Effect of cap micro-movement on the selection of implants' attachment type: three-dimensional finite element analysis

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Background/aim

Cap micro-movement may affect load transfer to the osseointegrated implant/bone interface, which in turn may affect the selection of attachment type to ensure the least amount of bone loss, fewer maintenance periods, and longer lifetime of the entire implant/attachment system. This study aimed to evaluate the cap micro-movement effect using various implant angulations on the selection of the best attachment system for each individual case.

Materials and methods

Six finite element models were prepared and were equally divided between locator attachment and ball attachment. Every three models simulate vertical implant and inclined implants by 10° and 20° of angulation, respectively. Meanwhile, frictional contact enabling cap micro-movement at the cap/attachment interface was implemented.

Results

Nonlinear static analysis results showed that implant and locator attachment body received very low stresses in comparison to the ball attachment. Nylon cap life expected to be longer in the case of 20° angulated implant with ball attachment, while all other cases indicated locator attachment superiority. Cortical bone received less stresses under locator attachment, while the gap in stress values in comparison to ball attachment will be reduced by increasing implant angulation.

Conclusions

Locator attachment seems to be more superior to ball attachment. However, increasing implant angulation up to 20° may result in showing a similar behavior with both attachment types.

Keywords:
ball attachment, finite element analysis, implants, locator attachment

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Introduction

The use of osseointegrated implants to replace missing teeth has a great impact on the quality of life of completely edentulous patients. Implant-retained prostheses have many advantages such as better mastication, enhanced tactile sensitivity together with overall noticeable better retention when compared with conventional dentures. According to WHO guidelines for rehabilitation of any completely edentulous patient, two implants were conceived such as a minimum one placed mainly in the inter-foraminal region, followed by implant-retained overdenture is the recommended gold standard treatment option [1].

The most widely utilized forms of anchorage systems of implants include ball attachments, locators, and clip/bar attachment. However, it is of utmost importance to be sure whether splinting implants together or leaving implants free-standing is better to withstand the suspected masticatory loads. Meanwhile, it is well known that the implants' long-term prognosis depends mainly on the utilized attachment system's ability to widely distribute the superstructures' transmitted stresses [2].

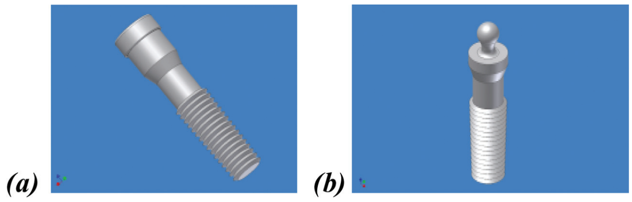
Ball and O-ring attachments are widely used because of their feasibility, handling ease, and minimal chairside time needed. These attachments are resilient; in addition, the polymeric retention ring offers good stress relief, reducing the stresses over the implants. However, the main concern associated with this attachment is the higher rate of maintenance and O-ring replacement needed, which usually causes retention loss over time [3].

On the other hand, the locator attachment is a universally resilient nonsplinted attachment system, which is selfaligning and is indicated for use with implant-supported overdentures as it can replace the existing ball attachment, especially for those patients who suffer from rapid wear of the ball components and in cases of limited interarch space and it also offers smallest attachment dimensions with a low risk of denture base fracture. Furthermore, locator attachments have gained great popularity as an alternative treatment option because of its excellent dual retention and quick and easy repair when needed in addition to its component durability [4–6].

It is well known that finite element analysis (FEA) has superior advantages over other assessment methods as it allows accurate modeling of geometries, which are so complex. Also, it offers the benefit of investigating the internal state of the stresses and allows easy simulation of various models [4].

In this study, a three-dimensional finite element model of a mandibular section together with an osseointegrated implant and implant-retained overdenture is modeled showing two different types of anchorage systems. The purpose of this study was to evaluate the cap micro-movement effect using various implant angulations on the selection of the most appropriate attachment system for each individual case whether locator attachment or ball attachment.

Figure 1



Geometrical model of the implant with locator abutment (a) and ball abutment (b).

Table 1 Material properties of assembly components

Materials	Young's modulus (MPa)	Poisson's
Cortical	13 700	0.30
Cancellous	1370	0.30
Implant/abutment (titanium)	110 000	0.35
Nylon ring	350	0.40

Materials and methods

Study design

This comparative study was performed for comparing between two attachment types (ball/locator attachments) joined to a vertical and inclined implant in two angulations: 10° and 20°, subjected to a vertical load of 100 N placed on the cap center point of its top surface.

Geometry and modeling

The geometrical models were created manually using a commercial three-dimensional modeling package, Inventor, version 8 (Autodesk Inc., San Rafael, California, USA). The system analyzed in this investigation consisted of the commonly available root-form threaded titanium dental implant (Zimmer Dental Inc., Carlsbad, CA, USA) with a ball attachment of height 6.0 mm or locator attachment of height 6.5 mm (Zest Anchors, Escondido, California, USA). The root-form dental implant had a nominal diameter of 3.7 mm, a length of 13 mm, and the shape of internal hex with a hex width of 3.5 mm (Fig. 1a, b).

The model was designed in such a way that the implant was placed in two coaxial cylinders; the outer layer represented the cortical bone of 1 mm thickness, 16 mm in diameter, and 24 mm in height. The inner cylinder represented the cancellous bone of 14 mm diameter and 22 mm height [7–10]. It was assumed that complete osseointegration was present between implants and the bone, whereas a frictional contact was assumed between the nylon cap and the attachment. Therefore, it was expected to have a relative motion (sliding) between the cap and the attachment.

Ethical consideration

The study was conducted in compliance with the ethical principles for medical research, according to the principles expressed in the World Medical Association Declaration of Helsinki. This research did not require ethical approval, according to the advice of the Ethical Committee of National Research Center, Egypt.

Material properties

Values of material properties were based on previously published data [11,12] and are listed in Table 1. All materials were assumed to be isotropic, homogenous, and linearly elastic.

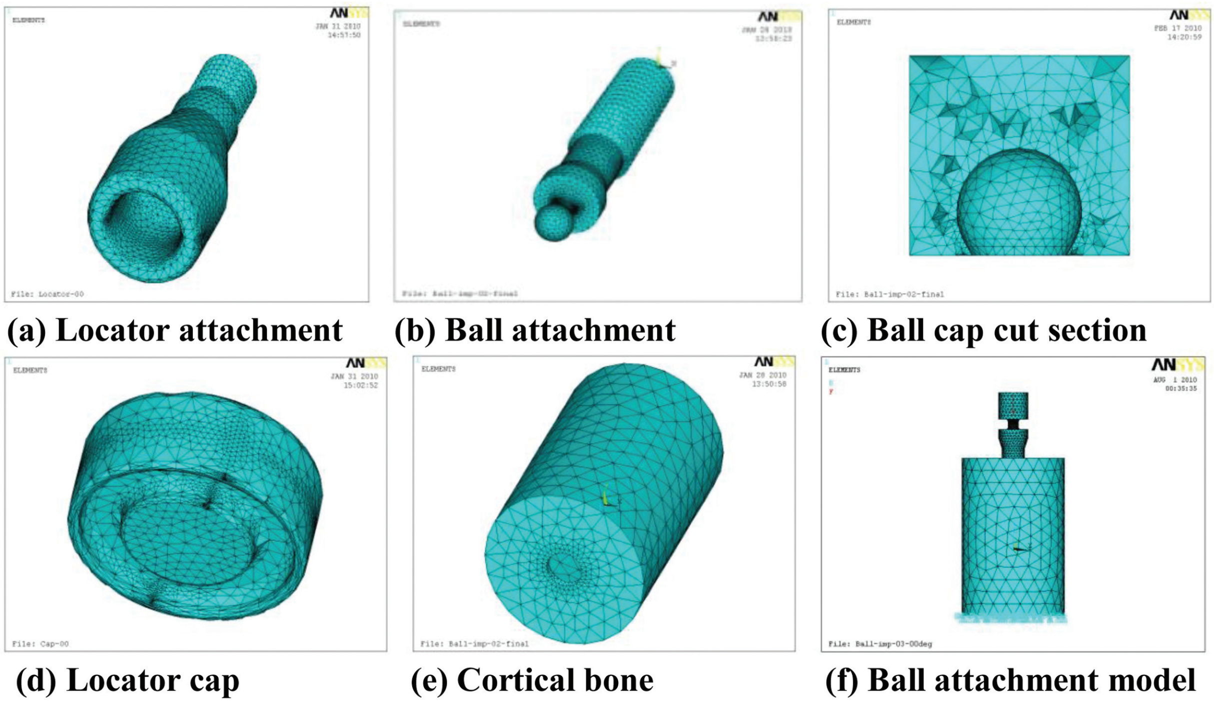
Meshing

After construction of all model components of, they were exported to the ANSYS, version 12 (ANSYS Inc., Canonsburg, Pennsylvania, USA) as IGES files [13] and were assembled together to obtain a finite element model after a set of Boolean operations between the imported components. The meshing element was an 8-node brick element (SOLID 185), which has three degrees of freedom (translations in the global

Table 2 Models meshing details of ball and locator abutments

Items	Locator attachment		Ball attachment	
	Nodes	Elements	Nodes	Elements
Cortical bone	1375	4233	1790	28 346
Cancellous bone	6280	28 737	68 571	95 829
Implant abutment	11 998	57 829	36 071	4180
Resilient cap	1865	8842	2242	63 303
Total	18 511	99 641	49 597	63 303

Figure 2



Meshed models' components: (a) locator attachment, (b) ball attachment, (c) ball cap cut section, (d) locator cap, (e) cortical bone, and (f) the ball attachment model.

directions). Frictional contact was defined by the elements CONTACT 174 and TARGET 170 as surface to surface contact with a friction coefficient of 0.1 between the cap and the attachment. Table 2 lists the number of nodes and elements on each models' component after meshing and Fig. 2a–f illustrates the components after meshing.

Application of load and boundary conditions

A vertical load of 100 N was applied at the central node of the top surface of either attachment's cap. The lowest area of the cortical bone (outer cylinder base) was considered fixed in all directions as a boundary condition.

Finite element calculations

Nonlinear 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 h.

Results

Demonstration of cap results to indicate the cap lifetime which is equivalent to longer maintenance periods

As presented in Table 3 the locator cap will have a longer lifetime in comparison to the ball attachment type for both vertical and inclined implants of up to 10°. However, a higher implant inclination makes the ball attachment cap survive for longer time periods and that under a vertical load the thicker cap will absorb the load energy and redistribute it in a better way in comparison to a thinner one as noticed by lower von Mises stress. It has been noticed that increasing the

Table 3 Von Mises stress on nylon caps

Attachment types	Vertical implant	Angulated 10°	Angulated 20°
Ball attachment	8.681	48.719	40.83
Locator attachment	1.628	47.678	53.182

Table 4 Von Mises stress on implant/abutment

Attachment types	Vertical implant	Angulated 10°	Angulated 20°
Ball attachment	15.338	185.265	365.318
Locator attachment	0.671903	55.748	94.632

Table 5 Von Mises stress on the cortical bone

Attachment types	Vertical implant	Angulated 10°	Angulated 20°
Ball attachment	1.749	9.864	11.713
Locator attachment	0.2E−5	8.795	11.366

Table 6 Vertical deformation on the cortical bone

Attachment types	Vertical implant	Angulated 10°	Angulated 20°
Ball attachment	0.002055	−0.010941	−0.015684
Locator attachment	−0.294E−9	−0.010099	−0.012778

implant inclination increases the shear stress on the locator's cap and that narrowing the behavior gap between the two types, even reverses the advantage of using the ball attachment.

Demonstration of implant complex results to indicate implant lifetime

Implant abutment complex with locator attachment showed a superior behavior of up to 20° of implant inclination over the ball attachment type. As illustrated in Table 4, ball attachment on the implant inclined by 20° may suffer from noticeable fatigue failure.

With a thicker cap (the locator cap), the applied load was distributed on a larger area in comparison with the ball cap. That resulted in reducing implant complex stresses on the locator system to be of the order to 1/30 of the ball system. This ratio reduced by increasing the implant angulation to reach about 1/3.5 that may be referred to as load decomposition between the vertical loading and the shearing one where the superiority of the locator under the vertical load gradually dismisses.

Furthermore, maximum von Mises stress appeared on the locator system at the implant-attachment connection, where this value is far from the endurance limit (fatigue limit) of titanium up to 20° inclination. On the other hand, ball attachment neck received the maximum von Mises stress, where its values with 10 and 20°implant angulation reach and exceed the titanium endurance limit, respectively, which indicate a limited lifetime in these cases.

Demonstration of cortical bone results

Both attachments are showing a good behavior with the cortical bone with complete osseointegration. Although locator attachment transfers less loads to both bone types (cortical and cancellous) by about 5–20%, however, the transferred loads generate acceptable low level of stresses whatever the attachment type used, ball or locator attachment as presented in Table 5.

As the cortical bone is a brittle material, its deformation should be too small, where increasing this deformation may cause failure and to be felt as pain. Table 6 shows the vertical deformation (pain indicator) of the cortical bone with a minimum deformation of 2 μm and a maximum of 15 μm with superiority of locator by lower deformation on the bone.

Discussion

In the present study the implant–cortical/cancellous bone interface was completely bonded, although it may not be the same in various clinical conditions as the bone density that is present in the mandibular anterior region is most commonly the D2 type. Misch has confirmed this in his FEA and had assumed an extremely high success rate for implants placed in such a bone type (100% success rate) [2,14].

It is well known that the stress distribution at the bone–implant interface is directly related to the bone type in this area where the cancellous bone cannot withstand stresses when compared with the compact bone, which appears to be more superior. Meanwhile, the compact bone can withstand a compressive strength of 140–170 MPa, whereas the cancellous bone compressive strength is only 22–28 MPa. However, the stress levels did not reach the maximum yield strength of the mandibular bone in the different loading conditions, so as to exclude the possibility of bone fracture [14].

It is to be mentioned that for favorable bone deposition around implants, the minimal amount of stresses required is about 1.3–1.7 MPa. However, it has been noticed from the studied loading records that the stress generated by the models were above this range. Thus, both the locator and the ball attachments enhances favorable stress distribution to the surrounding bone. Such a fact is being addressed by the present study; the attachments' choice now depends mainly on the amount of retention and stability that the attachments do offer to the patient himself in various clinical situations [15].

Different studies have been conducted on patient satisfaction with implant-supported overdentures and have revealed that patients do prefer the ball and O-ring attachment when retention and stability are primarily concerned. Hence, the best type of attachment to be used for implant-supported overdenture cases is the small-diameter ball and O-ring attachment [1,15]. Furthermore, Chaware and Thakkar [16] reported that patient satisfaction and compliance were higher for ball, locator, and bar attachments. Meanwhile, the ball and locator attachments proved better performance in terms of survival rate, maintenance, and patient satisfaction.

Nevertheless, Khurana *et al.* [17] reported that locator attachments have shown reduced and better stress distribution in the implant-supported overdentures when compared with ball attachments and concluded that attachments for implant-supported overdentures have to be as short as possible for better stress distribution. Locator type of attachment was highly recommended. In addition, ELsyad *et al.* [18] concluded that locator attachments have shown high retention and better stability after wear simulation with minimally evident loss of retention.

Meanwhile, the results of this three-dimensional FEA demonstrated that stress values were markedly lower for locator attachments in different implant angulation scenarios when compared with ball attachments; thus, the locator cap will show a longer lifetime in comparison to the ball attachment type for both vertical and inclined implants of up to 10°. These results were in accordance with those reported by Abdelhamid and Neena [19], who found better stress distribution with the use of locator attachments.

Furthermore, results also revealed that the implant/abutment complex with locator attachment showed superior behavior up to 20° of implant inclination over the ball attachment type, which suffered from noticeable fatigue failure. This may be due to the smaller dimensions of the locator attachment, which allows for adequate thickness of the overlaying acrylic resin aiding in better stresses distribution and dissipation of occlusal load applications [4,17,18]. Similarly, Sultana *et al.* [20] analyzed the retention of implant-supported overdentures at different degrees of implant angulations and found that there was a noticeable reduction in the ball attachment retention only when utilized with various implant angulations.

Moreover, cancellous bone results are similar under the two types of attachments used in this study. Safe values of von Mises and compressive stresses were obtained in all cases, which are mainly due to the low rigidity and the manner of distribution of stresses in the spongy bone as compared with the compact bone [4].The biomechanical performance of various implant systems, the load distribution manner, and the various types of stresses that are present at the bone–implant interface with different implant angulations has been carefully studied using FEA. Nevertheless, from a clinical point of view, attachments that provide the advantage of a more uniform masticatory load transmission are recommended for better bone preservation and reduction of prosthodontic complications [17].

Thus, the present study offers reliable data for the attachment type, which is recommended to be used in various cases with different implant angulations to ensure the least amount of bone loss, fewer maintenance recalls, better durability, and enhanced overall patient satisfaction [21,22].

Conclusion

Within the limitation of this study design, regarding attachment types used and angulations utilized, it could be concluded that the locator attachment may survive longer than ball attachment due to exerting lower stresses on the bone while ball attachment neck received high level of stresses, which may cause it to fail much faster under cyclic loading. Furthermore, the large movement of the ball attachment cap reduces the cap lifetime in comparison to its equivalent one with locator attachment. Therefore, locator attachment seems to be more superior to ball attachment; however, increasing implant angulation up to 20° may reduce the differences between both attachment types (showed a similar behavior).

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Conflicts of interest

There are no conflicts of interest.

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