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RESEARCH AND EDUCATION

Evaluating the effect of the protector cap for castable implant abutments on reverse tightening values

Mohammed A. Alfaifi, BDS, MS,[a] Chandur Wadhwani, BDS, MSD,[b] E. Ricardo Schwedhelm, DDS, MSD,[c] and Mathew T. Kattadiyil, BDS, MDS, MS[d]

ABSTRACT

Statement of problem. Screw loosening is the most common mechanical complication with implant prostheses. How the alteration of implant-to-abutment connection surfaces that occurs during laboratory procedures affects screw loosening is unclear.

Purpose. The purpose of this in vitro study was to compare the reverse tightening value (RTV) differences between custom castable abutments before casting, after casting in a conventional manner, and after casting with custom protector caps and pegs.

Material and methods. Thirty implants with a standard-diameter conical connection (NobelReplace Conical Connection 4.3×13 mm; Nobel Biocare AG) and 30 premachined 4.3-mm GoldAdapt abutments (GoldAdapt; Nobel Biocare AG) were selected for this study. Specimens were divided into 3 groups (n=10): the uncast custom castable abutment group (UCCA) in which abutments were new and not cast; the unprotected custom castable abutment group (UPCCA) in which abutments were cast and devested with airborne-particle abrasion; and the protected custom castable abutment group (PCCA) in which abutments were cast by using protector caps and pegs made by milling zirconia and then devested with airborne-particle abrasion. All abutments in each group were tightened to 35 Ncm with a calibrated digital tightening device. After 10 minutes, all screws were retightened to 35 Ncm. At 3 hours, each screw was loosened, and the value at which the initial loosening occurred was documented as the RTV. The results were statistically analyzed with 1-way ANOVA to explore differences, and post hoc tests with Tukey adjustment were used for multiple comparisons.

Results. Among the tested groups, the mean RTV ranged from 19.89 Ncm to 27.19 Ncm: UCCA 27.19 Ncm, UPCCA 19.89 Ncm, and PCCA 24.24 Ncm. A significant difference was found among the tested groups ($P<.05$).

Conclusions. Casting procedures, especially devestment with airborne-particle abrasion, affected implant-abutment connections and the seat site of the screw. Protecting the implant connection site and the seat site of the abutment screw with protector caps and pegs prevented a significant loss of the RTV. (J Prosthet Dent 2022;■:■-■)

Dental implants are the preferred treatment option for retaining and supporting dental prostheses and have a high success rate.[1] Biological and mechanical barriers that separate the microorganisms from the internal part of osseointegrated endosteal dental implants are achieved by good and passive soft-tissue integration and abutment-to-implant fit, respectively.[2,3] Passive fit has been described as an ideal contact fit between the abutment and implant surfaces to ensure that the restoration is not further mechanically challenged, leading to mechanical and biological complications.[4] However, clinical complications such as screw loosening and screw fracture are affected by a poor abutment fit, resulting in gingival inflammation and bone loss.[5-9] Abutment screw loosening as a result of excessive masticatory load and insufficient preload torque has been the most commonly reported mechanical complication.[10] The risk of screw loosening can be reduced with good implant-to-abutment fit, antirotational features on the implant, an appropriate abutment design, and by tightening the screws to the recommended values.[10]

[a]Faculty, Department of Prosthetic Dental Sciences, King Khalid University College of Dentistry, Abha, Saudi Arabia; Fellow in Advanced Digital Prosthodontics and Implant Dentistry, Department of Prosthodontics, Loma Linda University School of Dentistry, Loma Linda, Calif.
[b]Private practice, Bellevue, Wash; Affiliate Assistant Professor, Department of Restorative Dentistry, University of Washington School of Dentistry, Seattle, Wash.
[c]Clinical Associate Professor, Department of Restorative Dentistry, School of Dentistry, University of Washington, Seattle, Wash.
[d]Professor, Advanced Specialty Education Program in Prosthodontics, Loma Linda University School of Dentistry, Loma Linda, Calif.

Clinical Implications

The findings of this study strengthen and highlight the importance of protecting the fitting surfaces of castable abutments by using protector caps and pegs during casting to reduce the loss of the reverse tightening value (RTV). Reduction in the loss of the RTV by using protector caps and pegs can improve fit, thereby minimizing mechanical and biological complications.

Clinical outcomes can be influenced by inaccuracies that occur with different methods of fabricating the implant abutment, from a plastic abutment that is waxed and cast or milled by using the computer-aided design and computer-aided manufacturing (CAD-CAM) technology.[2,11] Conventionally made custom castable abutments are commonly used[12] and were originally designed to overcome the prosthetic limitations of the Brånemark titanium transmucosal abutment (Nobelpharma USA, Inc).[13] Limited interocclusal distance is one of the clinical situations that can be managed by using a custom abutment for a screw-retained definitive restoration. The abutment-to-implant connection can be placed subgingivally at the implant level to gain restorative space for the prosthesis.[13] Improved esthetics is another benefit of placing abutments subgingivally, as the apical positioning allows the creation of an improved emergence profile for improved gingival health.[14]

Custom castable abutments with machined metal alloy fitting surfaces are cast and then finished to fit the internal or external connection of the dental implant. They are designed to be incorporated into a wax pattern and then eliminated with the lost wax technique before casting with a metal alloy that is then veneered with ceramic.[13] The casting is typically milled to refine the abutment margins to achieve high accuracy of the surface between the restoration and implant. Success rates of the custom castable abutment were initially reported as high, especially when the margins between the abutment and implant were finished and polished well, thereby minimizing surface imperfections and increasing the abutment screw preload.[5,14] However, the screw head-seat area within the abutment may be affected by casting inaccuracies, affecting component fit and preload.[2]

Premachined bases for the castable custom abutment were developed as a modification to improve abutment-to-implant interface fit and screw seat.[2] Even when fabricating a prosthesis with a castable abutment with a premachined base, the casting and devesting processes can damage the mating or fitting surfaces.[5,15] CAD-CAM manufacturing is an alternative technique which eliminates the need for cast abutments. Nevertheless, the traditional lost-wax casting is still being used,[16] and some restorations still require investing before ceramic veneering.[17,18]

Figure 1. Custom castable abutment with milled cap and peg.

A custom castable abutment can be devested by airborne-particle abrasion or chemical treatment using 9.5% hydrofluoric acid.[15,19,20] Airborne-particle abrasion has been considered a reliable method of removing the investment material but can result in damage to the critical areas of the machined surface, altering the abutment-to-implant interface fit and affecting the area of the screw seat.[5,15,19,21] As a result, the optimum preload values may be affected, as the preload of the screw depends partly on the friction generated at the screw head-seat connection for the abutment-to-implant assembly.[5]

Dental implants and abutments are connected by tightening the screw according to the manufacturer's recommendation to form a secure clamping joint which should not loosen when subjected to occlusal loads.[22] The tensile preload generated during the initial screw tightening within the screw results in friction between the screw and the implant threads and between the head of the screw and the abutment. Because there is no ideal flat surface at the abutment-to-implant connection, the preload generated during the tightening of the screw is reduced over time because of the flattening of high-contact spots, referred to as the settling effect.[23,24] This embedment relaxation results in a loss of preload that has been reported to range from 2% to 10%.[23] The protocol recommended to minimize the joint-separating forces has been to apply 2 tightening forces with a 10-minute interval.[22,24-27]

To reduce damage from the casting and devesting processes of the abutment, Wadhwani and Chung[16] recommended the use of zirconia protector caps and pegs to minimize damage to critical areas.[16] However, the authors are unaware of studies on the effect of using the protector caps and pegs in evaluating reverse

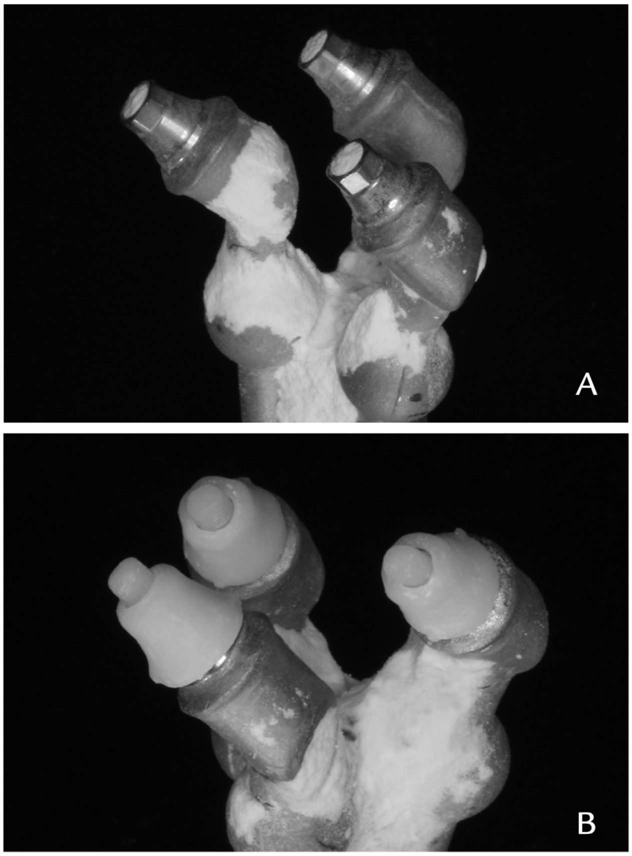

Figure 2. Specimens immediately after casting. A, Cast without protector caps and pegs. B, Cast with protector caps and pegs.

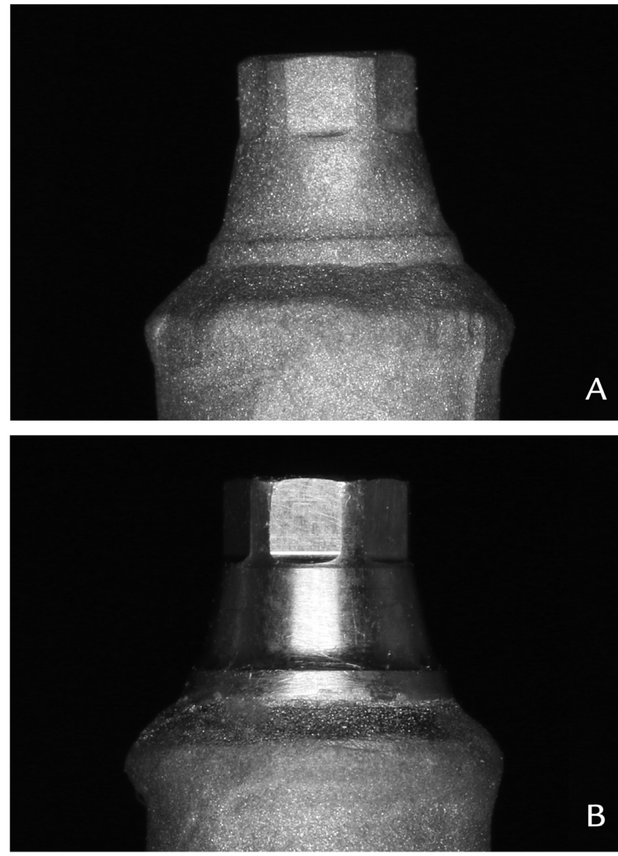

Figure 3. Airborne-particle abraded specimens. A, Without protector caps and pegs. B, With protector caps and pegs.

tightening values (RTVs). The null hypothesis was that no difference in RTVs would be found among the 3 groups: custom castable but uncast abutments; custom castable abutments cast in the conventional manner; and custom castable abutments cast using protector caps and pegs.

MATERIAL AND METHODS

A pilot study with 6 specimens was conducted to determine the sample size. The statistical analysis revealed a sample size of 10 specimens per group (n=10) that was adequate to achieve a power of 0.8 at a significant threshold (α=.05). Thirty Ø4.3-mm titanium implants with a conical connection (NobelReplace Conical Connection 4.3×13 mm; Nobel Biocare AG) and 30 premachined 4.3-mm engaging conical connection abutments (GoldAdapt; Nobel Biocare AG) were used in the study.[28] The abutments were divided into 3 groups (n=10). A cylindrically shaped container was used as a template for the construction of 30 epoxy resin blocks (Exakto-Form; Bredent) with a 12-GPa elastic modulus, similar to that of human bone (18 GPa). Eleven millimeters of the 13-mm implant was embedded in the resin.[29] The implant angulation was controlled and adjusted by attaching the interim cylinder and the implant assembly to a dental surveyor (Dental Surveyor; J. M. Ney Co) until the resin polymerized.

The conical connection site of the custom castable abutment was scanned with a desktop scanner (D1000 Desktop Scanner; 3Shape, Inc) to fabricate the protector caps and pegs. The caps were designed with a CAD software program (Meshmixer 3.5; Autodesk Inc) by creating a negative impression of the abutment scan. Twenty-five micrometers were added to the offset of the cap as space for the luting agent used to retain the caps. Pegs were designed on the CAD software program to have the same morphology and size as the abutment screw. The standard tessellation language (STL) files of the protector caps and pegs were used to mill the zirconia (ProgaMill 7; Ivoclar AG) (Fig. 1).

Twenty wax patterns for the implant abutments were designed with the CAD software program. Standardized design patterns were milled in wax by using CAD wax (ProArt CAD Wax Blue; Ivoclar AG). Twenty specimens were cast in a noble metal alloy (Protocol; Ivoclar AG) by using the induction casting technique. The abutments

Figure 4. Calibrated digital tightening device.

were retrieved from the investment, and the sprues were sectioned (Fig. 2).

Uncast custom castable abutments (UCCAs) served as the control group, which did not undergo any casting or airborne-particle abrasion. Unprotected custom castable abutments (UPCCAs) were waxed and cast by using the induction casting technique without protector caps or pegs. Protected custom castable abutments (PCCAs) were waxed and cast by using the induction casting technique and with protector caps and pegs. The standardized wax patterns were placed on the abutments with a previously constructed index. Protector caps and pegs made of zirconia were luted with a cyanoacrylate adhesive (Gorilla adhesive; The Gorilla Glue Co) externally at the junction of the caps and pegs to secure the parts and ensure a good seal to protect the abutment-to-implant connection site during casting. The cyanoacrylate can resist deformity to 104 °C (manufacturer information) but degrades during casting at temperatures up to 800 °C. This facilitated the removal of the protector caps and pegs. At the finishing stage, zirconia pegs were used to protect the internal screw seat area. The zirconia caps were retained and stabilized by luting the pegs to the caps at the junction of the caps and pegs with a small amount of cyanoacrylate resin to facilitate removal with an explorer.

Time, pressure, and rotation during the airborne-particle abrasion procedure were standardized by using a mounted assembly made with holding rods and a table turning at 25 rpm. Specimens in the UPCCA and PCCA groups were subjected to airborne-particle abrasion (Basic Quattro IS; Renfert GmbH) with 50-μm aluminum oxide at 0.7 MPa for 25 seconds at 15 mm from the nozzle followed by rinsing under running water and air drying (Fig. 3). No further polishing or finishing was performed.[30,31]

Each engaging abutment placed onto the implant and abutment screw was tightened to 35 Ncm

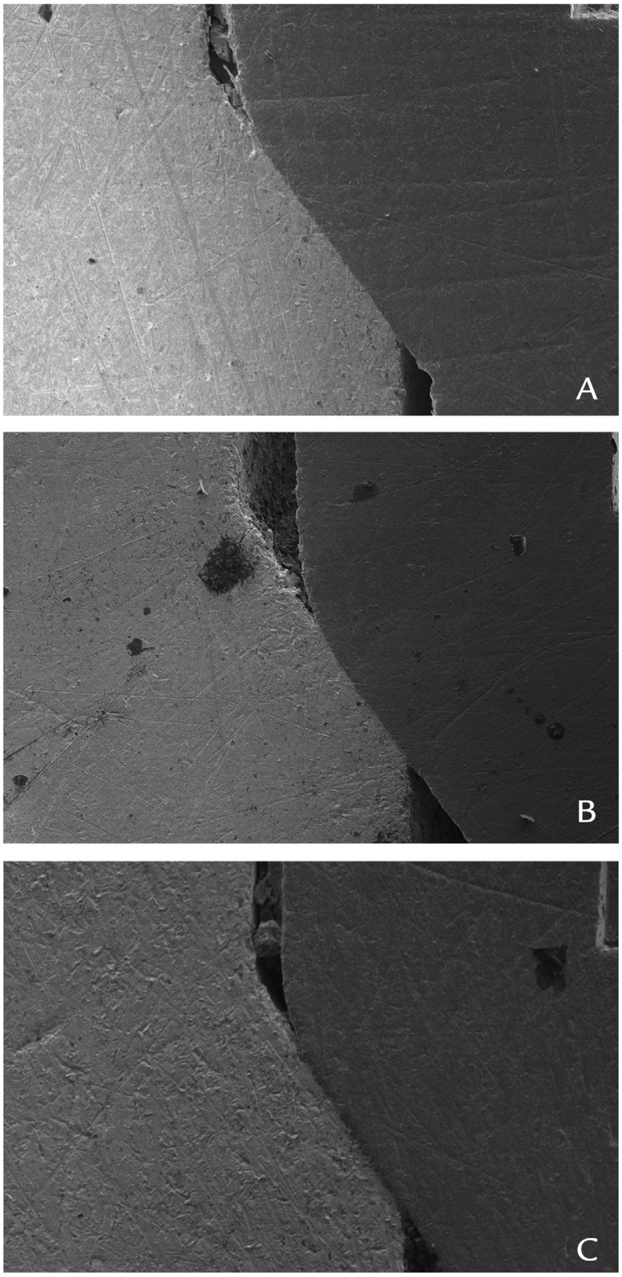

Figure 5. Scanning electron microscope images of abutment-to-screw head seating area. A, Uncast custom castable abutment (UCCA). B, Unprotected custom castable abutment (UPCCA). C, Protected custom castable abutment (PCCA). Original magnification ×200.

according to the manufacturer's recommendation by using a calibrated digital tightening device (HTG2-4 Digital Torque Gauge; IMADA Inc) (Fig. 4). After 10 minutes, the screws were retightened to 35 Ncm with the digital tightening measuring device. After 3 hours, each screw was loosened by using the digital tightening measuring device (HTG2-4 Digital Torque Gauge), and the value at which loosening occurred was documented as the RTV. The digital tightening

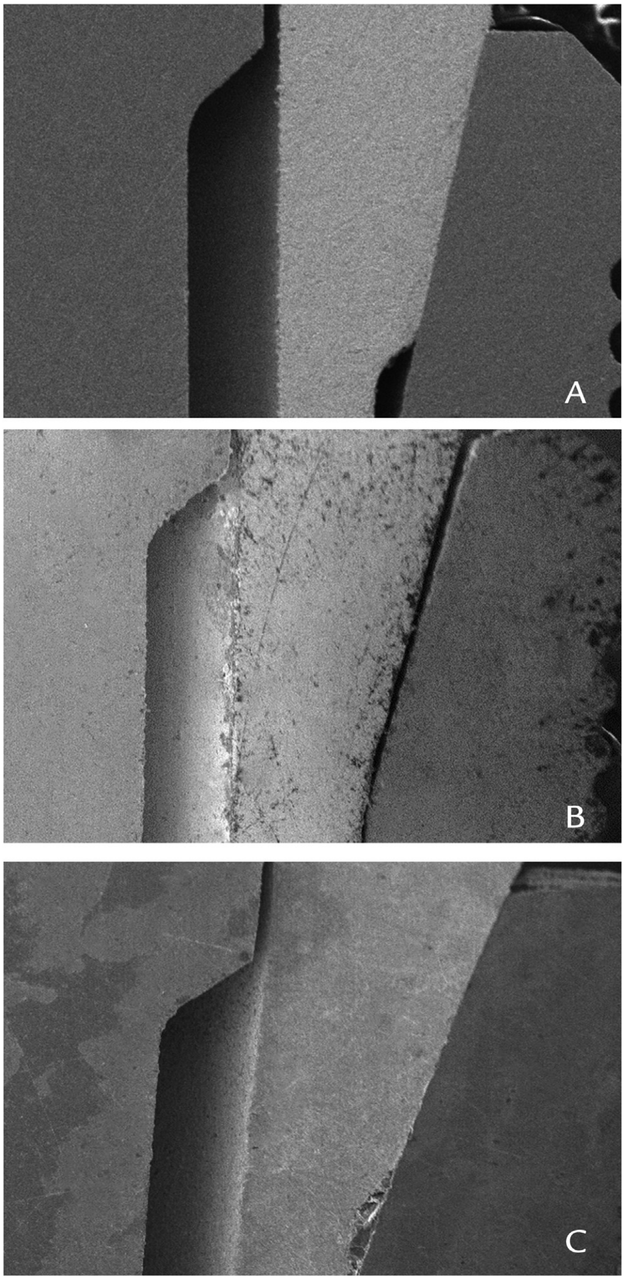

Figure 6. Scanning electron microscope images of abutment-to-implant interface sites. A, Uncast custom castable abutment (UCCA). B, Unprotected custom castable abutment (UPCCA). C, Protected custom castable abutment (PCCA). Original magnification ×60.

measuring device with an implant screwdriver (Nobel Biocare AG) was aligned perpendicular to the hexagon head of the screw when performing the RTV measurements.

The UCCA specimens were not cast and served as the control group. After airborne-particle abrasion, the abutments in the UPCCA and PCCA groups were placed on the implants, and the screws were tightened to 35

Table 1. Mean ±standard deviation and loss of reverse tightening value

	Abutment	Mean ±SD	Minimum	Maximum	% Change	P
RTV	UCCA	27.19 ±1.86	23.15	29.24		<.001[a]
	UPCCA	19.89 ±1.76	17.26	22.45	-26.86[b]; -17.94[c,e]	
	PCCA	24.24 ±1.83	22.16	27.48	-10.85[d,e]	

PCCA, protected custom castable abutment; RTV, reverse tightening value; SD, standard deviation; UCCA, uncast custom castable abutment; UPCCA, unprotected custom castable abutment. [a]One-way ANOVA. [b]UPCCA versus UCCA. [c]UPCCA versus PCCA. [d]PCCA versus UCCA. [e]Mean difference significant at 0.05 level by using Tukey-adjusted post hoc test.

Table 2. Changes in reverse tightening value (RTV)

	UPCCA vs UCCA*	UPCCA vs PCCA*	PCCA vs UCCA*
Test	Mean Difference [95% CI]	Mean Difference [95% CI]	Mean Difference [95% CI]
RTV changes	-7.30 [-9.32, -5.29]	-4.35 [-6.37, -2.34]	-2.95 [-4.96, -0.94]

PCCA, protected custom castable abutment; RTV, reverse tightening value; UCCA, uncast custom castable abutment; UPCCA, unprotected custom castable abutment. *Tukey-adjusted post hoc test.

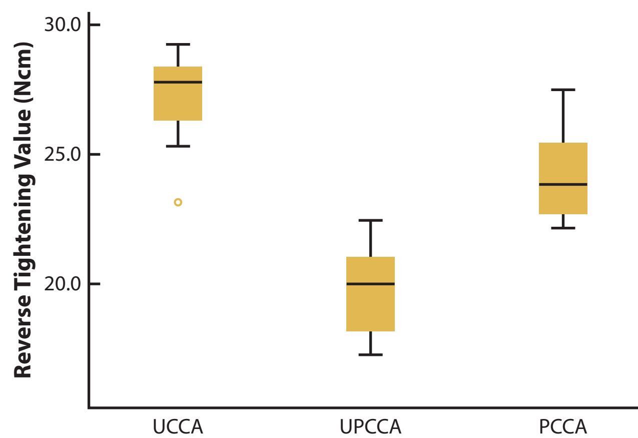

Figure 7. Box plot showing difference in the reverse tightening value (RTV) (Ncm) among uncast custom castable abutment (UCCA), unprotected custom castable abutment (UPCCA), and protected custom castable abutment (PCCA).

Ncm twice with a 10-minute interval. The RTV was measured for all groups after 3 hours.[23-26]

One specimen from each group was selected and sectioned in half at the same indicated areas for all the specimens with a diamond saw (L650 Low Speed Diamond Wheel Saw; South Bay Technology Inc) under water irrigation. The specimens were polished (Ecomet 3; Buehler) with 1200-grit silicon carbide papers for 1 minute, cleaned under running water, and air dried.[2] Specimens were inspected at the cut surfaces by scanning electron microscopy (SEM) (Figs. 5, 6). UPCCA specimens showed less contact area between the screw head and the abutment and a larger gap at the abutment-to-implant interface area than the UCCA and PCCA specimens.

RESULTS

The mean RTVs for the tested groups ranged from 19.89 Ncm to 27.19 Ncm. The mean RTV was 27.19 Ncm, 19.89 Ncm, and 24.24 Ncm for groups UCCA, UPCCA, and PCCA, respectively (Table 1). A significant difference was found in RTVs among all tested groups ($P<.05$) (Table 2). In the cast groups, PCCA, which used protector caps and pegs for casting, revealed significantly lower loss of RTV ($P<.05$) (Fig. 7).

DISCUSSION

Based on the results, the null hypothesis was rejected as significant differences in RTVs were found among the tested groups. Vertical discrepancies at abutment-to-implant and screw-to-abutment screw seat interfaces have been reported to be higher in cast abutments than in premachined abutments.[2] In this present study, discrepancies were visualized at the abutment-to-implant interface site in the group that was cast and airborne-particle abraded without protector caps or pegs. The discrepancies associated with the casting procedure produced more irregularities and roughness on the abutment surface when it came into contact with the implant and screw head, resulting in the loss of preload values as a result of embedment relaxation.[5,30,32]

Optimal abutment-to-implant fit is a critical factor in reducing the loading of abutment screws to ensure effectiveness.[2] This vertical discrepancy between the contact surfaces in the abutment-to-implant interface affects clamping forces between the implant, abutment, and screw, resulting in a loss of preload.[2] Wadhwani and Chung[16] proposed the protector cap technique as an effective method for protecting these connecting contact surfaces during the casting and finishing of castable abutments.

The RTVs for all tested groups ranged from 62.2% to 92.3% of the initial tightening value (ITV). These results were consistent with the findings of Haack et al [33] who tested gold custom hexagon abutments with gold and titanium screws, reporting RTVs ranging from 70% to 80% of the ITV. Schulte and Coffey[34] studied the RTV for titanium custom abutments and reported RTVs ranging from 80% to 93% of the ITV. Dixon et al[22] testing external hexagonal titanium custom abutments reported a similar loss of ITV (16.7%).

RTVs can differ based on abutment type, material, and design.[35] In addition, the RTVs can be influenced by the time before screw retightening, which has an effect on the vertical misfit and clamping force as a result of the settling effect.[23,24]

The present study found that mean RTVs were lowest for custom castable abutments that were cast in a conventional manner followed by abutments cast with protector caps and pegs. The use of protector caps and pegs significantly reduced the loss of RTV. Limitations of the present study included that only 1 type of custom castable abutment in terms of material and design was used to evaluate the RTVs and that no load simulation was applied to the abutments before recording the RTVs. Hence, further studies are required regarding the effect of the protector cap technique on custom castable abutments which include the simulation of masticatory forces. Although the use of protector caps and pegs during casting procedures appears to reduce RTV loss, additional clinical studies are needed to confirm clinical relevance.

CONCLUSIONS

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

1. RTV was reduced irrespective of the fit of the mating surface contacts.
2. When protector caps and pegs were used, a significantly lower loss of RTV was found.

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Corresponding author:
Dr Mohammed A. Alfaifi
Loma Linda University School of Dentistry
11092 Anderson St
Loma Linda, CA 92350
Email: dr.m-a-f@hotmail.com

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