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Peri-implant stress distribution assessment of various attachment systems for implant supported overdenture prosthesis by finite element analysis – A systematic review

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A B S T R A C T

Background: Various attachments like ball, bar-clip, magnetic attachments are used in implant supported overdentures. Finite Element Analysis (FEA) a newly innovated technology has been used in dental implantology to evaluate stress distribution patterns. There is little evidence available regarding the stress distribution in peri-implant region for implant supported overdentures. The purpose of the review was to generate scientific evidence on peri-implant stress distribution in FEA model with different types of attachments employed in implant supported overdentures.

Materials and methods: Systematic review was conducted as per the Preferred Reporting Items for Systematic Reviews Guidelines and Meta-Analyses statement (PRISMA). A comprehensive search was undertaken by two reviewers from January 2020 to June 2020 with no year limits to published articles. Only in-vitro FEA studies were included. Following electronic databases were searched for published studies- PubMed, Web of Science. Characteristics of the studies tabulated and analysis of articles was done to compare different attachment systems.

Results: Locator attachments showed better stress distribution than ball attachment system in all the studies but one. Two studies showed results in favour of ball attachment compared to bar-clip attachment system when stress was evaluated distal to the implants. No significant difference in terms of stress concentration could be generated between ball versus magnetic/equator versus locator attachment system due to less number of studies and conflicting results.

Conclusion: Various studies showed different results due to heterogenicity in selected attachment systems and study designs. Locator attachments showed favourable stress distribution around peri-implant bone than other attachments.

1. Introduction

Edentulous state is one of the major disabilities faced by the older individuals due to loss of teeth with advancing age. Implant supported overdenture prosthesis is a promising and cost effective treatment approach to combat the edentulous conditions.[1] Improvement in masticatory efficiency and chewing ability have also been stated by various studies on comparing implant supported overdentures and conventional complete denture prosthesis.[2–5] Compared to fixed implant supported prosthesis, implant supported overdentures have advantages like less accuracy needed in implant position, less number of implants to be placed to retain the prosthesis, patient can remove the denture in night (important in patients with parafunctional habits) etc.[6,7]

Various attachments like ball, bar-clip, magnetic, locator types are used in implant supported overdentures to retain the prosthesis. The positioning of the implant attachments is important for two-implant overdentures because in the presence of pathological overloading, the bone around the implants get deformed and resorbs due to the excessive stress. Strain gradients and various attachment systems behave differently in terms of survival rate of implants and bone loss.[8] Previously few studies have shown no significant relationship between masticatory performance, patient satisfaction and type of attachments used in implant supported overdentures.[9,10] However, findings from various studies in recent times have indicated that prosthesis maintenance and prosthetic complications may be modulated by the type of attachments used in overdenture prosthesis.[11–16] Finite element analysis (FEA) is a recent development in the field of biological research used for biomechanical analyses. Models replicating the biological structures and stress analysis by inducing mechanical forces on these models evaluate the materialistic properties of anatomical structures.[17,18] Data related to bone geometry and properties are transferred from digital images like CT scan/MRI scan to an FEA model assisted by various softwares.[19–21] In FEA models load is usually applied vertical or oblique to the long axis of

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Table 1
Excluded studies with reason.

Excluded study	Reason for exclusion
1. Bidez et al. (1993)[34]	Used four different hader bar designs
2. Luo et al. (1998)[35]	Used natural tooth as an abutment in some models
3. Luo X et al. (1998)[36]	Article in Chinese language
4. Chun HZ et al. (2005)[37]	Used only Dalbo type of attachments
5. Tanino F et al. (2007)[38]	Checked difference in stress patterns, using attachments of different modulus of elasticity only.
6. Daas M et al. (2008)[39]	Compared only different modulus of elasticity of attachments
7. Barao et al. (2009)[40]	Compared complete dentures and overdentures
8. Prakash V et al. (2009)[41]	Used only different number of bar attachment systems
9. Fatalla et al. (2012)[42]	Used teeth as an abutment in one model
10. Barao et al. (2013)[43]	Compared between implant supported fixed prosthesis and implant retained overdentures.
11. Dashti M et al. (2013)[44]	Evaluated stress patterns in mandibular residual alveolar ridge using two different attachment systems.
12. Bilhan SA et al. (2015)[45]	Evaluated the change in stress patterns when the number of implants supporting overdenture varies
13. Caetano CR et al. (2015)[46]	Used only different bar designs and compared stress in different implant angulations, vertical misfit, framework materials.
14. Lauritano F et al. (2016)[47]	Not accessible
15. El-Zawahry et al. (2018)[48]	Used only different number of ball attachments
16. Hu F et al. (2019)[49]	Used only different magnetic attachments in various models
17. Jiang MY et al. (2019)[50]	Article in Chinese language

the tooth to evaluate the stress in the model.[21] Different types of stress patterns can be seen in FEA model like Von Mises stress and principal stress, Von Mises stress is a theoretical stress pattern which is used to calculate yield strength or fatigue strength of ductile materials and principal stress is a less theoretical one, directly measurable stress.[22,23] Main drawback of the FEA models is the effect of facial form and craniofacial musculature on masticatory forces cannot be duplicated in models. All FEA models considered in the stress analysis are isotropic in behaviour. It is challenging to quantify the whole anisotropic structure of a bone, organ with current techniques.[24] FEA analysis offer major advantage in implant dentistry via simulating intraoral condition in vitro and analysing effect of change in implant number, material and effect of other component on anatomical structure. As per author's knowledge presently there is no systematic review available in terms of stress distribution pattern of implant overdenture attachments in FEA models. Results of this review may add more scientific evidence in this topic which can help us during selection of overdenture attachments in clinical scenario.

The aim of the present systematic review was to compare different types of attachments used in implant supported overdenture finite element models in terms of distribution of stress to the surrounding bone and other tissues.

2. Materials and methods

Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines were used and the checklist was followed in this Systematic review.

. Population, intervention, control, outcome, study design (PICOS) strategy.

P: Finite element models
I: Implant supported overdenture with attachments
C: Implant supported overdenture with a different type of attachment than interventional group in same model
O: Stress distribution around peri-implant region
S: Finite element analysis studies

Focus question: What is the pattern of stress distribution of various attachment systems for implant supported overdenture prosthesis in peri-implant region evaluated by Finite Element Models???

Search strategy: Eligibility criteria were determined before the literature search was performed. Published articles on finite element analysis using implant supported overdenture models were included. Prospective and retrospective studies, in-vivo studies**,** animal studies, literature reviews were excluded. Only articles written in English languages were selected. In-vitro studies were included in this study that were concerned with stress patterns under different types of attachment systems in implant supported overdenture FEA models. A comprehensive search was done from January 2020 to June 2020 with no year limits to published articles. Following electronic databases were searched for published studies- PubMed, Web of Science. Additionally manual search of the references and gray literature was done. Keywords used in this study during literature search were: "finite element analysis," "dental implants," "overdentures," "attachments." Two independent reviewers (BB and RS) performed the literature search and any disagreements between reviewers were solved through discussion.

Objective of the review: Evaluation of stress distribution pattern of different attachments used in implant supported overdenture in peri-implant region of finite element models.

Data extraction: The data was extracted by two independent reviewers (BB and RS) from all the included studies and filled into predetermined forms. The form consisted of the following informations: Study, year, country, FEM model designing, materials used in analysis, loading conditions, attachments used, and significant findings. The extracted data were stratified and tabulated according to chronological order. Information related to various characteristics of the included studies was described in a summary like format.

3. Results

The literature search yielded a total of 174 articles from two electronic databases (PubMed- 98, Web of Science - 76). After removal of the duplicates (n = 66), initial screening of titles and abstracts was performed by two independent reviewers (BB and RS). At this stage 81 articles got removed after screening of title and abstracts. A total of 27 articles were selected for full-text reading, of these 27 articles, 10 studies were included for qualitative analysis.[8,25–33] Three studies excluded due to non-English languages and non-accessibility, six studies not selected due to usage of only one type of attachment system in the study design. Among the excluded studies five studies used either tooth as an abutment or any other type of prosthesis to check the stress pattern and another study evaluated stress in edentulous ridge but not in peri-implant region. Remaining two studies employed attachments of different elastic modulus; no difference was present in between attachment types.[34-50] Excluded studies have been mentioned in (Table 1). Total ten studies from five different countries were included in this systematic review. Study selection procedure has been depicted in (Fig. 1). Among the included studies, six studies compared ball attachments and locator attachments.[8,27,28,30,31,33] Two studies compared between ball attachments and bar-clip attachment systems.[25,29] One study compared between locator and equator attachments and another study compared between ball attachments and magnetic attachments.[26,32] Characteristics of the individual studies are tabulated in chronological order in Tables 2 and 3. Typical setup of FEA model containing the attachment system have been shown in (Fig. 2).

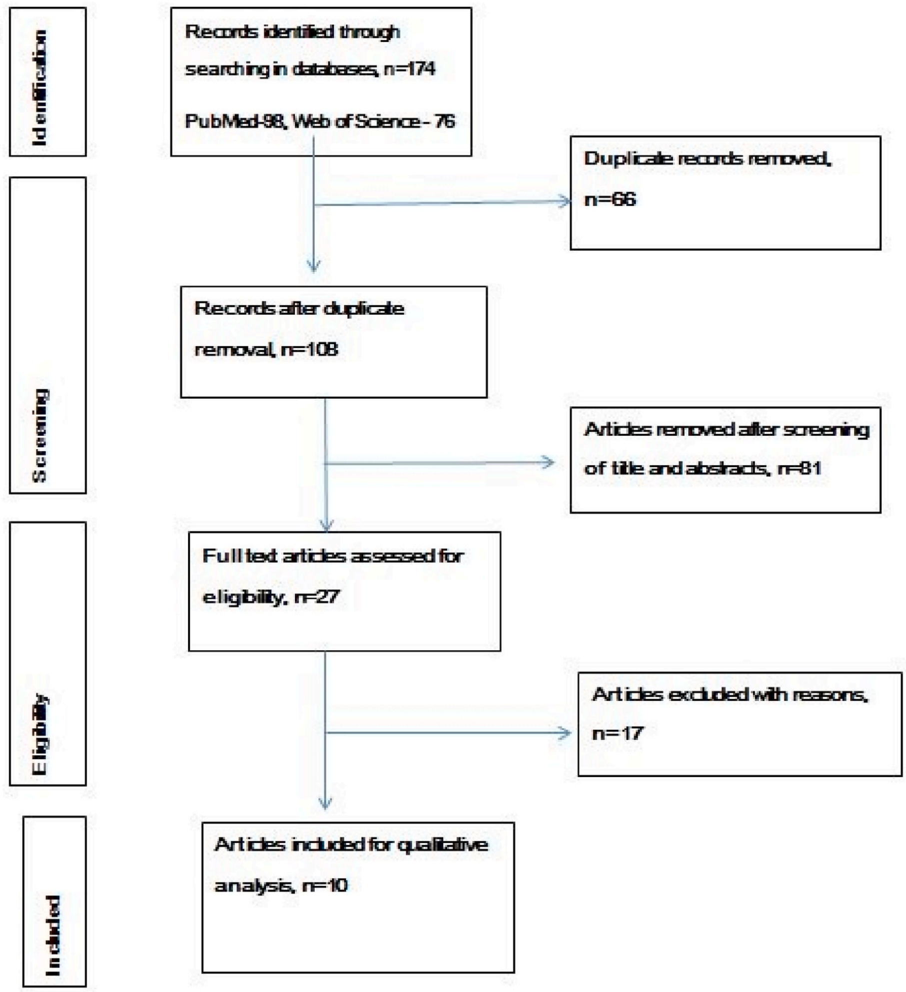

Fig. 1. Flowchart showing study selection process.

4. Discussion

Different attachment systems have been used till now in relation to implant supported overdenture prosthesis. Behaviour of the attachments under axial and non-axial forces modulates the survivability of attachment systems and can influence the marginal bone loss around implants. Success of implant supported overdenture prosthesis depends on peri-implant tissue responses, bone loss, hygiene and overall compliance of the patients.[16] Selection of attachment system is based upon various factors like inter-arch distance, inter-implant distance, bone quality, cost-effectiveness, arch form, amount of keratinized mucosa.[51] Maintenance of bone surrounding dental implants dependent upon material of implant and prosthesis, type of loading, direction and magnitude of force (axial/non-axial), quality and quantity of surrounding bone and other factors. In the present systemic review, included ten studies are divided into various sections according to the attachment types and discussed below.

4.1. Ball attachments vs locator attachments

Khurana et al. used different heights of the locator attachments and ball attachments in FEA models. According to the study locator attachment showed more homogenous stress distribution than ball attachments in all the models. Von mises stress value was found to be lowered with locator attachment than for ball attachment in the models. Stress value increased proportionally with the increasing height of attachments.[31] Similarly Ozan et al. showed that stress values were less in case of locator attachments. Stress concentration areas were also different for both the attachments. Locator attachments showed most of the stress concentrated at the top of attachment while neck region was the most stressed region in case of ball attachments.[8] El-anwar et al. used models with both the locator and ball attachments and measured stress values in different regions of prosthesis and denture bearing areas. Measured stress value in implant and prosthetic components showed less stress concentration in case of locator attachments. Conclusions from the study were that Locator attachments are more useful to increase prosthetic life span by dissipating stress around the attachments. However in case of weaker bone, ball attachments are more preferable.[30] In another study of el-anwar et al. different models were used consisting of ball and locator attachments and two/four implant supported overdentures. In this study, similarly, locator attachments proved to be beneficial in terms of distribution of stress in implant and peri-implant regions. Authors stated that this may be due to lower profile and resilient nature of locator attachments.[28] Cicciù et al. stated that locator attachments showed better response than ball attachment and universal abutment when five different types of load were directed in the model.[27]

Contradicting the other studies Unsal et al. showed that principal stress value was less for ball attachment models than the locator attachments. Von mises stress value was higher in case of ball attachments but not statistically significant. Authors concluded that this behaviour of ball attachments may be due to most of stress gets absorbed in the neck of the ball attachments.[33]

Table 2
Characteristics of the included studies.

Study	Country	FEA model designing	Materials used in the study	Loading conditions	Attachments used
Menicucci et al. (2000)[25]	Italy	The model was fabricated using Sprints software.	All the materials used in these FEA models were assumed to be isotropic, homogeneous, and linearly elastic.	Amplitude of the applied forces was such that the reaction force at a restrained point at the first molar of the prosthesis equaled 35 N vertical bite force to stimulate masticatory loading.	The ball attachments and one straight bar and two clips 6 mm apart.
John et al. (2012)[26]	India	ANSYS Software 8 was used to fabricate 3D finite element model from computed tomography scan of mandible.	2 mm thickness of uniform cortical bone was used, which was covered by mucosa. Overdenture prosthesis over implant consisted of an acrylic denture base and acrylic teeth. All materials used in this study were assumed to be homogeneous isotropic and linearly elastic.	Force of 35, 70, 10 N were directed from horizontal (lingual), vertical, and oblique (buccal) directions respectively on the surface of the modelled tooth.	The Ball attachment and Magnetic attachment.
Ozan et al. (2014)[8]	Turkey	The data used in this study obtained from the Visible Human Project®. Rhinoceros 4.0 software was used to establish a 3D mandible FEA model	3D mandible FEA model made up of 2 mm cortical bone covering the trabecular bone and 2 mm mucosa. Implant abutment (patrix) was made up of titanium and retentive gold alloy housing was used as matrix. Patrix part of the locator attachment system was modelled from titanium. Additionally, 4.7 mm-diameter resilient nylon (blue) cap was also used. Matrix part of the system modelled from 5.4 mm diameter denture cap.	Occlusal load of 100 N was used in different biting configurations.	Ball attachment and Locator® attachment.
Cicciù et al. (2015)[27]	Italy	Models of the jaw arches, the dental implants, and the prosthetic crowns fabricated with the help of a CAD (computer aided design) software.	In this study grade 4 titanium was used to fabricate implant components, attachment systems, and other prosthetic components. Cortical and cancellous bone was considered as orthotropic materials. Three different models were used in this study. Model A is as follows: (i) Dental implant (Ø 4,3 × 13 mm). (ii) Ball Abutment (Ø 4,3; gingival height 3 mm). (iii) Bone (midollar and cortical). Model B is as follows: (i) Dental implant (Ø 4,3 × 13 mm). (ii) Locator Abutment (Ø4,3; gingival height 3 mm). (iii) Bone (midollar and cortical). Model C is as follows: (i) Dental implant (Ø4,3 × 13 mm). (ii) Universal abutment (Ø4,3H11mm). (iii) Passing screw (iv) Bone (midollar and cortical).	The three implants were tested with static loads. Different loading conditions were considered: (i) Pure traction of 400 N. (ii) Pure compression of 400 N. (iii) Flexural force of 400 N. (iv) Mixed tensile-bending of 400 N. (v) Mixed compression bending of 400 N. All loads were distributed on the implant surface in contact with the tooth.	Ball attachment system, The Locator system,
El-anwar et al. (2015)[28]	Egypt	Commercial CAD/CAM software was used to fabricate 3D FEA model.	All the 3D model components were exported in SAT file format. The modelled implant consisted of titanium with ball or locator attachments.	Unilateral compressive loads of 50, 100, and 150 N were applied in a vertical direction, parallel to the longitudinal axes of the implants (central fossa in the molar region).	Ball and Locator attachments.
Satpathy et al. (2015)[29]	India	Finite element model was modelled from a spiral computed tomography scan image of 3 mm sections of a 60-year-old completely edentulous male patient.	Mechanical properties such as Young's modulus and Poisson's ratio of mandible, denture, mucosa and implants were analyzed. All materials used in this study considered to be isotropic, homogeneous, and linearly elastic.	Load of 0–100 N was used, increasing in 10 N incremental orders. The loads were applied both unilaterally and bilaterally in the second premolar and first molar region.	Ball/O-ring and Bar/Clip attachment systems
El-anwar et al. (2017)[30]	Egypt	The finite element models were created in "Autodesk Inventor" Version 8, then exported as SAT files.	Titanium used as a material of choice in fabrication of implants and attachments. The metal cover on nylon caps of both the attachments were ignored. All materials that were used including cortical and cancellous bone considered to be isotropic, homogenous and linearly elastic.	Vertical load, and oblique load of 100 N directed at an angle of 110° from the lingual side in right premolar/molar region.	Ball & socket attachments and Locator attachments
Khurana et al. (2018)[31]	India	3D surface model of the mandible was obtained by using data from a cone beam computerized tomography (CBCT) image of the human edentulous mandible. Data from CBCT image was then imported into Materialise MIMICS software. CATIA (Computer Aided 3D	The cortical and cancellous bone material was isotropic, homogenous, and linearly elastic. Ti6Al4V alloy was used to make implants, grade 4 titanium was used to fabricate attachments. The caps of the attachment were consist of - a retentive nylon rubber cap and a stainless steel housing. . The overdenture prosthesiswas made for the same patient using	Central fossa region of the right first molar tooth,- Vertical compressive load of 100 N (Direction- Unilaterally), Buccal incline of the buccal cusp right first molar tooth (buccal to lingual direction, unilaterally) - An oblique load (100 N) 30° in relation to the longitudinal axis of the implant	Ball attachment and Locator attachment at three heights (1, 3, 5 mm)

(continued on next page)

Table 2 (*continued*)

Study	Country	FEA model designing	Materials used in the study	Loading conditions	Attachments used
		Interactive Application) software was used in final fabrication of the model.	conventional heat-cured acrylic resin and cross-linked acrylic teeth which was used to later in fabrication of 3D model.		
Cicciù et al. (2019)[32]	Italy	Finite element models of jaw arches, overdentures and implants were processed from roster images using a 3D CAD "version 2014"	Physical behaviour of different materials were considered depending upon occlusal loading and lateral forces. The titanium alloy (Ti6Al4V) which was used considered as homogeneous, linear, and isotropic, whilst the bone tissues (cortical and cancellous) were considered as orthotropic materials	A compression load of 800 N was used to load the dental implants.	The Equator® attachment system and the Locator® attachment.
Unsal et al. (2019)[33]	Turkey	.Software was used to fabricate 3D models of completely edentulous mandibles of different bone heights from cone-beam computed tomography (CBCT) image.	Attachment parts were made up of metal alloys.The prostheses and denture teeth were considered as made up of acrylic resin. 2 mm thickness of cortical bone and 1 mm of mucosa considered in the control model. All materials used were considered as isotropic, homogenous, and linearly elastic.	Central fossa of the right and the left first molar teeth, unilaterally and bilaterally – Static and Vertical load. Center of the buccal cusp of the first molar of the overdenture (Direction-buccolinguely, Unilaterally) - oblique load of 100 N was applied at an angle of 30° with respect to the long axis of the implants.	The locator and the Ball attachments

4.2. Bar-clip attachment system vs ball attachments

Menicucci et al. evaluated stress patterns in models using attachment system of bar-double clip and ball. Due to limitation of rotational movement and less degree of freedom bar-clip attachment system concentrated most of the force distal to the implants. Ball attachments on the other hand produced much less amount of stresses in the models, which was concentrated mainly in medial portion in between two implants.[25]

Satpathy et al., measured the stress by both analog system and finite element analysis procedures between bar-clip and ball attachments. In their study they got slightly different results from the previous FEA analysis studies. Loading side implant showed less stress concentration in case of ball attachments when less amount of load was applied. This may be due to shock absorbing property of elastic O-ring used with ball attachments in this study. Bar-clip attachment produced more stress on the non-loading side of implant because of splinting effect even in lower amount of loads. Conditions with bilateral load application showed better dissipation of forces in case of bar-clip attachments than ball attachment system. Findings in higher loading condition were contradictory to the results of previous aforementioned studies.[29]

4.3. Ball attachments vs magnetic attachments

Only one study compared generated stress pattern between ball and magnetic attachments included in the review according to the pre-defined inclusion criteria. John et al. placed different diameters of ball attachments and magnetic attachments in finite element model in the study design. They concluded that stress can be reduced by using smaller diameter attachments but no significant difference was found in between two type of attachments.[26]

4.4. Equator attachments vs locator attachments

Cicciù et al. applied a load of 800 N in finite element models, three different attachments-universal abutment, equator attachment and locator attachment were used. Overall both equator and locator attachments showed better stress distribution in the bone around the implants than universal abutment. Both the attachments showed adequate resistance against fracture by dissipating the load. Retentive properties were adequate for both the systems.[32]

The commonly used attachment systems the bar and clip and ball and O-ring systems are most common system used. It has previously been

Table 3
Significant findings of the included studies.

Study name	Key findings
Menicucci et al. (2000)[25]	Cortical bone around neck and bottom part of dental implants concentrated more stress than other regions. In case of bar-clip anchorage stress more concentrated around the non-working side implant. Area between the two implants was the most stressed region in case of ball attachments. Highest peak stress found in case of bar-clip attachment system compared to ball attachments.
John et al. (2012)[26]	Both ball and magnetic attachment systems showed favourable stress distribution around peri-implant bone. Greater diameter attachment system generated more stress around implants. Therefore greater diameter of implants is always favourable when using greater diameter of atttachments.
Ozan et al. (2014)[8]	Stresses on the locator attachments showed lower values in peri-implant bone when compared with the ball attachment groups in all configurations. Ball attachment used in the study had rotational resiliency but no vertical resiliency. Therefore neck of the ball attachment concentrated more stress than other region.
Cicciù et al. (2015)[27]	Locator attachments used in the study showed better stress distribution (Model B) than other models containing ball attachments and universal attachment systems (Model A and Model C) in all five different types of stresses.
El-anwar et al. (2015)[28]	Locator and ball-socket attachments induced equivalent stress around peri-implant region. Overall stress on nylon caps, implant and prosthesis was less in case of locator attachment compared to other system,
Satpathy et al. (2015)[29]	Ball attachment dissipated less force during bilateral loading period and bar-clip attachment concentrated more stress in unilateral loading period. Bar-clip attachment was considered to be better during condition with higher occlusal load compared to ball attachment system.
El-anwar et al. (2017)[30]	Locator atttachments generated less stress around peri-implant bone due to its resilient nature and low-profile design. Ball attachments due to its high profile from alveolar bone and implant generated more stress by creating a longer lever arm. Cervical portion of the locator attachment and neck of the ball attachments were the most stressed region.
Khurana et al. (2018)[31]	Locator attachments showed even stress distribution than ball attachments in all the loading conditions. Increase in attachment height generated more stress than attachment with lower height. Neck of both the attachment systems was the highest stressed region.
Cicciù et al. (2019)[32]	Equator and locator attachment systems distributed stress evenly compared to universal abutment. Better distribution of stress incase of locator attachment system
Unsal et al. (2019)[33]	Ball attachment showed less principal stress values than locator attachment system. In case of bilateral loading there was less dissipation of stress with ball attachments compared to unilateral loading condition.

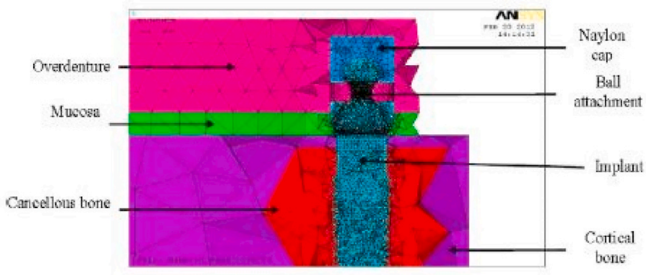

Fig. 2. Setup of an attachment in FEA model
Figure reference: El-Anwar MI, Yousief SA, Soliman TA, Saleh MA, Omar WS. A finite element study on stress distribution of two different attachment designs under implant supported overdenture. Saudi Dent J 2015; 27:201–7.

reported that most prosthetic maintenance related complications occur during the first year of loading and ball attachments have high maintenance rate due to the need to change the ring, over time.[52] Previously many studies addressed that repair and maintenance of attachment systems are important for survival of implant supported overdentures.[53,54,55,56] Designing and quality of implant attachment system, implant position, materials, occlusion all are responsible for better performance of prosthesis.[57] Reviewing the result from the study it can be stated that greater height and diameter of the attachments generated more stress around peri-implant region. Due to low-profile design and resilient nature of locator attachment it showed good result at dissipation of stress around dental implants. Rigidity of attachment system also influence force distribution pattern around implant, more force is generally concentrated in distal region of implant with rigid attachment system.

5. Conclusion

Within limitations of this systematic review evaluating studies using ball and locator attachments it can be concluded that locator attachments showed better stress distribution than ball attachment system in all the studies except one study. Two studies showed results in favour of ball attachment compared to bar-clip attachment system when stress was evaluated distal to the implants. No significant difference in terms of stress concentration can be generated between ball vs magnetic/equator vs locator attachment system due to less number of studies and conflicting results.

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Declaration of competing interest

There is no conflict of interest.

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Nil.

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