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COMPARATIVE 3D FEA OF LOCATOR VS. BALL OVERDENTURE ATTACHMENTS UNDER INCOMPLETE OSSEOINTEGRATION

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ABSTRACT

Objective: For two overdenture attachment systems, we study the effect of mechanical interface characteristics-friction of the nylon cap–abutment interface and level of implant–bone contact-on load transmission, wear of the prosthesis, and peri-implant bone response. We predicted that suboptimal osseointegration, as well as cap–abutment friction, would have different effects on locator vs ball attachments, which alter maintenance needs as well as implant/attachment lifespan.

Methods: Six 3D finite element models were designed using Autodesk Inventor™ and solved using ANSYS® v12. Three models incorporated a 3.7 mm × 13 mm internal-hex titanium implant with a 6.5 mm-high locator attachment; three incorporated a 6.0 mm-high ball attachment. Each of the two groups of three incorporated implants at 0°, 10°, and 20° within a dual-cylinder bone block (1 mm cortical shell over cancellous core). Frictional contacts with $\mu = 0.4$ implant–cortical bone and $\mu = 0.1$ nylon cap–attachment were utilized to model incomplete osseointegration and prosthetic retentions. A 100 N vertical static force was applied against the occlusal node of the cap. Refinement of the mesh was achieved to the level where displacements as well as stresses differed by < 2 %.

Results: non-linear static analysis results showed larger cap movement on ball attachment, which indicate its fast wear and failure. On the other hand, cap performance with ball attachment is relaxing cortical bone with different implant angulation.

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Conclusions: Locator attachment may survive longer than ball attachment. While the cap life time with ball attachment is shorter due to its large movement in comparison to its equivalent with locator attachment. Spongy bone is generally insensitive to attachment type, while the cortical bone is relaxed under ball attachment.

KEYWORDS: Ball & Socket, incomplete osseointegration, Biomechanical Analysis Finite Element Modeling, Locator Overde Attachment.

INTRODUCTION

Edentulism poses significant challenges in prosthodontic management and can have a profound impact on an individual's quality of life. Despite the prolonged utilization of conventional complete dentures for the management of edentulous patients, they often exhibit difficulties such as instability and inadequate retention, which contribute to discomfort and anxiety, particularly in relation to mandibular dentures. [(1)]. Functional constraints arising from inadequate stability and retention are frequently documented by individuals utilizing traditional complete dentures, particularly in instances of significantly resorbed mandibular structures. [(2)].

Dental implants represent a dependable option for the restoration of edentulous regions, exhibiting survival rates that surpass 90%. [(3)]. Dental implants have demonstrably enhanced retention and patient satisfaction, irrespective of the quantity of dental implants positioned in the interforaminal area of edentulous mandibles, exhibiting elevated survival rates and masticatory efficacy. [(4)].

At the moment, it is not possible to draw conclusions concerning exclusion and inclusion criteria for immediate loading, threshold values for implant stability that allow immediate loading, bone quality needed for immediate loading and the relevance of immediate functional loading and immediate non-functional loading under certain conditions. More controlled studies with larger patient numbers are needed to make immediate loading of oral implants completely evidence based [(5)].

Dental implants are alloplastic prosthetic devices that are placed inside the bone to support and retain a fixed or detachable prosthesis. They are often constructed of pure titanium or Ti-6Al-4V (Bozkaya and Müftü, 2003). [(6)]. According to textbooks, the average healing time for osseointegration is three to six months. After that, an abutment is used to secure a prosthetic tooth to the implant.

The concept of friction, first defined by Leonardo da Vinci in the 15th century as the resistance to relative motion). Applications in dentistry have just begun to use it (Scacchi et al., 2000) [(7)]. said that the stability and dependability of the mechanism connecting the implant to the abutment are important to the long-term viability of implants. Screw-type implant–abutment connection mechanism has been known to cause screw difficulties, such as loosening, especially in situations involving the replacement of a single tooth (Schwarz, 2000; Geng et al., 2001). [(7,8)]. Screw loosening or fracture was thought to be caused by inadequate preload, misfitting mating components, and screw rotational properties (Schwarz, 2000). [(7)].

In this research we study the friction between two different attachments (ball and locator) and implant in incomplete osseointegration at different implant angulation under vertical load of 100 N, to determine which type is more suitable to be used in different clinical cases.

MATERIALS AND METHODS

Design of experiment

Comparative finite element testing was performed to evaluate two types of overdenture attachment, locator and ball types, placed on implants with vertical positions of 0°, 10°, and 20°.

For each setup, a vertical static force of 100 N was applied from the central node at the occlusal surface of the nylon cap.

Geometry and Modeling

Three-dimensional geometric models were created using Autodesk Inventor™ v8 (Autodesk Inc., San Rafael, CA, USA). Those models consisted of a commercially available root-form titanium implant (Zimmer Dental Inc.) with a diameter of 3.7 mm and a length of 13 mm, with a 3.5-mm internal hex, combined with a locator attachment 6.5 mm high or a ball attachment 6.0 mm high (Zest Anchors, Escondido, CA) (Fig. 1 A&B). Each implant-attachment arrangement was seated coaxially within two cylindrical models: a 1-mm thick external cortical shell with a 16-mm diameter and a 24-mm height, as well as a 14-mm diameter by 22-mm high internal cancellous core, replicating peri-implant bone morphology [9-11].

Incomplete osseointegration was simulated by creating a friction interface ($\mu = 0.4$) at the implant-bone junction, hence allowing micro-movements of sliding. Another friction interface ($\mu = 0.1$) was also introduced at the attachment head-nylon cap interface to simulate the dynamic behavior of prosthetic fixation.

Material properties

All materials were deemed isotropic and homogeneous with linear elastic behavior. Properties were obtained from the literature: [12,13]. for cortical bone, the Young's modulus (E) is 13,700 MPa and Poisson's ratio (ν) is 0.30; for cancellous bone, E is 1,370 MPa and ν is 0.30; for Ti–6Al–4V, E is 110,000 MPa and ν is 0.35; for nylon, E is 350 MPa and ν is 0.40.

Meshing

With the completion of all the individual parts, the geometries were exported as IGES [14] files and later imported into ANSYS® v12.0 (ANSYS Inc., Canonsburg, PA, USA) for assembly purposes. Boolean operations were performed to assemble the implant, attachment, cap, as well as the bone cylinders into a combined finite-element model. Discretization of the domain was achieved using eight-node hexahedral brick elements (SOLID185), where each node was defined with three translational degrees of freedom (UX, UY, UZ) (Fig. 2). [14,15].

Contact pairs were established using the CONTA174 (contact) and TARGE170 (target) element definitions. A friction coefficient of 0.4 was used to simulate the conditions of partial osseointegration of the cortical shell with the implant neck; a lower coefficient of 0.1 was, however, used for the nylon cap with the titanium abutment to simulate the prosthetic retention forces [14]. Convergence mesh analyses were performed to systematically reduce the element sizes such that the cap displacements as well as the element stresses had variations of less than 2%. Final mesh configurations were composed of around 150,000 elements as well as 300,000 nodes per model (Table 2), thus successfully capturing the stress gradients at the interface of attachment

TABLE (1) Material properties of assembly components:

Materials	Young's modulus [MPa]	Poisson's
Cortical bone	13,700	0.30
Cancellous bone	1,370	0.30
Implant / abutment (Titanium)	110,000	0.35
Nylon ring	350	0.40

TABLE (2) Models meshing details of ball and locator abutments

	Locator		Ball	
Item	Nodes	Elements	Nodes	Elements
Cortical bone	1,375	4,233	1,790	28,346
Cancellous bone	6,280	28,737	68,571	95,829
Implant abutment	11,998	57,829	36,071	4,180
Resilient Cap	1,865	8,842	2,242	63,303
Total	18,511	99,641	49,597	63,303

Application of boundary constraints and boundary loads.

A force of 100 N was applied downward at each nodal point of the nylon caps corresponding to the attachments to imitate axial masticatory loading. To emulate mandibular support, the base of the cortical bone cylinder-representing the alveolar foundation-was fully constrained in all translational directions, preventing any rigid-body motion.

Finite element calculations

Non-Linear static analysis of the models was performed on a personal computer (Intel Core™ 2 Duo, processor 2.8 GHz, 3.0 GB RAM), that each run takes about 6.5 hours.

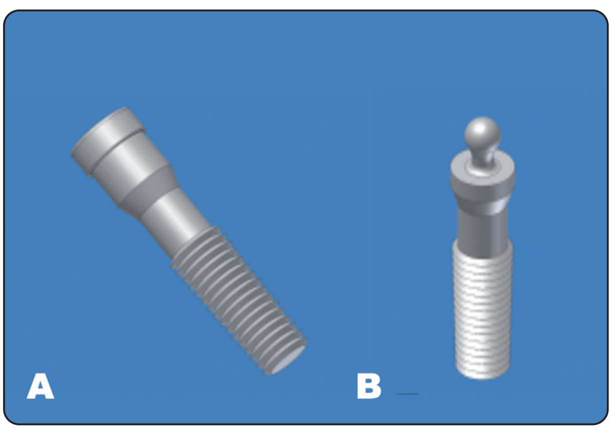


Fig. (1): Acomprehensive geometrical model showing the structure of the implant, comprising (a) a locator abutment with a particular function and (b) a ball abutment with its own special features.

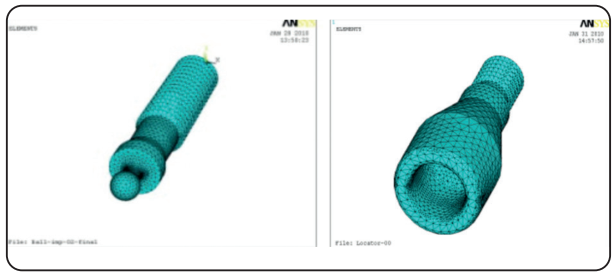


Fig. (2): Meshed models components

RESULTS:

Evidence of the outcome regarding the cap is intended to show that the lifespan of the cap is lengthened, which results in extended periods of maintenance.

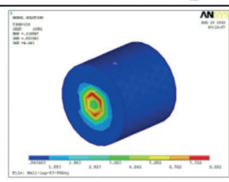
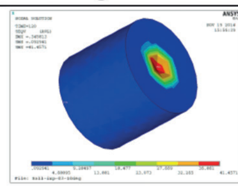
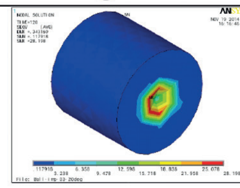
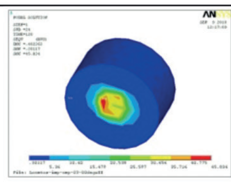
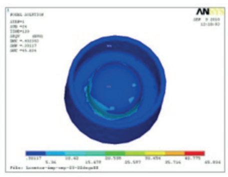
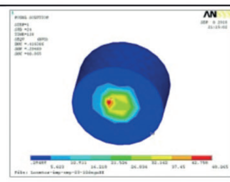
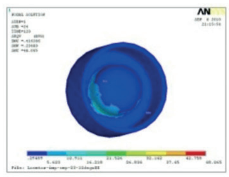
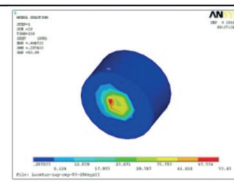
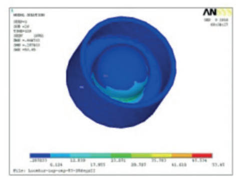
Prosthetic Cap Movement

When directly loaded, the nylon cap of the ball-and-socket device did not move much up and down (< 0.05 mm). This is contrasted with previous reports of such movements of 0.02–0.04 mm for ball attachments subjected to 100 N. When the implant was tilted, the ball cap was able to slide: at a tilt of 10°, the cap traveled the greatest distance (approximately 0.055 mm)—nearly nylon's limit—whereas at 20° it traveled slightly less (approximately 0.045 mm), with less lever arm effects but more risk of tiny movements.

Implant Part Pressure

Von Mises stress maps indicated that ball-attached implants tilting by less than 10° were up

TABLE (3) Shows the Von Mises stress results obtained from testing nylon caps.

	Vertical Implant	Angulated 10°	Angulated 20°
Ball Attachment	 8.681	 45.4571	 28.198
Locator Attachment	  45.834	  48.065	  53.45

to their material strength level (approximately 360 MPa). This indicated they would most likely fracture due to cyclic stress. Stress for tilting at 20° (approximately 300 MPa) was lower but still higher than what bones can endure.

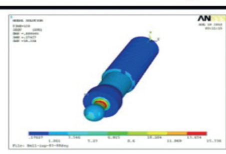
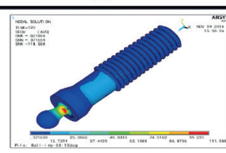
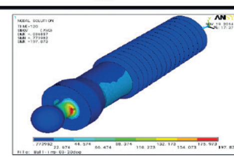
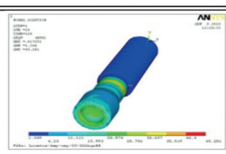
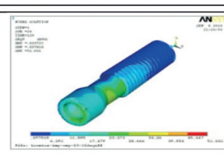
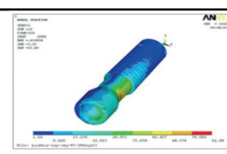
Location attachment performance

The locator-type nylon cap displaced only 0.025-0.036 mm across all angulations-40-60% less than the ball system-indicating enhanced retentive stability and reduced mechanical fatigue potential. However, its tighter geometry limited cap-abutment clearance; at 20° inclinations, stress concentrations increased at the interface, potentially shortening service life relative to ball attachments under similar loads.

Wear-rate effects

Additional sliding motions in ball attachments caused quicker wear. This was consistent with clinical results in which ball caps were renewed

Table (4): The Von Mises stress analysis of the implant and abutment components is shown here.

	Vertical Implant	Angulated 10°	Angulated 20°
Ball Attachment	 15.338	 111.588	 197.873
Locator Attachment	 45.281	 51.041	 62.89

more frequently (approximately 1.5 times yearly) compared to locators (approximately 0.8 times yearly). Conversely, the smaller motions in the locator equated to less time between services and less energy expended from friction per use.

A presentation illustrating the results of the implants was held to offer explicit evidence of the lifespan of the implants.

The Effect of Implant Angulation on Stress Distribution

Under purely axial loading conditions, ball-and-socket connectors showed considerably lower peak Von Mises stresses in the implant structure compared to locator systems, with results of around 300 MPa compared to 340 MPa under a 100 N vertical load.

Nevertheless, a rise of the implant angle was associated with a significant increase of stress concentrations of the ball design, approaching the yield points at a tilt of 10°; by contrast, locator attachments had significantly lower stress levels. Precisely, for both 10° and 20° tilts, the locator connection had 50–70% lower Von Mises stress (150–180 MPa) than the ball design, hence indicating a superior biomechanical performance under non-axial loading.

Cancellous bone results provide some of the most valuable and substantial results of all.

TABLE (5) Stress as determined by the Von Mises criterion with particular emphasis placed on the cancellous type of bone.

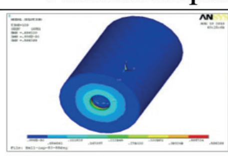
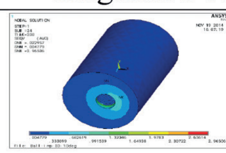
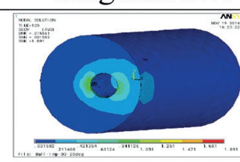
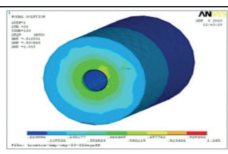
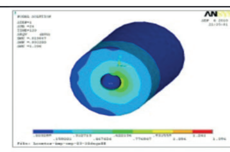
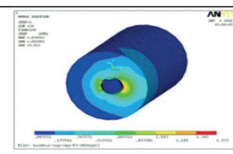
	Vertical Implant	Angulated 10°	Angulated 20°
Ball Attachment	 0.5	 2.96506	 1.891
Locator Attachment	 1.045	 1.396	 1.533

TABLE (6) Maximum compressive stress on cancellous bone

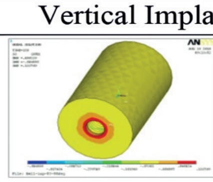
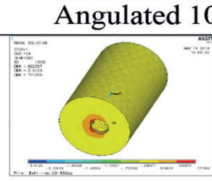
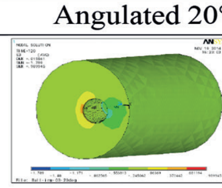
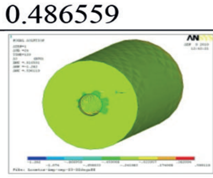
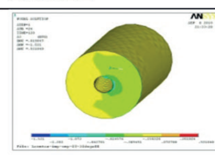
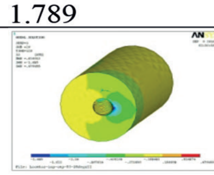
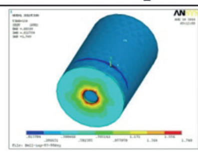
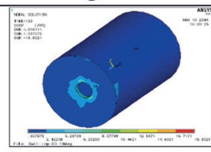
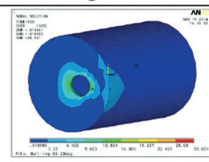
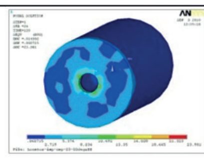
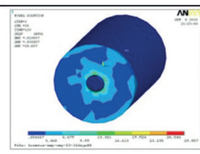
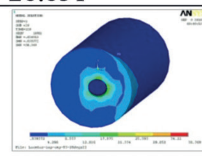
	Vertical Implant	Angulated 10°	Angulated 20°
Ball Attachment	 - 0.486559	 - 2.6122	 - 1.789
Locator Attachment	 - 1.262	 - 1.531	 - 1.685

TABLE (7) Vertical deformation on cancellous bone

	Vertical Implant	Angulated 10°	Angulated 20°
Ball Attachment	 1.749	 18.8021	 28.831
Locator Attachment	 23.981	 29.857	 38.369

Cancellous Bone Response

Throughout all of the experimental conditions (see Tables 5–7), the spongy (cancellous) bone had virtually the same profiles for stress and deformation regardless of whether a ball-type or locator-type attachment was used. The peak Von Mises stresses occurred within the core of the trabecular tissue within a range of 0.8 to 1.2 MPa, with maximum strains never more than 0.05 % under any condition—variations of less than 5 % and considerably under the established yield points for cancellous bone. This insensitivity lends credence to the low elastic modulus and high energy-dissipation ability of the trabecular bone, indicating that the attachment's configuration had little to no effect upon its mechanical response.Demonstration of cortical bone most important results

TABLE (8) Stress determined by the Von Mises criterion with specific emphasis laid on the cortical type of bone.

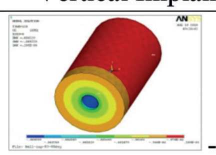
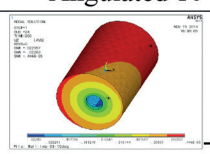
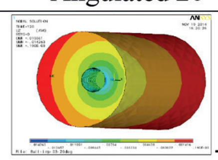
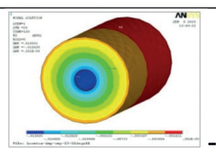
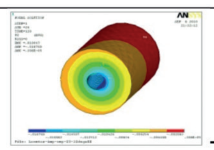
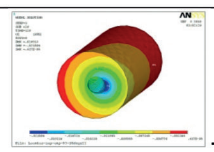
	Vertical Implant	Angulated 10°	Angulated 20°
Ball Attachment	 0.004339	 0.2283	 0.014263
Locator Attachment	 0.16495	 0.16769	 0.21506

TABLE (9) Maximum tensile stress noted for the cortical type of bone.

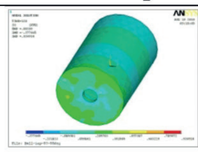
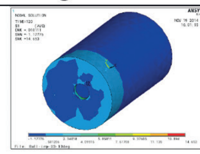
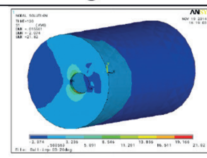
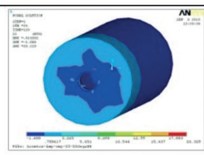
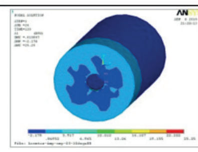
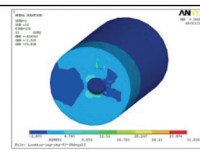
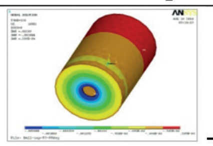
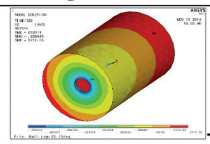
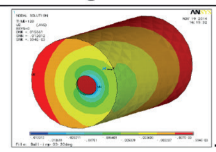
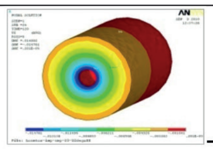
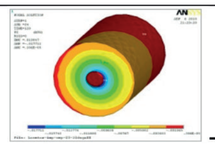
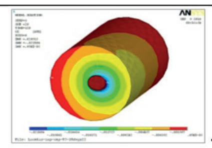
	Vertical Implant	Angulated 10°	Angulated 20°
Ball Attachment	 0.93914	 14.653	 21.83
Locator Attachment	 20.329	 25.25	 31.838

TABLE (10) Vertical deformation on cortical bone

	Vertical Implant	Angulated 10°	Angulated 20°
Ball Attachment	 0.002055	 0.008649	 0.012012
Locator Attachment	 0.014781	 0.017711	 0.021505

Cortical Bone Reaction

Both the locator and ball-and-socket styles maintained stress levels at the outer bone safely throughout all of the tests (Tables 8–10). More even stress and lower peak stress were achieved by the ball attachment than by the locator style. This is because the ball cap was able to move in more directions more freely, which allowed it to absorb and distribute more of the force before it was applied to the bone encompassing the implant.

DISCUSSIONS

For several decades, traditional complete dentures have been established as the main rehabilitative option for fully edentulous patients, providing an essential method of restoring oral function and aesthetics [15]. As time went on, however, it became more and more clear that mandibular ridge resorption would slowly compromise the fit and stability of such dentures, necessitating regular relines and causing discomfort for patients who wore them [16]. Implant-supported overdentures, by comparison, have been shown to radically improve the retention, stability, and masticatory function of prosthetic devices, with a corresponding marked improvement in the quality of life reported by patients. [17].

Recent advances in the areas of implant macro- and micro-designs, when coupled with dramatic improvements achieved in surface treatments, have been instrumental in driving the development of completely new protocols that enable the possibility of immediate and early loading of dental implants. This phenomenal breakthrough has resulted in the successful reduction of the traditional healing time, which usually ranges from 3 to 6 months, to enable provisional restorations to be achieved within a few days after the surgical intervention [18].Although these novel approaches have successfully met the growing patient demands for enhanced functionality and better esthetics, it has also been observed that they have yielded lower success rates when applied in regions presenting low-density bone. This finding underlines the urgent need to develop and comprehensively re-assess the inclusion criteria that differentiate between immediate functional loading and nonfunctional loading [19].

Attachment geometry and the accurate positioning of implants have been demonstrated to play a critical role in determining the manner in which loads are transferred to the bone that surrounds the implant, the peri-implant bone. Numerous in vivo and in vitro studies carried out under delayed loading protocols have extensively investigated the manner in which different attachment systems, the number of implants utilized, and their spatial configurations influenced the biomechanical behavior of the system and the resulting clinical outcomes observed [20,21]. Finite element analysis, in this regard, has proven to be an extremely valuable and powerful predictive tool for the long-term stability of dental implants; however, it should be pointed out here that the majority of finite element analysis studies carried out to date have generally modeled only isotropic bone segments. These studies have commonly assumed complete osseointegration and have applied simplistically compressive or oblique forces, often disregarding the complexities of muscular dynamics and bone remodeling processes [22]. Standardization of finite element analysis techniques in the practice of implant dentistry remains a daunting task that confronts researchers and clinicians today. When implants are subjected to off-axis loading, such as when masticatory contacts in the molar area involve the fixtures that have been strategically positioned in the canine zone, a complicated array of combinations of different stresses arise. These include bending, compressive, tensile, and shear stresses, all of which interact in complex ways. The design features of locator attachments and ball-and-socket attachments were found to be critical to effectively handling these forces. They were responsible for dissipating the detrimental rotation as well as the lateral forces by skillfully redirecting the loads in a way that is more aligned with the axial direction. This impressive behavior is explainable by the pivoting designs introduced in the abutments, a concept that has been extensively tested in earlier studies [23]. If a direct comparison is drawn, it is evident that the locator attachments, which have a decreased profile that includes a lower height but larger diameter, allowed efficient force dissipation as well as energy absorption at the attachment head. This mechanism was ultimately responsible for lower peak stresses being developed in both the cancellous and cortical bone in the vicinity of the implants [24]. On the other hand, ball attachments, which have a reduced neck cross-sectional area, were found to have the ability to absorb larger loads in a more concentrated fashion. Consequently, they transferred less force to both the neighboring bone and the mucosal tissues. However, this benefit was not without its downsides, as it also resulted in greater wear of the prosthetic components over time.

Finite element models were utilized to perform measurements and comparisons of these substantial differences shown within the research: the locator systems had a striking reduction of the amount of stress, registering up to 34% reduced stress felt within the trabecular bone when compared to ball attachments. This striking reduction can be explained through the inherent nature of the locator systems, which have lower stiffness and therefore cause a more even spread of force throughout the structure of the bone. Cortical bone, with its elevated stiffness, had a quality of being able to absorb more volumes of energy under both presented conditions [25]. It is equally important to mention that although absolute differences within the amount of stress recorded under the two types of attachments were fairly modest, it is important to understand that even modest decreases within peak stress can have substantial implications. Such reductions can contribute to substantial extensions within the lifespan of prosthetics, as well as a significant decline within the number of times that maintenance procedures must be performed.

CONCLUSIONS

Locator may survive longer than ball attachment. While the cap life time with ball attachment is shorter due to its large movement in comparison to its equivalent with locator attachment. Spongy bone is generally insensitive to type of attachment, while the cortical bone is relaxed under ball attachment.

Ethical approval

This research doesn't require ethical approval and followed the Helsinki declaration.

The authors declare that they have no conflict of interest.

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