RESEARCH PAPER

Stress Distribution Pattern in Implant-Abutment Connections: A Finite Element Comparison of Internal Hex and Varying External Hex Height

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ABSTRACT

Purpose: Implant abutment connection (IAC) marks the transition from surgery to prosthetics. It is the primary determinant of implant-supported prosthesis strength and stability. Over the years, many IACs have been designed to reduce stress on prosthetic components and bone-implant contact while providing stability. Currently, an internal hex connection is considered the standard for implant-supported prostheses. External hex is less preferred, due to screw loosening and micromotion, attributed to increased stress; however, it offers several advantages and a simpler prosthetic approach. Internal hex connections have a hex height of up to 1.5–2 mm. External hex connections range from 0.7 to 1.2 mm. There is limited research comparing stress distribution in external hex implants with varied hex heights to internal hex designs. If increasing the external hex height reduces stress, this could simplify the prosthetic phase which could be a major breakthrough.

Method: Thus, a three-dimensional finite element analysis was used to evaluate stress distribution between internal hex and various external hex heights.

Result: The three-dimensional finite element analysis demonstrated that increasing the external hex height resulted in a reduction in stress concentration at the implant–abutment interface and surrounding bone. External hex designs with greater hex height showed stress distribution patterns comparable to internal hex connections, indicating improved mechanical stability and reduced micromotion.

CLINICAL SIGNIFICANCE: Increasing the external hex height may reduce stress at the implant–abutment interface and surrounding bone, potentially improving mechanical stability while preserving the simpler prosthetic approach of external hex systems.

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INTRODUCTION

Dental implant therapy has evolved significantly over the last four decades, and long-term success is largely influenced by the biomechanical behavior of the implant–abutment complex. Osseointegration alone does not guarantee favorable outcomes; the manner in which functional loads are transferred through implant components to the surrounding bone plays a decisive role in maintaining peri-implant health and preventing mechanical complications. Excessive or unfavorable stress concentration at the crestal bone has been strongly associated with early marginal bone loss and subsequent biological or mechanical failure. [1–3]

The implant–abutment connection forms the junction between the implant fixture and prosthetic components, governing mechanical integrity and long-term stability of implant-supported restorations. Implant–abutment connection geometry remains a critical determinant in stress dissipation and overall implant performance. Over the years, various connection designs have been developed to reduce stress on the prosthetic component and bone–implant interface while providing acceptable prosthetic stability.

The external hex connection, introduced by Brånemark in the 1980s, was designed primarily as a prosthetic anti-

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rotational feature rather than a biomechanically optimized interface [4]. While offering excellent axial stability and clinical simplicity, traditional short external hex designs (0.7–1.2 mm) can lead to micromovement, screw loosening, and stress concentration under oblique loading [5,6]. Modifications such as increased hex height, reinforced geometry, and platform improvements have been proposed to enhance mechanical stability. Increasing external hex height beyond 1.2 mm improves rotational resistance and may alter load transfer patterns, making it an important variable for biomechanical assessment [7,8].

To overcome external hex limitations, the internal hex connection was developed, providing deeper engagement, improved lateral stability, reduced microgap movement, and better occlusal force distribution [9,10]. Internal connections generally offer improved mechanical performance and stress distribution [11], but they are more technique-sensitive, particularly for multi-unit prosthodontic rehabilitation, due to reduced tolerance for positional errors, potential misfit, and increased procedural requirements such as splinted impressions and repeated verification steps [12–14].

Despite the advantages of internal hex connections, direct comparisons with modified external hex geometries of varying heights remain limited. This highlights the need for a comprehensive evaluation of stress distribution patterns, which can guide clinical decision-making and optimize long-term implant success.

METHOD AND MATERIAL

Three-dimensional finite element models were created to represent an internal hex implant with a 1.5-mm connection and external hex implants with heights of 0.7, 1.2, and 1.5 mm using CAD-based 3D modeling software. Geometric models of dental implants were designed based on standard dimensions reported in the literature. Three models were assigned to Groups A, B, and C. Group A included an external hex implant with a 0.7 mm height and 4.1 mm diameter compared with an internal hex implant of 1.5 mm height and 4.6 mm diameter. Group B included an external hex implant with 1.2 mm height and 4.1 mm diameter compared with the same internal hex implant. Group C included an external hex implant with 1.5 mm height and 4.1 mm diameter compared with the internal hex implant. Each model incorporated a zirconia crown, a titanium implant fixture and screw, and surrounding cortical and cancellous bone. Mechanical properties for each component, including Young's modulus and Poisson's ratio, were assigned according to previously published literature and standardized for all models.

Vertical axial loads of 300 N were applied to the occlusal surface of the crowns in all models to evaluate stress distribution at the implant–abutment junction and surrounding structures. Von Mises equivalent stress analysis was performed to quantify stress concentration in the implants, abutments, crowns, and cortical and cancellous bone. Displacement and stress values were recorded for comparison across the different hex heights.

MATERIAL PROPERTIES

The mechanical properties assigned to each component were derived from previously published literature and are summarized below:

Table 1: Mechanical properties of the materials.

Location	**Material**	**Young's Modulus (MPa)**	**Poissions Ratio**
Crown	**Zirconia**	**172000**	**0.33**
Fixture Screw	**Titanium**	**103400**	**0.35**
Cortical Bone	**Cortical Bone**	**13700**	**0.30**
Cancellous Bone	**Cancellous Bone**	**1370**	**0.30**

All the 3D models of the implants and the abutment were build using Solid Edge software. Analysis was done by ANSYS software

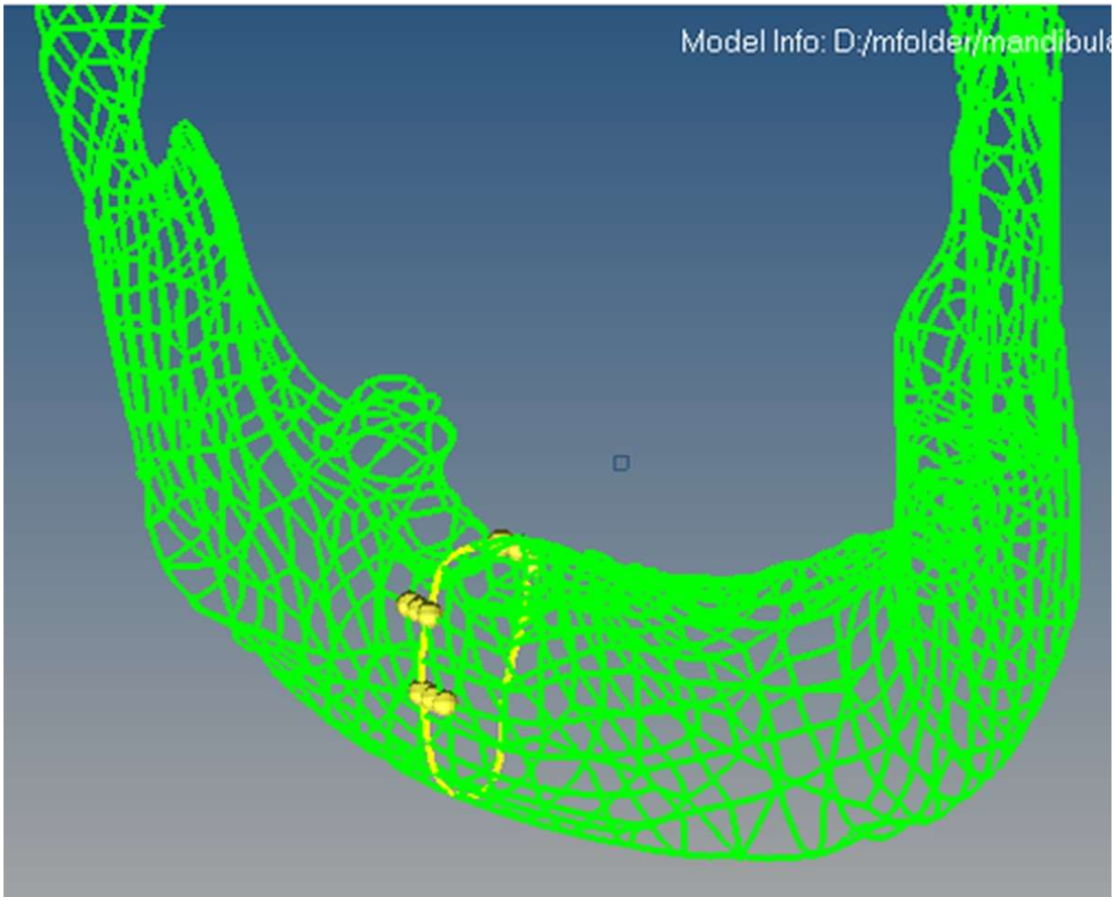


FIGURE 1 : Molar 1 region in the Mandible

FIGURE 2: Cortical and cancellous bone

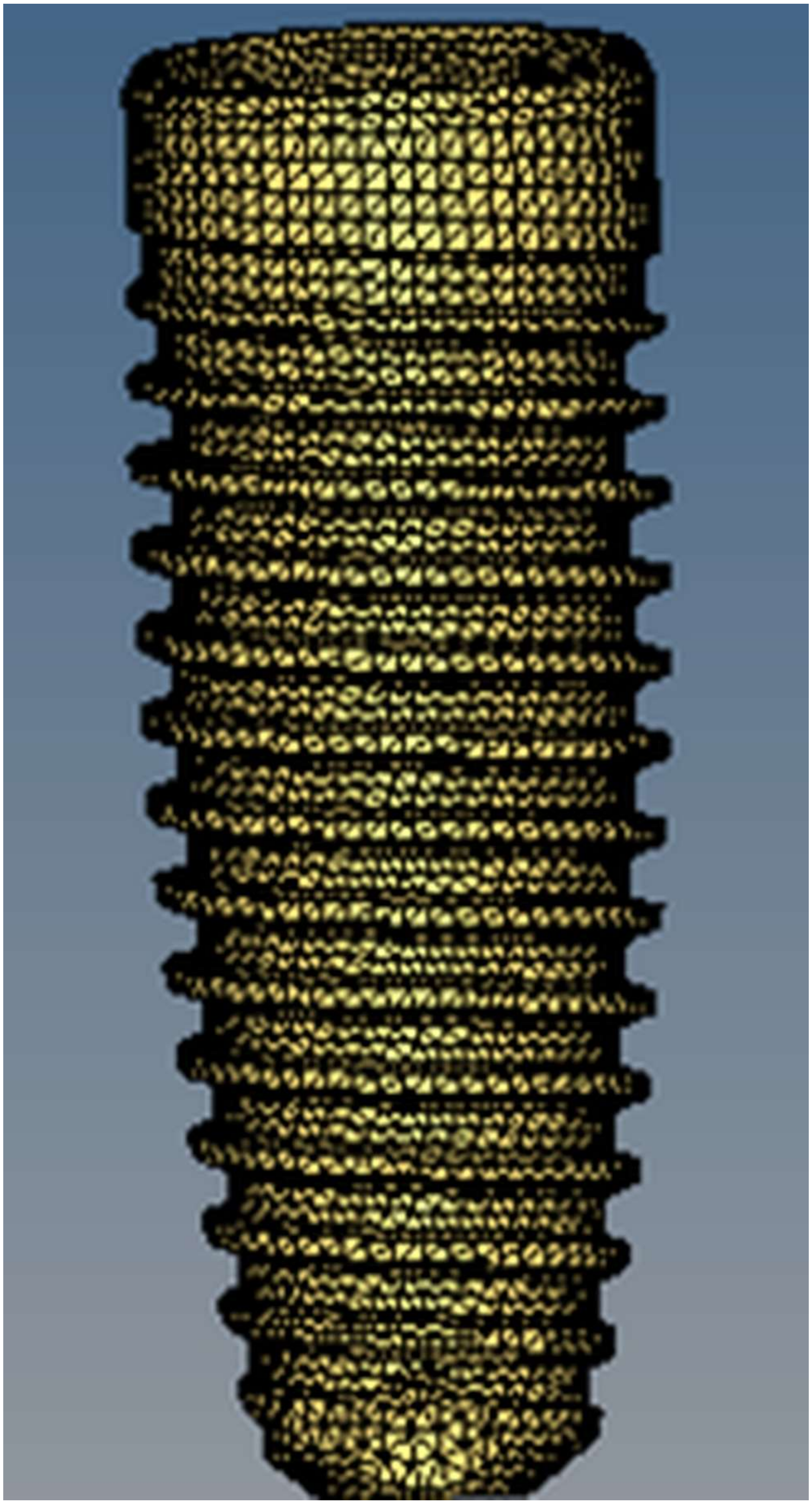


FIGURE 3: Implant model creation

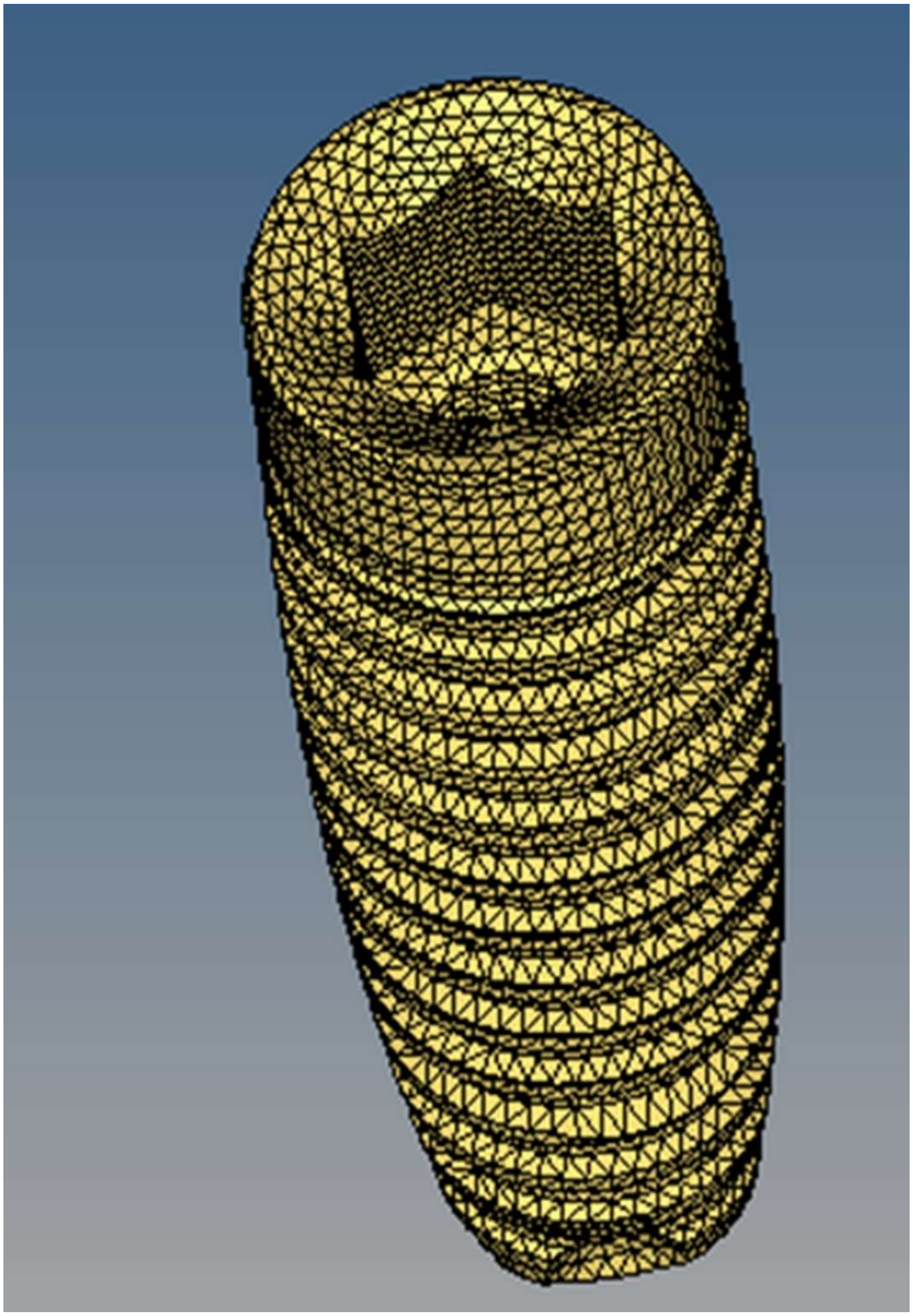


FIGURE 4 : IMPLANT MESH

Internal hex – implant -4.6mm diameter and 12mm length

No. of elements: 369001

No of nodes: 412392

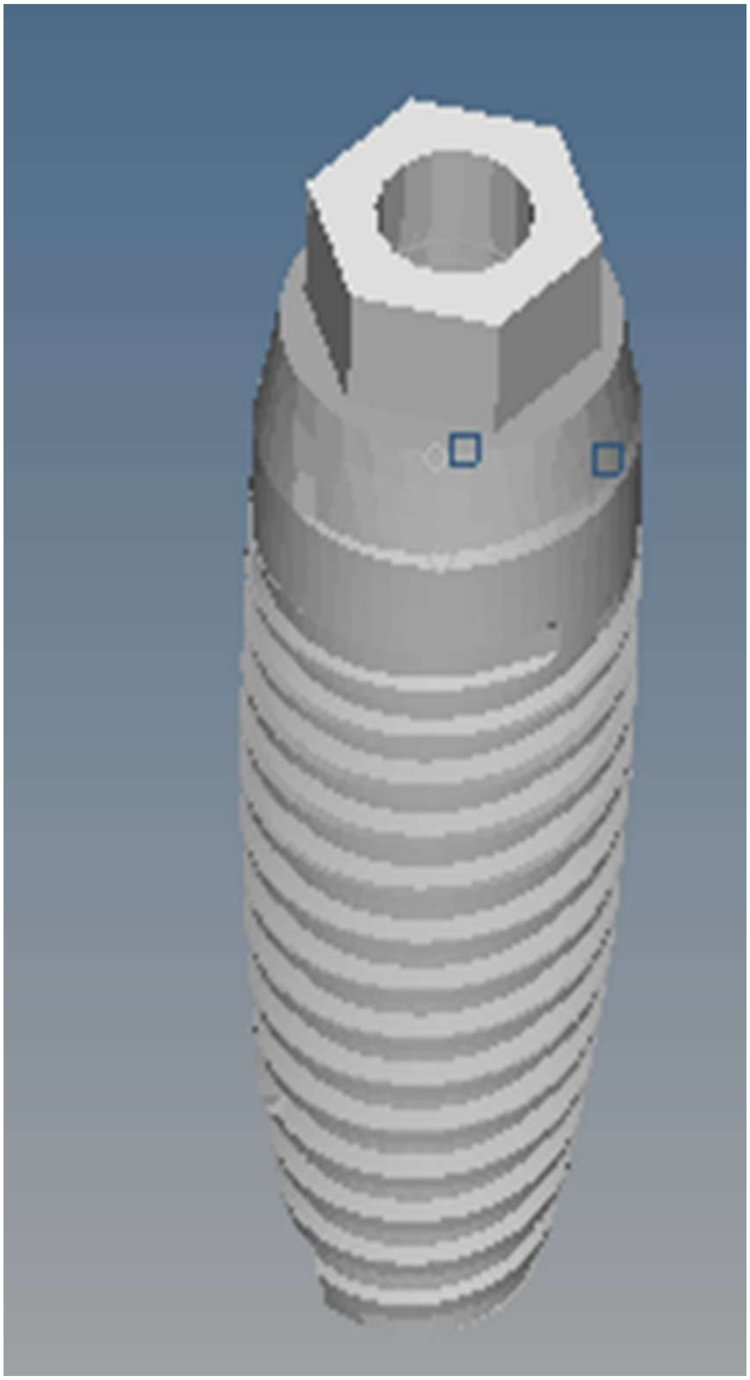


FIGURE 5 : External Hex connection : 1.5mm

Diameter at top of.implant : 4.1mm

Diameter of hex : 2.72mm

No. of elements: 345689

No of nodes: 392163

RESULT

The mean von Mises stress values and overall displacement under vertical axial loading are summarized in Table 2.

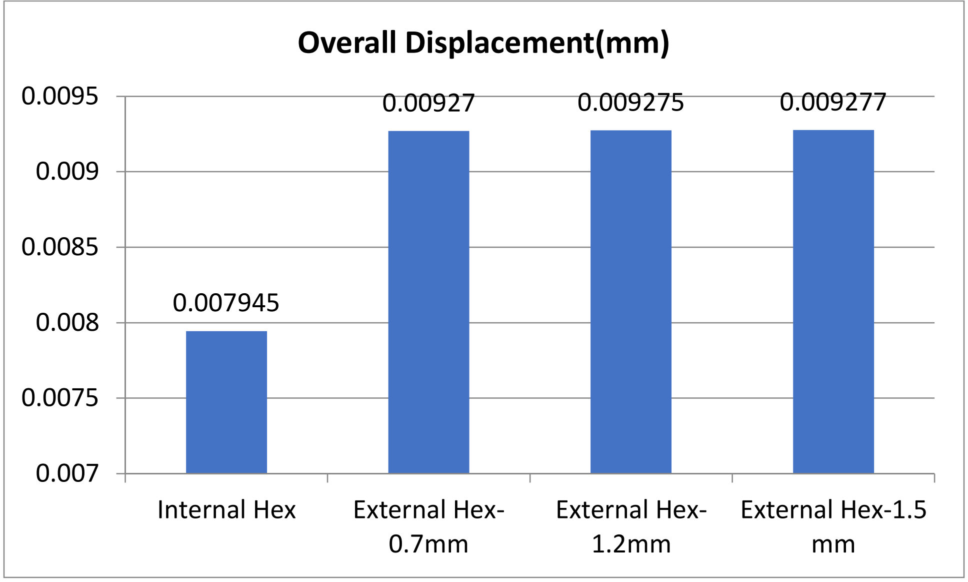
The internal hex connection consistently demonstrated the least displacement (0.007945 mm), whereas external hex designs exhibited slightly higher displacement, increasing marginally with hex height (0.00927–0.009277 mm). Overall stress was lowest in the internal hex (47.6577 MPa) and highest in the external hex of 1.2 mm (56.8973 MPa).

Cortical and Cancellous Bone Stress: Cortical bone stress was highest in the internal hex (24.4989 MPa) and lower across external hex designs (20.8505–21.3881 MPa). Similarly, cancellous bone stress was slightly higher in the internal hex (7.28398 MPa) compared to external hex implants (6.65732–6.66742 MPa), remaining within physiological limits.

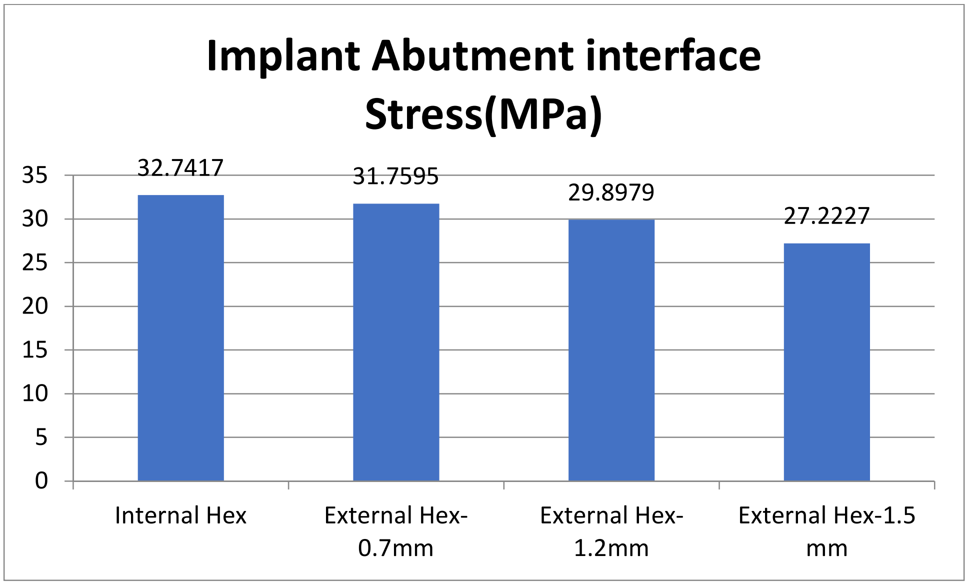
Implant and Abutment Stress: Implant stress was lowest in the internal hex (59.9349 MPa) and higher in external hex models (73.8767–75.9875 MPa). Abutment stress was highest in the internal hex (32.7417 MPa) and decreased progressively with increasing external hex height (27.2227–31.7595 MPa). The implant–abutment interface stress followed a similar pattern, mirroring abutment stress values.

Prosthetic Crown Stress: Crown stress was lowest in the internal hex (20.4464 MPa) and increased in external hex models, with the highest stress observed in the 1.2-mm external hex design (26.9488 MPa).

These findings are illustrated in Bar Charts 1–8, depicting displacement, overall stress, cortical and cancellous bone stress, implant stress, abutment stress, implant–abutment interface stress, and crown stress for all experimental groups.



BAR CHART 1: Displacement Plot



BAR CHART 2: Implant Abutment Interface stress plot

TABLE 2: Mean von mises stress values under vertical load **(Result summary)**

	Internal Hex	External Hex-0.7mm	External Hex-1.2mm	External Hex-1.5 mm
Overall Displacement (mm)	0.007945	0.00927	0.009275	0.009277
Overall Stress (MPa)	47.6577	53.6357	56.8973	54.229
Cortical Stress (MPa)	24.4989	20.8711	21.3881	20.8505
Cancellous Stress (MPa)	7.28398	6.66742	6.65817	6.65732
Implant Stress (MPa)	59.9349	75.9875	73.8767	75.2276
Abutment Stress (MPa)	32.7417	31.7595	29.8979	27.2227
Implant Abutment interface Stress (MPa)	32.7417	31.7595	29.8979	27.2227
Crown Stress (MPa)	20.4464	23.856	26.9488	26.8739

DISCUSSION

The long-term success of implant-supported prostheses depends not only on osseointegration but also on the biomechanical interactions at the implant–abutment interface and the resulting stress transmission to peri-implant bone. [45] Excessive stress concentration, particularly at the crestal cortical bone and implant–abutment junction, is a key factor in marginal bone loss, screw loosening, and mechanical complications. Therefore, understanding how implant–abutment connection (IAC) designs influence stress distribution is critical for clinical decision-making. [46]

The traditional external hex (EH) connection, originally designed as an anti-rotational feature rather than a load-bearing interface, has shown long-term clinical success [4], but limitations such as micromotion, stress concentration at the crestal region, and mechanical complications under non-axial loading are well documented [5–7,17,19]. Modifications increasing hex height from 0.7 mm to 1.2 mm have improved rotational resistance and facilitated prosthetic procedures, particularly in multi-unit frameworks, but biomechanical constraints remain. Internal hex (IH) connections were developed to provide deeper engagement, improved lateral stability, and more favorable occlusal force distribution.

Several finite element and experimental studies report superior biomechanical performance of IH connections compared to conventional EH designs; however, most analyses evaluate EH implants with standard or minimal hex heights, without considering the effects of increasing hex height [7,26,19,21]. In the present study, raising the EH height to 1.5 mm reduced implant–abutment interface stress (from 31.75 MPa in 0.7-mm EH to 27.22 MPa in 1.5-mm EH) while increasing implant body stress (59.9 MPa in IH to 75.2 MPa in 1.5-mm EH), indicating redistribution of load away from the interface. This stress shift is biomechanically advantageous, as it protects peri-implant bone while maintaining connection stability. [19,20,21]

Cortical stress was highest in the IH connection (24.49 MPa) and lower in the 1.5-mm EH (20.85 MPa), suggesting improved load dissipation with increased EH height, consistent with prior reports [26,47,49]. Cancellous bone stress followed a similar trend, with the lowest values in the 1.5-mm EH (6.66 MPa) compared to IH (7.28 MPa), indicating that taller EH geometries reduce trabecular bone stress and microdamage risk [26].

Abutment and interface stresses were highest in IH (32.74 MPa) and progressively decreased with increasing EH height, reaching 27.22 MPa at 1.5 mm. This reflects increased platform-level contact area in EH implants, which disperses stresses over a larger surface and reduces localized interface loading [17,21]. Overall displacement was slightly higher in EH designs (0.0092 mm) compared to IH (0.0079 mm), yet remained within physiological limits and did not increase bone stress, indicating that controlled micro-deformation within prosthetic components may act as a stress-absorbing mechanism [19,27].

Crown stress was lowest in IH (20.4 MPa) and higher in EH implants, increasing with hex height (23.8 MPa in 0.7-mm EH to 26.8 MPa in 1.5-mm EH). This reflects deeper internal engagement and efficient load transfer in IH, whereas EH connections permit controlled micro-deformation, shifting stress toward replaceable prosthetic components [19,20,27].

Collectively, the findings indicate that increasing EH height to 1.5 mm enhances biomechanical performance by improving stress dissipation, reducing peri-implant bone stresses, and minimizing interface stress. EH connections offer clinical advantages in prosthetic workflow, passive fit, and reduced impression distortion, particularly in multi-unit rehabilitations. Optimizing connection geometry, rather than solely selecting connection type, is critical in implant design and clinical application.

Future studies should evaluate the influence of increased EH height on screw stability under cyclic loading, occlusal variations, and long-term clinical outcomes to confirm whether these biomechanical benefits translate to reduced screw loosening and improved implant longevity.

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