



BIOMECHANICAL EVALUATION OF SCREW- AND CEMENT-RETAINED IMPLANT-SUPPORTED PROSTHESES: A NONLINEAR FINITE ELEMENT ANALYSIS

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Statement of problem. The mechanical stability of the prosthetic components in the implant-prosthesis complex is essential to the long-term success of the restorations. However, little is known about the differences in the biomechanical behavior of screw- and cement-retained prostheses.

Purpose. The purpose of this study was to compare the preload maintenance, stresses, and displacements of prosthetic components of screw- and cement-retained implant-supported prostheses by using the finite element method in a nonlinear analysis.

Material and methods. Two 3-dimensional models were constructed: implant-supported fixed partial prostheses with 3 elements retained either by screws (SFP) or cement (CFP). After the simulation of screw tightening, the preload was calculated for both prostheses. Then vertical and oblique loads (100 N) were applied on the models. The preload was identified, the maximum von Mises equivalent stresses (SEQV) were obtained on the screws, and the displacement among the abutment, the implant, and screw was identified by observing the penetration and gap in the contact interfaces.

Results. Under vertical load, there was a higher decrease in the preload and in the SEQV on the screw in the SFP. Under oblique load, the SEQV was 24% higher on the screw of the SFP. In the displacement analysis under vertical load, penetration was concentrated in the threads of the screw in the SFP and between the abutment and implant in the CFP. The gap was 118% greater for the SFP and was concentrated on the abutment extension. Under oblique load, the displacement pattern was similar for both prostheses, but with values 66% higher for penetration and 96% higher for gap for the SFP.

Conclusions. The SFP showed a higher biomechanical risk of failure than the CFP. (J Prosthet Dent 2014;112:1479-1488)

CLINICAL IMPLICATIONS

Screw loosening or fracture is a frequent complication in implant-supported prostheses. Screw-retained prostheses present a higher risk of such mechanical issues. Attention should be given to the proper tightening of the screws, fine occlusal adjustment, and precise fit of the prostheses to minimize mechanical failure.

Oral rehabilitation with implant-supported prostheses is a predictable treatment.¹ Initially, implant-supported prostheses were exclusively retained by screws, and studies have confirmed their success, particularly in fully edentulous patients.² However, with the development of new implant systems and new rehabilitation techniques,

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cement-retained prostheses have become a popular treatment option, mainly in treatments with single and fixed partial prostheses. Currently, cement-retained prostheses are frequently used with a high level of success.³⁻⁷

The advantages and disadvantages of screw- and cement-retained prostheses have received attention from researchers with regard to retention, quality of fit and marginal adaptation, occlusal stability, esthetics, reversibility, ease of manufacture, cost, maintenance of bone level, gingival health, and survival.^{4,6-8} The biomechanical behavior of screw- and cement-retained prostheses concerning the generation of stress on tissues and prosthetic components has been compared with different methods; however, the results were not consistent.⁹⁻¹⁸

High stress may lead to mechanical and biological problems in the prosthesis-implant-bone complex.¹⁹ The biomechanical stability of implant-supported prostheses depends on the stresses and displacements in this system.²⁰ High stresses on the prosthetic components may cause mechanical failure, such as screw loosening, fracture, and preload decrease.²¹⁻³³

The intensity and patterns of stress and displacement in the prosthesis-implant-bone complex may be influenced by the retention method of the implant-supported prosthesis and the abutment type.^{11,34} Consequently, a biomechanical analysis of the mechanism underlying stress and displacement generation is essential to predict the success of implant restorations by identifying the possible risks of mechanical problems. Therefore, the aim of this study was to compare the preload, stresses, and displacements in prosthetic components of implant-supported screw- or cement-retained prostheses by using the finite element method in a 3-dimensional (3D) nonlinear analysis.

MATERIAL AND METHODS

Two 3D models were developed: screw- or cement-retained metal ceramic fixed partial prostheses with 3

elements supported by implants in the area of the mandibular second premolar and second molar. Initially, a section of a human partially edentulous mandible was modeled. Cone-beam computed tomography (CT) (i-CAT; Imaging Sciences International) of the mandible of a partially edentulous patient was obtained from the files of patients treated by one of the authors (G.C.S.). The images of 3D CT reconstructions in STL format (3-D Systems) were transferred to 3D computer-aided design software (SolidWorks; Dassault Systèmes) for editing and refinement. The edentulous region between the second premolar and second molar was sectioned, and the mandibular canal was eliminated to reduce the volume and complexity of the computational model. The cortical portion of the bone was lineated in the form of a 1.50-mm-thick homogeneous layer simulating a type II bone,³⁵ and all contours of the mandible segment were rounded and smoothed.

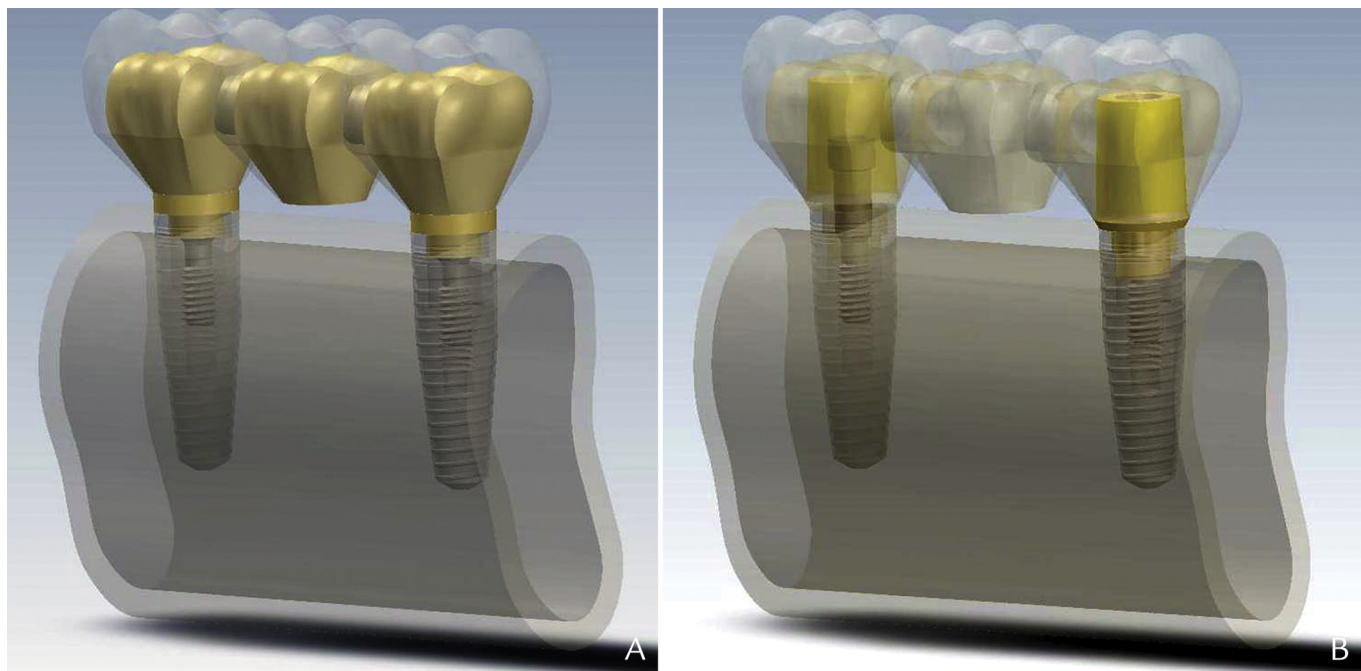
Implant and prosthetic components, which were obtained directly from the manufacturer, were modeled as previously described³⁶: the dental implant (NobelReplace 4.3×13 mm; Nobel Biocare), direct abutment for screw-retained multiple-unit prostheses (GoldAdapt Non-Engaging; Nobel Biocare), customized engaging titanium abutment for cement-retained prostheses (Esthetic Abutment; Nobel Biocare), and titanium abutment screw (29475 TorqTite; Nobel Biocare).

To model the outer contour of the prostheses, the crown of a second molar was modeled and posteriorly replicated 3 times. The crowns were joined in the proximal region by cylindrical connectors. After completion of the external design of the prostheses, 1.50 mm was determined as the outer layer of the entire volume that corresponded to the ceramic layer. For the cement-retained prosthesis, the entire area just below the ceramic layer before contact with the abutment represented the gold infrastructure. For the screw-retained prosthesis, gold was used for the entire inner area under the ceramic

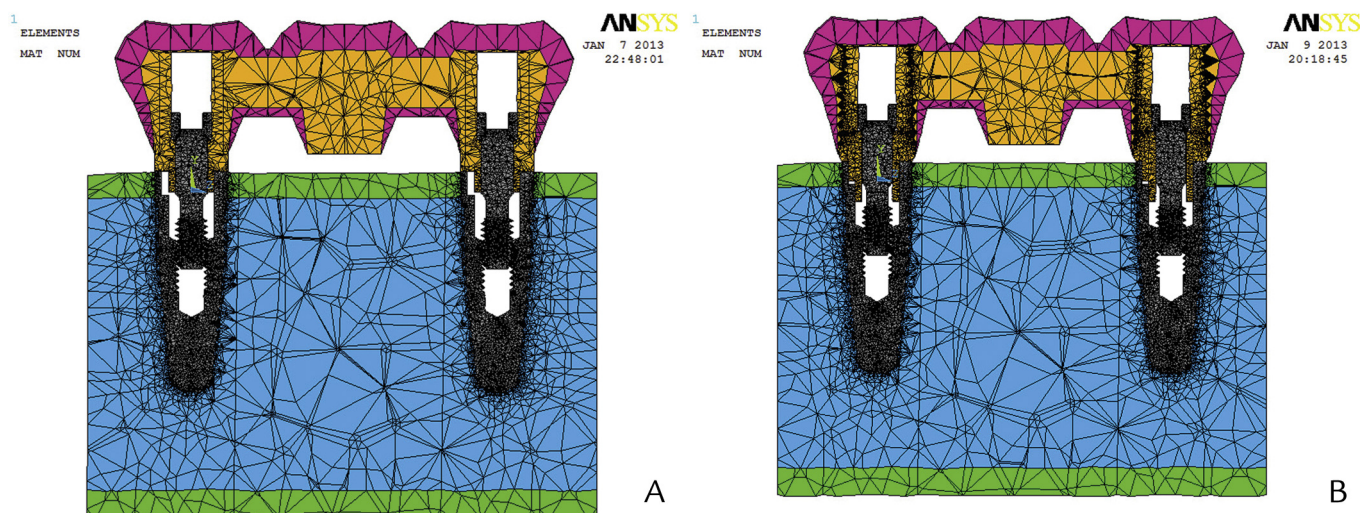
layer because it would fuse to the abutments. The screw access was obliterated with composite resin. For the cement-retained prosthesis, a homogeneous layer 25 μ m thick representing zinc phosphate cement was modeled between the gold infrastructure and the abutments (Fig. 1).^{5,37}

The mesh was generated with computer-aided engineering software (Ansys 14; Ansys Inc) (Fig. 2). A material with mechanical properties was assigned for each volume^{38,39} (Table I), and a coefficient of friction was assigned for each material (Table II).^{40,41} The bone was considered anisotropic^{42,43} (Table III), linear elastic, and homogeneous, and the other materials were defined as isotropic, linear elastic, and homogeneous. The contact areas between the different sections of the models were defined by using nonlinear contact elements. The behavior of the contact surface was different according to the interface of the materials. Between the implants and bone, a rough contact was selected, which allowed the formation of microspaces without sliding between the elements. An identical contact was selected in the area between the abutments×cement and between the cement×metallic infrastructure in the cement-retained prosthesis, because instead of chemical bonding, there is only mechanical imbrication between the cement and the metal. Between the screws×implants, implants×abutments, and abutments×screws, a standard contact was selected, which allowed the formation of microspaces and a small degree of sliding between the surfaces, a common occurrence between metal surfaces. The remaining volumes were considered bonded because they showed characteristics of a cohesive union: cortical×cancellous bone, ceramic×gold infrastructure, and resin×ceramic. The models were constricted in the mesiodistal (anteroposterior) and buccolingual (lateral to medial) directions.

The load simulations were identical for both models and were performed in 3 steps. First, before the imposition of loads on the models, the abutment



1 Three-dimensional models of prostheses. A, Screw retained. B, Cement retained.



2 Coronal section of meshes. A, Screw retained: 1 097 527 elements. B, Cement retained: 1 146 675 elements.

screws received a torque of 35 Ncm, a value recommended by the manufacturer, to represent the settling of the prostheses for the SFP and of the abutments for the CFP. For the torque simulation, nonlinear contact elements were selected on the 6 inner sides of the hexagonal screw head. Then a master node was determined in the spatial center of the screw head. A moment of 35 Ncm was applied clockwise on the master node in a rotation of all the nodes of the contact elements on the inner sides of the screw head, resulting in screw tightening. The rotation

TABLE I. Mechanical properties of materials used

Material	Young Modulus (MPa)	Poisson Ratio
Titanium	117 000	0.30
Gold	100 000	0.30
Porcelain	68 900	0.28
Zinc phosphate cement	17 000	0.35
Composite resin	7 000	0.20

Zinc phosphate cement³⁸; other materials.³⁹

moment was then finalized, indicating the end of the tightening. At that time, the value of preload was identified. For

this purpose, contact elements were selected from the interface between the screw head and the abutment, and the

pressure value occurring between these elements was obtained. The pressure in each element was multiplied by its respective area, obtaining a force value normal to the area. This force was then changed to force in the direction of the axis of the screw, resulting in the value of preload. Finally, with the screw pretensioned, vertically and obliquely (45 degrees in the buccolingual direction), 100 N loads were applied to the occlusal areas of the teeth in each prosthesis at different times.

The screws, implants, and abutments were plotted to observe the stresses and displacements externally and internally. The results of the second premolar were presented because the region of the second molar showed almost identical results. For analysis of the screws, the maximum von Mises equivalent stresses (SEQV) criterion, which is suitable for ductile materials, was used. A lower stress corresponds with a lower risk of failure. For analysis of the displacement among the abutment, implant, and screws, the penetration and gap were identified in the contact interfaces. A smaller displacement at the interface, also interpreted as a minor movement between the parts, corresponds with a lower risk of failure. The qualitative analysis was made by comparing the pattern of the distribution of the stresses and displacements. The quantitative analysis was given for the difference in the percentage of the maximum values found for each criterion used.

RESULTS

After screw tightening and before the imposition of loads, the pattern and value of the von Mises stresses in the screws were similar between SFP and CFP. Stresses were distributed across the smooth neck above the threads, the threads, and the base of the screw head, where the abutment is compressed into the implant. In the threads, an interleaved stress distribution, with high-stress areas followed by low-stress areas, was visualized. This was due to the imperfect contact

between the vertices of the threads of the screw and the inner area of the implant (Fig. 3).

Under vertical load, the pattern remained similar; however, a decrease was noted in the stresses and in the preload in both prostheses, most notably in the SFP (Fig. 4) (Table IV). Under oblique loading, a great increase in stresses was noted, most markedly in the SFP, which was concentrated near the smooth neck over the threads (Fig. 5) (Table V).

The plots of the displacements showed the contact surfaces of some parts of the abutment-screw-implant complex. In the plots of the gaps, the negative values showed the largest displacements.

Under vertical load, penetration was observed between the base of the abutment into the implant platform in both prostheses, with a higher

concentration in the vestibular part. However, the largest penetration was located differently in the prostheses. In the CFP, the highest penetration occurred between the abutment and the implant platform, while in the SFP it was located on the lingual threads of the screws. The penetration was higher in the SFP. A more homogeneous and less intense penetration was also observed in the screw threads of the CFP (Fig. 6). Under oblique loading, the penetration pattern was similar in both prostheses. The highest penetration was located between the lingual edge of the base of the abutment and the implant platform, with the SFP showing a higher value (Fig. 7) (Table VI).

Regarding the gap under vertical load, a distinct pattern was found between the prostheses. In the SFP, the gap was higher and was noted in

TABLE II. Friction coefficient of interfaces between different materials

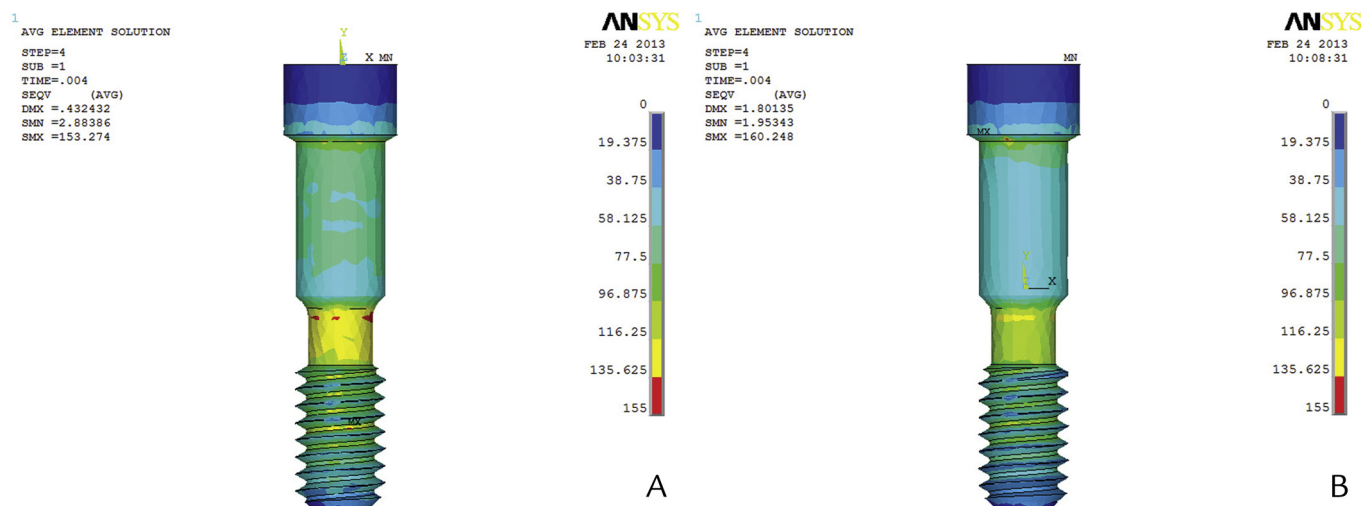
Interface	Friction Coefficient
Titanium abutment×titanium screw	0.16
Gold abutment×titanium screw	0.20
Titanium abutment×titanium implant	0.16
Gold abutment×titanium implant	0.20
Titanium screw×titanium implant	0.16
Titanium implant×bone	0.30
Zinc phosphate cement×titanium abutment	0.20
Zinc phosphate cement×gold	0.20

Zinc phosphate cement interfaces⁴⁰; other interfaces.⁴¹

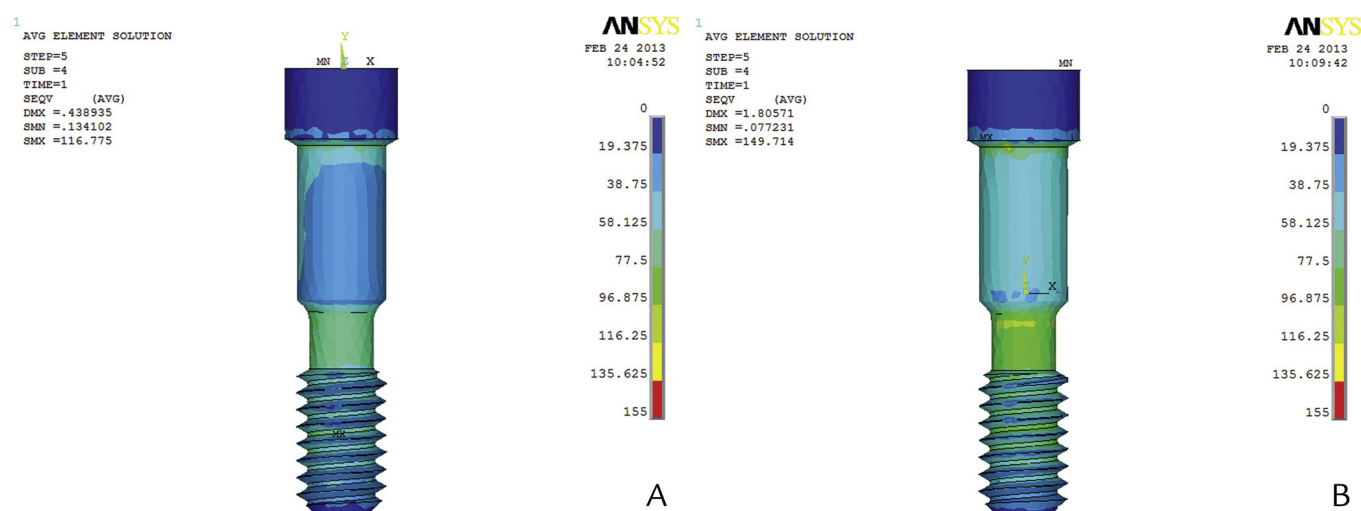
TABLE III. Bone properties

Property	Cortical Bone	Cancellous Bone
E_y	12 500	210
E_x	26 600	1148
E_z	17 900	1148
G_{yx}	4500	68
G_{yz}	7100	68
G_{xz}	5300	434
ν_{yx}	0.18	0.055
ν_{yz}	0.28	0.055
ν_{xz}	0.31	0.322

E_i , Young modulus (MPa); G_i , shear modulus (MPa); ν , Poisson ratio. y-axis is apicocoronal; x-axis is anteroposterior; z-axis is lateromedial. Cortical bone⁴²; cancellous bone.⁴³



3 Von Mises stresses on screws after torque and before imposition of loads. A, Screw retained. B, Cement retained.



4 Von Mises stresses on screws under vertical load. A, Screw retained. B, Cement retained.

TABLE IV. SEQV on screw and preload values after torque on screw and after vertical load on prostheses

Prosthesis	Torque: SEQV (MPa)/ Preload (N)	Vertical Load: SEQV (MPa)/ Preload (N)	Reduction (%)
Screw retained	153/413	116/284	23/31
Cement retained	160/401	149/322	6/19

SEQV, maximum von Mises equivalent stresses.

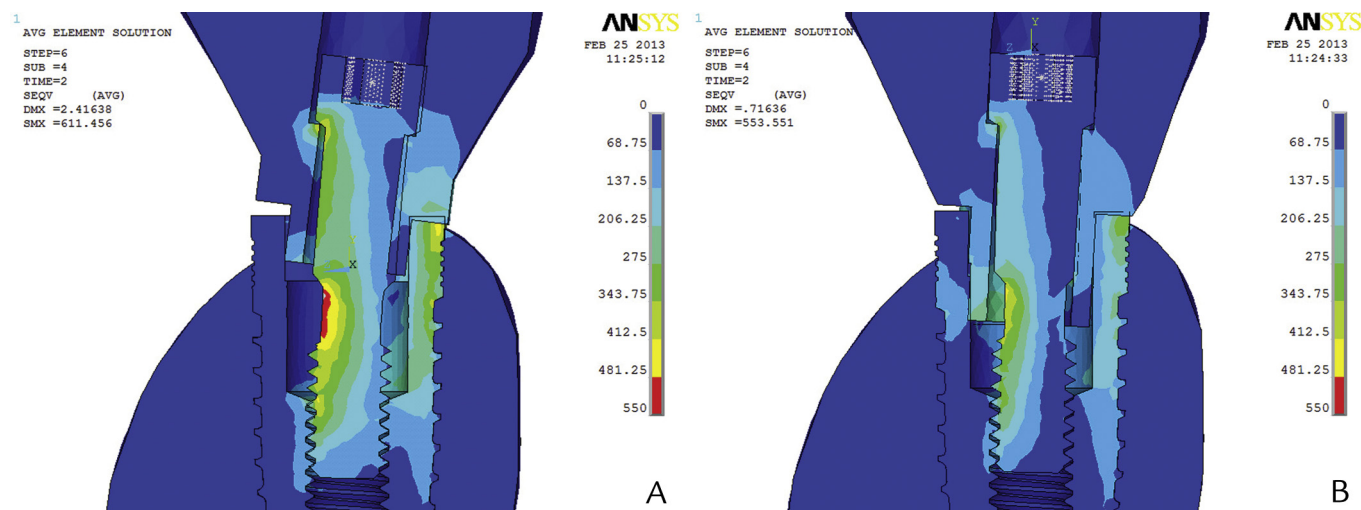
2 areas: the lobes of the implant and between the smooth extension of the abutment and the implant. In the CFP, the area of greatest gap was located in a band on the buccal face of the implant (Fig. 8). Under oblique load, the gap pattern was similar between the prostheses. The maximum gap was located between the buccal face of the base of

the abutment and the implant; it was higher in the SFP (Fig. 9) (Table VII).

DISCUSSION

The finite element method was selected for this comparative analysis because it is not invasive or destructive but rather is a computational numeric

technique that allows the analysis of various types of internal or external stresses, strains, and displacements in any area of the studied structure. With this method, patterns, stresses, and displacements in areas of the prosthesis-implant-bone complex that were inaccessible by other methods of biomechanical studies could be identified. The finite element method is frequently used in implant dentistry and is applied in a wide variety of simulations.^{39,41} However, this research method, as any other, has limitations, particularly when trying to extrapolate the results of this numerical technique for the clinical field. In a study analyzing the mechanical behavior between prosthetic components, the modeling of these parts must be precise.



5 Longitudinal section of prostheses showing von Mises stresses on prosthetic components under oblique load. Note tendency of prosthesis displacement. A, Screw retained. B, Cement retained.

TABLE V. SEQV on screw after torque on screw and after oblique load on prostheses

Prosthesis	Torque: SEQV (MPa)	Oblique Load: SEQV (MPa)	Increase (%)
Screw retained	153	611	298
Cement retained	160	490	205

SEQV, maximum von Mises equivalent stresses.

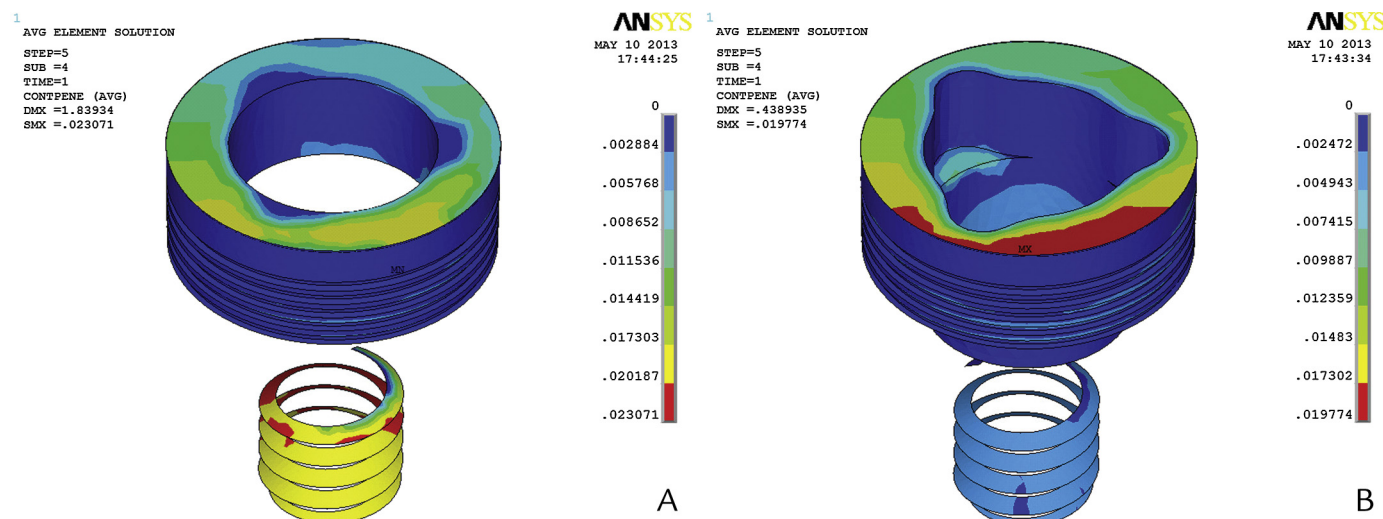
In the present study, the implant and prosthetic components were carefully modeled with reverse-engineering techniques.³⁶ To search for an analysis as close as possible to the clinical reality, some of the interactions between different components of the bone-implant-prosthesis system were simulated with nonlinear contact elements. Many parts that make contact in the bone-implant-prosthesis system do not present a perfectly cohesive union. Therefore, the contact elements should be incorporated at the interface between these structures, allowing the occurrence of sliding and microspaces. A properly conducted finite element study permits clinical inferences to be made, including observing that one type of prosthesis shows better biomechanical behavior or identifying the most likely site of mechanical failure.

The most common technical failure in implant-supported prostheses is the loosening or fracture of the screw.^{5-7,22,23-29} Screw fracture is

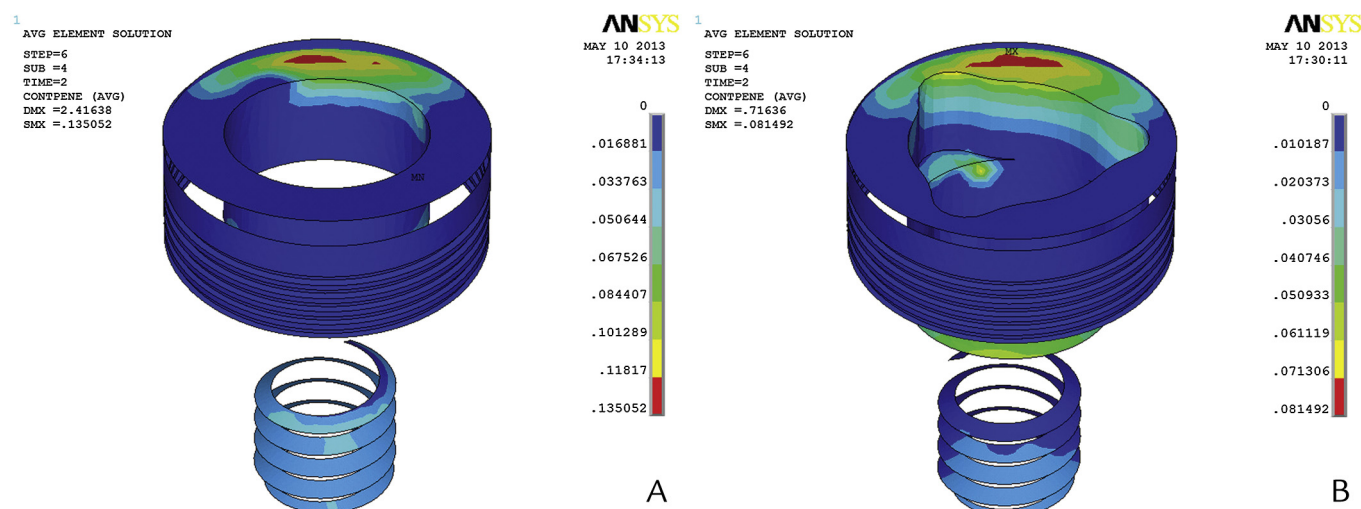
usually preceded by loosening and originates in fatigue, a process initiated by microcracks and highly dependent on stress and displacement acting on the screw.³⁰ This results in discomfort to the patient and cost to the clinician. If not corrected, it also may promote bacterial accumulation in the misfit, increasing the risk of periimplant mucositis.

When the abutment is screwed into the implant through the torque on the screw, stresses are generated causing elongation of the screw. These stresses generate the preload, a clamping force between the implant and abutment, which is responsible for the stability of the prosthetic system. The preload should be greater than the forces that tend to separate the components in order to keep the components together. The maintenance of preload is dependent on several factors, such as the amount of torque, quality of the fit, lubrication of the screw, and especially the external loads acting on the bolt

joint.⁴¹ These factors may decrease the preload on the screw, contributing to its loosening or deformation.^{31,32} The present study showed similar values of preload and stresses in the pre-tensioned screw of both prostheses, which was expected because the components of the bolt-joint system were essentially the same. However, when vertical load was applied to the occlusal surfaces of the prostheses, a decrease in SEQV in the screw of both models was observed, as in another study,³² particularly in the SFP. Consequently, there was also a reduction in the preload. When the prosthetic system is under compressive axial loads, a reduction of stresses in the screw is expected because of the decreased friction of the screw threads in contact with the inner surface of the implant. This enables its rotational displacement, with consequent loss of preload. Under vertical load, the SEQV in the screw decreased 23% in the SFP and only 6% in the CRP, and the preload was reduced by 31% in the SFP and 19% in the CFP. In the displacement analysis under vertical load, a greater penetration between the lingual screw threads and the inner wall of the implant was noted in the SFP, demonstrating movement in the screw. In the CFP, the highest penetration was located between the base of the abutment and the implant, consistent with the compression caused by the vertical load that tends to unite the components



6 Buccal view of penetration of contact surfaces of abutment base, implant platform, and screw threads under vertical load. A, Screw retained. B, Cement retained.



7 Buccal view of penetration of contact surfaces of abutment base, implant platform, and screw threads under oblique load. Note tendency of abutment displacement. A, Screw retained. B, Cement retained.

TABLE VI. Maximum displacement (penetration) among screw, abutment, and implant

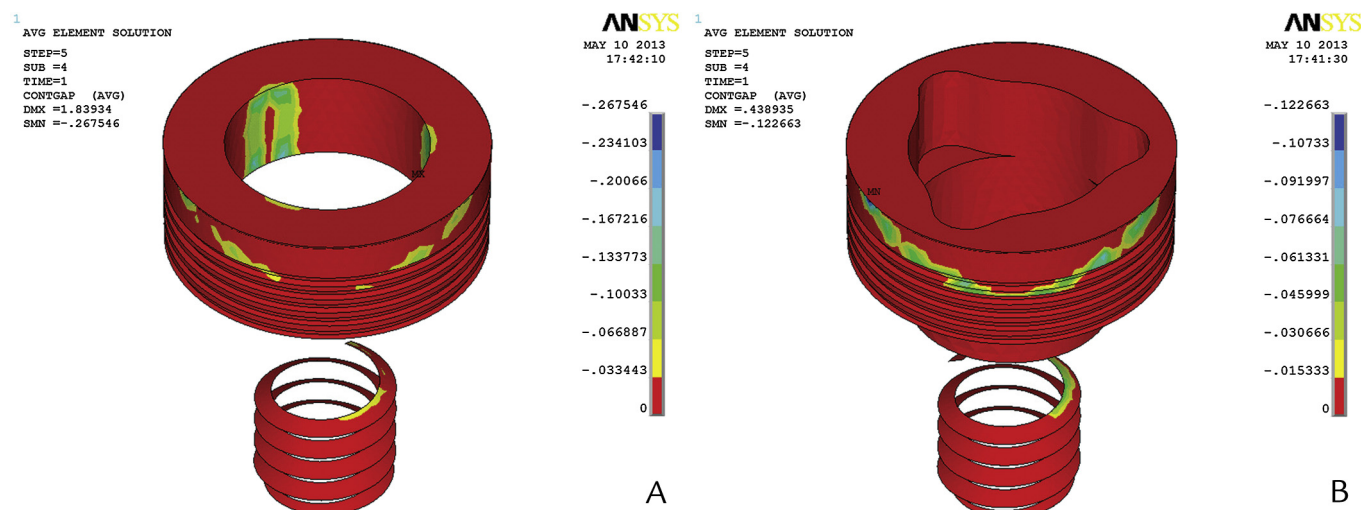
Prosthesis/ Type of Loading	Screw Retained (mm)	Cement Retained (mm)	Difference (%)
Vertical	0.023	0.019	21
Oblique	0.135	0.081	66

of the prosthesis. In the gap analysis under vertical load, the SFP showed the largest displacement in the smooth extension of the abutment (non-engaging feature) that penetrates into the implant in the region of the 3 lobes, whereas in the CFP, the largest areas were observed over a wide range in the neck of the implant. The gap was 118%

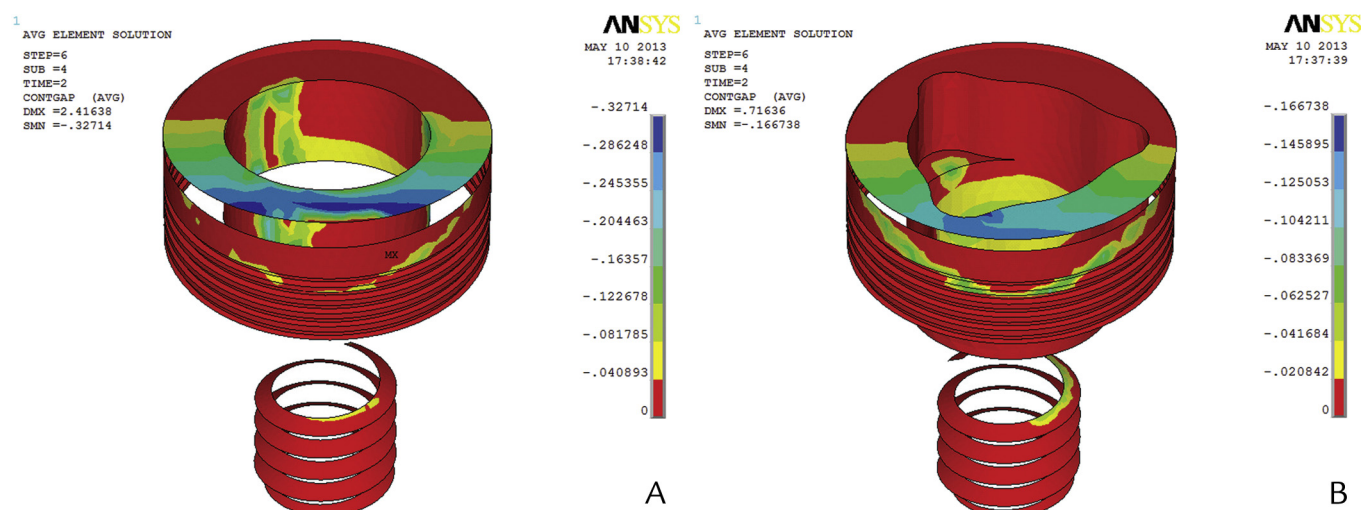
higher in the SFP. Interestingly, almost no displacement was found between the extension of the abutment of the CFP and the implant lobes, indicating the importance of nonrotational lobes (engaging feature) of the abutment to the mechanical stability of the complex. All of these situations observed under vertical load may indicate a higher risk

of screw loosening in the SFP because the preload was lower and the displacement was concentrated on the threads of the screw and on the abutment, unlike the CFP.

When the oblique load was applied, the SEQV on the screws increased to almost 300% when compared to the stresses generated by the torque. The oblique load tended to displace the screw in the direction of the load, but as it was engaged in the internal structure of the implant and abutment, it tended to bend and deform the screw, indicating a risk of fracture. The SEQV in the screw of the SFP was 24% higher than in the CFP, suggesting an increased risk of fracture. In the displacement analysis, a



8 Buccal view of gap of contact surfaces of abutment base, implant platform, and screw threads under vertical load. A, Screw retained. B, Cement retained.



9 Buccal view of gap of contact surfaces of abutment base, implant platform, and screw threads under oblique load. Note tendency of abutment displacement. A, Screw retained. B, Cement retained.

TABLE VII. Maximum displacement (gap) among screw, abutment, and implant

Prosthesis/ Type of Loading	Screw Retained (mm)	Cement Retained (mm)	Difference (%)
Vertical	0.267	0.122	118
Oblique	0.327	0.166	96

similar pattern between the prostheses was observed, with differences only in the magnitude of penetration and gap. A penetration of the lingual face of the base of the abutment in the implant platform could be seen, while the gap was located between the abutment and the implant on the buccal face, consistent with the lever caused by the oblique load applied in buccolingual direction.

The penetration was 66% higher and gap 96% higher in the SFP. This difference in the magnitude of the stresses and displacements can be explained by the design of the connection of the abutment. The trilobe-engaging connection appeared to provide greater mechanical stability with smaller displacements while also being better able to distribute the stresses across the

joint, minimizing stresses on the screw. A study using the same system of implants as the present study evaluated the effect of using 1 antirotational abutment with 1 nonengaging abutment on a fixed prosthesis. It showed that the presence of an antirotational abutment on the prosthesis significantly increased the force required to fracture the prosthetic screw.³⁴

The results of the present simulation confirmed the more favorable behavior of the CFP reported in the clinical literature, which indicates a higher frequency of complications in SFP.^{6,7,24,25} Other studies that compared the mechanical behavior of screw- and cement-retained prostheses are not relevant to the present investigation

because the techniques used did not identify displacements and the stress analysis did not allow an isolated view of the screw, just a more generalized view.⁹⁻¹⁸ Some studies found better biomechanical behavior in cement-retained prosthesis,^{11,13,16,17} while others found no important differences.^{9,10,12,14,15,18} The more favorable mechanical behavior found in cement-retained prostheses was probably due to a more passive fit,¹¹ but differences in behavior were also found in the present research, in which the fit was perfect for both prostheses. The presence of an intermediate layer of cement in addition to the engaging feature of the abutment seems to favorably alter the biomechanical behavior of cement-retained prostheses.

Even with the higher risk of mechanical issues reported in the literature and in the present study, the screw-retained prosthesis is a reliable treatment^{1,2,4,6,7,26,29,33} and may have some biological advantages over the cement-retained prosthesis,⁷ most likely due to the absence of a subgingival cement interface. If well indicated, clinicians may use both methods of restoration because neither can be considered an inferior form of care.³³ Furthermore, newer prosthetic connections seem to present fewer technical issues such as screw loosening.³³ However, when a clinical situation allows the clinician to choose between a screw- or cement-retained prosthesis and the choice is a screw-retained one, special attention should be given to factors that can minimize the loads and stresses acting in the prosthetic complex. These factors include proper and careful occlusal adjustment, prostheses with passive fit, the right amount of torque on the screw, and the use of lubricated low-friction screws. Clearly, these issues are also important when a cement-retained prosthesis is chosen.

CONCLUSIONS

Within the limitations of the method and with regard to the analyzed implant-supported prostheses

designs, the screw-retained prosthesis showed a higher risk of screw loosening and fracture.

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