Influence of Implant Inclination and Prosthetic Abutment Type on the Biomechanics of Implant-Supported Fixed Partial Dentures

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Obtaining parallelism during implant placement is often difficult, leading to inclination of implants. The present study evaluated the stress distribution in 3-unit fixed partial dentures supported by 2 implants with different inclinations and prosthetic abutments. Universal castable long abutments (UCLAs) or tapered abutments were used considering 17° of implant angulation in different directions (mesial, distal, buccal, or lingual). To do so, 3-dimensional finite element models were built and exported to specific analysis software. Forces were applied to the functional cusps. Data were obtained with regard to the maximum principal and von Mises stresses (in MPa). No relevant differences were observed in the stress values in the cortical and cancellous bone nor in the prosthesis with UCLA or tapered abutments. However, a relevant stress reduction in the prosthetic screws of the tilted implant was observed when using UCLA abutments. According to the obtained results, it is possible to suggest that both UCLA or tapered abutments can be used for 3-unit fixed partial dentures when 1 of the implants is tilted. UCLA abutment might lead to less biomechanical problems related to screw loosening or fracture.

Key Words: dental implant, abutment, finite element method, dental prosthesis

INTRODUCTION

Implant-supported rehabilitations are considered the best treatment option for fully or partial edentulous patients, presenting favorable rates regarding success of implants and prostheses in all kinds of rehabilitations (ie, full-arch fixed prostheses, fixed partial dentures, single crowns, and overdentures).[1] When planning a rehabilitation, it is generally recommended that multiple implants should be placed parallel to each other, to better distribute occlusal stresses at the implant level, for subsequent dissipation of this stress within peri-implant bone tissue, and to facilitate abutment selection.[2] However, during surgical procedures, this parallelism is often hard to achieve because of possible intercurrences and local factors (mouth opening, bone quality, etc) as well as operator skills (nonguided surgeries). Among several possible complicating factors, insufficient bone height and width is commonly the most present condition that could jeopardize implant placement. In cases in which bone graft is not feasible, implant position is usually determined by the available crestal bone that allows primary stability.[3] Nevertheless, sometimes primary stability cannot be achieved at the most desired position, as some adjustments are necessary at the moment of surgery. Although uncommon, this can occur even in cases in which a previous bone graft was already performed, depending mainly on the bone quality of the region.

Although implant inclination may often be seen in clinical practice, cases presenting excessive inclination can still be corrected by using several types of abutments; the most used are the universal castable long abutment (UCLA) and the angled tapered abutment. These abutments may correct the screw hole position but do not alter the position of the implants that support the prosthesis, which could have a critical biomechanical behavior. Such situations could generate higher stresses within the prosthetic screws, implants, and peri-implant bone tissue, which might lead to increased marginal bone loss and prosthetic complications.[4,5]

Regarding implant-supported fixed partial dentures, a high survival rate of implants (92%–97%) and prostheses (86%–100%) has been reported.[1,6–8] Despite such high survival rates, a wide variation in prosthetic complications is present in the literature, in which the main reported failures are fracture of the veneer material and/or prosthetic framework and fracture or loosening of the prosthetic screws.

Although all of these complications can be seen in clinical practice, research questions addressing the reasons why they occur are usually related to the biomechanical behavior of dental materials and prosthetic rehabilitations under functional

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Table 1

Studied groups*

	Implant Inclination	Abutment
Control 1	Parallel	UCLA
Control 2	Parallel	Tapered abutment
G1	17°/buccal	UCLA
G2	17°/buccal	Tapered abutment
G3	17°/lingual	UCLA
G4	17°/lingual	Tapered abutment
G5	17°/mesial	UCLA
G6	17°/mesial	Tapered abutment
G7	17°/distal	UCLA
G8	17°/distal	Tapered abutment

*UCLA indicates universal castable long abutment.

loads.[9–12] Because intraoral biomechanical behavior assessment is unpractical and unfeasible most of the time, computer-assisted methods have become an important tool in dentistry research, more specifically in restorative dentistry and prosthodontics in the past 2 decades. More recently, the application of these tools has gained ground in implantology, allowing clinicians to better understand what happens at the peri-implant level and between the components used for these rehabilitations.[9–13]

Thus, the present study aimed to assess the stress distribution of fixed partial dentures retained by 2 implants, presenting different abutments (UCLA and tapered abutment) and implant inclination in different directions (mesial, distal, buccal, and lingual) throughout a 3-dimensional finite element analysis.

Materials and Methods

Three-dimensional (3D) models were obtained using 3D modeling software (SolidWorks 2016, SolidWorks Corp, Concord, Mass) representing a clinical situation considered prevalent in implant-supported rehabilitations. The model considered a posterior mandibular section with a fixed partial denture supported by 2 implants, distancing 16 mm between its centers. Mandibular geometry was modeled from a computed tomography image; the implants were based on Mark III external hex (Nobel Biocare) presenting a 4.1-mm platform with 3.75- × 11.5-mm dimensions.

Two variables were assessed in this study: the inclination of 17° of one of the implants in different directions (mesial, distal, buccal, and lingual) and the type of prosthetic abutment (customized UCLA or tapered abutment). Parallel implants were considered as control groups for both types of prosthetic abutment. Figure 1 shows a schematic representation of the different studied variables, and the assessed groups are presented in Table 1.

All 3D models were exported as IGES (*.igs) format and imported into the computer-aided engineering environment of ANSYS Workbench 16 (Ansys Inc, Canonsburg, Penn). This file format was selected because the software in question can import the geometry with IGES files without altering any surface and/or curve, avoiding mesh alteration.

All materials were considered linearly elastic, homogeneous, and isotropic. Table 2 presents the adopted properties of the used materials in this study, obtained from the literature.[14–16] The finite element meshes were defined by tetrahedral elements, characterized by triangular base pyramids, with one node at each vertex and another at the center of each edge, totaling 10 nodes per element. The mesh was refined until the results obtained by the analysis were not significantly affected by it, being verified by means of convergence tests. Table 3 presents the numbers of nodes and elements of each model.

Table 2

Properties of the materials adopted

Material	Young's Modulus, GPa	Poisson Ratio
Cortical bone	13.7	0.3
Cancellous bone	1.37	0.3
Ti (implant)	110	0.33
Ti (screw)	110	0.28
Nickel-chromium	203.6	0.3
Porcelain (Vita VMK 68)	70	0.19

The analyses were performed using the mechanical simulation software ANSYS Workbench 16. With regard to the boundary conditions, the base of the mandible was considered the fixed point, and forces were applied to the functional cusps of the 3 prosthetic crowns. The force vector applied was composed by 110 N vertical and 15 N horizontal.[17]

Results were analyzed by qualitative evaluation through figures and color gradients according to the stress concentration in each region and quantitative analysis by means of numerical reading of the stress in certain nodes of the mesh. All analyses were performed considering the maximum and minimum principal and von Mises stresses (in MPa).

Results

Parallel positioned implants presented similar stress values in the prosthesis, regardless of the abutment used. However, when the anterior implant was tilted 17°, the stresses generated by UCLA in the prosthetic framework were higher in

Table 3

Number of nodes and elements of the finite element mesh of the models*

Model	Nodes	Elements
UCLA		
Parallel	71.653	40.464
17° mesial	71.239	40.095
17° lingual	77.881	43.861
17° distal	70.560	39.569
17° buccal	70.934	39.932
Tapered abutment		
Parallel	75.875	42.664
17° mesial	75.599	42.490
17° lingual	81.680	45.790
17° distal	76.171	42.790
17° buccal	74.815	41.908

*UCLA indicates universal castable long abutment.

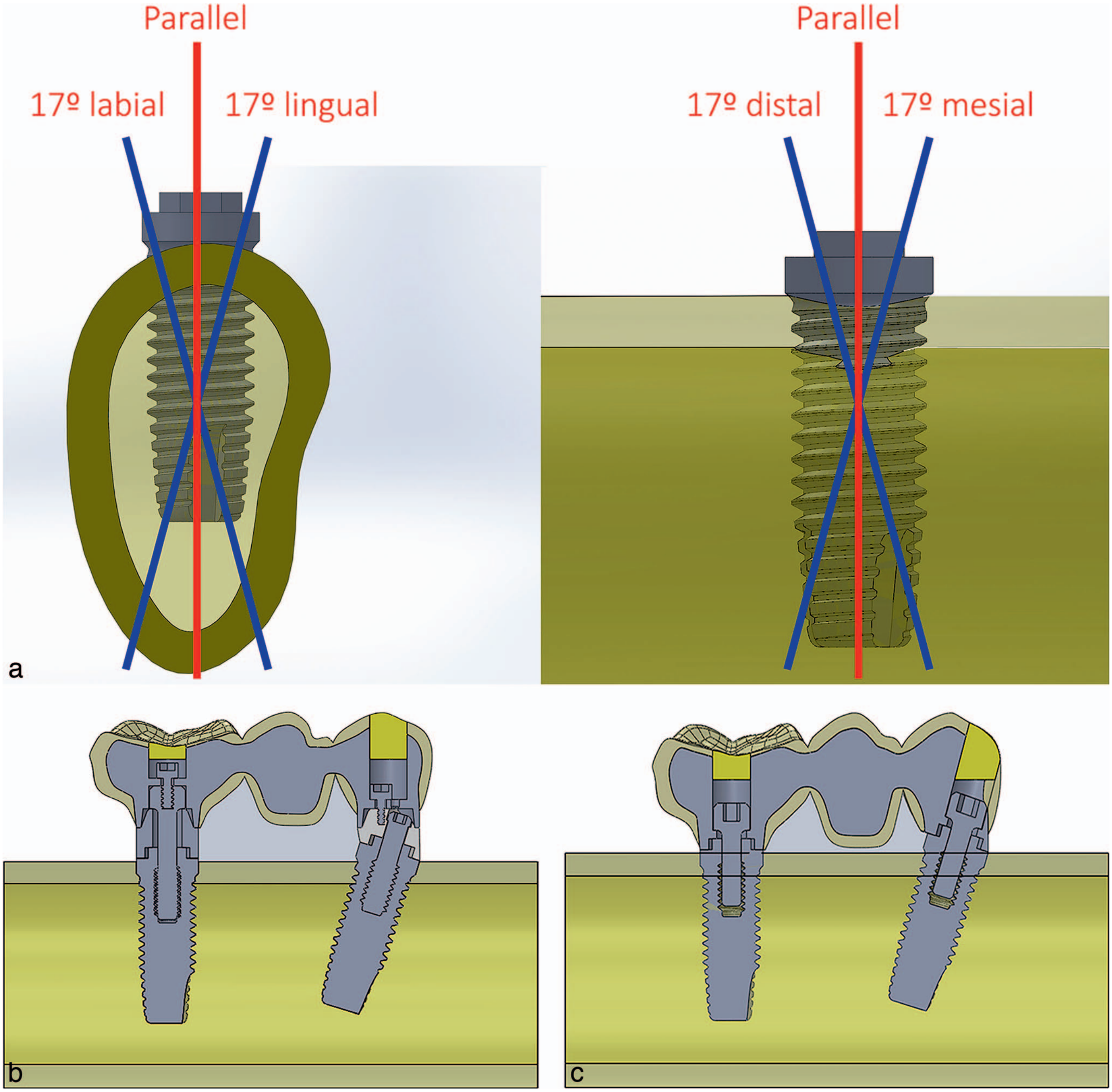


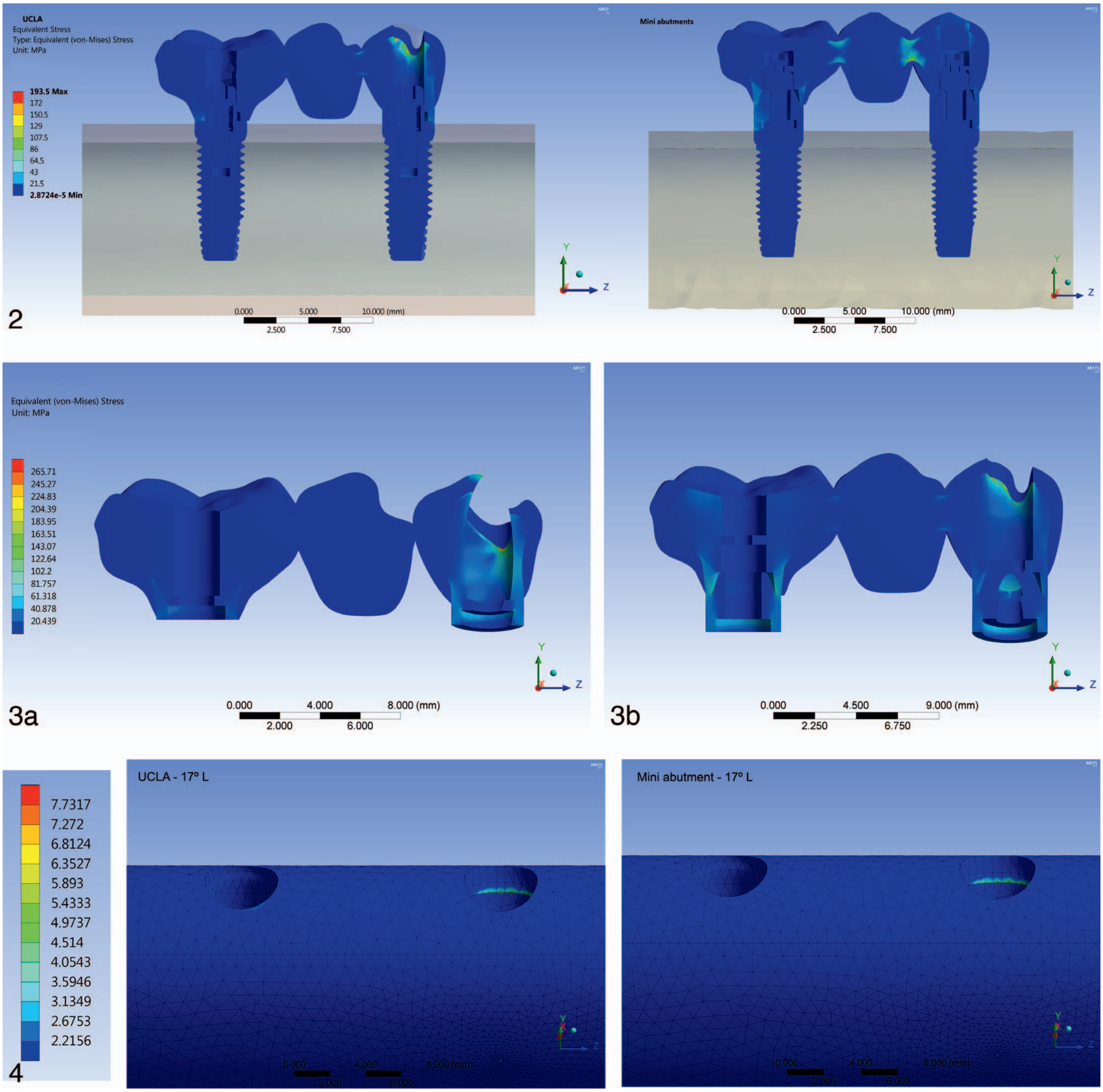
Figure 1. Schematic representation of the different inclination adopted in the study. (a) Cross-section view of the models: tapered abutment (b) or universal castable long abutment (c).

comparison with tapered abutments tilted to mesial, lingual, and distal. When the anterior abutment was angled to the buccal direction, prosthetic frameworks made with UCLA abutments presented lower values of stress than tapered abutments (Figure 2).

The von Mises stress values in the screw that connects the tapered abutment to the anterior implant was relevantly higher to that found with UCLA (Figure 3). On the other hand, the values generated in the same prosthetic screw on the posterior implant were reduced approximately 50% in comparison with the use of UCLA. The prosthetic screw of the anterior tapered abutment presented a relevant increase in stress values when implants were tilted. This increase of stress was not observed in the posterior abutment screws.

Stresses in the anterior tapered abutment were relevantly higher when the implant was tilted, except in the distal inclination group. The inclination of the anterior abutment did not influence the stress in the posterior one. The stress values in the anterior implant increased relevantly only when it was tilted buccally. The use of UCLA caused higher stresses values when distal and lingual inclinations were assessed. No relevant differences were found in the stresses in the posterior implant.

Bone tissue maximum principal stress values ranged from 8 to 6 MPa and from 0.5 to 0.8 MPa for minimum principal stress



Figures 2–4. Figure 2. Distribution of the von Mises stress in models with universal castable long abutment–type abutments and tapered abutments in parallel implants. **Figure 3.** Distribution of von Mises stresses in prosthesis and abutments made with (a) universal castable long abutment or (b) tapered abutments when the anterior implant was tilted 17° lingually. Note the higher stress concentration in the porcelain-framework interface in (a) and a more homogeneous dissipation along the entire prosthesis and the conical tapered abutments in (b). **Figure 4.** Maximum principal stress distribution, in MPa, in the peri-implant bone tissue in the situation that presented the highest stress concentration values (17° lingual) for both the universal castable long abutment and tapered abutment groups.

among studied groups (Table 4; Figure 4), and no relevant differences were recorded in the variations in abutments or implant inclinations.

Discussion

Implant positioning[18,19] and the type of prosthetic abutments has demonstrated an influence in the biomechanical behavior of peri-implant bone (both cancellous and cortical) in previous studies[20,21]; however, no relevant difference was observed in the present study. Although an accumulation of stresses in the cortical-cancellous bone interface could be observed in the groups with lingually tilted implants, the maximum values of stress found in all studied models presented a small variation and should not be considered relevant. The influential increase in stress in inclined implants has also been observed by Tribst et al.[19]

Table 4

von Mises stress values for prosthetic components and maximum and minimal principal stress the peri-implant bone (in MPa)*

	Parallel		17° Mesial		17° Lingual		17° Distal		17° Buccal	
	TA	UCLA	TA	UCLA	TA	UCLA	T	UCLA	TA	UCLA
Anterior implant	20.97	19.91	15.96	16.73	15.23	19.80	18.74	22.55	23.38	25.37
Anterior implant screw	47.36	33.02	51.72	33.83	49.21	31.06	55.90	29.70	35.17	28.08
Posterior implant	20.79	20.54	20.16	20.62	21.26	22.43	21.22	21.13	19.33	19.25
Posterior implant screw	11.45	21.54	11.09	21.46	11.70	23.85	11.82	22.51	10.89	20.95
Anterior tapered abutment	17.52		34.36		66.11		19.37		26.34	
Anterior tapered abutment screw	3.97		12.11		9.53		15.78		7.84	
Posterior tapered abutment	16.96		16.38		17.57		17.25		16.18	
Posterior tapered abutment screw	3.88		3.78		3.91		4.00		3.76	
Prosthesis	27.86	27.09	28.96	35.46	29.99	58.14	29.63	33.07	29.12	25.63
Cortical										
Max	8.36	8.35	7.89	7.86	8.24	8.20	8.14	8.12	6.06	6.06
Min	2.36	2.36	2.29	2.30	2.34	2.33	2.30	2.29	1.77	1.77
Cancellous										
Max	0.69	0.69	0.60	0.61	0.63	0.63	0.81	0.80	0.49	0.50
min	0.09	0.09	0.08	0.08	0.13	0.12	0.16	0.16	0.06	0.06

*TA indicates tapered abutment; UCLA, universal castable long abutment.

This stress concentration might occur because of the geometry of the adopted models and its relationship to the positioning of the lingually tilted implant and the direction of the applied forces,[22] since nonaxial loading increases the stress compared with axial loading.[19] Regarding this topic, there is no consensus as to whether the use of UCLA or tapered abutments plays a role in biomechanical stress situations. A study carried by Ochiai et al[23] suggested that the use of UCLA or tapered abutments demonstrates minimal differences in the stress distribution in the peri-implant bone. However, another recent study[21] evaluated the influence of the use of UCLA or tapered abutments on immediately loaded single crowns using the finite element method and observed that UCLA showed higher stress values at the peri-implant bone when compared with tapered abutments. The findings of the present study suggest that in 3-unit fixed partial dentures, the stress values in the peri-implant bone tissue did not vary in a relevant way. This may be because 3-unit fixed partial dentures have a greater volume than single crowns, which could favor the stress distribution, regardless of the type of prosthetic abutment.

Regarding the prosthesis, it was noted that parallel implants with both abutment types did not alter the stress distribution. The inclination of the implant results in a noncentered force application to the prosthesis, resulting in a fulcrum that increases the stress values in the prosthesis and surrounding tissues.[19] Thus, in most situations, when one of the implants was malpositioned, there was a greater stress concentration in the UCLA prostheses, except for the buccal inclination of the anterior implant. It can be supposed that this different behavior of the buccally inclined implants could be related to the direction of the loading application and the anatomy of the 3D model adopted in the present study, since modeling simplifications could affect the strain-stress distribution.[24]

The maximum stresses were concentrated at the junction of the porcelain veneer and the metallic framework. This can be considered a risk factor for future chipping of the porcelain veneer, which is a common failure in implant prostheses.[25]

When the influence of the abutment on the stress distribution was assessed in the prosthetic screws, it was observed that the stress values of the posterior tapered abutments were reduced to almost half, regardless of the anterior implant inclination (Table 4). Previous studies corroborate our findings, suggesting a worse dissipation of forces[26] and greater loosening torque for screws of prostheses made directly on the implant platform, which is the same situation that occurs with UCLA.[27] On the other hand, in the anterior implant screw, higher stress values were observed in the prosthetic screws when using tapered abutments compared with UCLAs. Furthermore, this configuration showed the highest values of stress on the screws, which could also be related to the nonaxial loading application and the bone anatomy.

Stress values in the tapered abutment were higher than in UCLA, especially in the group with 17° of lingual inclination (66 MPa). Although the analyses have shown some stress variations in the components, all values observed are within the limits of fracture strength and fatigue of the titanium alloy used for prosthetic abutments.[28] Thus, the evidence presented in this study does not contraindicate the use of tapered abutments. Conversely, it has already been reported that the use of tapered abutments promotes a better distribution of stresses in the prosthesis-implant complex,[27] which in turn may reduce future mechanical complications. Thus, there is still no consensus regarding the use of UCLA or tapered abutments.[21]

Clinical evaluations based on randomized clinical trials provide, undoubtedly, the highest level of scientific evidence. However, the study of the biomechanical behavior of intraosseous structures is rendered infeasible by ethical and methodological aspects.[16,29,30] Finite element analysis allows biomechanics to be investigated in a similar way to what happens in vivo and in a nondestructive way, providing accurate and reliable information,[31,32] which could help clinicians to be better prepared to interpret a clinical situation. However, it should be emphasized that this study did not consider important variables that should be taken into account when indicating and planning implant-supported prostheses, such as interocclusal space and divergence in implant inclination, as well as clinical aspects such as soft-tissue anatomy, esthetics, and, mainly, costs.[23,26,27] These aspects (soft-tissue anatomy, esthetics, and costs) should be considered a limitation of the present method and thus should be addressed by future studies to clarify possible differences when considering different types of abutments in situations in which parallel or angled implants would retain a 3-unit fixed partial denture.

Conclusion

The UCLA and tapered abutments can be indicated for 3-unit implant-supported fixed partial dentures. However, when one of the implants present an unfavorable inclination, the use of angled tapered abutments could be beneficial because of the reduction of stress in the prosthetic screws, preventing their loosening over time.

Abbreviations

MPa: Megapascal
TA: tapered abutment
UCLA: universal castable long abutment

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Note

The authors deny any conflict of interest.

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