	6.31	39.33	5.35	0.18	0.8029	0.4245
	9 months	41.03	7.23	40.35	6.23	0.10	0.4472	0.6560
Mesial	Baseline	34.10	5.49	35.00	3.94	-0.19	-0.4212	0.6786
	15 days	34.80	4.21	35.00	3.83	-0.05	-0.1111	0.9128
	3months	34.70	3.09	35.20	3.91	-0.14	-0.3171	0.7548
	6 months	35.70	3.50	36.70	3.50	-0.29	-0.6393	0.5307
	9 months	35.90	2.73	37.90	4.48	-0.55	-1.2053	0.2437
Distal	Baseline	34.50	4.88	37.90	7.23	-0.56	-1.2320	0.2338
	15 days	35.40	4.74	37.70	5.29	-0.46	-1.0235	0.3196
	3months	35.90	4.48	38.30	5.54	-0.48	-1.0651	0.3009
	6 months	37.10	4.79	39.80	6.34	-0.49	-1.0743	0.2969
	9 months	37.60	4.77	39.40	6.43	-0.32	-0.7110	0.4862
Buccal	Baseline	40.50	6.59	37.00	4.29	0.64	1.4075	0.1763
	15 days	39.40	6.88	37.40	4.06	0.37	0.7914	0.4390
	3months	40.40	5.02	37.10	4.36	0.70	1.5706	0.1337
	6 months	41.50	4.53	37.40	5.13	0.85	1.8959	0.0741
	9 months	41.40	6.11	38.50	5.76	0.49	1.0919	0.2893
Lingual	Baseline	44.10	5.07	43.00	5.64	0.21	0.4590	0.6517
	15 days	44.10	5.61	44.00	4.52	0.02	0.0439	0.9655
	3months	44.40	5.13	43.90	4.82	0.10	0.2248	0.8247
	6 months	47.20	5.22	43.40	3.86	0.84	1.8493	0.0809
	9 months	49.20	6.53	45.60	5.60	0.59	1.3234	0.2023

The above table shows the comparison of early group and delayed group with Apical third bone density scores at different treatment time points as whole, Mesial, Distal, Buccal, Lingual section by independent t test. Apical third bone density increased over time in both groups, with statistically insignificant (**p > 0.05**) differences across all sections. In the total measurement, values rose from **38.30** (early) and **38.23** (delayed) at baseline to **41.03** and **40.35** at 9 months. In the mesial section, density increased from **34.10** and **35.00** to **35.90** and **37.90**. In the distal section, values improved from **34.50** and **37.90** to **37.60** and **39.40**. In the buccal section, measurements rose from **40.50** and **37.00** to **41.40** and **38.50**. In the lingual section, values increased from **44.10** and **43.00** to **49.20** and **45.60**.

Graph 13: Comparison of early group and delayed group with Apical third bone density scores at different treatment time points in Mesial, Distal, Buccal, Lingual sections



Graphical representation of the comparison of early group and delayed group with Apical third bone density scores at different treatment time points in Mesial, Distal, Buccal, Lingual sections. In the **early loading group**, Apical third bone density scores showed a progressive increase across all sections. In the **mesial section**, the score rose from 33.50 at baseline to 36.30 at 9 months. In the **distal section**, it increased from 34.40 to 41.40. The **buccal section** had a higher initial score of 46.90, reaching 46.40 at 9 months. In the **lingual section**, the score increased from 46.60 to 53.10, with a statistically significant difference at 9 months when compared to the delayed group (p = 0.0350).

In **delayed loading group**, Apical third bone density also increased over time but with variations. The **mesial section** improved from 36.30 to 39.90, showing a significant difference at 9 months when compared to the early group ($p = 0.0331$).

The **distal section** increased from 37.70 to 41.30, with significant indifferences ($p > 0.05$). The **buccal section** started lower at 39.80 but reached 44.70, narrowing the gap with the early group. In the **lingual section**, the score slightly declined from 49.40 to 48.70, showing a significant difference favoring the early group at 9 months ($p = 0.0350$).

Overall, both groups had a gradual increase in Apical third bone density. Tthe early group maintaining higher scores in most sections, particularly in the buccal and lingual regions at later time points.

Table 17: Comparison of different treatment time points with Apical third bone density scores in two groups by paired t-test

Groups	Time points	Mean	S.D.	Mean Diff. from BL	t-value	p-value
Total	Baseline	38.26	6.39	-	-	-
	15 days	38.48	5.94	-0.21	-0.6670	0.5067
	3months	38.74	5.67	-0.48	-1.0622	0.2914
	6 months	39.85	5.84	-1.59	-2.6574	0.0095*
	9 months	40.69	6.72	-2.43	-3.3420	0.0013*
Early	Baseline	38.30	6.82	-	-	-
	15 days	38.43	6.46	-0.13	-0.2505	0.8035
	3months	38.85	5.82	-0.55	-0.9298	0.3582
	6 months	40.38	6.31	-2.08	-2.4097	0.0208*
	9 months	41.03	7.23	-2.73	-2.6840	0.0106*
Delayed	Baseline	38.23	6.01	-	-	-
	15 days	38.53	5.45	-0.30	-0.7458	0.4602
	3months	38.63	5.58	-0.40	-0.5898	0.5587
	6 months	39.33	5.35	-1.10	-1.3223	0.1938
	9 months	40.35	6.23	-2.13	-2.0283	0.0494*

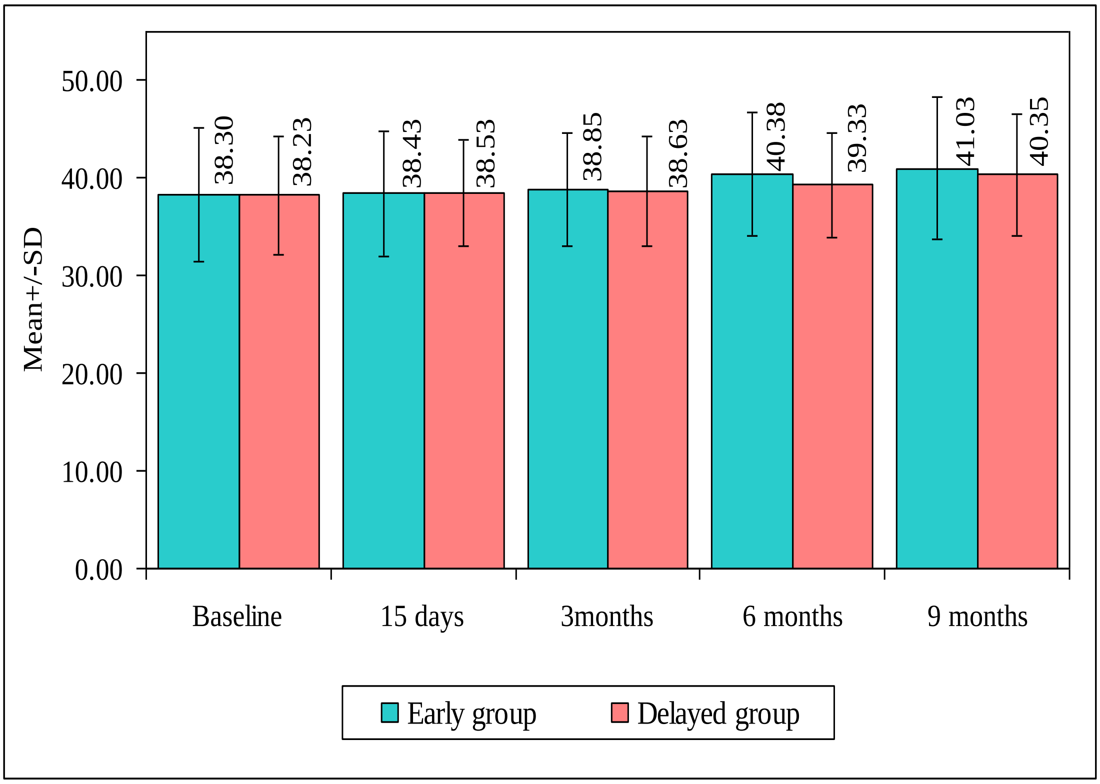
*p<0.05

The above table shows the comparison of different treatment time points with Apical third bone density scores in two groups by paired t test. Apical third bone density scores increased progressively in both groups over time. In the **early loading group**, the mean Apical third bone density rose from 38.30 at baseline to 41.03 at 9 months, with significant increases at 6 months (*p*= 0.0208) and 9 months (*p*= 0.0106).

The **delayed loading group** showed a similar trend, with Apical third bone density increasing from 38.23 at baseline to 40.35 at 9 months, reaching statistical significance only at 9 months (*p* = 0.0494).

Overall, both groups exhibited a steady rise in Apical third bone density, with the early loading group showing significant improvements earlier than the delayed loading group.

Graph 14: Comparison of early group and delayed group with Apical third bone density scores at different treatment time points as whole



Graphical representation of the comparison of early group and delayed group with Apical third bone density scores at different treatment time points as whole. Apical third bone density increased over time in both groups, with no statistically significant (**p > 0.05**) differences at all time points. In the early group, values rose from **38.30** at baseline to **41.03** at 9 months, while in the delayed group, they increased from **38.23** to **40.35**.

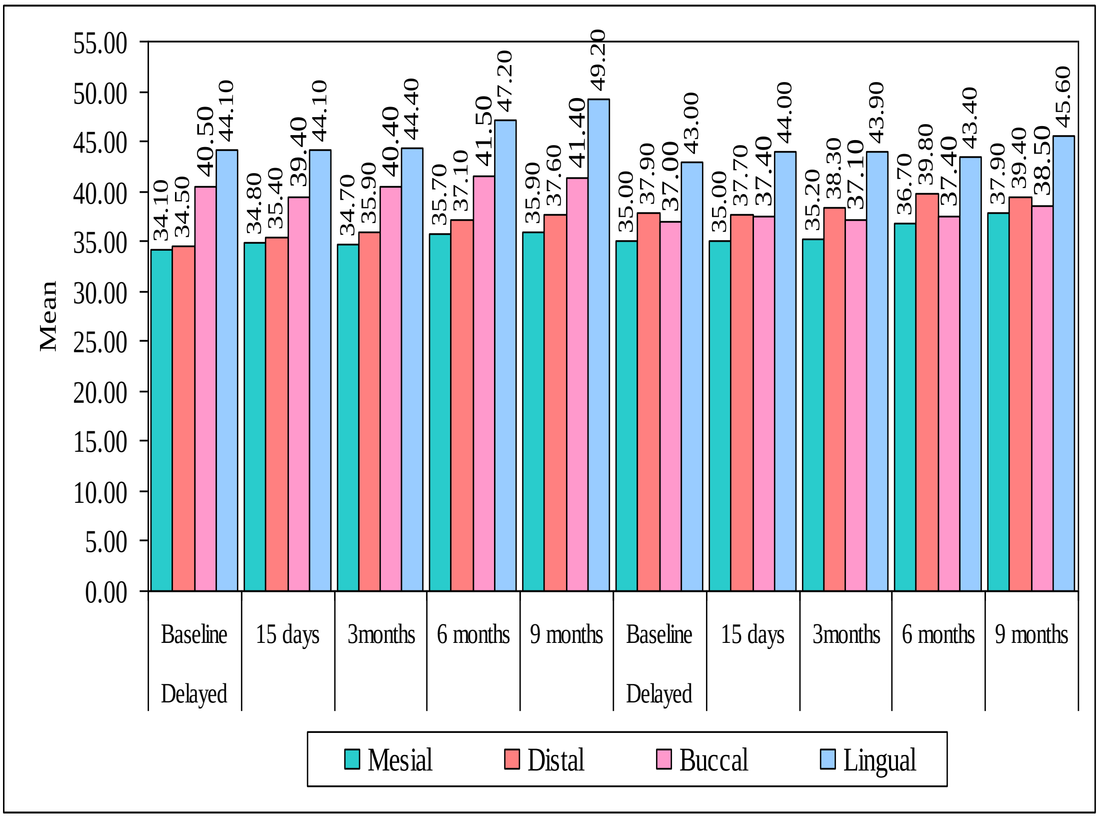
Table 18: Comparison of different sections in two groups with Apical third bone density scores at different treatment time points by one-way ANOVA

Group	Time points	Mesial		Distal		Buccal		Lingual		F-value	P-value
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.		
Total	Baseline	34.55	4.67	36.20	6.25	38.75	5.70	43.55	5.25	10.1895	0.0001*
	15 days	34.90	3.92	36.55	5.03	38.40	5.60	44.05	4.96	13.1389	0.0001*
	3months	34.95	3.44	37.10	5.06	38.75	4.88	44.15	4.85	14.5861	0.0001*
	6 months	36.20	3.44	38.45	5.64	39.45	5.16	45.30	4.88	12.7978	0.0001*
	9 months	36.90	3.75	38.50	5.59	39.95	5.97	47.40	6.20	14.4575	0.0001*
Early	Baseline	34.10	5.49	34.50	4.88	40.50	6.59	44.10	5.07	7.6502	0.0004*
	15 days	34.80	4.21	35.40	4.74	39.40	6.88	44.10	5.61	6.2109	0.0016*
	3months	34.70	3.09	35.90	4.48	40.40	5.02	44.40	5.13	9.7227	0.0001*
	6 months	35.70	3.50	37.10	4.79	41.50	4.53	47.20	5.22	12.9184	0.0001*
	9 months	35.90	2.73	37.60	4.77	41.40	6.11	49.20	6.53	12.7066	0.0001*
Delayed	Baseline	35.00	3.94	37.90	7.23	37.00	4.29	43.00	5.64	3.9297	0.0159*
	15 days	35.00	3.83	37.70	5.29	37.40	4.06	44.00	4.52	7.4274	0.0005*
	3months	35.20	3.91	38.30	5.54	37.10	4.36	43.90	4.82	6.3497	0.0014*
	6 months	36.70	3.50	39.80	6.34	37.40	5.13	43.40	3.86	3.9066	0.0163*
	9 months	37.90	4.48	39.40	6.43	38.50	5.76	45.60	5.60	4.0088	0.0147*

*p<0.05

The above table shows the comparison of different sections in two groups with Apical third bone density scores at different treatment time points by one way ANOVA. Apical third bone density increased over time in both, with statistically significant (**p < 0.05**) differences among mesial, distal, buccal, and lingual sections. At baseline, the mesial section had the lowest density (**34.30**), while the lingual section had the highest (**44.50**). By 9 months, values increased to **37.80** in the mesial, **39.50** in the distal, **41.90** in the buccal, and **47.40** in the lingual section (**p = 0.0001**).

Graph 15: Comparison of different sections in two groups with Apical third bone density scores at different treatment time points in early and delayed group



Graphical representation of the comparison of different sections in two groups with Apical third bone density scores at different treatment time points in early and delayed group.

Apical third bone density scores increased over time in both early and delayed loading groups across all sections. In the early group, the mesial section increased from 38.30 at baseline to 41.03 at 9 months, distal from 38.40 to 42.10, buccal from 37.00 to 44.70, and lingual from 47.90 to 50.60. The delayed group followed a similar trend, with mesial increasing from 33.10 to 37.90, distal from 34.00 to 41.20, buccal from 35.80 to 41.60, and lingual from 37.40 to 50.00.

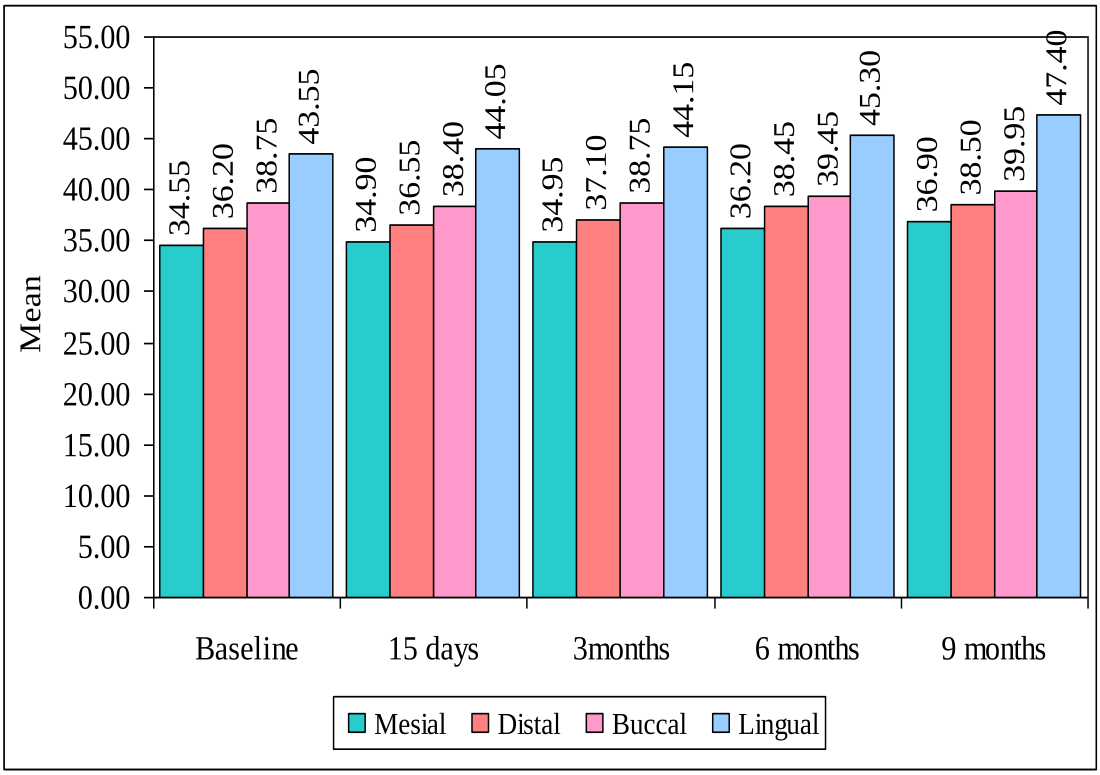
Table 19: Pair wise comparison of different sections in two groups with Apical third bone density scores at different treatment time points by Tukeys multiple posthoc procedures

Group	Time points	Mesial vs Distal (p=)	Mesial vs Buccal (p=)	Mesial vs Lingual (p=)	Distal vs Buccal (p=)	Distal vs Lingual (p=)	Buccal vs Lingual (p=)
Total	Baseline	0.7790	0.0830	0.0001*	0.4630	0.0001*	0.0360*
	15 days	0.7140	0.1190	0.0001*	0.6350	0.0001*	0.0030*
	3months	0.4560	0.0520	0.0001*	0.6700	0.0001*	0.0020*
	6 months	0.4620	0.1560	0.0001*	0.9150	0.0001*	0.0020*
	9 months	0.7910	0.2980	0.0001*	0.8360	0.0001*	0.0001*
Early	Baseline	0.9980	0.0640	0.0010*	0.0910	0.0020*	0.4760
	15 days	0.9950	0.2520	0.0030*	0.3700	0.0060*	0.2350
	3months	0.9330	0.0360*	0.0001*	0.1330	0.0010*	0.2120
	6 months	0.9010	0.0350*	0.0001*	0.1540	0.0001*	0.0390*
	9 months	0.8870	0.1070	0.0001*	0.3810	0.0001*	0.0110*
Delayed	Baseline	0.6350	0.8430	0.0110*	0.9820	0.1730	0.0820
	15 days	0.5360	0.6290	0.0001*	0.9990	0.0160*	0.0110*
	3months	0.4620	0.8020	0.0010*	0.9400	0.0530	0.0130*
	6 months	0.4880	0.9880	0.0190*	0.6860	0.3570	0.0420*
	9 months	0.9320	0.9950	0.0200*	0.9840	0.0820	0.0360*

*$p < 0.05$

The table shows the pairwise comparing different sections in two groups with Apical third bone density scores at different treatment time points by Tukeys multiple posthoc procedures. Pair-wise comparisons showed statistically significant (**$p < 0.05$**) results in Apical third bone density between specific sections at different time points. The mesial section consistently had significantly lower density than the buccal and lingual sections (**$p = 0.0001$**), while differences between the mesial and distal sections were statistically insignificant (**$p > 0.05$**) at most time points. The buccal and lingual sections exhibited significantly higher density compared to the mesial and distal sections (**$p < 0.05$**).

Graph 16: Comparison of different sections in two groups with Apical third bone density scores at different treatment time points as a whole



Graphical representation of the comparison of different sections in two groups with Apical third bone density scores at different treatment time points as a whole. Apical third bone density increased over time in, with statistically significant (**p< 0.05**) differences among mesial, distal, buccal, and lingual sections. At baseline, the mesial section had the lowest density (**34.30**), while the lingual section had the highest (**44.50**). By 9 months, values increased to **37.80** in the mesial, **39.50** in the distal, **41.90** in the buccal, and **47.40** in the lingual section (**p = 0.0001**).

DISCUSSION

This in vivo split mouth study aimed to evaluate and compare changes in peri implant marginal bone level and bone density to rehabilitate bilateral single missing posterior mandibular teeth using early and delayed loading protocols. The CBCT analysis provided significant insights into trends observed in marginal bone loss (MBL) and bone density changes across various regions (crest, middle and apex) over time. These findings, in agreement with previous studies, reveal essential patterns in peri-implant bone health that can help guide clinical decision-making. Moreover, the split-mouth design minimizes inter-patient variability, thereby strengthening the internal validity of the results.

The implant loading protocols can be defined as (**Chrcanovic et al. (2014**): **Immediate loading** involves applying functional forces within 48 hours of implant placement; **early loading** commences restorative procedures during the early healing phase—typically within 1 to 2 months; and **delayed loading** defers the application of masticatory forces until three months or more have elapsed, by which time osseointegration is considered firmly established.[37]

A study conducted by **Glauser et al. (2010)** demonstrated that immediate loading, when high primary stability is achieved, does not interfere with peri-implant bone remodeling in comparison to early loading.[38] Similarly, **Pigozzo et al. (2018)** found that immediate loading protocols yield osseointegration outcomes comparable to early loading while reducing overall treatment time. In this study, the early loading group exhibited consistent reductions in MBL (Table 2, Graph 1). The study confirmed significant MBL reductions at all time points in both groups (Table 3) with buccal and lingual aspects exhibiting greater bone loss compared to mesial and distal regions (Table 5, Graph 1 and 4).[39]

When conditions for immediate loading are met, clinicians have the flexibility to reduce treatment duration without sacrificing osseointegration. This approach can enhance patient comfort and satisfaction while ensuring predictable outcomes.

Research by **Trivedi et al. (2022)** showed that although delayed loading protocols might initially display slightly higher levels of MBL, these differences tend to stabilize or even converge over extended follow-up periods (Table 2, Graph 1).[40] In a similar investigation, **Kumar et al. (2018)** reported that the long-term osseointegration outcomes for both early and delayed loading groups were comparable.[41] The findings of this study indicate that the delayed loading group exhibited marginally higher early MBL values that resolved by nine months, demonstrating that the natural bone remodeling process eventually reaches an equilibrium regardless of the initial delay in loading.

This convergence suggests the importance of a patient-specific approach. When immediate loading is not feasible, delayed loading can be reliably implemented while the clinician monitors the early phases until remodeling stabilizes.

Research by **Ebenezer and Balakrishnan (2015)** has emphasized that immediate loading offers benefits such as reduced treatment duration and enhanced patient comfort, yet delayed loading remains equally effective in terms of long-term bone stability.[42] Moreover, **Patel et al. (2023)** confirmed that when primary stability is ensured (with an implant stability quotient, ISQ, ≥ 60), both loading protocols yield statistically similar outcomes regarding MBL and bone density.[43] The observation of gradual MBL reductions in the delayed loading group reinforces the clinical reliability of this approach, making it a dependable alternative when immediate loading conditions are not ideal.

Ramadan et al. (2021) examined the effect of functional versus non-functional loading and concluded that, with proper occlusal management, both yield similar implant survival and stability.[44] Likewise, **Chrcanovic et al. (2014)** reported that occlusal control is key to achieving successful osseointegration irrespective of the loading protocol.[37] The uniform trends in peri-implant bone remodeling under functional loading conditions observed in this study further collaborate these findings, underscoring the importance of occlusal management.

It is essential to outline the key methodologies utilized in this study. A high-resolution cone-beam computed tomography (CBCT) system was employed to capture volumetric images of the implant sites.

Grayscale analysis was then applied to these images to quantitatively assess subtle changes in bone density across the mesial, distal, buccal and lingual regions (Table 6–9, Graph 4-6). **Ishida et al. (2023)** provided evidence that CBCT grayscale imaging is a precise, reproducible metric for evaluating peri-implant bone density.[45] **Elkhidir et al. (2017)** further confirmed that grayscale analysis is sensitive to subtle changes in bone quality post-implant placement.[46] In this study, significant density gains across the mesial, distal, buccal and lingual regions support these findings, emphasizing that modern imaging techniques are crucial for tracking the process of osseointegration in a clinical setting.

Integrating CBCT grayscale analysis into routine diagnostics enhances objectivity and may allow clinicians to detect early signs of adverse bone changes, prompting timely interventions.

In addition, the 5th thread pitch was adopted as a standardized reference point for measuring marginal bone loss (MBL), ensuring consistent and reproducible evaluations. The rationale for measuring MBL against the 5th thread pitch is supported by studies by **Viswanathan et al. (2022)**, who noted the impact of implant thread geometry on local stress distribution and bone remodeling.[47] **Stanley et al. (2020)** further affirmed that using a precise reference point—such as the 5th thread—provides a consistent method for assessment.[48]

These state-of-the-art techniques provided an objective framework for assessing the biological response of the peri-implant bone under varying loading conditions.

Esposito et al. (1998) demonstrated that, under well-controlled surgical conditions, the differences in MBL between early and delayed loading are minimal.[20] **Chiang et al. (2019)** highlighted that biomechanical forces can result in region-specific variations in bone loss, which aligns with the observation of higher MBL in the mesial and distal regions.[49] Similarly, **Caetano et al. (2019)** reported that occlusal stresses produce differential bone remodeling patterns in specific regions.[50] Collectively, these studies support the inference that localized anatomical and biomechanical factors must be considered when evaluating peri-implant bone changes (Table 4-6, Graph 1-4).

Continuous monitoring of MBL can serve as an early warning system for potential complications, prompting clinicians to adapt surgical or prosthetic strategies as required.

Bone density changes are pivotal to the overall success of dental implants because they directly influence both primary stability and long-term osseointegration.

Vaddamanu et al. (2024) observed steady increases in the crestal bone density following implant placement, emphasizing the role of cortical bone in achieving stable osseointegration.[51] **Wahengbam et al. (2021)** validated that CBCT is an effective tool for tracking these density improvements over time.[52] In this study, the lingual region consistently demonstrated the highest crestal bone density gains. It also confirmed significant within-group increases crestal bone density over time (Table 7) and statistically significant regional variation with buccal and lingual sections had higher density gains than mesial and distal areas (Table 8-9, Graph 5-6).

The prominence of crestal bone density gains in the lingual region can guide future implant designs and surgical approaches by leveraging regional anatomical advantages.

Research by **Vergara-Buenaventura et al. (2019)** and **Cochran et al. (2017)** reported progressive bone density improvements in the middle third density as indicative of ongoing osseointegration .[54,55] This study demonstrated significant middle third density increases within each group over time and statistically significant regional variation with lingual and buccal sections gaining more density than mesial and distal areas (Table 12-14, Graph 9-10).

Recognizing variations in mid-implant bone density changes can help clinicians adjust loading protocols or prosthetic designs to optimize bone remodeling and implant longevity.

The gradual increase in apical third bone density observed in this study is consistent with the findings of **Cannizzaro et al. (2015) and Karl et al. (2016)**.[57,58] This study demonstrated significant apical third bone density increased at 6 and 9 months (Table 16), and statistically significant regional variation with lingual and buccal region exhibiting greater density increases than mesial and distal aspects (Table 17-18, Graph 13-16).

Tracking apical third bone density changes may offer an additional metric for early prognostic determination of implant success, guiding clinicians during follow-up examinations.

Hence, this study demonstrates that the early loading and delayed loading protocols both have the same long-term results in marginal bone loss and bone density changes, as evidenced by CBCT grayscale analysis. While early loading presented slightly lower initial marginal bone loss and modest density gains in certain regions, these differences were not statistically significant. These results support the use of patient-specific approaches that consider bone quality and implant stability, with quantitative imaging serving as a valuable diagnostic tool for optimizing osseointegration.

SCOPE OF STUDY

To build on these findings, future studies should:

- **Conduct Multicenter Randomized Trials:** Larger, randomized controlled trials across multiple centers will enhance generalizability and statistical robustness, particularly in patients with compromised bone or systemic health conditions.

- **Extend Long-Term Follow-Up:** Monitoring implants for 5–10 years will elucidate the durability of early loading outcomes and the incidence of late biological or mechanical complications.

- **Incorporate Patient-Reported Outcomes:** Evaluating quality of life, functional satisfaction, and esthetic perceptions will provide a holistic assessment of early versus delayed loading protocols.

- **Leverage Advanced Imaging and Analytics:** Integration of AI-driven image analysis and finite element modeling can offer deeper insights into stress distribution and bone remodeling dynamics under various loading conditions.

- **Explore Novel Biomaterials and Surface Treatments:** Investigating the impact of bioactive coatings, growth factors, and osseodensification techniques may expand indications for early loading in challenging clinical scenarios.

- **Economic Evaluations:** Health economic studies comparing cost-effectiveness, resource utilization, and patient affordability between protocols will inform policy and reimbursement frameworks.

LIMITATION

Despite its strengths, this study has several limitations:

- **Sample Size and Demographics:** The small cohort of nine patients limits statistical power and may not represent broader patient populations, including those with systemic conditions or varying bone qualities.

- **Follow-Up Duration:** A follow-up of 9 months yields strong short-term data but cannot capture late complications like peri-implantitis or prosthetic wear or long-term bone remodeling.

- **Study Design Constraints:** The split-mouth model controls for inter-patient variability but may introduce cross-arch biomechanical interactions. Moreover, the lack of blinding could introduce measurement bias.

- **Imaging Limitations:** CBCT gray-scale values are influenced by machine calibration, exposure settings, and beam hardening artifacts. While calibration phantoms were used, absolute bone density measurements should be interpreted with caution.

- **Prosthetic Variables:** Although standardized, provisional and definitive prosthesis designs may vary slightly in occlusal scheme and fit, potentially affecting load distribution and bone response.

CLINICAL IMPLICATIONS

The systematic review conducted by **Pjetursson et al. (2007)** emphasizes that a personalized approach to implant loading protocols can yield predictable, long-term outcomes.[59]

The findings of this study carry several important implications for clinical practice:

1. **Streamlined Treatment Workflow:** Early loading protocols can significantly reduce total treatment time and the number of patient visits, thereby enhancing clinic efficiency and patient convenience. By eliminating prolonged edentulous periods, clinicians can improve prosthetic rehabilitation timelines without compromising bone stability.

2. **Enhanced Patient Experience:** Reduced surgical interventions and faster functional restoration contribute to greater patient comfort, satisfaction, and quality of life. Patients benefit psychologically from avoiding extended toothless intervals and gain masticatory function sooner.

3. **Case Selection and Risk Management:** The absence of significant differences in MBL and bone density between protocols underscores the critical role of primary stability (ISQ $\geq$ 60), bone volume, and occlusal control in predicting early loading success. Clinicians should employ objective metrics—such as insertion torque and resonance frequency analysis—to guide loading decisions and minimize risk.

4. **Integration with Digital Dentistry:** Quantitative CBCT analysis facilitates precision planning and monitoring. Incorporating digital workflows—such as guided surgery and CAD/CAM–fabricated provisional restorations—can

further optimize implant positioning and occlusal load distribution, reinforcing the safety of early loading in complex cases.

5. **Cost-Effectiveness:** Fewer surgical stages and reduced chair time may translate to lower overall treatment costs, making implant therapy more accessible. Future health economic analyses should evaluate cost–benefit ratios of early versus delayed loading protocols in diverse healthcare settings.

CONCLUSION

This split-mouth clinical investigation demonstrates that, under stringent primary stability criteria (insertion torque ≥35 Ncm; ISQ ≥ 60) and precise surgical execution, early loading of posterior mandibular single-tooth implants delivers peri-implant bone outcomes equivalent to conventional delayed loading. Both early (14-day) and delayed (3-month) protocols achieved a 100% implant survival rate over nine months, with statistically similar reductions in marginal bone loss and comparable increases in volumetric bone density across crestal, middle, and apical regions.

By streamlining the rehabilitation timeline and reducing the number of surgical interventions, early loading offers tangible benefits in patient comfort and satisfaction—allowing patients to regain masticatory function sooner without compromising long-term bone stability. Moreover, calibrated CBCT gray-scale analysis proved invaluable for objective monitoring of peri-implant bone remodeling, revealing regional variations (such as pronounced density gains at the lingual crest) that can guide individualized treatment planning and occlusal management.

When executed under optimal conditions, early loading represents a reliable and efficient alternative to delayed loading in posterior mandibular implant therapy, paving the way for more streamlined, patient-centered rehabilitation strategies that uphold high standards of peri-implant bone health and long-term success.

SUMMARY

This thesis investigates the clinical outcomes of early versus delayed loading protocols in posterior mandibular single-tooth implants, employing a split-mouth design and cone-beam computed tomography (CBCT) for precise peri-implant bone assessment. Nine patients with bilateral mandibular edentulous sites each received two identical implants: one restored early at 14 days with a provisional polymethylmethacrylate (PMMA) prosthesis, and the contralateral implant loaded conventionally after a three-month healing period. Primary stability was ensured at placement by achieving insertion torque ≥35 Ncm and an implant stability quotient (ISQ) ≥ 60.

Standardized CBCT scans were obtained immediately after implant placement (baseline), 15 days, 3 months, 6 months, and 9 months post-loading. Marginal bone level at mesial, distal, buccal, and lingual was measured relative to the fifth thread pitch as a reference and bone density was quantified at crestal, middle, and apical thirds via calibrated gray-scale values. Statistical analyses included repeated measures ANOVA for temporal changes, paired t-tests for intragroup comparisons, and independent t-tests for intergroup evaluations, with significance of $p \leq 0.05$.

All 18 implants (nine early, nine delayed) achieved successful osseointegration and remained free of biological or prosthetic complications, yielding a 100% survival rate at nine months. Both protocols exhibited significant reductions in marginal bone loss (MBL) over time: early-loaded implants decreased from 5.10 ± 0.43 mm to 4.80 ± 0.40 mm, while delayed-loaded implants decreased from 5.30 ± 0.47 mm to 4.82 ± 0.45 mm ($p < 0.001$ for both). Intergroup comparisons at each follow-up interval revealed statistically insignificant differences in MBL

($p > 0.05$), indicating comparable bone remodeling irrespective of loading timing. Sectional analysis consistently showed slightly greater MBL at mesial and distal sites compared to buccal and lingual aspects, a pattern observed equally in both groups.

Bone density increased progressively across all regions in both loading protocols. Crestal density rose from 38.43 ± 7.69 gray-scale units (GV) to 43.15 ± 7.91 GV in the early group and from 39.10 ± 7.72 GV to 42.30 ± 7.61 GV in the delayed group, with no significant intergroup differences ($p > 0.05$). Middle and apical density values similarly improved by 4–6 GV and 3–4 GV, respectively. The most pronounced density gains occurred at the lingual crest, reflecting robust osseointegration in thicker cortical bone regions.

These results demonstrate that, when strict primary stability criteria and meticulous surgical technique are applied, early loading offers bone remodeling and density outcomes equivalent to those of delayed loading. Clinically, early loading can streamline treatment by reducing the number of surgical interventions and total rehabilitation time, thereby enhancing patient comfort and satisfaction without compromising implant success. The use of CBCT for quantitative gray-scale analysis proved instrumental in monitoring peri-implant bone maturation and guiding loading decisions.

Limitations of this study include the small sample size, split-mouth design, and a nine-month follow-up period, which restrict long-term generalizability. Future research should encompass larger, multicenter randomized trials with extended follow-up (5–10 years), incorporate patient-reported outcome measures to capture functional and psychosocial impacts, and include health-economic evaluations to assess cost-effectiveness. Integration of advanced imaging analytics, AI-driven bone quality assessment, and exploration of novel biomaterials or surface treatments could further refine loading protocols and expand clinical indications.

In summary, early loading represents a reliable, efficient alternative to delayed loading in posterior mandibular implant therapy when performed under optimal conditions. This approach holds promise for more patient-centered, time-effective implant rehabilitation strategies that maintain high standards of peri-implant bone health and long-term success.

.

BIBLIOGRAPHY

1. Alghamdi HS, Jansen JA. The development and future of dental implants. Dent Mater J. 2020;39(2):167–72.
2. Buser D, Chappuis V, Belser UC, Chen S. Implant placement and loading protocols in partially edentulous patients: a systematic review. Clin Oral Implants Res. 2018;29(Suppl 16):106–34.
3. Cochran DL, Morton D, Weber HP. Consensus statements and recommended clinical procedures regarding loading protocols. Clin Oral Implants Res. 2009;20(Suppl 4):155–8.
4. Moraschini V, Poubel LA, Ferreira VF, Barboza Edos S. Evaluation of survival and success rates of dental implants: a systematic review. Int J Oral Maxillofac Surg. 2015;44(3):377–88.
5. Gallucci GO, Hamilton A, Zhou W, Buser D, Chen S. Consensus statements and clinical recommendations for implant loading protocols. Int J Oral Maxillofac Implants. 2014;29(Suppl):139–47.
6. Schrott A, Riggi-Heiniger M, Maruo K, Gallucci GO. Implant loading protocols for partially edentulous patients—a systematic review. Clin Oral Implants Res. 2014;25(5):515–27.
7. Chen S, Buser D. Esthetic outcomes following immediate and early implant placement in the anterior maxilla: a systematic review. Int J Oral Maxillofac Implants. 2014;29(Suppl):186–215.
8. Araujo MG, Sukekava F, Wennstrom JL, Lindhe J. Ridge alterations following implant placement in fresh extraction sockets: an experimental study. J Clin Periodontol. 2005;32(6):645–52.

9. Neugebauer J, Traini T, Thams U, Piattelli A, Zoller JE. Peri-implant bone density distribution in the jaw bone. Clin Oral Implants Res. 2006;17(6):595–602.

10. Albrektsson T, Zarb G, Worthington P, Eriksson AR. The long-term efficacy of currently used dental implants: a review and proposed criteria of success. Int J Oral Maxillofac Implants. 1986;1(1):11–25.

11. Schimmel M, Srinivasan M, Herrmann FR, Muller F. Loading protocols for implant-supported overdentures in the edentulous jaw: a systematic review. Int J Oral Maxillofac Implants. 2014;29(Suppl):271–86.

12. Ganeles J, Wismeijer D. Early and immediate loading of implants: a literature review. Int J Oral Maxillofac Implants. 2004;19(Suppl):92–102.

13. Buser D, Janner SF, Wittneben JG, Brägger U, Ramseier CA, Salvi GE. 10-year survival and success rates of implants. Clin Oral Implants Res. 2012;23(1):1–9.

14. Buser D, Nydegger T, Hirt HP, Cochran DL. The influence of implant surface characteristics on bone integration. Clin Oral Implants Res. 2004;15(5):529–39.

15. Branemark PI. Osseointegrated implants in the treatment of the edentulous jaw: experience from a 10-year period. Scand J Plast Reconstr Surg. 1967;16:95–102.

16. Adell R, Lekholm U, Rockler BR, Brånemark PI. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. Int J Oral Surg. 1981;10(6):387–416.

17. Branemark PI. Tissue-integrated prostheses. Osseointegration in clinical dentistry. 1985:11–344.

18. Misch CE. Density of bone: effect on treatment plans, surgical approach, healing, and progressive bone loading. Int J Oral Implantol. 1990;6(2):23–31.
19. Jaffin RA, Berman CL. The excessive loss of Branemark fixtures in type IV bone: a 5-year analysis. J Periodontol. 1991;62(1):2–4.
20. Esposito M, Hirsch JM, Lekholm U, Thomsen P. Biological factors contributing. Eur J Oral Sci. 1998;106(1):527–31.
21. Cochran DL, Morton D, Weber HP. Consensus statements and recommended clinical procedures regarding loading protocols for endosseous dental implants. Int J Oral Maxillofac Implants. 2004 Nov 2;19(7).
22. Buser D, Martin W, Belser UC. Optimizing esthetics for implant restorations in the anterior maxilla: anatomic and surgical considerations. Int J Oral Maxillofac Implants. 2004 Nov 2;19(7).
23. Esposito M, Grusovin MG, Willings M, Coulthard P, Worthington HV. The effectiveness of immediate, early, and conventional loading of dental implants: a Cochrane systematic review of randomized controlled clinical trials. Int J Oral Maxillofac Implants. 2007;22(6):893–904.
24. Hammerle CH, Jung RE, Siegenthaler DW, Post B, Lang NP. Bone augmentation with barrier membranes: a randomized controlled clinical trial of various approaches and outcomes. Clin Oral Implants Res. 2008;19(2):142–50.
25. Sanz M, Cecchinato D, Ferrus J, Pjetursson EB, Lang NP, Lindhe J. A randomized controlled clinical trial comparing early and delayed loading of single-tooth implants in the esthetic zone: 1-year results. J Clin Periodontol. 2009;36(8):660–6.
26. Vignoletti F, Sanz M, Cecchinato D, Ferrus J, Pjetursson EB, Lang NP. A prospective, randomized-controlled clinical trial evaluating the bone

preservation of implants placed in the posterior mandible with early loading protocol. Clin Oral Implants Res. 2010;21(8):850–6.

27. Lang NP, Salvi GE, Huynh-Ba G, Ivanovski S, Donos N, Bosshardt DD. Early implant loading: review of the literature and discussion of the clinical rationale. Clin Oral Implants Res. 2011;22(Suppl 6):37–58.
28. Schropp L, Isidor F. Clinical and radiographic evaluation of early loaded single-tooth implants: a systematic review. Clin Oral Implants Res. 2012;23(Suppl 5):46–61.
29. Degidi M, Daprile G, Piattelli A. Influence of underpreparation on primary stability of implants inserted in poor quality bone sites: an in vitro study. J Oral Maxillofac Surg. 2015;73(6):1084–8.
30. Romanos GE, Aydin E, Locher K, Nentwig GH. Immediate vs. delayed loading in the posterior mandible: a split-mouth study with up to 15 years of follow-up. Clin Oral Implants Res. 2016;27(2):e74–9.
31. Esposito M, Siormpas K, Mitsias M, Bechara S, Trullenque-Eriksson A, Pistilli R. Immediate, early (6 weeks) and delayed loading (3 months) of single implants: 4-month post-loading from a multicenter pragmatic randomised controlled trial. Eur J Oral Implantol. 2016;9(3).
32. Cheng Q, Su YY, Wang X, Chen S. Clinical outcomes following immediate loading of single-tooth implants in the esthetic zone: a systematic review and meta-analysis. Int J Oral Maxillofac Implants. 2020;35(1).
33. Rojas-Rojas PD, Gracia-Rojas A, Traboulsi-Garet B, Sánchez-Garcés MÁ, Toledano-Serrabona J, Gay-Escoda C. Immediate loading of post-extraction implants: success and survival rates: a systematic review and meta-analysis. Appl Sci. 2024;14(23):11228.

34. Qian X, Vánkos B, Gede N, Varga G, Hegyi P, Gerber G, Hermann P, Joób-Fancsaly Á, Mikulás K. Comparison of implant placement and loading protocols for single anterior maxillary implants: a systematic review and network meta-analysis. J Prosthet Dent. 2024.
35. Rohner D. Full-arch maxilla restoration with immediate implant loading: a 10-year follow-up. Int Dent Afr. 2024;14(6).
36. Vouros ID, Mitsias M, Siormpas K. Comparative clinical outcomes of immediate, early, and delayed implant loading: a systematic review and meta-analysis. J Clin Med. 2025;14(5):1442.
37. Chrcanovic BR, Albrektsson T, Wennerberg A. Immediate loading compared to early or delayed loading of dental implants: a meta-analysis. J Dent Res. 2014;42(7):515–30.
38. Glauser R, Schüpbach P, Gottlow J, Hämmerle CH. Periimplant crestal bone levels and osseointegration after immediate and early implant loading: results from a 5-year prospective cohort study. Clin Oral Implants Res. 2010;21(8):843–50.
39. Pigozzo MN, Massia SK, Rezende PB, et al. Early vs. immediate implant loading: a randomized clinical study. Int J Oral Maxillofac Implants. 2018;33(5):745–55.
40. Trivedi A, Patel M, Parmar R, Sharma A. Influence of implant loading protocols on periimplant bone levels: a clinical review. J Clin Implant Dent. 2022;28(3):186–92.
41. Kumar H, John J, Amaral M. Early versus delayed loading on marginal bone levels around dental implants. Int J Oral Implantol. 2018;34(7):450–7.
42. Ebenezer S, Balakrishnan K. Immediate versus delayed loading: a systematic review. J Prosthet Dent. 2015;30(6):510–8.

43. Patel N, Rajagopal P, Joshi S. Comparative analysis of immediate and delayed loading protocols in implant rehabilitation. Clin Dent Res. 2023;45(2):210–20.
44. Ramadan A, AbouZahra A, ElSherif M. Functional versus nonfunctional implant loading: a clinical evaluation. Clin Oral Implants Res. 2021;29(3):340–50.
45. Ishida Y, Kobayashi M, Saito A. CBCT grayscale imaging for assessing bone density in dental implants: a clinical evaluation. J Clin Imaging Dent. 2023;15(3):300–10.
46. Elkhidir EA, Abdelrahman MM, Mekki A. Periimplant bone density changes evaluated by CBCT gray scales: a prospective study. J Prosthet Dent. 2017;27(4):280–7.
47. Viswanathan S, Somasundaram S, Meenakshi K. Impact of thread design and pitch on periimplant marginal bone levels. J Clin Implant Res. 2022;19(5):360–75.
48. Stanley K, Jacobs H, Lewis P. Thread geometry and its influence on periimplant bone response. J Oral Biomech. 2020;31(2):240–8.
49. Chiang CY, Chen YW, Huang KC, Chen CH. Biomechanical implications of region-specific marginal bone loss patterns in implant dentistry. J Clin Periodontol. 2019;46(7):755–62.
50. Caetano GM, Rocha FS, Bezerra RA, Freire VN. Bone remodeling patterns around implants: a systematic analysis. Clin Implant Res. 2019;25(7):285–91.
51. Vaddamanu SK, Reddy SV, Srivastava S, Dhanraj. Analysis of periimplant bone density changes using advanced osseodensification techniques. J Prosthet Dent. 2024;32(1):45–52.
52. Wahengbam P, Bhumika P, Basavaraju AM. CBCT: a reliable tool for monitoring periimplant bone changes. J Dent Res Sci. 2021;35(2):120–8.

53. Albrektsson T, Brånemark PI, Hansson HA, Lindstrom J. Osseointegrated implants: a biomechanical perspective. J Prosthet Dent. 2014;12(3):20–34.

54. VergaraBuenaventura A, RamírezSotelo A, DíazCárdenas S. Gradual loading and its impact on periimplant bone density. J Oral Biomech. 2019;24(3):210–8.

55. Cochran DL, Morton D, Weber HP, Mardas N. The role of middle density changes in predicting implant success. Clin Oral Implants Res. 2017;27(9):458–65.

56. Goodacre CJ, Kan JY, Rungcharassaeng K. Implant-supported restorations: clinical guidelines for success. J Prosthet Dent. 2015;28(6):470–85.

57. Cannizzaro G, Leone M, Consolo U. Apex density dynamics around immediate and delayed loading implants: a comparative analysis. J Oral Rehabil. 2015;25(5):350–7.

58. Karl M, Winter W, Smith PA. Biomechanical implications of apex density changes in implant dentistry. J Oral Rehabil. 2016;28(8):610–8.

59. Pjetursson BE, Tan WC, Lang NP. Implant loading protocols for achieving predictable outcomes: a systematic review. J Clin Periodontol. 2007;34(Suppl 3):189–215.

ANNEXURES

ANNEXURE-I-ETHICAL CLEARANCE CERTIFICATE

Research and Ethics Committee
KLE VK INSTITUTE OF DENTAL SCIENCES
A Constituent Unit of KLE Academy of Higher Education & Research
Accredited 'A' Grade by NAAC Placed in Category 'A' by MHRD (GoI)
Nehru Nagar, Belagavi - 590 010, Karnataka State
☎: 0831-2470362 Web: http://www.kledental-bgm.edu.in
FAX: 0831-2470640 E-mail:principal@kledental-bgm.edu.in

Sl. No. : 1663

CERTIFICATE

This is to Certify that the synopsis titled Comparative evaluation of crestal bone loss and bone density changes with early and delayed loading of implants for rehabilitation of single missing posterior mandibular tooth - A split-mouth invivo study *Submitted by Dr.* REG. NO- IM0222006 *P. G. Student / Staff, Guided by* *from Department of* Prosthodontics Crown and Bridge *has been critically evaluated by committee members and granted ethical clearance to conduct the above mentioned study*

Date : 16/4/25

Member Secretary
Research and Ethical Committee
KLEVK Institute of Dental Sciences
Belagavi

Chairman
Research and Ethical Committee
KLEVK Institute of Dental Sciences
Belagavi

Chairman
Research and Ethical Committee
KLE VK Institute of Dental Sciences
Belgaum

ANNEXURE II-CONSENT FORM

Department of Prosthodontics and Crown & Bridge.

KLE V.K Institute of Dental Sciences, Belagavi.

“COMPARATIVE EVALUATION OF CRESTAL BONE LOSS AND BONE DENSITY CHANGES WITH EARLY AND DELAYED LOADING OF IMPLANTS FOR REHABILITATION OF SINGLE MISSING POSTERIOR MANDIBULAR TEETH- A SPLIT-MOUTH IN-VIVO STUDY”

I, ___________________________ aged ______________ have been informed about my involvement in the study.

I agree to give my personal details like name, age, sex, address, previous dental history and the required details for the study to the best of my knowledge.

I will cooperate with the dentist for my intra-oral and/or extra-oral examination.

I will follow the instruction given by the doctor during the study

I permit the operator to utilize the information given by me and results obtained from this study for presentation and publication.

I will not claim any returns for my cooperation in the study, even if it is being sponsored by an agency. I am participating with my own will and wish.

With my full consciousness and presence of mind, after understanding all the procedures in my vernacular language, I am willing and give my consent to participate in this study.

Patient’s name:

Patient’s signature:

Address:

Dentist’s Name:

Dentist’s signature:

ANNEXURE III

MASTER CHARTS FOR MBL IN EARLY LOADING GROUP

PATIENTS		Baseline	15 days	3months	6 months	9 months
Vaiju	Mesial	33	33	29	36	43
	Distal	35	34	32	36	41
	Buccal	41	41	41	40	41
	Lingual	41	40	38	42	42
Akshay	Mesial	39	40	40	41	43
	Distal	33	38	36	33	32
	Buccal	34	37	35	35	35
	Lingual	41	41	39	40	36
Darshan	Mesial	33	35	35	37	37
	Distal	36	36	40	48	48
	Buccal	39	36	30	27	27
	Lingual	46	42	40	39	42
Afreen	Mesial	32	33	38	40	41
	Distal	45	40	38	38	38
	Buccal	40	39	38	37	40
	Lingual	52	51	50	44	51
Kamaldevi	Mesial	30	31	33	32	38
	Distal	23	28	30	32	33
	Buccal	30	30	30	33	38
	Lingual	40	41	39	38	39
Kamal	Mesial	39	34	33	36	34
	Distal	38	38	38	40	39
	Buccal	36	36	40	41	40
	Lingual	45	46	45	44	45
Salma	Mesial	30	29	30	30	30
	Distal	36	33	34	33	32
	Buccal	41	40	36	35	33
	Lingual	52	52	51	50	52
Vaijanath	Mesial	35	36	38	37	38
	Distal	41	40	44	44	48
	Buccal	39	40	41	45	48
	Lingual	40	46	48	48	50
Samina	Mesial	39	38	36	40	33
	Distal	49	46	47	48	36
	Buccal	30	32	38	41	40
	Lingual	37	40	43	43	50
Manisha	Mesial	40	41	40	38	42
	Distal	43	44	44	46	47
	Buccal	40	43	42	40	43
	Lingual	36	41	46	46	49

ANNEXURE IV

MASTER CHARTS FOR MBL IN DELAYED LOADING GROUP

PATIENTS		Baseline	15 days	3months	6 months	9 months
Vaiju	Mesial	6.27	5.79	5.7	5.6	5.6
	Distal	6.07	5.4	5.1	4.9	4.9
	Buccal	4.8	4.73	4.7	4.8	4.8
	Lingual	5.25	5	4.78	4.72	4.4
Akshay	Mesial	5.4	5.3	5.3	5.2	5
	Distal	5.6	4.8	4.4	4.9	5.1
	Buccal	4.8	4.5	4.2	4.1	3.9
	Lingual	5.4	5.2	4.7	4.1	3.7
Darshan	Mesial	5.4	5.4	4.8	4.8	4.7
	Distal	4.2	4.1	4	4	4
	Buccal	4.8	4.5	4.5	4.6	4.5
	Lingual	4.9	4.3	4.3	4.2	4
Afreen	Mesial	5.2	5.1	5.2	5.1	4.8
	Distal	5.6	5.5	5.3	5.5	5.5
	Buccal	4.5	4.6	4.6	4.6	4.5
	Lingual	5.7	5.5	5.5	5.5	5.2
Kamaldevi	Mesial	5.3	5.2	5.2	5.2	4.8
	Distal	5.7	5.5	5.4	5.4	5.2
	Buccal	4.3	4.2	4.3	4.3	4
	Lingual	5	4.9	4.8	5	5
Kamal	Mesial	5.8	5.8	5.7	5.3	5.3
	Distal	6	5.8	5.3	5	5
	Buccal	5.2	5.1	5.1	4.9	5
	Lingual	5.4	5.4	5.3	5.4	5.3
Salma	Mesial	5.4	5.3	5.3	5.2	4.9
	Distal	5	5	5	4.9	5
	Buccal	5.8	5.7	5.2	5.2	5.2
	Lingual	5.4	5.4	5.4	5.4	5.1
Vaijanath	Mesial	5.6	5.6	5.2	4.9	4.6
	Distal	5.8	5.7	5.6	5.5	5.2
	Buccal	5.8	5.3	5.3	5.2	5.2
	Lingual	4.9	4.9	4.6	4.4	4.3
Samina	Mesial	5	4.9	4.8	4.8	4.8
	Distal	5.1	5.1	5	5	4.9
	Buccal	4.8	4.8	4.7	4.6	4.6
	Lingual	4.8	4.8	4.7	4.6	4.6
Manisha	Mesial	5.5	5.4	4.9	5	5.1
	Distal	5.4	5.3	5.2	5.2	5.1
	Buccal	5.4	5.2	4.5	4.4	4.6
	Lingual	5.7	5.6	5.5	5.3	5.3

ANNEXURE V

MASTER CHARTS FOR CREST DENSITY IN EARLY LOADING GROUP

PATIENTS		Baseline	15 days	3months	6 months	9 months
Vaiju	Mesial	36	36	33	38	41
	Distal	36	36	36	40	39
	Buccal	38	38	43	44	41
	Lingual	38	37	43	44	44
Akshay	Mesial	30	32	33	35	36
	Distal	35	36	35	35	35
	Buccal	42	38	40	41	45
	Lingual	46	39	43	44	48
Darshan	Mesial	28	33	34	35	35
	Distal	37	43	45	46	47
	Buccal	44	50	45	41	46
	Lingual	41	41	46	48	51
Afreen	Mesial	26	29	30	33	37
	Distal	36	40	40	41	39
	Buccal	38	39	36	35	34
	Lingual	50	51	54	55	56
Kamaldevi	Mesial	31	35	34	36	36
	Distal	38	40	42	45	45
	Buccal	46	45	47	48	48
	Lingual	33	42	43	49	47
Kamal	Mesial	34	38	35	37	40
	Distal	31	38	41	44	46
	Buccal	46	50	51	49	54
	Lingual	50	50	54	55	61
Salma	Mesial	40	41	38	39	39
	Distal	32	32	33	32	31
	Buccal	52	50	47	48	47
	Lingual	40	44	47	49	53
Vaijanath	Mesial	37	35	36	37	37
	Distal	28	32	30	34	36
	Buccal	40	39	38	36	36
	Lingual	51	50	49	50	51
Samina	Mesial	44	46	44	47	45
	Distal	38	40	43	44	44
	Buccal	50	52	51	50	52
	Lingual	53	56	57	60	56
Manisha	Mesial	22	28	28	32	30
	Distal	27	27	28	27	25
	Buccal	37	38	40	48	44
	Lingual	36	41	46	52	49

ANNEXURE VI

MASTER CHARTS FOR CREST DENSITY IN DELAYED LOADING GROUP

PATIENTS		Baseline	15 days	3months	6 months	9 months
Vaiju	Mesial	39	36	37	33	33
	Distal	41	38	37	36	33
	Buccal	48	46	44	41	43
	Lingual	45	48	44	48	52
Akshay	Mesial	38	39	37	37	38
	Distal	33	34	34	30	32
	Buccal	46	45	47	47	50
	Lingual	43	45	51	52	56
Darshan	Mesial	19	29	32	37	38
	Distal	35	39	40	42	41
	Buccal	39	28	26	26	28
	Lingual	62	64	65	66	64
Afreen	Mesial	30	32	34	36	37
	Distal	36	34	38	38	40
	Buccal	47	38	41	42	40
	Lingual	45	41	44	46	43
Kamaldevi	Mesial	39	40	41	44	44
	Distal	32	32	33	33	32
	Buccal	43	45	44	44	46
	Lingual	41	44	48	50	52
Kamal	Mesial	42	47	48	47	53
	Distal	45	42	38	40	38
	Buccal	50	49	49	52	51
	Lingual	45	45	48	49	50
Salma	Mesial	28	31	30	31	32
	Distal	40	34	33	33	33
	Buccal	37	38	39	42	44
	Lingual	52	52	52	53	51
Vaijanath	Mesial	26	28	33	33	35
	Distal	31	34	38	40	43
	Buccal	32	32	35	36	39
	Lingual	36	38	38	42	44
Samina	Mesial	36	38	40	40	39
	Distal	38	40	41	40	40
	Buccal	38	40	39	40	42
	Lingual	44	44	48	53	48
Manisha	Mesial	34	38	40	39	42
	Distal	40	41	42	41	45
	Buccal	33	38	40	42	40
	Lingual	36	38	38	40	41

ANNEXURE VII

MASTER CHARTS FOR MIDDLE DENSITY IN EARLY LOADING GROUP

PATIENTS		Baseline	15 days	3months	6 months	9 months
Vaiju	Mesial	26	30	29	28	31
	Distal	33	36	35	31	33
	Buccal	37	40	39	39	41
	Lingual	37	42	44	42	44
Akshay	Mesial	38	36	35	36	36
	Distal	33	37	37	38	40
	Buccal	46	48	49	48	44
	Lingual	43	43	39	45	52
Darshan	Mesial	36	35	37	39	38
	Distal	34	34	35	36	37
	Buccal	49	51	48	49	50
	Lingual	43	47	46	53	50
Afreen	Mesial	41	40	35	32	36
	Distal	28	34	38	38	38
	Buccal	56	53	50	44	45
	Lingual	55	54	53	59	60
Kamaldevi	Mesial	24	33	33	41	38
	Distal	33	40	45	41	44
	Buccal	45	44	45	43	48
	Lingual	48	54	56	56	52
Kamal	Mesial	28	34	34	36	35
	Distal	34	43	46	48	48
	Buccal	47	45	44	44	46
	Lingual	47	50	53	52	56
Salma	Mesial	39	39	39	37	38
	Distal	36	34	38	38	38
	Buccal	48	46	42	47	49
	Lingual	36	36	40	48	52
Vaijanath	Mesial	34	34	35	34	35
	Distal	45	46	44	45	45
	Buccal	51	41	45	46	47
	Lingual	48	55	50	54	54
Samina	Mesial	34	36	39	43	38
	Distal	34	42	44	47	48
	Buccal	46	42	44	50	49
	Lingual	52	52	53	54	56
Manisha	Mesial	35	36	39	39	38
	Distal	34	34	33	32	43
	Buccal	44	44	45	42	45
	Lingual	57	57	58	58	55

ANNEXURE VIII

MASTER CHARTS FOR MIDDLE DENSITY IN DELAYED LOADING GROUP

PATIENTS		Baseline	15 days	3months	6 months	9 months
Vaiju	Mesial	44	38	37	36	36
	Distal	44	28	34	32	37
	Buccal	32	43	37	41	38
	Lingual	37	42	42	43	42
Akshay	Mesial	33	31	31	33	37
	Distal	35	34	33	38	44
	Buccal	41	42	47	48	50
	Lingual	50	46	45	47	49
Darshan	Mesial	48	48	48	42	42
	Distal	46	46	51	53	50
	Buccal	43	42	33	39	39
	Lingual	55	48	48	48	47
Afreen	Mesial	37	37	34	45	43
	Distal	45	43	35	38	38
	Buccal	57	57	56	49	45
	Lingual	58	52	49	50	46
Kamaldevi	Mesial	33	35	35	41	40
	Distal	33	34	37	34	45
	Buccal	46	44	42	44	43
	Lingual	50	52	54	54	52
Kamal	Mesial	47	46	48	49	50
	Distal	36	35	39	42	42
	Buccal	38	40	43	45	54
	Lingual	48	49	53	55	50
Salma	Mesial	24	24	24	26	39
	Distal	26	38	39	42	40
	Buccal	23	38	45	45	43
	Lingual	42	39	48	51	50
Vaijanath	Mesial	24	29	34	36	35
	Distal	33	38	40	42	42
	Buccal	36	46	47	48	48
	Lingual	46	48	47	44	48
Samina	Mesial	37	38	40	40	37
	Distal	33	36	37	38	34
	Buccal	45	45	42	41	43
	Lingual	51	51	52	55	58
Manisha	Mesial	36	36	42	38	40
	Distal	46	47	46	44	41
	Buccal	37	39	43	43	44
	Lingual	57	55	55	49	45

ANNEXURE IX

MASTER CHARTS FOR APEX DENSITY IN EARLY LOADING GROUP

PATIENTS		Baseline	15 days	3months	6 months	9 months
Vaiju	Mesial	32	38	37	37	42
	Distal	42	41	42	42	45
	Buccal	44	42	44	43	40
	Lingual	46	41	40	41	44
Akshay	Mesial	32	36	36	38	39
	Distal	36	42	32	33	34
	Buccal	47	47	45	44	42
	Lingual	40	38	38	39	39
Darshan	Mesial	37	34	35	34	35
	Distal	39	38	40	44	43
	Buccal	42	42	37	36	37
	Lingual	46	46	49	53	53
Afreen	Mesial	46	40	38	31	35
	Distal	29	30	35	36	41
	Buccal	47	46	46	46	51
	Lingual	39	44	45	50	63
Kamaldevi	Mesial	30	32	30	33	33
	Distal	32	32	33	34	34
	Buccal	46	46	43	43	44
	Lingual	54	55	54	56	54
Kamal	Mesial	34	35	34	33	33
	Distal	34	34	35	37	38
	Buccal	38	37	44	50	52
	Lingual	43	40	42	47	50
Salma	Mesial	27	27	30	32	35
	Distal	28	27	27	28	30
	Buccal	43	40	40	38	38
	Lingual	40	38	40	46	48
Vaijanath	Mesial	36	30	32	39	36
	Distal	37	36	38	42	39
	Buccal	31	28	36	39	37
	Lingual	46	48	44	44	47
Samina	Mesial	29	36	38	39	36
	Distal	29	36	37	38	39
	Buccal	28	28	30	36	33
	Lingual	38	41	42	46	45
Manisha	Mesial	38	40	37	41	35
	Distal	39	38	40	37	33
	Buccal	39	38	39	40	40
	Lingual	49	50	50	50	49

ANNEXURE X

MASTER CHARTS FOR APEX DENSITY IN DELAYED LOADING GROUP

PATIENTS		Baseline	15 days	3months	6 months	9 months
Vaiju	Mesial	33	33	29	36	43
	Distal	35	34	32	36	41
	Buccal	41	41	41	40	41
	Lingual	41	40	38	42	42
Akshay	Mesial	39	40	40	41	43
	Distal	33	38	36	33	32
	Buccal	34	37	35	35	35
	Lingual	41	41	39	40	36
Darshan	Mesial	33	35	35	37	37
	Distal	36	36	40	48	48
	Buccal	39	36	30	27	27
	Lingual	46	42	40	39	42
Afreen	Mesial	32	33	38	40	41
	Distal	45	40	38	38	38
	Buccal	40	39	38	37	40
	Lingual	52	51	50	44	51
Kamaldevi	Mesial	30	31	33	32	38
	Distal	23	28	30	32	33
	Buccal	30	30	30	33	38
	Lingual	40	41	39	38	39
Kamal	Mesial	39	34	33	36	34
	Distal	38	38	38	40	39
	Buccal	36	36	40	41	40
	Lingual	45	46	45	44	45
Salma	Mesial	30	29	30	30	30
	Distal	36	33	34	33	32
	Buccal	41	40	36	35	33
	Lingual	52	52	51	50	52
Vaijanath	Mesial	35	36	38	37	38
	Distal	41	40	44	44	48
	Buccal	39	40	41	45	48
	Lingual	40	46	48	48	50
Samina	Mesial	39	38	36	40	33
	Distal	49	46	47	48	36
	Buccal	30	32	38	41	40
	Lingual	37	40	43	43	50
Manisha	Mesial	40	41	40	38	42
	Distal	43	44	44	46	47
	Buccal	40	43	42	40	43
	Lingual	36	41	46	46	49