Influence of the Connector and Implant Design on the Implant–Tooth-Connected Prostheses

Edmar Ferreira da Silva, DDS, MS;* Eduardo Piza Pellizzer, DDS, MS, PhD;†
José Vitor Quinelli Mazaro, DDS, MS, PhD;* Idelmo Rangel Garcia Júnior, DDS, MS, PhD‡

ABSTRACT

Purpose: The purpose of this study was to evaluate stress transfer patterns between implant–tooth-connected prostheses comparing rigid and semirigid connectors and internal and external hexagon implants.

Materials and Methods: Two models were made of photoelastic resin PL-2, with an internal hexagon implant of 4.00×13 mm and another with an external hexagon implant of 4.00×13 mm. Three denture designs were fabricated for each implant model, incorporating one type of connection in each one to connect implants and teeth: 1) welded rigid connection; 2) semirigid connection; and 3) rigid connection with occlusal screw. The models were placed in the polariscope, and 100-N axial forces were applied on fixed points on the occlusal surface of the dentures.

Results: There was a trend toward less intensity in the stresses on the semirigid connection and solid rigid connection in the model with the external hexagon; among the three types of connections in the model with the internal hexagon implant, the semirigid connection was the most unfavorable one; in the tooth–implant association, it is preferable to use the external hexagon implant.

Conclusions: The internal hexagon implant establishes a greater depth of hexagon retention and an increase in the level of denture stability in comparison with the implant with the external hexagon. However, this greater stability of the internal hexagon generated greater stresses in the abutment structures. Therefore, when this association is necessary, it is preferable to use the external hexagon implant.

KEY WORDS: dental implant, implant design, photoelasticity, tooth–implant connection

INTRODUCTION

Fixed partial implant-supported dentures are an efficient treatment alternative for patients with missing tooth elements. However, anatomic limitations, osseointegration failure, or teeth with compromised periodontium requiring ferrulization could create a situation in which it would be necessary to connect an implant and a natural tooth by means of a fixed partial denture.

In spite of the tooth–implant connection being indicated in the above-mentioned situations, there are divergences of opinion related to this type of treatment, normally associated with difference in the mobility of teeth when compared with osseointegrated implants.[1–10]

Some researchers have found that tooth- and implant-supported dentures are as predictable a treatment as dentures supported by implants only, but for this purpose, the connection should be of the rigid type.[3,8,9,11,12] However, confirming the predictability of the treatment, other researchers indicate the semirigid connection,[1,10] in spite of this type of connection being related to intrusion[13–16] and increased stress values in the implant and denture.[17,18]

In the literature, studies were also found related to soft and hard tissues around the implants and teeth,

*Postgraduate student, Department of Dental Materials and Prosthodontics, São Paulo State University at Aracatuba, São Paulo, Brazil; †adjunct professor, Department of Dental Materials and Prosthodontics, São Paulo State University at Aracatuba, São Paulo, Brazil; ‡associate professor, Surgery and Integrated Clinical Department, São Paulo State University at Aracatuba, São Paulo, Brazil

Reprint requests: Prof. Dr. Eduardo Piza Pellizzer, Department of Dental Materials and Prostheses, Department of Dental Materials and Prosthodontics, São Paulo State University at Aracatuba, José Bonifácio, 1193, 16015-050 Araçatuba, São Paulo, Brazil; e-mail ed.pl@uol.com.br

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when these were connected to the fixed partial dentures. The authors observed that there was no significant negative influence on these tissues.[3,7,8,12,19–23]

Contrary to the above-mentioned studies, implant- and tooth-supported dentures are associated with stress, increased moments, and/or damaging extraction forces on the abutments. It is therefore presumed that they should be avoided, as there is no universally accepted system capable of reproducing the shock-absorbing effect of the periodontal ligament.[5,15,24–27]

For a good treatment plan, it is necessary to verify not only the system that satisfies the patient's aesthetic and functional requirements but the one that also guarantees the stability of screw-retained dentures. Generally speaking, from a biomechanical point of view, the design of the internal hexagon implant establishes a greater hexagon retention depth and an increase in the level of stability of these dentures, in comparison with the external hexagon implant.[28–30] However, Cehreli and colleagues,[31] using the photoelastic stress analysis, concluded that these implants have similar force distribution characteristics and that the design of an abutment–implant connection is not a decisive factor affecting the magnitude of stress and tension in a bone simulator.[32] To have a better understanding of the influence of this clinically relevant parameter, the time-dependant bone reactions around implants must be examined with well-controlled in vivo experiments under load.[33]

The aim of this study was to assess the stress distribution between implants and teeth in fixed partial dentures, to compare rigid and semirigid connectors and internal and external hexagon implants, by means of the photoelasticity method.

MATERIALS AND METHODS

Fabrication Master Model

For this study, an experimental dentistry mannequin was used. It was duplicated then and prepared for a complete metal-ceramic crown in the lower-right and left second premolar region, which would serve as abutments for the prosthesis. Perforations were made in the regions corresponding to the lower-right and left second molars with the use of a delineator, accompanying the parallelism of the lower second premolar preparations. Afterward, the set formed by the implant analog with a 4.1-mm platform (3i, Palm Beach Gardens, FL, USA) connected to the square transfer molding (3i) was fixed in the perforations with Duralay with the use of a delineator (Figure 1). Next, the model was molded with duplication silicone to obtain the mold.

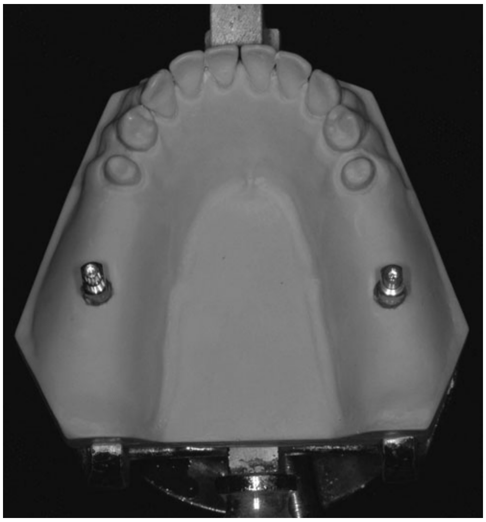

Figure 1 Model with the lower right and left second premolar prepared and the square copings connected to the implant analogs.

Photoelasticity Method

Photoelastic materials with different modules of elasticity were used to represent the teeth (resin PL-1; Measurements Group, Inc., Raleigh, NC, USA) and the mandible body (resin PL-2; Vishay Micro-Measurements, Raleigh, NC, USA).

After making the teeth with photoelastic resin PL-1 from a silicone matrix of each artificial tooth (right and left mandibular canines and first premolars), the teeth were placed in the silicone mold.

The external hexagon implant, 4.00 mm in diameter and 13-mm long, with a 4.1-mm platform (3i), was also adapted in the mold in the right mandibular second molar region, and the internal hexagon implant, 4.00 mm in diameter and 13-mm long, with a 4.1-mm platform (3i), in the left mandibular second molar region.

Correct seating of the components was verified, and the photoelastic resin PL-2 was poured, thus obtaining the final model (Figure 2).

After obtaining the photoelastic model, it was photoelastically tested in order to verify whatever stress could have occurred while it was being made, to guarantee that there would be no interference in the final results. Conventional techniques were used to fabricate

Figure 2 Photoelastic models: external hexagon (*left*); internal hexagon (*right*).

the fixed prostheses. A silicone matrix was used so that their dimensions were constant.

Fabrication Frameworks

All the fixed prostheses were made of a palladium-silver alloy (Porson IV®; Degussa, Düsseldorf, Germany), using UCLA-type abutments (3i). The occlusal surfaces were flattened so that the cuspids would not interfere in the direction of the load.

After welding (DeguDent, Hanau, Germany), the frameworks were evaluated to verify the fit and passivity of placement in the photoelastic model.

Three frameworks were fabricated for each implant model, incorporating one type of connection in each one: 1) solid rigid connection; 2) semirigid connection located in the mesial position of the implant (Attachment PDC™ small; Attachments International, Inc., San Mateo, CA, USA); and 3) rigid connection with occlusal screw between the implant and the pontic (Tube Screw™; Attachments International, Inc.).

The prostheses were cemented one by one with temporary cement (Temp Bond®; Kerr Corp., Orange, CA, USA), and the photoelastic model was placed in a load applicator device. The set was put into a glass receptacle with mineral oil until the model became completely immersed, with the object of minimizing refraction from the surface and facilitating photoelastic observation. The receptacle was placed between a polarizing filter and an analyzer filter. A light diffuser was coupled to the polarizer filter, which allowed a source of white light (Photoflood®; General Electric Co., Cleveland, Ohio, USA) to fall uniformly on the receptacle with the photoelastic model. The analyzer filter was coupled to a digital photographic camera (Nikon D70™, Nikon Corporation, Tokyo, Japan) to capture the images. Next, the 100-N axial load applications began at fixed points on the prostheses surfaces, on the regions that would correspond to the lower second premolars (tooth), first molars (pontic), and second molars (implant).

Analysis of the Results

The stress resulting on all areas of the photoelastic model was monitored and recorded photographically, and subsequently seen with a computer graphic program (Photoshop 7.0®; Adobe Systems, San Jose, CA, USA) in which it could be better visualized and qualitatively analyzed.

RESULTS

Analyzing the denture where the external hexagon implant and semirigid connection (HE-SR) were used, it was observed that when the load was applied on the tooth, a greater stress concentration on its apical third and no fringe formation on the implant occurred. When the load was applied on the pontic, the fringe formation region was the same on the tooth but in less quantity; on the implant, the beginning of fringe formation in the apical region was perceived. When load was applied on the implant, the fringes on the tooth disappeared and increased in an accentuated manner in quantity and intensity on the implant, also presenting yellow and red fringes (Figure 3).

With regard to the screwed rigid connection and the external hexagon implant (HE-RS), when load was applied on the tooth, fringes were generated in the mesial, distal, and apical regions of the tooth and implant. However, the greatest intensity occurred in the mesial region of the implant, characterized by the appearance of red fringes. When the load was applied on the pontic, the red fringes diminished in the mesial region and increased in the apical region of the implant; furthermore, the blue fringes in the distal region disappeared, and yellow fringes appeared in the apical third of the mesial region of the implant. When analyzing the load applied on the implant, it was verified that the fringes on the teeth disappeared, and yellow and red fringes, characteristic of high stress concentration, formed around the entire implant (Figure 4).

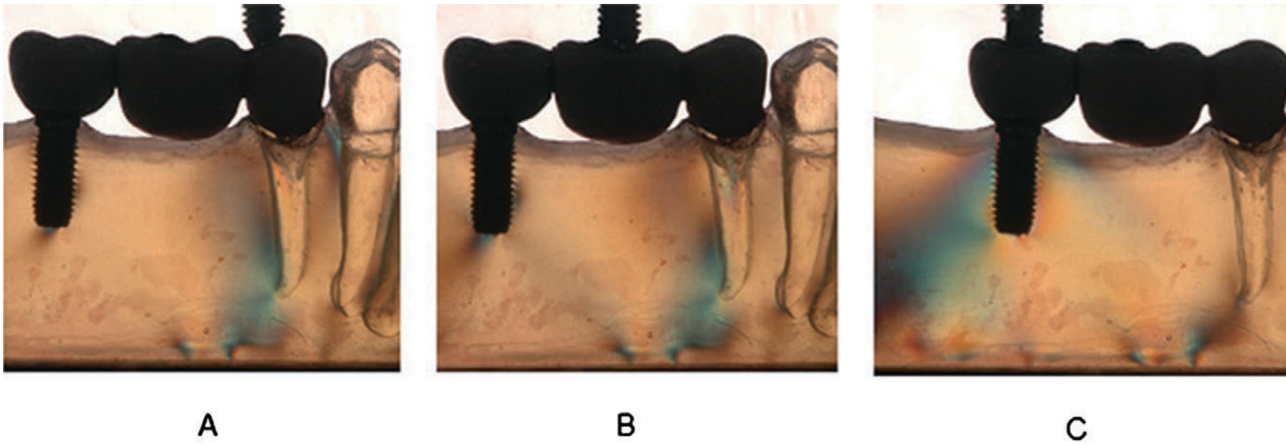

Figure 3 Model external hexagon implant and semirigid connection: application of load: (A) tooth; (B) pontic; (C) implant.

In the solid rigid connection and the external hexagon implant (HE-RW), fringe formation in the mesial and apical regions and in the entire distal region of the tooth were verified when load was applied to it, without fringe formation on the implant. When the load was applied on the pontic, it was verified that there was a reduction of fringes in the mesial and distal regions of the tooth, with the beginning of fringe formation in the apical region of the implant. Finally, when the load was applied on the implant, almost complete disappearance of the fringes, especially yellow and red, was verified in its apical and distal regions (Figure 5).

With regard to the internal hexagon implant and semirigid connection (HI-SR), it was observed that when the load was applied on the tooth, there was fringe formation in the mesial, disto-cervical, and disto-apical regions of the tooth, whereas on the implant, there was fringe formation only in the disto-apical region. After the load was applied on the pontic, it was verified that the fringes in the disto-apical region of the tooth increase and those in its disto-cervical region diminished. On the implant, an increase in fringe formation was also perceived in its disto-apical region. Lastly, when the load was displaced to the implant, it was perceived that fringes on the tooth diminished in the mesial region and disappeared in the disto-cervical region. Whereas on the implant, there was an increase in fringes and, consequently, in stresses in all the regions (Figure 6).

With the internal hexagon implant and screwed rigid connection (HI-RS), it was verified that after load application on the tooth, there was fringe formation, including red ones, and stress concentration in its mesial and disto-cervical regions, and absence of stress on the implant. However, when the loads were applied on the pontic, these fringes diminished on the tooth and appeared on the implant, especially in its apical and disto-apical regions. When the loads were directed onto the implant, it was perceived that the fringes in the

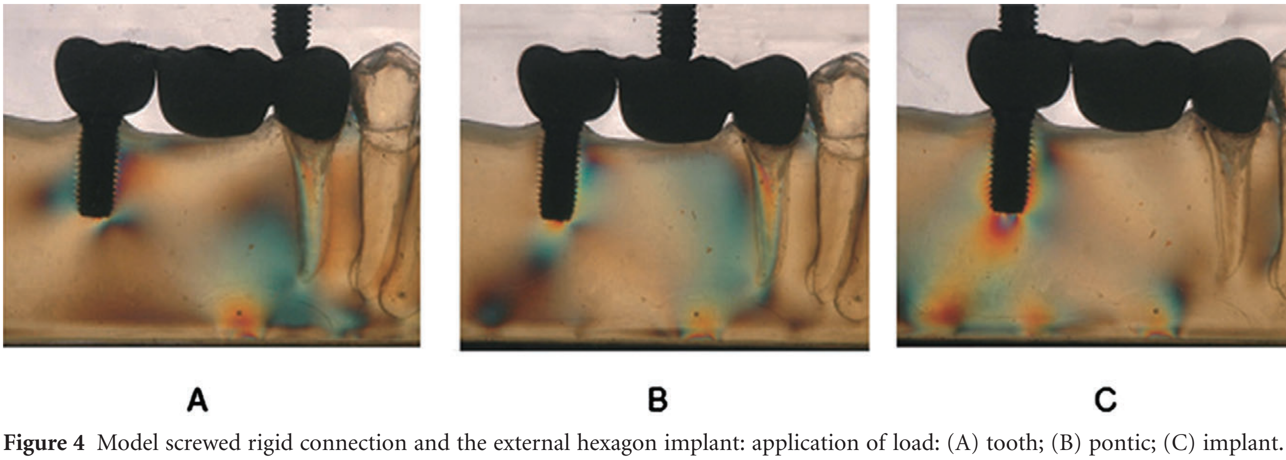

Figure 4 Model screwed rigid connection and the external hexagon implant: application of load: (A) tooth; (B) pontic; (C) implant.

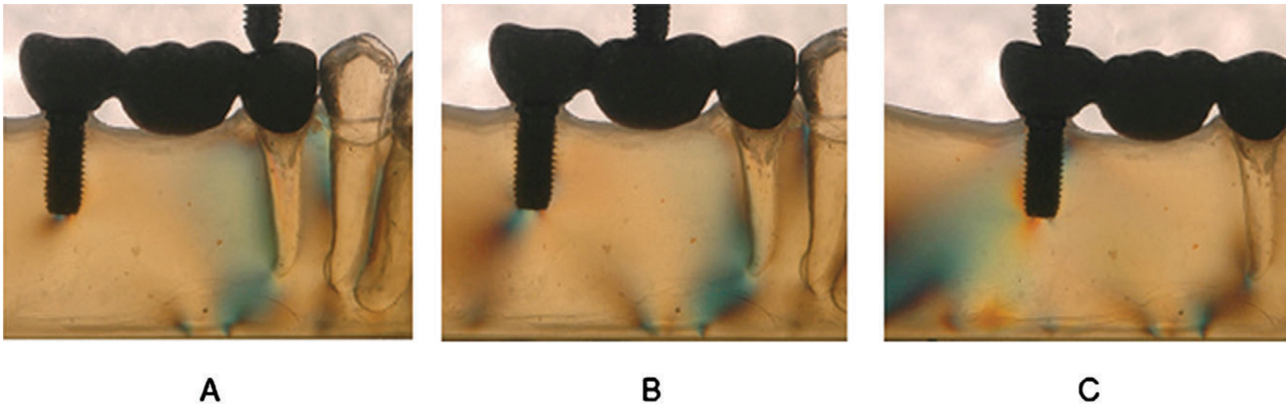

Figure 5 Model solid rigid connection and the external hexagon implant: application of load: (A) tooth; (B) pontic; (C) implant.

mesial region of the tooth diminished but increased in the distal region, especially in the apical and middle thirds. Whereas on the implant, a clear increase in fringes, especially in the apical third of the mesial region was perceived (Figure 7).

Finally, with the internal hexagon implant and solid rigid connection (HI-RW), it was verified that after load application on the tooth, there was a high concentration of stresses in the mesial region of the tooth and no fringe formation on the implant. However, when the load was applied on the pontic, the stress on the tooth diminished a little, but on the implant, it became very clear in all the mesial, distal, and apical regions. Next, when the load was displaced to the implant, it was perceived that stresses in the mesial region of the tooth disappeared, becoming clear in its entire distal region. Whereas on the implant, there was greater yellow and red fringe formation, when compared with the load applied on the pontic (Figure 8).

DISCUSSION

The implant connection to the natural tooth is still a point of controversies, because of the differences in the resilience of the structures involved[34]; while that of the tooth is around 50 to 200 μm,[8] that of the implant is less than 10 μm.[1]

There are several studies that indicate the rigid connector as the alternative for the tooth–implant connection, with the justification that its use will avoid tooth intrusion,[3,6,8,11,12] and there would be no risk of overload on the implant, as its moment of torsion would be below its load capacity.[9]

On the other hand, there are few studies that suggest the semirigid connection with the female component placed on the crown of the tooth,[10,15] or with the female component placed in the crown of the implant.[1] In the present study, it was resolved to place the female component on the crown of the implant to avoid there being a moment ($M = F \cdot d$) with regard to the implant that is

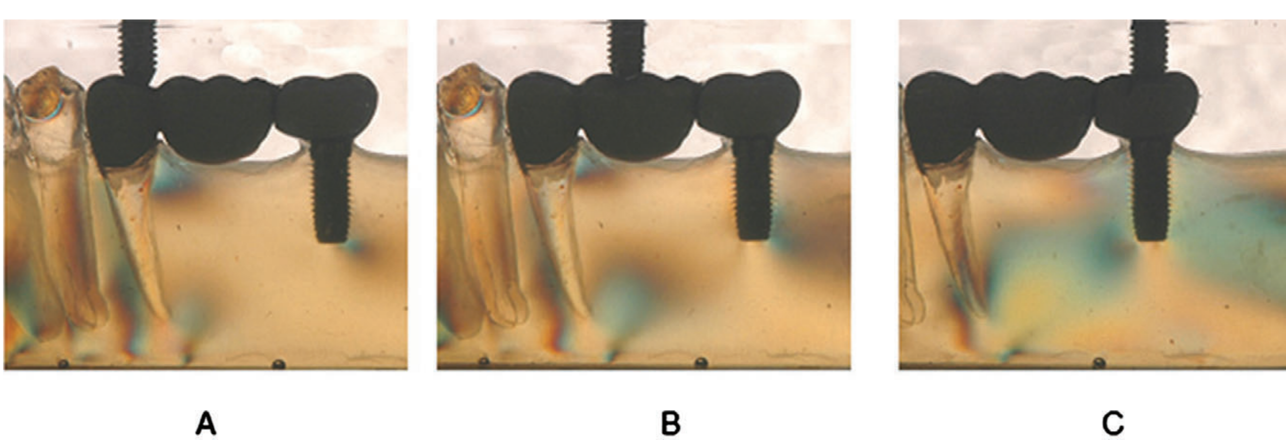

Figure 6 Model internal hexagon implant and semirigid connection: application of load: (A) tooth; (B) pontic; (C) implant.

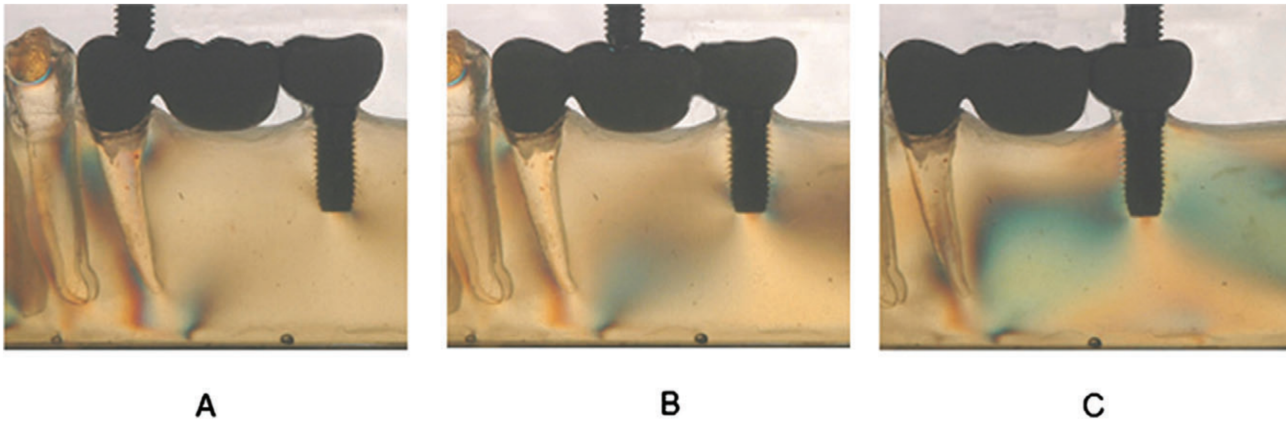

Figure 7 Model internal hexagon implant and screwed rigid connection: application of load: (A) tooth; (B) pontic; (C) implant.

rigid, considering that it would be more favorable if the moment was on the tooth, as it had movement within the periodontal ligament, being in agreement with Cohen and Orenstein,[1] who justified that this conduct would guarantee stability of the tooth, avoiding its intrusion by means of the support provided by the implant. Furthermore, the implant would be protected from excessive lateral forces by means of the reduction in the cantilever effect exercised by pontic extension to the tooth.

After analyzing the three types of connections (semirigid, welded rigid, and screwed rigid) in the implant with external hexagon, when the load was applied to the tooth and implant, it was verified that HE-SR abutments behaved almost like individual retainers, with the stresses concentrating only where the load was applied. This was probably because of the absence of the cantilever effect between the abutments in the semirigid connection. These results are confirmed by the studies of Weinberg and Kruger,[10] in which the authors affirmed, through biomechanical considerations, that a nonrigid connection relieves the stress and the overload between the structures. When displacing the load application point to the pontic, stress was distributed to the abutment structures (tooth/implant) possibly because of the pressure of the male connector of the pontic on the female connector of the implant, thus characterizing a distribution of forces between the two supports.

In the HE-RW, the situations were similar to that of the semirigid connection, as the support also behaved as individual retainers when the load was applied on the tooth and implant. This behavior could be associated with the presence of the cementing agent acting on the reduction of the cantilever effect and on stress dissipation. When loading the pontic, a slightly higher stress intensity occurred than that found in the semirigid connection.

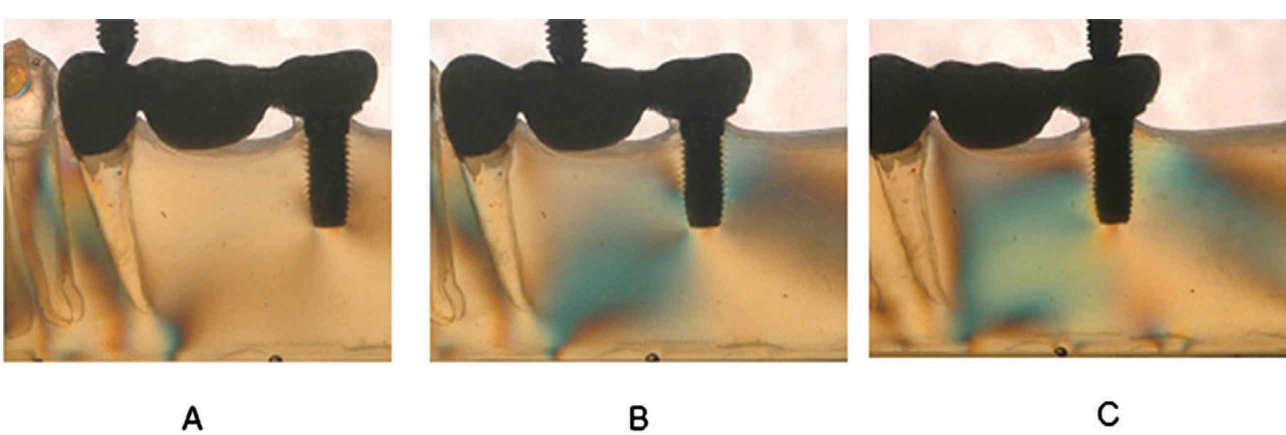

Figure 8 Model internal hexagon implant and solid rigid connection: application of load: (A) tooth; (B) pontic; (C) implant.

Clinically, such differences may not be noted because of the closeness of the biomechanical behavior between the two situations (welded rigid and semirigid connections). Nevertheless, complications such as dental intrusion may be generated by food being interposed between the male and female connectors on the tooth.

Among the studied connections on the external hexagon implant (see Figures 3–5), the screwed rigid connection presented the worst stress distribution; however, according to Lindh and colleagues,[12] such stress levels can be borne by the structures seeing that when the rigid connection with occlusal screw was clinically assessed, no bone loss was found in the implants or adverse effects on the natural teeth with the use of this attachment system.

With regard to the model with the internal hexagon implant (see Figures 6–8), it was verified that when the load was applied on the tooth and implant, there were no significant differences between the types of connections. This may be associated with the greater stability of the internal hexagon design, in which the increased antirotational aspect and conical shape of the internal hexagon connection provides the system a greater lateral stability, making it more rigid.[28]

In the HI-SR, there was greater stress concentration in the disto-cervical region of the tooth at the same time as there was a diminishment in the intensity of the stresses on the first half of the mesial region, suggesting the formation of a flector moment by the freedom that exists in the semiprecision attachment. When compared with the studies of Lin and colleagues,[18] this pattern occurred in a different way, as the authors found higher stress on the implant when the semirigid connection was used, and explained that this occurred because only the implant supported the load in this type of connection. The explanation for the difference between the results of these authors and those of the present study could be the location of the female connectors: while the authors used this connector on the crown of the tooth, it was used on the crown of the implant in the present study.

In the HI-RS, there was stress concentration in the disto-cervical region of the tooth, however, at lower intensity than in the semirigid connection. This also characterized the beginning of a flector moment formation by the possible micromovement that exists in the rigid screwed connection. This micromovement would therefore be counteracted by the rigidity and stability of the internal hexagon implant.

In the HI-RW, when the load was applied on the tooth and pontic, the stresses on the tooth were more concentrated in the mesial region. However, when the load was applied on the implant, the stresses on the tooth were more concentrated in the distal region. In this type of connection, there was more demand on the implant in comparison with the tooth, as the forces of moment began to act on the implant. These results reinforce the affirmations of Weinberg and Kruger[10] that when a natural tooth and an implant are rigidly connected, it is the implant that supports the tooth. Although there is more demand on the implant than on the tooth, the difference between the two elements was not significant. This probably occurred because of the stability and rigidity of the internal hexagon implant having been equaled to the rigidity of the welded rigid connection, thus producing better stress distribution between the supports.

When the internal hexagon implant was assessed in the three types of connections, it was observed that the stresses on it occurred more in the apical region in comparison with the external hexagon, probably because of the greater depth of union of the denture to the implant. These results are in agreement with the studies of Hunt and colleagues,[29] in which the authors affirmed that the greater denture retention depth and the more precise and safer antirotational component of the internal hexagon system reduced the stress at the neck of the implant and retention screw. However, Cehreli and colleagues,[31] who used the photoelastic method to assess the connection of the denture to the implant, believed that the influence of the denture–implant interface is still not clear from a functional load point of view, implant loading and the time required for the functional adaptation of the bone to the oral implants being more important than the nature of the implant itself.

When observing the pattern of stresses generated among the models with internal and external hexagon implants, it was verified that with load application on the implant, the internal hexagon design presented a trend toward better stress dissipation characteristics than the external hexagon design, presenting lower stresses over a larger area. According to Krennmair and colleagues,[30] transferring the fulcrum point from the neck of the implant (external hexagon) to close to the middle third of the implant (internal hexagon), as well as the greater denture retention depth in the internal hexagon implant, reduced the power arm in the face of the biomechanical behavior, making the implant more stable, with less tendency to screw loosening of fracturing, and improving the dissipation of tensions.

When load was applied on the pontic and tooth, the internal hexagon design was shown to be more unfavorable in comparison with the external hexagon. This probably occurred because of the greater denture retention depth and consequent stability, together with the internal attachments in the shape of the sharp corners, which could act as stress concentrators during rotation or moment of force generated by the cantilever, and could thus cause microfractures under tension, harming the internal walls of the hexagon and overloading the system in the face of stress dissipation.[29,30]

In order to be able to suggest the most feasible tooth–implant connection among the options, it is important to verify which structure must be protected. Thus, from the biomechanical point of view, when the implant is loaded, it supports the load itself, because of its resistance. On the contrary, the tooth has a lower module of elasticity than the implant and is more prone to the occurrence of fractures when submitted to loads. Therefore, the structure that should be most preserved is the tooth.

Therefore, the HE-SR and HE-RW presented a tendency toward a more favorable stress distribution when compared with the HE-RS.

This biomechanical behavior among the above connections may be associated with harm to the tooth–implant union, because of the greater rigidity and stability of the internal hexagon design. However, further research should be conducted in order to have a better understanding of the relationship *type of connector × hexagon design of osseointegrated implants* in the union of the tooth and implant.[35,36]

CONCLUSIONS

Within the limitations of this in vitro study, it could be concluded that among the three types of connections with the external hexagon implant, the semirigid connection and the welded rigid connection presented tendencies toward lower intensity and better distribution of the stresses between the supports; among the three types of connections with the internal hexagon implant, the semirigid connection was the most unfavorable one, and in the tooth–implant association, it is preferable to use the external hexagon implant.

REFERENCES

1. Cohen SR, Orenstein JH. The use of attachments in combination implant and natural-tooth fixed partial dentures: a technical report. Int J Oral Maxillofac Implants 1994; 9:230–234.
2. Ericsson I, Lekholm U, Branemark P-I, Lindhe J, Glantz PO, Nyman S. A clinical evaluation of fixed-bridge restorations supported by the combination of teeth and osseointegrated titanium implants. J Clin Periodontol 1986; 13:307–312.
3. Lindh T, Dahlgren S, Gunnarsson K, et al. Tooth-implant supported fixed prostheses: a retrospective multicenter study. Int J Prosthodont 2001; 14:321–328.
4. Menicucci G, Mossolov A, Mozzati M, Lorenzetti M, Preti G. Tooth-implant connection: some biomechanical aspects based on finite element analyses. Clin Oral Implants Res 2002; 13:334–341.
5. Naert IE, Duyck JAJ, Hosny MMF, Quirynen M, van Steenberghe D. Freestanding and tooth-implant connected prostheses in the treatment of partially edentulous patients. Part I: an up to 15-years clinical evaluation. Clin Oral Implants Res 2001; 12:237–244.
6. Nishimura RD, Ochiai KT, Caputo AA, Jeong CM. Photoelastic stress analysis of load transfer to implants and natural teeth comparing rigid and semirigid connectors. J Prosthet Dent 1999; 81:696–703.
7. Olsson M, Gunne J, Astrand P, Borg K. Bridges supported by free-standing implants versus bridges supported by tooth and implant. A five-year prospective study. Clin Oral Implants Res 1995; 6:114–121.
8. Pesun IJ, Steflik DE, Parr GR, Hanes PJ. Histologic evaluation of the periodontium of abutment teeth in combination implant/tooth fixed partial denture. Int J Oral Maxillofac Implants 1999; 14:342–350.
9. Rangert B, Gunne J, Sullivan DY. Mechanical aspects of a Branemark implant connected to a natural tooth: an in vitro study. Int J Oral Maxillofac Implants 1991; 6:177–186.
10. Weinberg LA, Kruger B. Biomechanical considerations when combining tooth-supported and implant-supported prostheses. Oral Surg Oral Med Oral Pathol 1994; 78:22–27.
11. Rangert B, Gunne J, Glantz P-O, Svensson A. Vertical load distribution on a three-unit prosthesis supported by a natural tooth and a single Branemark implant. An in vivo study. Clin Oral Implants Res 1995; 6:40–46.
12. Lindh T, Gunne J, Danielsson S. Rigid connections between natural teeth and implants: a technical note. Int J Oral Maxillofac Implants 1997; 12:674–678.
13. Cordaro L, Ercoli C, Rossini C, Torsello F, Feng C. Retrospective evaluation of complete-arch fixed partial dentures connecting teeth and implant abutments in patients with normal and reduced periodontal support. J Prosthet Dent 2005; 94:313–320.

14. Gross M, Laufer BZ. Splinting osseointegrated implants and natural teeth in rehabilitation of partially edentulous patients. Part I: laboratory and clinical studies. J Oral Rehabil 1997; 24:863–870.
15. Naert IE, Duyck JAJ, Hosny MMF, Quirynen M, van Steenberghe D. Freestanding and tooth-implant connected prostheses in the treatment of partially edentulous patients: part II: an up to 15-years radiographic evaluation. Clin Oral Implants Res 2001; 12:245–251.
16. Schlumberger TL, Bowley JF, Maze GI. Intrusion phenomenon in combination tooth-implant restorations: a review of the literature. J Prosthet Dent 1998; 80:199–203.
17. Lin C-L, Wang J-C, Kuo Y-C. Numerical simulation on the biomechanical interactions of tooth/implant-supported system under various occlusal forces with rigid/non-rigid connections. J Biomech 2006; 39:453–463.
18. Lin C-L, Chang S-H, Wang J-C, Chang WJ. Mechanical interactions of an implant/tooth-supported system under different periodontal supports and number of splinted teeth with rigid and non-rigid connections. J Dent 2006; 34:682–691.
19. Akagawa Y, Hosokawa R, Sato Y, Kamayama K. Comparison between freestanding and tooth-connected partially stabilized zirconia implants after two years function in monkeys: a clinical and histologic study. J Prosthet Dent 1998; 80:551–558.
20. Gunne J, Astrand P, Lindh T, Borg K, Olsson M. Tooth-implant and implant supported fixed partial dentures: a 10-year report. Int J Prostodont 1999; 12:216–221.
21. Hosny M, Duyck J, van Steenberghe D, Naert I. Within-subject comparison between connected and non-connected tooth-to-implant fixed partial prostheses: up to 14-year follow-up study. Int J Prosthodont 2000; 13:340–346.
22. Lindh T, Bäch T, Nyström E, Gunne J. Implant versus tooth-implant supported prostheses in the posterior maxilla: 2 year report. Clin Oral Implants Res 2001; 12:441–449.
23. Palmer RM, Howe LC, Palmer PJ. A prospective 3-year study of fixed bridges linking Astra Tech ST implants to natural teeth. Clin Oral Implants Res 2005; 16:302–307.
24. Kayakan R, Ballarini R, Mullen RL. Theoretical study of the effects of tooth and implant mobility differences on occlusal force transmission in tooth/implant-supported partial prostheses. J Prosthet Dent 1997; 78:391–399.
25. Laufer BZ, Gross M. Splinting osseointegrated implants and natural teeth in rehabilitation of partially edentulous patients. Part II: principles and applications. J Oral Rehabil 1998; 25:69–80.
26. Ormianer Z, Brosh T, Laufer B-Z, Shifman A. Strains recorded in a combined tooth-implant restoration: an *in vivo* study. Implant Dent 2005; 14:58–62.
27. Sheets CG, Earthman JC. Tooth intrusion in implant-assisted prostheses. J Prosthet Dent 1997; 77:39–45.
28. Balfour A, O'Brien GR. Comparative study of antirotational single tooth abutments. J Prosthet Dent 1995; 73:36–43.
29. Hunt PR, Gartner JL, Norkin FJ. Choice of a dental implant system. Compend Contin Educ Dent 2005; 26:239–248.
30. Krennmair G, Schmidinger S, Waldenberger O. Single tooth replacement with the Frialit-2 system: a retrospective clinical analysis of 146 implants. Int J Oral Maxillofac Implants 2002; 17:78–85.
31. Cehreli M, Duyck J, De Cooman M, Puers R, Naert I. Implant design and interface force transfer: a photoelastic and strain-gauge analysis. Clin Oral Implants Res 2004; 15:249–257.
32. Clelland NL, Gilat A, McGlumphy EA, Brantley WA. A photoelastic and strain gauge analysis of angled abutments for an implant system. Int J Oral Maxillofac Implants 1993; 8:541–548.
33. Kim WD, Jacobson Z, Nathanson D. *In vitro* stress analysis of dental implants supporting screw-retained and cement-retained prostheses. Implant Dent 1999; 8:141–151.
34. Ochiai KT, Ozawa S, Caputo AA, Nishimura RD. Photoelastic stress analysis of implant-tooth connected prostheses with segmented and nonsegmented abutments. J Prosthet Dent 2003; 89:495–502.
35. Naert IE, Duyck JA, Hosny MM, Van Steenberghe D. Freestanding and tooth-implant connected prostheses in the treatment of partially edentulous patients. Part I: an up to 15-years clinical evaluation. Clin Oral Implants Res 2001; 12:237–244.
36. Naert IE, Duyck JA, Hosny MM, Quirynen M, van Steenberghe D. Freestanding and tooth-implant connected prostheses in the treatment of partially edentulous patients Part II: an up to 15-years radiographic evaluation. Clin Oral Implants Res 2001; 12:245–251.

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