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EFFECT OF NOVALOC AND EQUATOR ATTACHMENTS RETAINING 3D-PRINTED MANDIBULAR SINGLE-IMPLANT OVERDENTURES ON PERI-IMPLANT BONE HEIGHT AND BONE DENSITY: A RANDOMIZED CLINICAL TRIAL

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Abstract

Background: Mandibular implant overdentures have become a well-established treatment modality for the rehabilitation of completely edentulous patients by improving prosthesis retention, stability, masticatory efficiency, and patient satisfaction compared with conventional complete dentures. Although two-implant overdentures are considered the standard of care, a single midline implant has emerged as a cost-effective and less invasive alternative while maintaining favorable clinical outcomes. Recent advances in digital dentistry and additive manufacturing have further improved prosthetic fabrication by enabling the production of highly accurate three-dimensional (3D)-printed overdentures with reduced manufacturing time and enhanced reproducibility. Despite these developments, the influence of different stud attachment systems on peri-implant bone preservation in 3D-printed single-implant mandibular overdentures remains insufficiently documented. **Materials and Methods:** Twenty completely edentulous patients were enrolled in this prospective randomized clinical study and received a single implant placed in the mandibular symphyseal region. After the osseointegration period, all participants were rehabilitated with 3D printed mandibular single implant overdenture. Patients were randomly allocated into two equal groups (n = 10): Group I received the OT Equator attachment system, whereas Group II received the Novaloc attachment system. Peri-implant crestal bone height and peri-implant bone density were assessed using cone-beam computed tomography (CBCT) at overdenture insertion (T0), six months (T1), and twelve months (T2). Statistical analysis was performed to evaluate both intergroup and intragroup differences, with the level of significance set at $P < 0.05$. **Results:** Both attachment systems demonstrated successful clinical performance throughout the one-year follow-up period. A reduction in peri-implant bone height and bone density were observed in both groups over time. No statistically significant differences were detected between the groups at baseline or after six months. However, after twelve months, the Novaloc group exhibited significantly greater preservation of peri-implant bone height and bone density compared with the Equator group ($P < 0.05$). The percentage of crestal bone loss and reduction in bone density were consistently lower in the Novaloc group throughout the study period.: **Conclusions:** Both OT Equator and Novaloc attachment systems provided effective retention for 3D-printed mandibular single-implant overdentures and demonstrated favorable clinical outcomes during the first year of function. Nevertheless, the Novaloc attachment exhibited superior preservation of peri-implant bone height and bone density, suggesting a more favorable biomechanical distribution of occlusal stresses. Long-term clinical studies with larger sample sizes are recommended to confirm these findings.

Keywords: Single Implant Overdenture; 3D-Printed Overdenture; Novaloc Attachment; OT Equator; Peri-Implant Bone Height; Bone Density; CBCT; Cone-Beam Computed Tomography.

INTRODUCTION

Complete edentulism remains a significant global health problem, particularly among older adults, owing to its adverse effects on mastication, speech, facial esthetics, and oral health-related quality of life (Borg-Bartolo et al., 2022). Although conventional complete dentures remain the most widely used treatment option for edentulous patients, mandibular dentures frequently exhibit inadequate retention and stability because of progressive alveolar ridge resorption, reduced denture-bearing area, and the influence of surrounding musculature. These limitations often result in impaired masticatory function and reduced patient satisfaction (Soboleva & Rogovska, 2022).

Advances in digital dentistry have further expanded the application of implant-retained overdentures. Three-dimensional (3D) printing technologies provide a fully digital workflow capable of producing dentures with improved dimensional accuracy, reduced fabrication time, and enhanced reproducibility compared with conventional manufacturing techniques. Consequently, 3D-printed overdentures have become an increasingly attractive treatment option in contemporary prosthodontics (Elawady et al., 2021).Implant-retained mandibular overdentures have become a predictable and evidence-based treatment modality for overcoming the limitations associated with conventional complete dentures.

Among the available treatment options, the mandibular single-implant overdenture has gained considerable attention as a cost-effective and minimally invasive alternative that improves denture retention, stability, and patient comfort while reducing both surgical intervention and treatment cost (Fayad et al., 2019). The long-term clinical success of implant-retained overdentures is influenced not only by implant survival but also by the attachment system used to retain the prosthesis. Attachment systems play a fundamental role in determining prosthesis retention, stress distribution, denture movement, and the transmission of functional loads to the supporting implant and surrounding bone. Variations in attachment design, resilience, material composition, and retentive characteristics may therefore affect peri-implant bone preservation during function (Nassar & Abdelaziz, 2022).

Peri-implant bone height and bone density are considered important biological indicators of implant success and long-term treatment stability. Evaluating changes in these parameters provides valuable information regarding the biological response of peri-implant tissues and the biomechanical behavior of different attachment systems. Cone-beam computed tomography (CBCT) offers a reliable three-dimensional imaging modality for assessing peri-implant bone changes during longitudinal clinical follow-up (del Amo et al., 2024). Selection of the appropriate attachment system is particularly important in mandibular single-implant overdentures, where prosthesis rotation and load distribution

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differ from those observed in multiple-implant restorations. Comparing attachment systems with different mechanical characteristics may therefore improve understanding of their influence on peri-implant bone preservation, especially when combined with modern digital workflows such as 3D-printed denture fabrication (Turker & Buyukkaplan, 2020). Although the clinical application of 3D-printed overdentures has increased considerably, evidence comparing the influence of different attachment systems on peri-implant bone changes remains limited.

Therefore, the present clinical study was conducted to evaluate and compare the effects of OT Equator and Novaloc attachment systems on peri-implant bone height and bone density in patients rehabilitated with 3D printed mansibular single implant overdenture. The null hypothesis was that no significant difference would exist between the two attachment systems regarding peri-implant bone height and bone density.

MATERIALS AND METHODS

Study Design

This prospective randomized clinical trial was conducted to evaluate the influence of two resilient attachment systems, OT Equator and Novaloc, on peri-implant bone height and bone density retained 3D-printed mandibular single-implant overdentures. The study was carried out in the Department of Prosthodontics, Faculty of Dentistry, Suez Canal University, in collaboration with the Faculty of Dentistry, October University for Modern Sciences and Arts (MSA). Ethical approval was obtained from the institutional Research Ethics Committee before commencement of the study, and all participants signed written informed consent prior to enrollment. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Sample Size and Patient Selection

Twenty completely edentulous male patients were recruited for the study. Participants were selected according to predetermined inclusion and exclusion criteria to minimize confounding variables that might influence peri-implant bone remodeling.

Inclusion Criteria

Participants Fulfilled The Following Criteria:

- Completely edentulous for at least one year.
- Adequate bone volume in the mandibular symphyseal region to receive a dental implant.
- Bone quality corresponding to Misch Classes I, II, or III.
- Sufficient keratinized mucosa surrounding the implant site.
- Interarch restorative space of at least 12 mm.
- American Society of Anesthesiologists (ASA) physical status I or II.
- Ability and willingness to attend all follow-up appointments.

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Exclusion Criteria

Patients Were Excluded If They Presented With:

- Uncontrolled systemic diseases.
- History of head and neck radiotherapy.
- Heavy smoking.
- Bruxism or severe parafunctional habits.
- Poor oral hygiene.
- Severe ridge deformities requiring augmentation procedures.
- Any condition contraindicating implant surgery.

Randomization

Following successful osseointegration, participants were randomly allocated into two equal groups (n = 10 each) using computer-generated random numbers.

- **Group I:** 10 patients received an OT Equator attachment retaining 3D printed mandibular single- implant overdenture
- **Group II:** 10 patients received a Novaloc attachment retaining 3D printed mandibular single- implant overdenture.
- Randomization was performed by an investigator not involved in clinical measurements to reduce allocation bias.

Prosthetic Procedures

All participants received maxillary complete dentures and mandibular overdenture fabricated using a fully digital workflow.Primary and secondary impressions were made according to conventional prosthodontic procedures. The impressions were scanned using 3D extraoral scanner (MEDIT) (Figure 1) to obtain digital Standard Triangulation Language (STL) files. Maxillomandibular relations were recorded conventionally and digitized before virtual articulation (Figure 2).

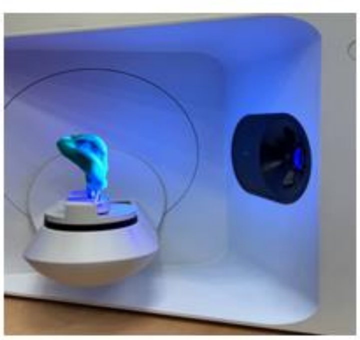

Figure 1: Scanning Of Secondary Impression

Figure 2: Scanning Of The Jaw Relation Record

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The dentures were digitally designed using CAD software. Artificial teeth were arranged digitally (Figure 3), and both denture bases and teeth were fabricated using additive manufacturing (3D printing). Following printing, cleaning, post-curing, finishing, polishing, and bonding of the printed teeth to the denture bases were performed according to the manufacturer's recommendations (Figure 4). Occlusion was clinically adjusted before denture delivery.

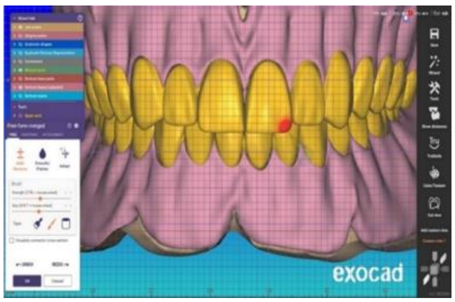

Figure 3: Setting Up Teeth

Figure 4: The Final 3d Printed Denture

Surgical Procedures

The dentures were duplicated using self-curing transparent acrylic resin, which was later modified by ball-shaped gutta percha placed in the intaglio surface at the midline of the denture base, to allocate the implant site radiographically. The radiographic stent was later used as a surgical guide (Figure 5).

Figure 5: Radiographical Stent

Twenty NewDent Implants (3.5mm x11.5mm*dual tapered implant) were placed for all participants at the midline

Each participant received one NewDent Implant (3.5mm x11.5mm*dual tapered implant) was placed in the mandibular midline (symphysis region).

Following local anesthesia, a crestal incision with two short vertical releasing incisions was performed, and a full-thickness mucoperiosteal flap was reflected (Figure 6). Implant osteotomy preparation was completed using sequential drilling under copious sterile saline irrigation according to the manufacturer's drilling protocol, started with initial drill,

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then drill 2.0 followed by the actual drill size for the used implant, 3.5 drill (Figure 7).A tapered implant was inserted using a hand ratchet until adequate primary stability was achieved. A cover screw was placed (Figure 8), and the surgical site was sutured using non-resorbable silk sutures (Figure 9).Postoperative medications included systemic antibiotics, analgesics, and chlorhexidine mouth rinse. Sutures were removed after one week, and implants were allowed to heal for three months before prosthetic loading. Using the surgical guide to locate the implants' placement site, the implants were then exposed following local anesthesia, the cover screw were removed and then replaced by healing abutment with a great care to minimize trauma of the surrounding tissues

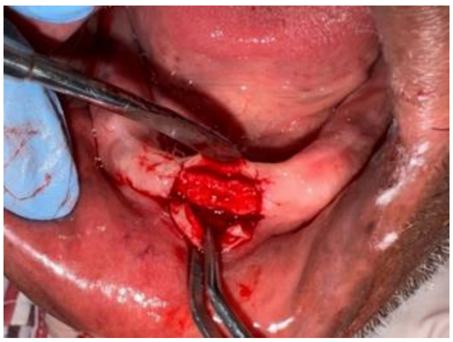

Figure 6: The Flab Reflection

Figure 7: Drill 3.5

Figure 8: Cover Screw Secured

Figure 9:000silk Non Resorbable Sutures

Attachment Placement and Overdenture Pickup

After completion of osseointegration, healing abutments were removed and replaced with the assigned attachment system. For Group I, OT Equator attachments were connected to the implants using the manufacturer's recommended insertion torque (Figure 10). Pink-Medium retention nylon caps were selected for all participants (Figure 11). For Group II, Novaloc abutments were connected using the recommended torque values (Figure 12). Yellow-Medium PEEK retentive inserts were used throughout the study (Figure 13). Direct chairside pickup was performed using the definitive retained 3D printed mandibular single implant overdenture. Relief holes were prepared in the fitting surface to allow excess resin escape and prevent hydraulic pressure during pickup. The attachment housings were secured intraorally using a dual-cure composite pickup material while patients occluded

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in maximum intercuspation. Excess material was removed, and occlusion was adjusted before denture delivery (Figure 14).

Figure 10: Equator male part

Figure 11: Equator Pink Cap

Figure 12: Novaloc male part

Figure 13: Novaloc Yellow Cap

Figure 14: Denture Insertion

Radiographic Evaluation

Peri-implant bone changes were evaluated using cone-beam computed tomography (CBCT) immediately after overdenture insertion (baseline)(T0), six months(T1), and twelve months(T2) following functional loading. All scans were obtained using the same CBCT machine (NewTom) with standardized exposure parameters to ensure consistency throughout the study.

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Bone height assessment

Peri-Implant Crestal Bone Height Was Measured In Four Standardized Locations:

- Mesial
- Distal
- Buccal
- Lingual

Measurements were obtained on reconstructed sagittal and coronal CBCT images using dedicated imaging software. The mean value of the four measurements represented the peri-implant bone height for each implant at each observation period (Figure 15).

Bone Density Assessment

Peri-implant bone density was assessed using the CBCT software by selecting standardized regions of interest surrounding the implant. Gray values obtained from identical regions at each follow-up interval were recorded. Although CBCT gray values are not equivalent to Hounsfield Units, standardized scanning conditions enabled reliable longitudinal comparison of relative bone density changes within each participant (Figure 16).

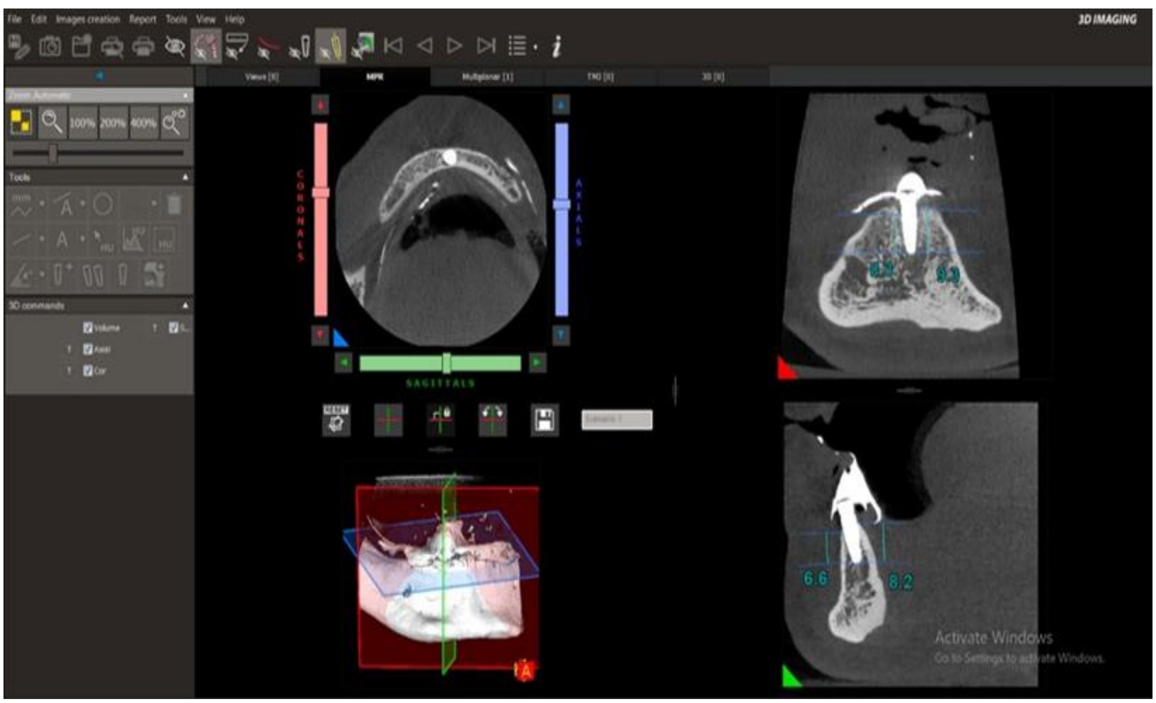

Figure 15: Bone Height Assessment

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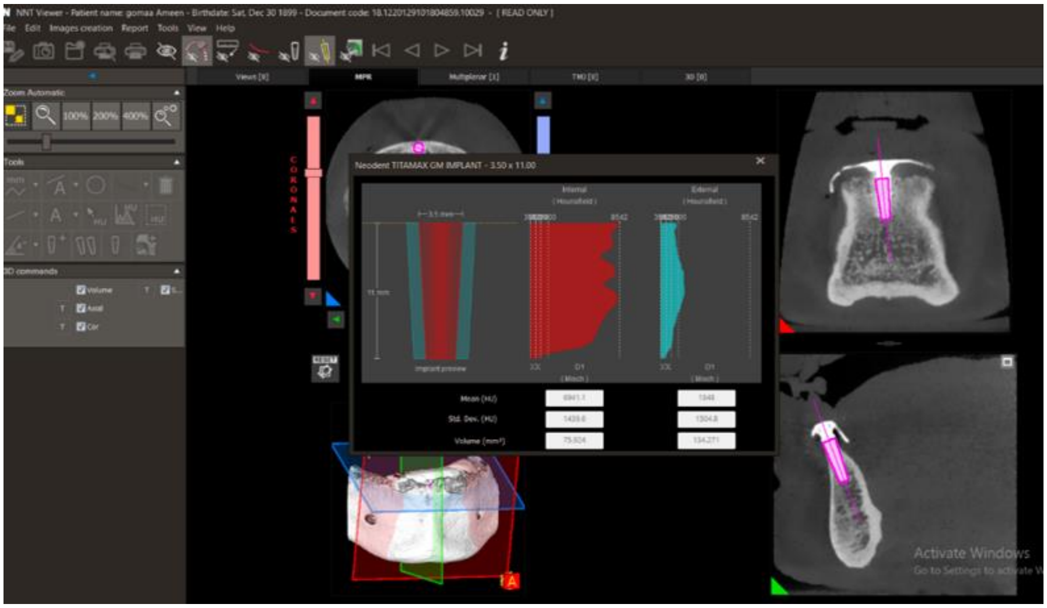

Figure 16: Bone Density Assessment

Outcome Measures

Primary Outcomes

- Peri-implant bone height.
- Peri-implant bone density.

Both parameters were evaluated at:

- Baseline (T0)
- Six months (T1)
- Twelve months (T2)

Statistical Analysis

Collected data were entered into the Statistical Package for Social Sciences (SPSS) software.

Data distribution was assessed prior to statistical analysis. Descriptive statistics were calculated as mean ± standard deviation.

Intergroup comparisons at each observation period were performed using the independent samples *t*-test. Intragroup comparisons across the three observation periods were analyzed using repeated-measures analysis of variance followed by appropriate post hoc multiple comparisons when significant differences were detected.

A probability value of **$P \leq 0.05$** was considered statistically significant for all statistical analyses.

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RESULTS

Twenty completely edentulous patients completed the study according to the planned follow-up protocol. All implants achieved successful osseointegration and remained functional throughout the 12-month observation period, resulting in an implant survival rate of 100%.

Peri-Implant Bone Height

The mean peri-implant bone height values for both groups at baseline (T0), six months (T1), and twelve months (T2) are presented in **Table 1, (Figure 17)**.

At baseline, no statistically significant difference was observed between the Equator and Novaloc groups regarding peri-implant bone height (P = 0.174). Likewise, after six months of functional loading, both groups demonstrated comparable bone height values without statistically significant differences (P = 0.116).

After twelve months, however, the Novaloc group demonstrated significantly greater preservation of peri-implant crestal bone compared with the Equator group. The mean bone height was **7.83 ± 0.13 mm** in the Novaloc group and **7.60 ± 0.19 mm** in the Equator group, representing a statistically significant difference (P = 0.006).

Table 1: Comparing Bone Height Changes between Two Groups, Equator and Novaloc, At Three Time Points (T0, T1, and T2)

Time point	Equator		Novaloc		T test	P value
	mean	SD	mean	SD		
T0	8.45	0.19	8.35	0.12	1.414	0.174
T1	8.25	0.17	8.15	0.08	1.651	0.116
T2	7.60	0.19	7.83	0.13	3.126	0.006**

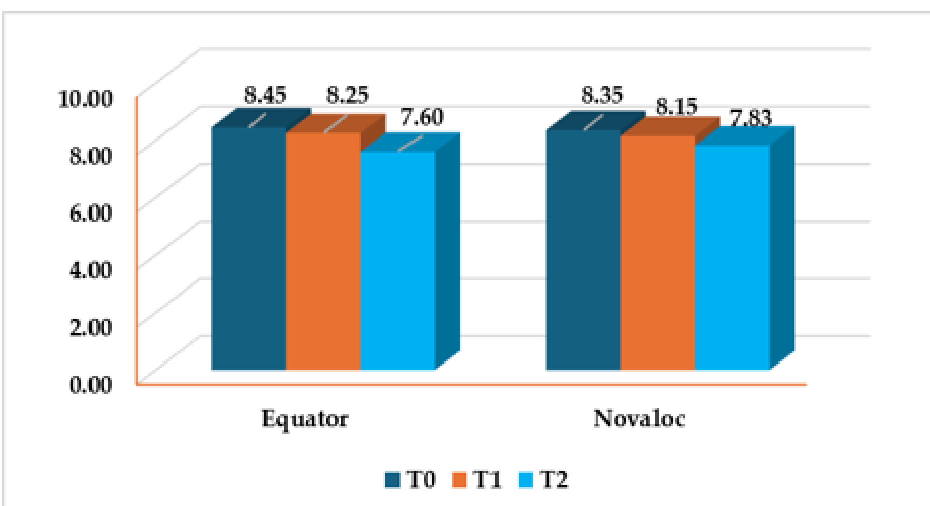

Figure 17: Comparing Bone Height Changes Between Two Groups, Equator And Novaloc, At Three Time Points (T0, T1, And T2)

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Bone Height Changes Over Time

Repeated measurements demonstrated a progressive reduction in peri-implant bone height in both groups throughout the observation period.The Equator attachment exhibited a total mean bone height reduction of **10.06%** between baseline and twelve months, whereas the Novaloc attachment demonstrated a smaller reduction of **6.29%**.

During the first six months, bone height reduction was relatively limited in both groups. Greater bone remodeling occurred during the second six-month interval; however, bone loss remained consistently lower in the Novaloc group **Table 2**.

Table 2: Compares Bone Height Changes Changes Over Time within the Equator and Novaloc Groups,

Time point	Equator		Novaloc	
	Mean	SD	Mean	SD
T0	8.45	0.19	8.35	0.12
T1	8.25	0.17	8.15	0.08
T2	7.60	0.19	7.83	0.13
F test	58.59		56.375	
P value	<0.001**		<0.001**	
%change				
T0 vs T1	-2.37		-2.40	
T0 vs T2	-10.06		-6.29	
T1 vs T2	-7.88		-3.99	
** mean significant difference at p<0.05				

Peri-implant Bone Density

Mean peri-implant bone density values obtained from CBCT gray values are presented in **Table 3, (Figure 18)**.

No statistically significant differences were observed between the two attachment systems at baseline (P = 0.861) or after six months of function (P = 0.649).

Following twelve months of functional loading, peri-implant bone density remained significantly higher around implants retained with the Novaloc attachment than around those retained with the Equator attachment.The mean bone density values after twelve months were **1739.55 ± SD** for the Novaloc group and **1702.30 ± SD** for the Equator group, with the difference reaching statistical significance (P = 0.010).

Table 3: Comparing Bone Density Changes between Two Groups, Equator and Novaloc, At Three Points (T0, T1, and T2). Bone Density

Time point	Equator		Novaloc		T test	P value
	Mean	SD	mean	SD		
T0	1988.5	24.42	1987.10	5.11	0.177	0.861
T1	1831.35	39.51	1837.25	8.23	0.462	0.649
T2	1702.30	38.50	1739.55	13.42	2.889	0.010**
** mean significant difference at p<0.05						

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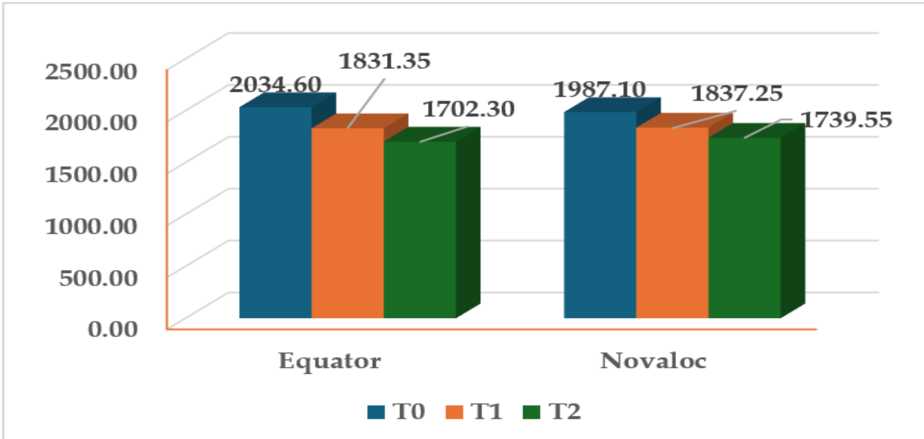

Figure 18: Comparing Bone Density Changes Between Two Groups, Equator And Novaloc, At Three Time Points (T0, T1, And T2)

Bone Density Changes Over Time

A gradual reduction in peri-implant bone density was observed in both attachment groups during the study period **Table 4**.

The Equator group demonstrated a total reduction of **14.39%**, whereas the Novaloc group exhibited a lower reduction of **12.46%** from baseline to twelve months.

Most of the density reduction occurred during the early healing period, while the subsequent six-month interval demonstrated a slower rate of decrease, particularly in the Novaloc group.

Table 4: Compares Bone Density Changes Over Time within the Equator and Novaloc Groups

Time point	Equator		Novaloc	
	Mean	SD	Mean	SD
T0	1988.5	24.42	1987.10	5.11
T1	1831.35	39.51	1837.25	8.23
T2	1702.30	38.50	1739.55	13.42
F test	231.297		703.035	
P value	<0.001**		<0.001**	
T0 vs T1	-7.90		-7.54	
T0 vs T2	-14.39		-12.46	
T1 vs T2	-7.05		-5.32	
** mean significant difference at p<0.05				

Summary of Findings

Within the limits of the present randomized clinical trial, both attachment systems maintained satisfactory peri-implant bone conditions during the first year of function. Nevertheless, Novaloc attachments demonstrated superior preservation of peri-implant bone compared with Equator attachments.

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The Principal Findings Of This Study Were:

- No statistically significant differences in peri-implant bone height or bone density were detected between the two groups at baseline or after six months.
- Both attachment systems exhibited reductions in bone height and bone density throughout the follow-up period.
- After twelve months, Novaloc attachments showed significantly less crestal bone loss and significantly greater preservation of peri-implant bone density than Equator attachments.
- These findings indicate that the attachment design and material composition may influence peri-implant bone remodeling under functional loading.

DISCUSSION

The present randomized clinical trial evaluated the influence of two resilient stud attachment systems, OT Equator and Novaloc, on peri-implant bone height and bone density supporting 3D-printed mandibular single-implant overdentures over a one-year follow-up period. Preservation of peri-implant bone remains one of the most important indicators of long-term implant success, as bone loss may compromise implant stability and ultimately affect the longevity of implant-supported prostheses (Thanissorn et al., 2022; Simão et al., 2022). Therefore, understanding how different attachment systems influence peri-implant bone remodeling is of considerable clinical importance.

The current study demonstrated a 100% implant survival rate during the first year of functional loading, indicating that both attachment systems provided successful clinical performance when used with mandibular single-implant overdentures. This favorable survival rate agrees with previous investigations reporting excellent short-term survival of single midline implants supporting mandibular overdentures (Fayad et al., 2019; Ahmed Elawady et al., 2017; Elawady et al., 2021). These findings further support the concept that a single implant positioned in the mandibular symphysis represents a predictable, minimally invasive, and cost-effective treatment option for completely edentulous patients.

The absence of statistically significant differences in peri-implant bone height and bone density between the Equator and Novaloc groups at baseline confirmed successful randomization and comparable initial clinical conditions. Because all implants were placed using the same surgical protocol and prosthetic procedures, the similarity of baseline measurements indicates that any differences observed during follow-up were primarily related to the attachment system rather than variations in implant placement or patient characteristics.

Both attachment systems exhibited progressive reductions in peri-implant bone height during the observation period. This finding is expected because crestal bone remodeling commonly occurs after implant loading as part of the physiological adaptation of bone to functional stresses. Early marginal bone changes have been attributed to biological width

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establishment, remodeling of cortical bone adjacent to the implant neck, and functional adaptation to occlusal loading (Kant et al., 2019; Kim et al., 2022; Simão et al., 2022). The magnitude of bone loss observed in the present study remained within the clinically acceptable limits reported for successful implant therapy during the first year of function (Thanissorn et al., 2022).

Interestingly, no statistically significant difference in bone height was detected between the two attachment systems after six months of functional loading. This finding suggests that the early biological response surrounding the implant was largely influenced by physiological bone remodeling rather than by differences in attachment design. During the initial healing phase, remodeling processes associated with functional adaptation may mask the mechanical influence of different attachment systems. Similar observations have been reported in previous clinical studies evaluating various overdenture attachment systems, where significant differences became evident only after prolonged functional loading (Elawady et al., 2024; Ibrahim et al., 2025).

After twelve months, however, Novaloc attachments demonstrated significantly greater preservation of peri-implant bone height compared with Equator attachments. Total crestal bone reduction reached approximately 10.06% in the Equator group compared with 6.29% in the Novaloc group. This finding suggests that attachment design and material characteristics may influence stress transmission to the supporting bone during long-term function.

One possible explanation for the superior performance of the Novaloc attachment lies in its unique material composition. Unlike conventional nylon-based attachment systems, Novaloc utilizes a polyether ether ketone (PEEK) retentive matrix combined with an amorphous diamond-like carbon (ADLC)-coated abutment. PEEK exhibits excellent wear resistance, favorable elastic properties, and high fatigue strength, allowing controlled resiliency during functional loading. The ADLC coating reduces friction and surface deterioration, thereby maintaining consistent retention and minimizing mechanical wear over time. These characteristics may promote more uniform stress distribution around the implant and consequently reduce crestal bone remodeling. This explanation is supported by studies demonstrating that resilient attachment systems improve stress distribution and decrease peri-implant stress concentrations (Nassar & Abdelaziz, 2022; Sailer et al., 2022).

Conversely, the OT Equator attachment relies on replaceable nylon retentive caps. Although nylon inserts provide satisfactory retention and resilience, they are more susceptible to wear, deformation, and gradual loss of retention during repeated insertion and removal cycles. Progressive wear of the nylon matrix may alter the biomechanics of the overdenture, potentially increasing localized stress concentration around the implant and contributing to the greater bone loss observed after prolonged function. Similar maintenance requirements and wear characteristics have been reported for stud attachment systems in previous investigations (Abou-Ayash et al., 2023; Shrivastava et al., 2023; Sutariya et al., 2021).

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Assessment of peri-implant bone density revealed a pattern similar to that observed for bone height. Bone density gradually decreased in both groups during the first year, reflecting normal bone remodeling associated with functional loading. Although no significant differences were observed at baseline or after six months, the Novaloc group demonstrated significantly greater preservation of peri-implant bone density after twelve months.

Bone density is considered an important indicator of bone quality and functional adaptation surrounding dental implants. Reduction in bone density may reflect continuous remodeling in response to mechanical loading. The smaller reduction observed around Novaloc attachments suggests that functional forces may have been distributed more evenly to the surrounding bone, reducing excessive stress concentrations and preserving trabecular architecture (Han et al., 2023; Simão et al., 2022).

These findings are consistent with biomechanical principles suggesting that resilient attachment systems capable of controlled movement can decrease peak stresses transferred to peri-implant bone. The resilient behavior of the PEEK matrix may allow limited overdenture movement during mastication, thereby reducing unfavorable lateral loading and minimizing stress accumulation around the implant neck, where marginal bone loss most commonly occurs (Nassar & Abdelaziz, 2022; Bhattacharjee et al., 2022).

CONCLUSION

Within the limitations of this randomized clinical trial, the following conclusions can be drawn:

1) Both OT Equator and Novaloc attachment systems successfully retained 3D-printed mandibular single-implant overdentures and demonstrated satisfactory clinical performance throughout the 12-month follow-up period.
2) Progressive reductions in peri-implant bone height and bone density were observed in both groups following functional loading, reflecting normal physiological bone remodeling around dental implants.
3) No statistically significant differences were found between the two attachment systems at baseline or after six months regarding peri-implant bone height or bone density.
4) After twelve months of functional loading, the Novaloc attachment system demonstrated significantly greater preservation of peri-implant bone height and bone density than the OT Equator attachment system.
5) The improved biological performance observed with the Novaloc attachment may be attributed to its resilient PEEK retentive matrix and amorphous diamond-like carbon (ADLC)-coated abutment, which may contribute to more favorable stress distribution around the supporting implant.

6) The results suggest that attachment selection plays an important role in the long-term preservation of peri-implant supporting bone in mandibular single-implant overdenture therapy.

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