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RESEARCH AND EDUCATION

Resistance to loosening of intentionally shortened screws used to solve the unsuccessful removal of fractured prosthetic screws

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ABSTRACT

Statement of problem. Fractured prosthetic implant screws cannot be removed in all patients, ultimately leading to the removal of the implant. Whether an intentionally shortened prosthetic implant screw (SPIS) can provide adequate retention is unclear.

Purpose. The purpose of this in vitro study was to evaluate the resistance to loosening of SPISs engaging the remaining coronal internal threads as a possible solution to maintaining both implant and restoration.

Material and methods. Fifty grade V titanium SPISs were used to tighten 50 titanium transepithelial abutments on implants to 30 Ncm. The specimens were distributed into 5 groups (n=10) according to the conditions under which the screws were secured to manufacturer-recommended preload: dry (D), moistened in saliva (AS), moistened in chlorhexidine (CLHX), wrapped in polytetrafluoroethylene tape (PTFE), and resin cemented (RE). All groups were subjected to a cyclic loading test (240 000 cycles). The reverse torque value (RTV) of the SPIS was registered twice: 24 hours after initial tightening (T1); and after retightening and the cyclic loading test (T2). The resultant RTV was compared with the 30-Ncm tightening torque to assess torque loosening. The Kruskal-Wallis and Mann-Whitney tests were used for the comparisons between groups and the Wilcoxon test for the intragroup comparisons (α=.05 with Bonferroni correction).

Results. At T1, all groups found lower mean ±standard deviation RTVs than the reference tightening torque (30 Ncm) (D 24.82 ±2.34 Ncm, AS 25.56 ±2.89 Ncm, PTFE 26.02 ±2.26 Ncm, CLHX 26.26 ±1.82 Ncm), except the resin-cemented group, which increased its RTV (RE 44.01 ±19.94 Ncm). At T2, all the groups found lower RTVs than the reference tightening torque, and the torque values at T1 (D 19.81 ±6.59 Ncm, CLHX 18.98 ±6.36 Ncm, AS 21.28 ±7.32 Ncm), with the exception of PTFE (24.07 ±3.41 Ncm) and RE (41.47 ±21.68 Ncm), where RTV was similar to that recorded at T1. At T1, significant differences were found among the groups (P=.024). At T2, after cyclic loading, the RE group found the highest RTV, reporting significant differences with the D and CHLX groups (P<.05) and statistically similar to the AS group (P=.068).

Conclusions. PTFE-wrapped screws found similar RTVs after the fatigue test than dry, moistened with saliva, and moistened with chlorhexidine screws. Resin-cemented shortened prosthetic implant screws were found to be the most resistant to loosening after cyclic loading. (J Prosthet Dent 2024;132:165-171)

Implant-supported fixed prostheses are a predictable treatment option with a high success rate, although they are not free of complications,[1,2] including screw loosening.[3–5] The incidence of screw loosening has been significantly reduced through improvements to implant design, materials, and methodologies, and also the introduction of torque control devices and manufacturer recommendations as to what preload is recommended for each type of screw.[2,6] If screw loosening occurs repeatedly, it affects treatment success and patient satisfaction[7–10] and

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Clinical Implications

Resin cement increases screw loosening resistance when with intentionally shortened prosthetic screws to solve the unsuccessful removal of fractured implant screws. Further studies are needed to probe the efficacy of wrapping shortened screws with PTFE tape.

sometimes leads to screw fracture.[11] A fractured screw can often be easily removed when the apical screw portion has been loose. However, when a screw fractures without previous loosening, the apical fragment is strongly joined to the implant, and its removal can prove challenging.[11–13] Such situations can even lead to unrectifiable damage to the implant and the restoration,[14,15] requiring implant removal, an undesirable and costly solution that can be painful and time consuming.

When the apical portion of the fractured prosthetic implant screw cannot be removed, a possible solution is to place an intentionally shortened screw, taking advantage of the remaining useful coronal threads. Techniques aiming to increase resistance to loosening of the screws, including wrapping them with sterilized polytetrafluoroethylene (PTFE) tape and the use of gold screws have been described.[16–18]

Screw loosening is directly related to the reduction of the preload (or tensile force generated within the screw during tightening in screw joints). This reduction is positively correlated with the value of the applied torque, as long as the elastic limit of the screw material is not exceeded.[19–22] In addition, parameters such as the type of implant connection,[23,24] abutment angulation,[25] and variations in the tightening conditions, such as screw lubrication,[18,22–27] have been described as factors affecting screw loosening. Furthermore, the reverse torque value (RTV) has been reported as a measure of the remaining preload.[16,22,28]

The present in vitro study was carried out to evaluate resistance to loosening from the measurement of RTV after cyclic loading of intentionally shortened prosthetic implant screws (SPISs) treated with different techniques (dry, saliva-moistened, chlorhexidine moistened, PTFE coated, and resin cemented), seeking to simulate fractured prosthetic screw implants where the apical fragment could not be extracted. The null hypothesis was that the different techniques would not demonstrate higher removal torque values than the nontreated shortened screws.

MATERIAL AND METHODS

Sample size was estimated with a software program (G*Power v3.1.9.7; Heinrich-Heine-Universität Dusseldorf) allowing for the detection of relative resistance losses of 10% and 20% (between 2 groups), with a statistical power of 80%. Calculations were performed assuming a standard deviation of 5% and a confidence level of 95% for a Mann-Whitney U-test based on the minimum relative efficiency method.

Fifty conical titanium grade IV internal hexagonal connection implants were used (Ø4.25×11.5 mm) (Kohno; Sweden & Martina). The implants were fixed in nylon specimens (Specimen stations; SD Mechatronik GmbH) with epoxy resin (Exakto-Form; bredent) with an angulation of 30 degrees following the specifications of the 14 801 International Organization for Standardization protocol.[29] Fifty engaging grade V titanium transepithelial abutments (Echo Chairside; Sweden & Martina) were tightened to the implants by using grade V titanium shortened prosthetic screws with a completely threaded body (REF VM2-200). The original length of the screwed apical portion was 5 mm, and they were intentionally shortened by removing 2 mm, resulting in a 3-mm threaded portion (Fig. 1A) simulating an unrecoverable 2-mm apical fragment of a fractured screw. The distance was measured with a periodontal probe (PCPUNC156; Hu-Friedy), and the screw was cut with a diamond-coated disk (918PB.104.180; Komet). Once cut, the 3-mm length was verified with calipers (Iwanson caliper; CHL Medical Solutions SRL).

The screws were tightened to 30 Ncm according to the manufacturer's instructions by using an electric screwdriver (IA-400 prosthodontic screwdriver; W&H). The screws were retightened after 10 minutes to compensate for the screw seating factor.[24,30,31] A preliminary study done on 10 screws ensured that the actual value of the initial torque was consistently 30 Ncm.

The specimens were divided into 5 groups according to the technique used: Group D, Dry screw (Fig. 1B); Group CLHX, Screw moistened in 0.2% chlorhexidine bioadhesive gel (Chlorhexidine bioadhesive gel 50 mL; Lacer, S.A.) (Fig. 1C); Group AS, Screw moistened in artificial saliva (Fusayama/Meyer; Pickering Laboratories Inc) (Fig. 1D); PTFE Group, Screw coated with 3 turns of 100-µm-thick PTFE tape (PTFE tape 19 mm×50 m×0.1 mm; Miarco) (Fig. 1E); and RE Group, Screw cemented with polyethyleneglycol dimethacrylate resin (CekaBond; Alphadent NV) (Fig. 1F). The RE group was allowed to polymerize for 5 minutes before torque application according to the manufacturer's recommendations. Also, the 10-minute retightening was not done in the RE group because of the resin polymerization.

To evaluate screw loosening resistance, 2 RTV tests were performed: 24 hours after the screws were tightened (T1) and after retightening them 24 hours later and subjecting them to a fatigue test of 240 000 cycles in a mastication simulator machine (Chewing Simulator CS-4.2; SD Mechatronik GmbH) at 2 Hz and an 80-N load (T2) (Fig. 2).[11] The RTV was registered by a calibrated device (Ichiropro; Bien Air). From T1 to T2, the

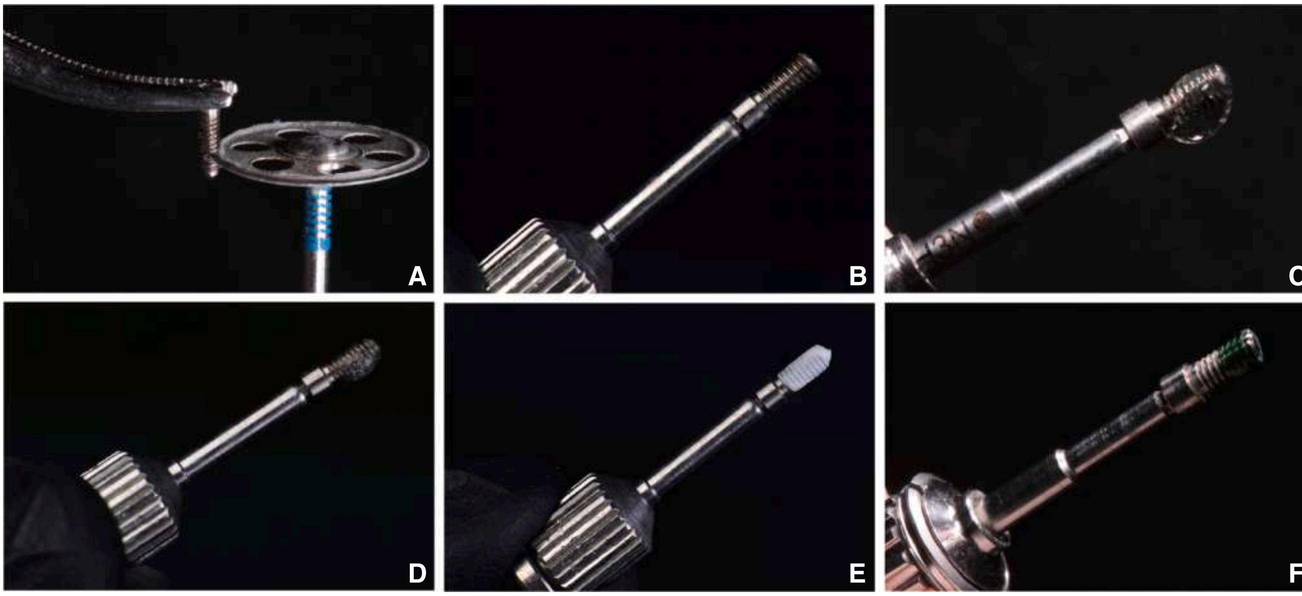

Figure 1. A, Screw shortening with a diamond disk. B, Dry shortened-screw. C, Shortened-screw moistened in chlorhexidine gel. D, Shortened-screw moistened in artificial saliva. E, Shortened-screw wrapped in polytetrafluoroethylene tape. F, Shortened-screw moistened with resin.

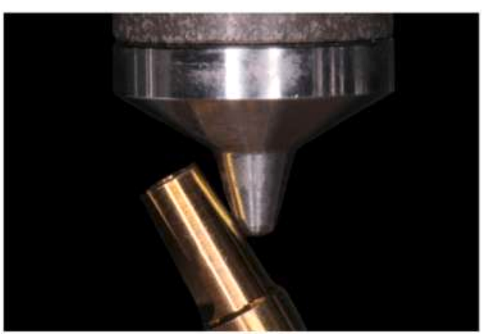

Figure 2. Dynamic mechanical load test of implant-prosthetic abutments.

RE group specimens were heated in a furnace at 650 °C for 1 minute (Programat EP 3010; Ivoclar AG) to pyrolyze the resin. They were then examined with a light microscope (M-80; Leica) at ×60 to ensure there was no resin residue on the screw in the internal threads of the implant. Then, the resin cement was applied again before retightening.[32]

The results were expressed in both Ncm and percentage loss of resistance to report an absolute and a relative manner of describing the loss of resistance. The differences in RTVs among groups and also between prefatigue (T1) and postfatigue (T2) values were analyzed by using the nonparametric Kruskal-Wallis test. For multiple comparisons between pairs of specific groups, the Mann-Whitney U-test was used, adjusting the confidence level according to the Bonferroni criterion. Wilcoxon tests were used for within-group comparisons (α=.05). For a confidence level of 95% and considering an effect size to be detected d=1.3, the power achieved with the Mann-Whitney U-test was 73.7% for detecting differences in mean resistance loss between two groups. A statistical software program (IBM SPSS Statistics for Windows, v26; IBM Corp) was used for all the statistical analysis.

RESULTS

Descriptive statistical data were reported as the median and interquartile range (IQR), preventing outliers from interfering with the interpretation and based on the methodology of previous studies.[5,9] Absolute reverse torque values (Ncm) are shown in Table 1. At T1, all the groups experienced a decrease in reverse torque value (D 24.00 Ncm [IQR: 26.10 to 23.20], AS 25.95 Ncm [IQR: 27.50 to 24.80], PTFE 26.35 Ncm [IQR: 26.80 to 24.00], CLHX 25.70 Ncm [IQR: 26.50 to 25.20]), except the resin-cemented group, which increased its resistance to loosening (RE 39.15 Ncm [IQR: 71.40 to 30.60]) (Table 1). Loss of RTV was expressed in percentages, comparing the reverse torque values with the initial torque (30 Ncm). At T1, the RE group found a median gain of 30.5% (IQR: −138.0 to −2.0), although the other groups lost within a range from 12.2% to 20% (PTFE 12.2% [IQR: 10.7 to 20.0], AS 13.5% [IQR: 8.3 to 17.3], CLHX 14.3% [IQR: 11.7 to 16.0], D 20.0% [IQR: 13.0 to 22.7]) (Table 2, Fig. 3). The Kruskal-Wallis test found significant differences among groups (P=.024). Nevertheless, on analyzing the results by using the Mann-Whitney U-test and Bonferroni correction, no statistical significance was found between any pairs of groups (Table 2).

Table 1. Reverse torque values at time points T1 and T2 (Ncm)

Group	T1-Mean	T1- SD	T1- Median	T1- 25th and 75th Percentiles	T2- Mean	T2- SD	T2- Median	T2- 25th and 75th Percentiles
D	24.82	2.34	24.00	26.10-23.20	19.81	6.59	20.25	24.80-14-0
CLHX	26.26	1.82	25.70	26.50-25.20	18.98	6.36	18.40	25.0-15.90
AS	25.56	2.89	25.95	27.50-24.80	21.28	7.32	23.45	27.50-16.90
PTFE	26.02	2.26	26.35	26.80-24.0	24.07	3.41	23.50	26.80-21.00
RE	44.01	19.94	39.15	71.40-30.60	41.47	21.68	35.75	70.40-28.00

AS, moistened in saliva; CLHX, moistened in chlorhexidine; D, dry; PTFE, wrapped in polytetrafluoroethylene tape; RE, resin cemented. SD, standard deviation; T1, 24 h after initial tightening; T2, after retightening and cyclic loading.

Table 2. Retention loss (%) at timepoints T1 and T2

Group	T1- Mean	T1- SD	T1- Median	T1- 25th and 75th Percentiles	T2- Mean	T2- SD	T2- Median	T2- 25th and 75th Percentiles
D	17.27	7.79	20.00[a]	13.00-22.67	21.43	20.63	12.73[a]	4.98-42.39
CLHX	12.47	6.06	14.33[a,b]	11.67-16.00	28.27	21.59	28.78[b]	11.86-39.31
AS	14.80	9.63	13.50[a,c]	8.33-17.33	17.82	23.40	8.42[a]	0.00-31.85
PTFE	13.27	7.54	12.17[a,d]	10.67-20.00	7.68	7.94	4.65[a]	1.00-16.42
RE	-46.70	66.48	-30.50[a,e]	-138.00 to −2.00	8.63	10.35	5.72[c]	1.40-12.82

AS, moistened in saliva; CLHX, moistened in chlorhexidine; D, dry; PTFE, wrapped in polytetrafluoroethylene tape; RE, resin cemented. SD, standard deviation; T1, 24 h after initial tightening; T2, after retightening and cyclic loading.

The groups that present the same superscript (a, b, c, d, e) indicate that there are no statistically significant differences (Kruskal-Wallis test).

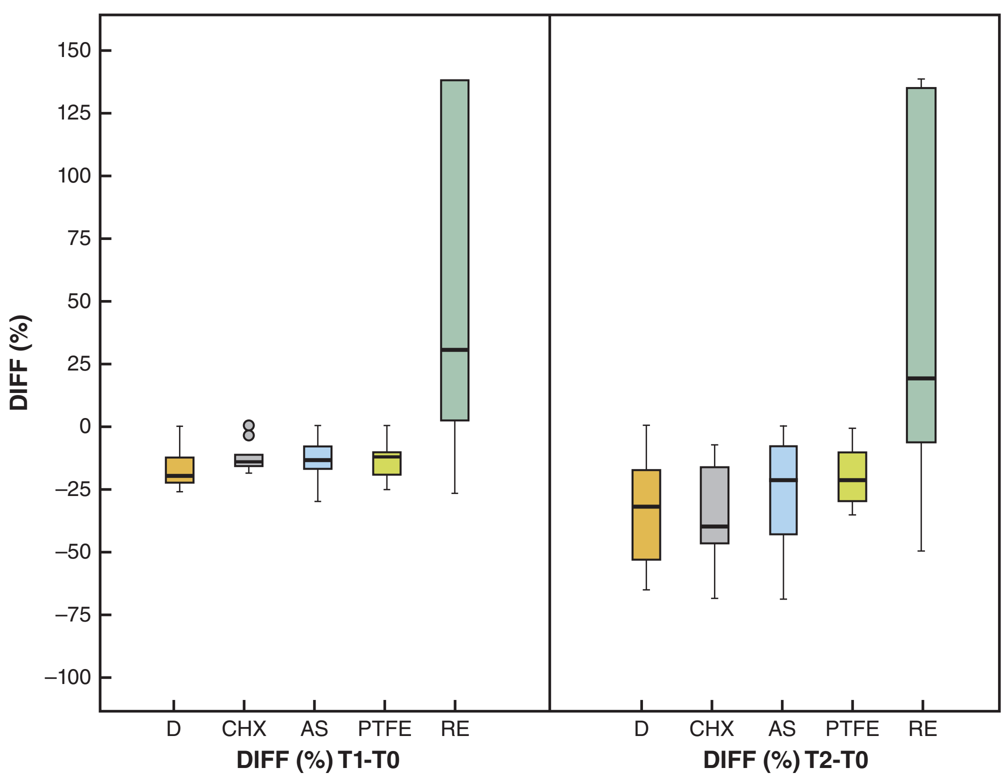

Figure 3. Box plot of percentage reverse torque value loss at T1 (prefatigue) and T2 (postfatigue). D (dry); CLHX (chlorhexidine gel 0.2%); AS (artificial saliva); PTFE (polytetrafluoroethylene); RE (resin).

At T2, the RTV of all the groups was also lower than the tightening torque (D 20.25 Ncm [IQR: 24.80 to 14.00], CLHX 18.40 Ncm [IQR: 25.00 to 15.90], AS 23.45 Ncm [IQR: 27.50 to 16.90], PTFE 23.50 Ncm [IQR: 26.80 to 21.00]), with the exception of RE (35.75 N [IQR: 70.40 to 28.00]) (Table 1). The loss of retention was also expressed in percentages, comparing recorded RTV with the prefatigue data (T1) (Table 2). Most of the groups found loss of resistance to loosening at T2, ranging from 8.4% to 28% (D 12.73% [IQR: 4.98 to 42.39], AS 8.4% [IQR: 0.00 to 31.85], CLHX 28.8% [IQR: 11.86 to 39.31]). The PTFE-coated and resin-cemented screws were the best performers, with losses of only 4.65% (IQR: 1.0 to 16.4) and 5.72% (IQR: 1.40 to 12.82), respectively, showing a lesser influence of the cyclic loading fatigue test. However, on performing the Kruskal-Wallis test, Mann-Whitney U-test, and Bonferroni correction, the results in terms of loosening at T2 versus T1 among the different types of screws were statistically similar (P=.169), also between pairs of groups (P>.05).

Wilcoxon tests were used to compare retention losses between both time points within each group. The values were significantly different only in the CLHX group (P=.037), associated with the drop in median at T2, and in the RE group (P=.017) because of the gain at T1 and the small loss at T2. Significant differences were not found in groups D (P=.374) and AS (P=.953), because the medians remained similar at T1 and T2, though variability increased at T2. In the PTFE group, there were no significant differences between T1 and T2 because the distributions were similar, and the medians remained stable (P=.114). According to these results, the PTFE-coated screws appeared to be the most clinically predictable, because no more preload was lost after fatigue than had already been lost in the first 24 hours.

Considering the absolute values of median resistance to loosening after cyclic loading (N) (Table 1), a difference was observed between the RE group, 35.75 Ncm (IQR: 70.40 to 28.00), and the other groups, with similar medians of between 18 and 24 Ncm. In the RE group, the release of the screw was probably impacted by the cement engaging the screw threads and internal threads of the implant. In the statistical analysis based on the Kruskal-Wallis test, the final resistance was not homogeneous among all the groups, and significant differences were observed (P=.008). On comparing pairs of groups, the only significant differences emphasized the advantage of resin-cemented screws over dry screws (P=.039) and over screws moistened with CLHX (P=.029). but not with the saliva-moistened screws (P=.068). No significant differences were found with respect to the PTFE group (P=.355).

DISCUSSION

The present study evaluated the use of SPIS as a solution in cases of apical fracture of the prosthetic implant screw when the fragment could not be retrieved, considering that such apical fractures are less amenable to extraction than coronal and middle-third fractures. Different tightening conditions were used in the study, with a view to obtaining greater resistance to the loosening of these shortened screws.

The null hypothesis was accepted because the PTFE and RE groups presented the highest values of resistance to loosening at T2 versus T1, but these were not statistically significant when compared with the other groups (P=.169). In general, the higher the preload, the tighter and more secure the connection, resulting in greater resistance to loosening.[21,22,29] Preload, in addition to being affected by the tightening torque, is affected by the coefficient of friction between the contact surfaces of the connection, which in turn is influenced by the presence and type of lubricant.[33] A consensus regarding the use of lubricants when tightening implant screws is lacking. Some authors favor lubrication to reduce friction between components and increase preload because the screw turns more with the same tightening torque,[17,18] although others reject this theory.[26,27,34] In the present study, the groups with lubricated screws (CLHX and AS), together with group D, had the lowest resistance values, with no statistically significant differences among them, suggesting lubrication is beneficial. These results were consistent with Gumus et al,[27] Ghanbarzadeh et al,[35] and Al Rafee et al,[36] who also did not find significant differences between the different lubricants and the dry environment but were not consistent with Koosha et al,[31] who used the same concentration of CLHX (0.2%) as in the present study but in rinse format and did report a significant decrease in loosening.

The settling effect has also been reported to cause screw loosening with a loss of initial preload (2% to 10%) shortly after tightening without loading.[37] Settling was taken into account in the present study and the SPIS, except when resin-cemented, was retightened after 10 minutes, although the authors were unaware that the effectiveness of this technique had been previously verified. After 24 hours, and in addition to calibrating the torque wrench and eliminating possible biases, RTV quantification served to quantify the loss of preload after the initial torque and the compensation torque for the settling effect: all screws lost retention, with the exception of the RE group, which increased its resistance to loosening. Therefore, the screws continued to lose retention throughout the first 24 hours despite retightening.

The choice of screw material can influence screw loosening. In previous studies, gold-coated screws have been described as the standard, as they maintain higher preload levels.[9,17] However, the lower-cost titanium screws are currently more popular, although if associated with repeated screw loosening may lead to expensive and irremediable consequences.[9,16] Sterilized PTFE tape,[38] a recently introduced coating approach, has been tested by Felix et al,[16] who recorded an RTV increase in loosened screws wrapped in PTFE versus the control group (dry screws). Consistent with the authors, the present study found the lower percentage of retention loss after fatigue was with PTFE tape (4.7%). This group also found the most predictable behavior according to the Wilcoxon analysis.[16] However, in certain countries, only medical-grade PTFE tape can be used because even autoclaved industrial PTFE tape is not approved as a medical device.

Resin-cemented screws, although having the highest RTVs in absolute terms, exhibited variability before and after cyclic loading. Resin-cemented screws found an increase in loosening resistance of up to 138% in the first 24 hours. The resin used (Cekabond) was a laboratory-use elastomeric resin marketed for cementing attachment components in removable prostheses. The cement has a rubbery consistency and was easily detached from the screws. This made the second tightening straightforward after first loosening, cleaning, and reapplying the cement to the screw surface. According to the material safety data sheet, the use of Cekabond should not cause any harm, such as irritation of the eyes and respiratory tract or dermatitis when appropriate hygienic measures are followed (adequate ventilation and the use of gloves). Considering that the role of such resin is only to fix the screw inside the implant, it is unlikely to create skin sensitization. In contrast, cleaning a dual-polymerization composite resin cement from the screws could have been challenging. However, in critical situations where the only alternative to successful screw shortening would be removal of the implant, cementation with a resin cement should be considered, and future studies are indicated.

Limitations of the study included that a nonparametric inferential analysis was performed because of the low sample size. Therefore, the means were not statistically representative values, because of the disparity of the results within some groups, unlike the medians and percentiles which were statistically representative. The clearest example was in the RE group, which at T1 found a mean resistance loss of 46.7%—a high percentage with respect to the median (30.5%) because some specimens had a large increase in resistance. As no previous studies assessing the exact length of fractured screw apical fragments were found, the implant screws used in the present study were shortened by 2 mm. Different lengths should be explored to gain a better understanding of the effects of length on successful recovery. Another limitation was the focus of the study on the internal hexagonal connection, which, together with the Morse taper, has been reported to be a more stable connection than the external hexagonal, as it better resists cyclic loading in terms of screw loosening in single implants.[34] In vitro fatigue analysis involving other types of connections is indicated to determine whether they would benefit more from the use of lubricants or materials such as PTFE. Furthermore, 300 000 cycles of cyclic loading represented only about 10 months of simulated function, so further studies involving more cycles are needed.[39] As SPISs have been simulated under in vitro conditions of dynamic loading, it would be interesting to extrapolate this study to the clinical level to assess the different behaviors of each group of screws under oral conditions.

CONCLUSIONS

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

1. All groups presented lower reverse torque values after retightening and cyclic loading, with the exception of the resin-cemented group in which resistance increased.
2. The PTFE-wrapped screws had statistically similar removal torque values after the fatigue test as dry, moistened with saliva, and moistened with chlorhexidine screws. Resin-cemented SPIS was found to be the most resistant to loosening after cyclic loading.

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