JPD
THE JOURNAL OF PROSTHETIC DENTISTRY

RESEARCH AND EDUCATION

Influence of abutment angulation on loss of prosthetic abutment torque under mechanical cycling

Decio Hein, DDS, MSc,[a] Júlio C. Joly, DDS, PhD,[b] Marcelo H. Napimoga, DDS, PhD,[c]
Daiane C. Peruzzo, DDS, PhD,[d] andElizabethF.Martinez,DDS,PhD-2021

ABSTRACT

Statement of problem. Internal conical connections provide mechanical stability for the prosthetic abutment and implant connection. However, some clinical situations require the use of angled prosthetic abutments that may increase stress on supportive implants by difference force vectors under cyclic loading.

Purpose. The purpose of this in vitro study was to measure the screw loosening values of prosthetic abutments with internal conical connections (indexed and nonindexed) having different angles under mechanical cycling.

Material and methods. Thirty-six implants (4.0×13 mm, Titamax) with internal conical connections and their respective universal prosthetic abutments (n=36, 3.5×3.3 mm) were divided into indexed and nonindexed groups (n=18) with abutment inclinations of 0 (straight), 17, and 30 degrees. An insertion torque of 15 Ncm was applied according to the manufacturer's specifications. The specimens underwent fatigue testing of 500 000 cycles at a frequency of 2 Hz with a dynamic compressive load of 120 N at an angle of 30 degrees. The detorque values were measured by using a digital torque meter and tabulated for statistical analyses.

Results. The specimens with indexed abutments had mean ±standard deviation detorque values of 6.72 ±2.29 Ncm under mechanical cycling, whereas those with nonindexed abutments had values of 8.98 ±1.84 Ncm. In the indexed group, the lowest detorque value was observed for abutments at 30 degrees compared with the straight group ($P<.05$). As for nonindexed abutments, similar detorque values were observed after increasing the abutment inclination ($P>.05$).

Conclusions. A decrease in detorque values in the indexed abutments related to their inclination was found under mechanical cycling, whereas the prosthetic abutments with 30 degrees of angulation had the lowest values. No decrease was found in the nonindexed abutments. (J Prosthet Dent 2020;■:■-■)

Understanding the biomechanics of dental implants is essential for providing a stable, clinically successful implant-supported restoration. Mechanical problems include loosening and fracture of the abutment screw, deformation of the implant shoulder, and even fracture of the implant itself.[1-3] High rates of clinical complications related to the fixation screw have been reported, particularly with single-unit restorations.[4,5] This problem has prompted research aimed at modifying prosthetic components and the implant shoulder.[6,7]

In engineering, Morse taper connection systems are frequently used when a highly retentive and stable connection is needed.[8] This internal conical connection concept has been applied to dental implants with advantages that include decreasing the rate of abutment screw loosening, improved adaptation among the prosthetic components, and decreased micromovement between abutment and implant, resulting in improved resistance of the abutment-implant assembly.[3,9-12] Tapered connection systems typically feature 2 forms of abutments, solid and fixed by a through screw, commonly used in angled

---

[a] Post Graduate student, Division of Oral Implantology, Faculdade São Leopoldo Mandic (SLMandic), Campinas, São Paulo, Brazil.
[b] Professor, Division of Oral Implantology, Faculdade São Leopoldo Mandic (SLMandic), Campinas, São Paulo, Brazil.
[c] Professor, Division of Immunology, Faculdade São Leopoldo Mandic (SLMandic), Campinas, São Paulo, Brazil.
[d] Professor, Division of Oral Implantology, Faculdade São Leopoldo Mandic (SLMandic), Campinas, São Paulo, Brazil.
[e] Professor, Division of Cell Biology, Faculdade São Leopoldo Mandic (SLMandic), Campinas, São Paulo, Brazil.

Clinical Implications

The indexation and angulation of abutments may influence detorque values in universal abutment screws under mechanical cycling, even with an internal tapered connection.

components and often requiring torque values lower than half the torque applied to solid-screw abutments.[10,13,14]

Because the adaptation of the abutment and the resulting preload torque depend on component design, abutment angulation could be important given the different force vectors during cyclic loading.[15-17] In this respect, when dental implants are installed, they should be aligned with mastication forces.[18] However, some clinical situations, such as limited bone volume, may require angulation of the prosthetic abutment to compensate for installation of an implant in a nonoptimal position.[19-21] Although prosthetic rehabilitation is possible, esthetics may be compromised, and increased stress may occur on the implants, the adjacent bone, and the prostheses.[22]

An internal hexagonal index may be provided in the components with a tapered connection to facilitate the prosthetic procedure.[21] Although indexes improve accuracy for prosthetic rehabilitation, they reduce the internal conical area in contact with the abutment, thus influencing mechanical stability.[22]

Therefore, considering the possibility of long-term mechanical complications,[23-29] this study focused on comparing the detorque values of universal abutment screws at different angles under mechanical cycling, with both indexed and nonindexed systems for implants with internal tapered connection. The research hypothesis was that screw loosening would increase with increasing abutment angulations.

MATERIAL AND METHODS

Titamax implants were used (Titamax CM Cortical, 4.0×13 mm; Instradent AG) (n=36) with an internal tapered connection and their respective universal prosthetic abutments (n=36) with a tapered fixation screw and transmucosal abutment height of 3.5 mm, 3.3 mm profile, and 6.0 mm of cementation height (Universal Abutment CM; Instradent AG). Of these, 18 were indexed (Universal Abutment CM Exact; Instradent AG), with an internal contact area of 12.781 mm^2, and 18 were nonindexed, with an internal contact area of 13.671 mm^2 (Fig. 1).

Figure 1. Prosthetic abutments. A, Indexed. B, Nonindexed.

The specimens had a study factor “index” for the prosthetic abutment and were subdivided into groups (n=6) with 3 different angulations: 0 (straight), 17, and 30 degrees. An a priori sample size calculation was performed by using an analysis software program (G*Power 3.1.9.4; Heinrich-Heine-Universität Düsseldorf) to estimate the number of specimens needed to detect differences in detorque values. The effect size was identified as 0.830 based on a pilot study carried out with 3 specimens from each group. Such effect sizes would require at least 4 specimens per group to detect differences among the treatments at α=.05 and β=.80. In the present study, 6 specimens per group were used.

The abutments were installed on the implants, and the assembly was fixed into place with a vise (Somar; Schulz. Answer: please, correct.–>). The depth of the internal chamber of the implant was measured to ensure implant fixation on the vise, below and adjacent to the chamber, to avoid deformation, which could influence the results.[30-32] The prosthetic abutments were coupled manually to the implants by using a 0.9-mm torque wrench (Neodent) to stabilize the assembly. A torque of 15 Ncm was applied as specified by the manufacturer with a digital torque gauge (Torque Meter TQ-8800; Lutron). All the specimens were activated at the same time by the same operator (D.H.).

Brass bases were used to fix and stabilize the specimens to perform the mechanical cycling. Each base had a final cylindrical configuration measuring 2.0 cm in diameter, with different angles for fixing the specimens. For straight prosthetic abutments (0 degrees), the base

Table 1. Mean values ±standard deviation of detorque (Ncm) for indexed and nonindexed implants with different angulations

	Groups		t Test
Angulations	Indexed	Nonindexed	Independent Samples (Uppercase Letters)
Straight	8.63 ±2.40Ab	9.20 ±3.05Aa	t=-0.35736 df=10 P=.728
17 degrees	6.55 ±1.02Aab	9.30 ±0.74Ba	t=-5.327 df=10 P<.001
30 degrees	5.00 ±1.75Aa	8.45 ±1.04Ba	t=-4.1418 df=10 P=.002
Mean ±standard deviation	6.72 ±2.29	8.98 ±1.84	–
ANOVA and Tukey (lowercase letters)	df=17 F=6.06 P=.012	df=17 F=0.354 P=.708	–

Different uppercase letters indicate significant differences between indexed and nonindexed groups (P<.05). Different lowercase letters indicate significant differences among angulations (P<.05).

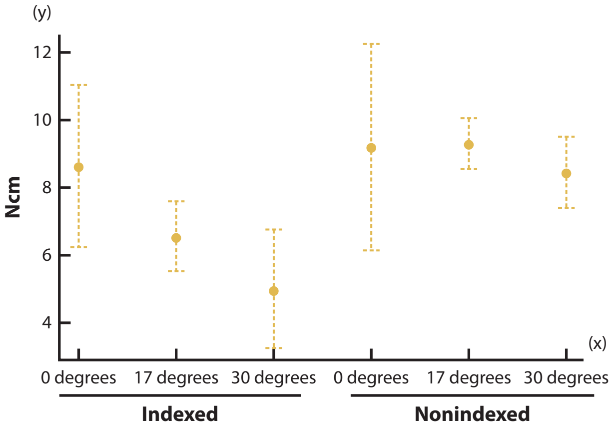

Figure 2. Linear representation of mean detorque values ±standard deviation across conditions studied.

between the long axis of the implant and the ground was 30 degrees. For prosthetic abutments with a 17-degree angle, the base between the long axis of the implant and the ground was 27 degrees. Finally, when the angle was 30 degrees, the base between the long axis of the implant and the ground was 40 degrees.

The specimens were adapted to the mechanical cycling equipment (MSFM mastication electromechanical chewing machine performed by Elquip) and received a compressive load of 120 N at a 30-degree angle to the long axis of the implant. The load applied represented the average of occlusal and masticatory load in the region of premolars and molars in humans.[33] Approximately 6 months of masticatory function was simulated with 500 000 cycles per specimen and a frequency of 2 Hz.[33,34]

After mechanical cycling, all the assemblies were inspected for permanent deformation. A digital torque wrench was used to loosen the screws and measure and tabulate the detorque values for statistical analyses.

Normal distribution of data was determined with the Shapiro-Wilk test. One-way analysis of variance (ANOVA) with the post hoc Tukey test was applied to determine the differences among the indexed, nonindexed, and abutment angulation groups. The Student t test was also applied to assess significant differences between the indexed and nonindexed groups, regardless of angulation (α=.05). A statistical software program (R. Commander; McMaster University) was used, and the statistical methodology was reviewed by an independent statistician.

RESULTS

The abutment screw became loose under mechanical cycling in all the specimens (Table 1). The specimens with indexed abutments presented mean detorque values of 6.72 ±2.29 Ncm after mechanical cycling, whereas those from the nonindexed group had values of 8.98 ±1.84 Ncm. Therefore, considering an initial torque value of 15 Ncm, only 44.8% of the torque was maintained in the indexed group and 59.9% in the nonindexed group. The detorque value was higher in the nonindexed groups for all angulations studied (Table 1).

Regarding the indexed group, a decrease in detorque value was observed under mechanical cycling, with the lowest values recorded for abutments at 30-degree angulation compared with the straight group (P<.05). Also, regarding the indexed group, straight versus angled abutments yielded a 24.1% reduction in torque for the 17-degree abutments and an 18.0% decrease for the 30-degree abutments. These values depict a cumulative torque loss of 42.1% from the straight abutments to those angled at 30 degrees, representing a mean torque loss of 1.4% for every degree increased. As for the nonindexed group, no significant differences in detorque values were observed at the different angulations (P>.05) (Fig. 2).

DISCUSSION

The results of this study supported the research hypothesis that screw loosening intensifies with increasing angulation of the prosthetic abutment under mechanical cycling, especially in indexed abutments. The most frequently reported complication in implant-supported restorations, especially for single-unit crowns, has been the loosening of the fixation screw under masticatory loads.[3] These complications are less common with tapered connection implants, where load distribution occurs throughout the abutment-implant interface because of the friction between the implant walls and the prosthetic abutment.[3,11-13,30]

Tapered connection implants have been evaluated for component retention by comparing solid 1-piece abutments to those fixed by retention or with a screw.[14,15,30] The remaining torque value is important to maintain the preload and is therefore an important factor for abutment retention and, consequently, restoration longevity.[16] In the present study, the influence of abutment angulation was evaluated based on the torque maintenance of 2-piece abutments (abutment and fixation screw) in tapered-connection implants under mechanical cycling.

In most implant systems, angled abutments are secured by fixation screws. According to Coppedê et al,[14] the locking torque value recommended by the implant manufacturers for the screw should be less than half the torque value used in solid abutment systems. The prosthetic abutments selected for the present study were able to withstand only low values of initial torque because of a fragile area within the screw from the weld between the thread and the body of the screw.[22]

Another feature related to the internal, tapered connection design of the screw was the possible influence of indexers in maintaining screw torque. Indexers have been developed for tapered connection implants to provide greater rotational stability to the connection and allow repositioning of the abutment to its original position after screw loosening.[34] The indexers also provide a vertical stop and reduce the effect of axial displacement of the screw against dynamic loads, also known as the settling effect. The outcome would be loss of preload because of elastic elongation of the screw and consequent loosening.[23] The results of the stop effect were not observed in the present study because the detorque values obtained for the screws in the indexed abutments were significantly lower (Student *t* test, $P<.05$) than the respective values for the nonindexed group. When the specimens were compared individually by using the Tukey test, screw loosening was greater ($P<.05$) in the 30-degree abutments. The poor outcome observed for the indexed group can be explained based on the findings of Dailey et al[24] who reported that when the abutments are tightened to the implants in tapered connection implants without indexers, an axial movement of the abutment occurs toward the internal chamber of the implant. This movement promotes imbrication between the prosthetic abutment and the implant surface, which produces frictional retention. This is an important factor for maintenance of the preload and, consequently, for preservation of the elastic elongation values of the screw and reduction in micromovements of the abutment under cyclic loads. Micromovements can lead to loosening of the abutment fixation screw[2,12] in addition to loss of preload and changes to the contact surfaces between the implant and the abutment under cyclic loading.[17,18]

The initial torque applied to the fixation screw is another factor involved in promoting and maintaining the preload values and, consequently, the screw detorque values. Increased torque values have been reported to cause higher preload values, but load values above the elastic limit of the screw lead to deformation and fracture of the screws.[16,25] Other factors in addition to the torque value may be responsible for the quality of the preload. These include the convergence of the internal walls of the implants, the coefficient of friction between the internal chamber and the screw threads and between the abutment and the implant walls, the rigidity of the fitting parts, the screw material, the screw head design, and the internal abutment area between the prosthetic abutment and the implant.[7,23,26-28]

Systems with smaller contact areas between the abutment and the implant will have lower preload stability, thus requiring screws that support higher torque values to maintain the preload.[2] Considering that the implant-abutment contact area has a great influence on maintaining the preload value, the results of the present study may have been influenced by the smaller contact area of the indexed abutments evaluated (12.781 mm^2) than that of the nonindexed abutments (13.671 mm^2) according to the manufacturer. This 6.5% decrease in contact area may have undermined the stability of the implant-abutment assembly under cyclic loading.[9] Additionally, the highest detorque values observed in the nonindexed group versus the indexed groups seem to be connected to higher abutment stability, lower micromovement, and, consequently, higher preload maintenance under cyclic loading.

In some clinical situations, angled prosthetic abutments will be required where the implant is not installed in the ideal axial position.[19,20] The effect of abutment angulation on stability is unclear. Implant positioning (angulation) has been reported to induce significant stress on the implant, the abutment connection, and the peri-implant bone.[30,31] Therefore, the use of angled prosthetic abutments should be avoided when possible, even though their disadvantage may not be as great in tapered connection implants. In this situation, a greater area of closer contact occurs between the implant and the prosthetic abutment, causing frictional retention between the component and the inner wall of the implant. Additionally, the torque from the fixation screw provides improved mechanical stability, even when the force applied to secure the abutment is lost.[9] The present study evaluated whether abutment angulation influenced maintenance of the initial torque values applied to the fixing screws in internal tapered connection abutments, despite the improved mechanical stability offered by this type of platform.

The 30-degree angulation used in the present study has been previously used to test implants in vitro[21,30,32] and is in accordance with the recommendations established in the International Organization for Standardization (ISO) 14801:2016.[35] This standard also specifies that 500 000 cycles should be used per specimen to simulate approximately 6 months of masticatory function at a load of 120 N and frequency of 2 Hz.

Although internal tapered connection systems offer advantages regarding mechanical stability, represented by a favorable balance of forces, increased angulation may cause greater screw loosening.[9] Thus, the higher detorque values between the implant and abutment in the nonindexed group maintained higher preload values. This was demonstrated when evaluating the effects of abutment angulation where a load increase caused by increased abutment angulation did not bring about any statistically significant changes to the detorque values of the screws in the nonindexed group. This probably occurred because of a sedimentation effect of the abutment, whereas screw loosening in the indexed group may have been caused by external functional forces applied to the abutments. According to Xia et al,[29] these forces constitute one of the reasons for loss of preload and consequent destabilization of the implant system.

Although this in vitro study was designed to simulate a clinical situation, some limitations should be considered in interpreting its results, including the complexity of the oral cavity environment. The humidity of the oral cavity, as well as thermal changes, combined with the masticatory function over time can contribute to screw loosening. In this respect, further studies should be performed to evaluate the influence of the abutment inclination in the conditions of the oral cavity.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. A decrease in detorque values in the indexed abutments related to their inclination was found under mechanical cycling.
2. Prosthetic abutments with 30 degrees of angulation presented the lowest values, whereas no decrease was found in the nonindexed abutments.

REFERENCES

1. Schulte JK, Coffey J. Comparison of screw retention of nine abutment systems: a pilot study. Implant Dent 1997;6:28-31.
2. Lee J, Kim YS, Kim CW, Han JS. Wave analysis of implant screw loosening using an air cylindrical cyclic loading device. J Prosthet Dent 2002;88:402-8.
3. Gracis S, Michalakis K, Vigolo P, Vult von Steyern P, Zwahlen M, Sailer I. Internal vs. external connections for abutments/reconstructions: a systematic review. Clin Oral Implants Res 2012;23:202-16.
4. Jung RE, Zembic A, Pjetursson BE, Zwahlen M, Thoma DS. Systematic review of the survival rate and the incidence of biological, technical, and aesthetic complications of single crowns on implants reported in longitudinal studies with a mean follow-up of 5 years. Clin Oral Implants Res 2012;23 Suppl 6:2-21.
5. Tey VHS, Phillips R, Tan K. Five-year retrospective study on success, survival and incidence of complications of single crowns supported by dental implants. Clin Oral Implants Res 2017;28:620-5.
6. Wentaschek S, Tomalla S, Schmidtmann I, Lehmann KM. Preload, coefficient of friction, and thread friction in an implant-abutment-screw complex. Int J Prosthodont 2017;30:542-4.
7. Krishnan V, Tony Thomas C, Sabu I. Management of abutment screw loosening: review of literature and report of a case. J Indian Prosthodont Soc 2014;14:208-14.
8. Schmitt CM, Nogueira-Filho G, Tenenbaum HC, Lai JY, Brito C, Döring H, et al. Performance of conical abutment (Morse Taper) connection implants: a systematic review. J Biomed Mater Res A 2014;102:552-74.
9. Bozkaya D, Muftu S. Mechanics of the taper integrated screwed-in (TIS) abutments used in dental implants. J Biomech 2005;38:87-97.
10. Nentwig HG. The Ankylos implant system: concept and clinical application. J Oral Implantol 2004;30:171-7.
11. Luterbacher S, Fourmousis I, Lang N, Bragger U. Fractured prosthetic abutments in osseointegrated implants: a technical complication to cope with. Clin Oral Implants Res 2000;11:163-70.
12. Khraisat A, Abu-Hammad O, Dar-Odeh N, Ai-Kayed AM. Abutment screw loosening and bending resistance of external hexagon implant system after lateral cyclic loading. Clin Implant Dent Relat Res 2004;6:157-64.
13. Ricomini Filho AP, Fernandes FSF, Straioto FG, Silva WJ, Del Bel Cury AA. Preload loss and bacterial penetration on different implant-abutment connection systems. Braz Dent J 2010;21:123-9.
14. Coppedê AR, Mattos MG, Rodrigues RC, Ribeiro RF. Effect of repeated torque/mechanical loading cycles on two different abutment types in implants with internal tapered connections: an in vitro study. Clin Oral Implants Res 2009;20:624-32.
15. Pintinha M, Camarini ET, Sábio S, Pereira JR. Effect of mechanical loading on the removal torque of different types of tapered connection abutments for dental implants. J Prosthet Dent 2013;110:383-8.
16. Elias CN, Figueira DC, Rios PR. Influence of the coating material on the loosing of dental implant abutment screw joints. Mater Sci Eng C Mater Biol Appl 2003;26:1361-6.
17. Aguirrebeitia J, Abasolo M, Vallejo J, Ansola R. Dental implants with conical implant-abutmernt interface: influence of the conical angle difference on the mechanical behavior of the implant. Int J Oral Maxillofac Implants 2013;28:72-82.
18. Zirprich H, Weigl P, Lauer HC, Lange B. Micro-movements at the implant-abutment interface: measurements, causes and consequences. Implantologie 2007;15:31-45.
19. Hotinski E, Dudley J. Abutment screw loosening in angulation-correcting implants: an in vitro study. J Prosthet Dent 2019;121:151-5.
20. Clelland NL, Ismail YH, Zaki HS, Pipko D. Three-dimensional finite element stress analysis in and around the screw-vent implant. Int J Oral Maxillofac Implants 1991;6:391-8.
21. Ding TA, Woody RD, Higginbottom FL, Miller BH. Evaluation of the ITI Morse taper implant abutment design with an internal modification. Int J Oral Maxillofac Implants 2003;18:865-72.
22. El-Sheikh MAY, Mostafa TMN, El-Sheikh MM. Effect of different angulations and collar lengths of conical hybrid implant abutment on screw loosening after dynamic cyclic loading. Int J Implant Dent 2018;4:39.
23. Binon PP. Implants and components: entering the new millennium. Int J Oral Maxillofac Implants 2000;15:76-94.
24. Dailey B, Jordan L, Blind O, Tavernier B. Axial displacement of abutments into implants and implant replicas, with the tapered cone-screw internal connection, as function of tightening torque. Int J Oral Maxillofac Implants 2009;24:251-6.
25. Lang LA, Wang R, May KB. The influence if abutment screw tightening on screw joint configuration. J Prosthet Dent 2003;87:74-9.
26. Merz BR, Hunenbart S, Belser UC. Mechanics of the implant abutment connection: an 8-degrees taper compared to o butt joint connection. Int J Oral Maxillofac Implants 2000;15:519-26.
27. Bozkaya D, Muftu S. Mechanics of the tapered interference fit in dental implants. J Biomech 2003;36:1649-58.
28. Coppedê AR, Faria AC, de Mattos Mda G, Rodrigues RC, Shibli JA, Ribeiro RF. Mechanical comparison of experimental conical-head abutment screws with conventional flat-head abutment screws for external-hex and internal tri-channel implant connections: an in vitro evaluation of loosening torque. J Oral Maxillofac Implants 2013;28:321-9.
29. Xia D, Lin H, Yuan S, Bai W, Zheng G. Dynamic fatigue performance of implant-abutment assemblies with different tightening torque values. Biomed Mater Eng 2014;24:2143-9.
30. Alves DCC, de Carvalho PSP, Elias CN, Vedovatto E, Martinez EF. In vitro analysis of the microbiological sealing of tapered implants after mechanical cycling. Clin Oral Investig 2016;20:2437-45.
31. Alves DC, Carvalho PS, Martinez EF. In vitro microbiological analysis of bacterial seal at the implant-abutment interface using two morse taper implant models. Braz Dent J 2014;25:48-53.
32. da Silva KRN, Joly JC, Peruzzo DC, Napimoga MH, Martinez EF. Influence of transmucosal height on loss of prosthetic abutment torque after mechanical cycling. J Oral Implantol 2018;44:423-6.
33. Stanford CM, Brand RA. Toward an understanding of implant occlusion and strain adaptive bone modeling and remodeling. J Prosthet Dent 1999;81:553-61.

34. Cibirka RM, Nelson SK, Lang BR, Rueggeberg FA. Examination of the implant abutment interface after fatigue testing. J Prosthet Dent 2001;85:268-75.
35. International Organization for Standardization. ISO 14801. Dentistry — implants — dynamic loading test for endosseous dental implants. Geneva: International Organization for Standardization; 2016. (Date: 2016-11-01). Available at: http://www.iso.org/iso/home.html.

Corresponding author:

Dr Elizabeth F. Martinez
Faculdade São Leopoldo Mandic
Rua José Rocha Junqueira, 13
Campinas CEP 13045-755, SP
BRAZIL
Email: dr.efmartinez@gmail.com

Authors' contributions

D.H. conceived the ideas and contributed to data collection and writing of article. M.H.N. analyzed the data and gave approval to the article. J.C.J. and D.C.P. revised and approved the article. E.F.M. conceived the ideas, contributed to designing the study, analyzed the data, and contributed to writing the article.

Acknowledgment

We would like to thank Dr Jonas Joacir Radtke from Universidade Tecnológica Federal do Paraná (Paraná, Brazil) for the statistical analysis.

https://doi.org/10.1016/j.prosdent.2020.10.010