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Effect of digital workflow contaminants and steam cleaning on the reverse torque value of implant abutment screws

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Abstract

Objective: This study investigated the impact of digital workflow contaminants, including scanning lacquer (SL), scanning spray (SS), and 3D printing resin (PR), on the reverse torque value (RTV) of implant abutment screws.

Methods: In this in vitro study, 28 implant-abutment assemblies were randomly allocated into four groups (n=7), based on the type of surface contamination: scanning lacquer (SL), scanning spray (SS), 3D printing resin (PR), and an uncontaminated control group. In the experimental groups, abutment screws and internal implant surfaces were coated with the assigned material for 1 minute, while the control group remained uncontaminated. Abutments were tightened to 25 Ncm, and RTV values were recorded. All specimens then underwent standardized steam cleaning, were retightened to 25 Ncm, and RTV measurements were repeated.

Results: Pre-cleaning RTV differed significantly among groups (P<0.001). The SL and SS groups exhibited significantly lower RTV values than the control and PR groups (P<0.05). After steam cleaning, significant differences remained among groups (P<0.001). The control, SL, and SS groups showed comparable RTV values, which were significantly higher than that of the PR group. Following cleaning, RTV increased significantly in the SL (P=0.002) and SS (P=0.03) groups, whereas it decreased significantly in the PR group (P=0.02), and showed no significant change in the control group (P=0.051).

Conclusions: Digital workflow contaminants can affect implant screw RTV in a material-dependent manner. Steam cleaning effectively reduced torque loss caused by contamination from scanning lacquer and scanning spray, but it adversely affected RTV in implants exposed to 3D-printing resin.

Keywords: Dental implants, Dental implant-abutment design, Digital dentistry, Screw loosening, Surface properties, Torque

Introduction

Implant-supported restorations are widely used as a predictable treatment option for rehabilitation of partial and complete edentulism (1-3). Despite the favorable outcomes of implant-supported restorations, mechanical complications remain clinically relevant.

Abutment screw loosening is among the most frequently reported problems, especially in single-unit restorations (4, 5). Abutment screw loosening can compromise prosthesis stability, leading to micromovement at the implant–abutment interface, consequently leading to patient discomfort, screw fracture, or damage to implant components (6, 7).

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The stability of a screw-retained implant-abutment connection depends primarily on preload, which is generated when the applied tightening torque elongates the screw and creates a clamping force between the components (8, 9). However, only a portion of the applied torque contributes to preload, as a notable part is dissipated as friction at the screw threads and at the contact surface between the screw head and the abutment (10-12). Preload retention immediately after tightening is influenced by multiple factors, including the torque delivery method, settling (embedment relaxation) of the contacting surfaces, material properties of the screw, connection design of implant components, and the presence of contaminants that alter frictional behavior (13, 14). Reverse torque value (RTV) is commonly used as an indirect measure of preload retention, indicating the amount of clamping force remaining after tightening and initial settling (15).

Contamination of abutment screws and internal implant connections can occur during clinical manipulation and laboratory procedures. Previous studies have investigated biological and chemical contaminants, including saliva, blood, chlorhexidine, fluoride, and lubricating agents, and have shown that these substances can alter RTV by modifying friction at the implant–abutment interface. Depending on their viscosity and interaction with titanium surfaces, contaminants may reduce RTV by facilitating slip or, in some cases, may increase resistance to loosening by enhancing interfacial adhesion (16, 17).

With the increasing use of digital dentistry workflows, additional materials are frequently introduced during laboratory procedures. Scanning lacquer and scanning spray are commonly applied to reduce surface reflectivity and enhance the accuracy of optical scanning, while 3D printing resins are used in additive manufacturing for diagnostic and prosthetic components (12). Such materials may inadvertently contaminate abutment screws, screw channels, or internal implant connections during laboratory procedures. Residual particles or films can alter surface interactions at the implant–abutment interface, potentially affecting frictional behavior and seating conditions. Consequently, these contaminants may compromise preload retention and RTV, thereby increasing the risk of screw loosening (18).

Steam cleaning is widely used in dental laboratories as a rapid and convenient method for decontaminating implant components. However, evidence is limited on its effectiveness at removing contaminants specific to digital workflows, particularly resin-based materials, and on its ability to restore RTV to levels comparable to uncontaminated conditions.

The present in vitro study aimed to evaluate the effects of three digital workflow contaminants, including scanning lacquer (SL), scanning spray (SS), and 3D printing resin (PR), on the reverse torque value (RTV) of implant abutment screws, and to assess the effectiveness of steam cleaning in mitigating these effects.

Materials and methods

Study design and ethical approval

The protocol of this in vitro study was approved by the ethics committee of Tabriz University of Medical Sciences (ID: IR.TBZMED.VCR.REC.1399.104).

Sample size was calculated using G*Power software (version 3.1; Heinrich Heine University Düsseldorf, Düsseldorf, Germany), assuming a medium effect size of 0.5, an α level of 0.05, and a statistical power of 0.80. The calculation indicated a minimum of six specimens per group. To compensate for potential exclusions, seven specimens were included in each group, resulting in a total of 28 specimens.

Study groups and contamination protocols

A total of 28 cylindrical implants (DIO UF; Dio Implants, Seoul, South Korea) with an internal hex connection, a diameter of 4.1 mm, and a length of 11.5 mm were used.

Corresponding abutments (diameter: 4.5 mm; gingival height: 2 mm) and abutment screws from the same system were also included. All components were new and unused.

Specimens were allocated into four groups (n = 7 per group) based on the type of contaminant:

Group 1 (SL): The specimens were contaminated with scanning lacquer (Contact Marker; al dente Dentalprodukte GmbH, Goslar, Germany) for 1 minute.

Group 2 (SS): The specimens were contaminated with scanning spray (VITA Powder Scan Spray; VITA Zahnfabrik,Bad Säckingen, Germany) for 1 minute.

Group 3 (PR): The specimens were contaminated with 3D printing resin (FreePrint Cast; DETAX GmbH & Co. KG, Ettlingen, Germany) for 1 minute.

Group 4 (Control): The specimens in this group were not contaminated.

Each implant fixture was embedded vertically in gypsum die stone (Velmix, Kerr Dental, Orange, CA, USA) within standardized blocks (50 × 20 × 20 mm). Vertical alignment was ensured using a dental surveyor (Ney Surveyor, Dentsply Sirona, York, PA, USA). The implant platform was positioned 1 mm above the gypsum surface, and the height was verified with a digital caliper (Mitutoyo Corp., Kawasaki, Japan).

In the experimental groups, abutment screws and internal implant surfaces were immersed in the assigned material for 1 minute without agitation. Excess material was removed by gentle shaking and blotting with lint-free gauze to create a uniform thin coating on the screw threads and internal implant surfaces. The control group underwent identical handling without contamination.

All procedures were performed under standardized laboratory conditions at 23 ± 1°C.

Torque application and pre-cleaning RTV measurement

Following contamination, abutments were connected and tightened to 25 Ncm according to the manufacturer's recommendations using a calibrated digital torque meter (TQ-8800; Lutron Electronic Enterprise Co., Ltd, Taipei, Taiwan).

Reverse torque value (RTV) was recorded 5 minutes after tightening to allow for embedment relaxation (initial settling of microscopic surface irregularities at the screw-abutment interface), which reduces preload.

The measurements were recorded as pre-cleaning RTV. All procedures were performed by a single operator to ensure consistency.

Steam cleaning procedure and post-cleaning RTV measurement

After recording pre-cleaning RTV, all specimens underwent steam cleaning using a steam jet device (KFP Dental, Tehran, Iran). Cleaning was performed under standardized conditions with a nozzle distance of 5 cm, steam pressure of 5 bar, and temperature of approximately 100°C for 30 seconds. Specimens were then dried with oil-free compressed air for 10 seconds to remove residual moisture (17).

Following cleaning, each specimen was visually inspected under standard laboratory lighting conditions (~500 lux). Specimens showing any visible residue or discoloration were excluded.

Abutment screws were then reinserted and tightened to 25 Ncm using the same calibrated torque meter and protocol. RTV measurements were repeated 5 minutes after retightening and recorded as post-cleaning RTV.

Statistical analysis

Data were analyzed using IBM SPSS Statistics for Windows, Version 21.0 (IBM Corp., Armonk, NY, USA). Normality was assessed using the Shapiro–Wilk test. As the data were not normally distributed ($P = 0.047$), non-parametric tests were applied.

Between-group comparisons at each time point were performed using the Kruskal–Wallis test, followed by Dunn's post hoc test for pairwise comparisons. Within-group comparisons (pre- vs. post-cleaning values) were analyzed using the Wilcoxon Signed Rank test. Statistical significance was set at $P < 0.05$.

Results

Pre-cleaning and post-cleaning RTV values are presented in Table 1. Before steam cleaning, the highest mean RTV was observed in the PR group (23.00 ± 1.15 Ncm), followed by the control (21.57 ± 1.90 Ncm), the SS (18.85 ± 1.95 Ncm), and the SL (17.42 ± 1.39 Ncm) groups. Kruskal-Wallis test showed a significant difference in pre-cleaning RTV values among the groups ($P < 0.001$; Table 1). Post hoc analysis indicated that the control and PR groups had significantly higher RTV values than the SL and SS groups ($P < 0.05$). No significant difference was found between the control and PR groups, nor between SL and SS groups ($P > 0.05$; Table 1).

After steam cleaning, the control group showed the highest mean RTV (24.14 ± 0.89 Ncm), followed by the SL (23.14 ± 1.57 Ncm) and SS (22.28 ± 1.38 Ncm) groups, whereas the PR group exhibited the lowest value (18.00 ± 1.41 Ncm). Between-group comparison demonstrated a significant difference in RTV values after cleaning among groups ($P < 0.001$; Table 1). Post hoc analysis revealed no significant differences between the control, SL, and SS groups ($P > 0.05$), whereas the PR group showed significantly lower RTV than all other groups ($P < 0.05$).

Within-group comparisons showed that steam cleaning resulted in significant changes in RTV in all contaminated groups (Table 1). RTV increased significantly in the SL ($P = 0.002$) and SS ($P = 0.03$) groups, whereas a significant decrease was observed in the PR group ($P = 0.02$). However, no significant change was found in the control group ($P = 0.051$).

Discussion

This in vitro study evaluated the effects of contamination with scanning lacquer (SL), scanning spray (SS), and 3D printing resin (PR) on the reverse torque value (RTV) of implant abutment screws,

Table 1: Mean and standard deviation (SD) of RTV values (Ncm) pre- and post-steam cleaning in the study groups

Group	Definition	Pre-Cleaning RTV*	Post-Cleaning* RTV (Ncm)	P-value
		Mean ± SD	Mean ± SD	
Group 1	Scanning lacquer (SL)	17.42 ± 1.39[a]	23.14 ± 1.57[a]	0.002*
Group 2	Scanning spray (SS)	18.85 ± 1.95[a]	22.28 ± 1.38[a]	0.03*
Group 3	3D printing resin (PR)	23.00 ± 1.15[b]	18.00 ± 1.41[b]	0.02*
Group 4	Uncontaminated (control)	21.57 ± 1.90[b]	24.14 ± 0.89[a]	0.051
P-value		<0.001	<0.001	

SL: scanning lacquer; SS: scanning spray; PR: 3D printing resin; RTV: Reverse torque values

*Different lowercase superscript letters indicate significant differences between groups at P < 0.05.

*Different superscript letters within each column indicate statistically significant differences between groups (P < 0.05).

compared with an uncontaminated control group, before and after steam cleaning. The findings demonstrated that digital workflow materials significantly influenced preload maintenance in a material-dependent manner.

Pre-cleaning RTV values were lower than the applied tightening torque in all groups, indicating an initial loss of preload after tightening. This reduction is primarily attributed to embedment relaxation, a well-established phenomenon in which microscopic surface irregularities at the contact interfaces of the screw threads and the screw head–abutment interface undergo plastic deformation under load, leading to a decrease in clamping force shortly after tightening (19). This process explains why reverse torque values are consistently lower than the applied torque.

The reduction observed in the control group of the present study reflects this inherent mechanical behavior of screw joints, whereas the greater reductions in the SL and SS groups suggest an additional influence of contaminants on friction and seating conditions.

Pre-cleaning torque loss was more pronounced in the SL and SS groups compared with the control and PR groups. Mean RTV values decreased from the applied torque of 25 Ncm to 17.42 ± 1.39 Ncm in the SL group (~30% reduction) and to 18.85 ± 1.95 Ncm in the SS group (~25% reduction), whereas smaller reductions were observed in the control (~14% reduction) and PR (~8% reduction) groups. This pattern suggests that both particulate contaminants (scanning spray) and film-forming coatings (scanning lacquer) interfere with proper contact at the implant–abutment interface, thereby increasing preload loss.

Comparison of pre-cleaning torque values among groups revealed significantly lower RTV values in the SL and SS groups than in the PR and control groups. It can be assumed that residual particles from scanning materials remain at the implant–abutment interface and interfere with proper thread engagement. These particles can disrupt direct metal-to-metal contact, alter frictional conditions, and increase micro-movement during tightening and thereby reduce preload. Similar effects have been reported in previous studies, demonstrating that contamination of abutment screws alters friction at the interface and influences preload (20, 21).

The slightly greater torque reduction observed in the SL group compared with the SS group may be attributed to differences in material behavior. Scanning lacquer tends to form a more continuous and adherent film, whereas scanning spray produces a thinner and more dispersed particulate layer (22, 23). A more cohesive coating may increase interference with thread seating and friction during tightening, leading to greater preload loss.

These findings are broadly consistent with previous studies showing that the effect of contamination on RTV depends on the physical and chemical properties of the contaminant. Shemtov-Yona et al. (24) reported that under static testing, different media did not produce significant differences in initial torque loss. However, under dynamic loading, chlorhexidine, chlorhexidine gel, and fluoride mouthwash were associated with greater torque loss, while blood and saliva showed an opposite trend with higher reverse torque values. This indicates that contaminants may either reduce or increase RTV depending on how they modify friction, lubrication, and interfacial damage.

In the present study, a similar material-dependent pattern was observed, as scanning lacquer and scanning spray reduced RTV more markedly than the control and 3D printing resin groups.

The outcomes of this study are consistent with the findings of Koosha et al.(8) who showed that saliva contamination significantly reduced RTV compared with uncontaminated controls, supporting the concept that contamination can impair preload retention by altering interfacial friction. Adawi et al. (25) showed that blood contamination significantly reduced RTV compared with decontaminated conditions, and that appropriate cleaning protocols, particularly sodium hypochlorite, could effectively restore RTV to higher levels. Overall, these studies indicate that contamination of the implant–abutment interface, whether biological, chemical, or laboratory-related, can alter screw joint mechanics in clinically relevant ways. The present findings extend this concept to digital workflow materials, demonstrating that scanning-related contaminants may adversely affect RTV in a manner comparable to previously studied contaminants.

The behavior of the PR group deserves particular attention. Unlike the SL and SS groups, the PR group did not exhibit a statistically significant torque reduction before cleaning. One possible explanation is that fresh resin may initially act as a lubricating medium, reducing friction variability and allowing more efficient torque-to-preload conversion. This explanation is supported by the findings of Nithyapriya et al. (26), who demonstrated that lubricating agents such as petroleum jelly, when applied immediately before tightening, can reduce friction and improve preload retention. In this context, the oil-based composition of 3D-printing resin may have temporarily enhanced preload stability during initial tightening.

After steam cleaning, the PR group exhibited a marked reduction in RTV, in contrast to the control, SL, and SS groups, whereas the control, SL, and SS groups had RTV values closer to the applied torque. Between-group comparisons revealed no significant differences between the control, SL, and SS groups, whereas the PR group showed significantly lower RTV than all other groups. A plausible explanation is that exposure to heat and moisture during steam cleaning may alter the physicochemical properties of residual resin, leading to increased adhesion or uneven distribution within the screw threads and internal connection. This can disrupt consistent contact at the interface and compromise preload retention. A similar limitation of steam cleaning has been reported by Kim et al. (13), who demonstrated that steam cleaning alone was insufficient to completely remove contaminants from implant abutments, whereas combined protocols such as ultrasonic cleaning with chemical agents achieved more effective decontamination.

Comparison of RTV values in each group before and after steam cleaning showed that RTV values increased in the SL and SS groups after steam cleaning, whereas the PR group showed a marked decrease in RTV. These findings indicate that steam cleaning effectively restores preload in the presence of particulate (scanning spray) and film-forming (scanning lacquer) contaminants, but may adversely affect RTV when resin-based contamination is present.

In contrast to the findings of the present study, which demonstrated the effectiveness of steam cleaning to restore RTV after exposure to particulate and film-forming contaminants, previous studies have reported superior outcomes with alternative decontamination methods. Micarelli et al. (17) observed higher RTV values following argon plasma cleaning, either alone or combined with chlorhexidine, compared with steam cleaning. Similarly, Adawi et al. (25) showed that chemical decontamination protocols, such as sodium hypochlorite and saline, significantly improved RTV after contamination. These findings indicate that the effectiveness of decontamination is not only dependent on the type of contaminant but also on the cleaning method employed, and that no single technique can be considered universally optimal.

From a clinical perspective, materials such as scanning sprays, scanning lacquers, and 3D-printing resins are routinely used during laboratory procedures, and thus, inadvertent contamination of implant components is likely. The present results indicate that steam cleaning is generally effective for removing powder-based or lacquer-based contaminants; however, it appears insufficient when resin-based contamination is present. In such cases, alternative cleaning protocols, including ultrasonic cleaning with suitable solvents or plasma-based treatments, may be necessary to ensure adequate decontamination and preserve optimal preload.

Several limitations should be considered when interpreting these results. As an in vitro study, the experimental conditions did not replicate clinical factors such as cyclic loading, thermal changes, biofilm formation, and occlusal forces, all of which may influence long-term screw stability. The study was limited to one implant system and specific materials, which may restrict generalizability. In addition, the amount and distribution of contaminants were not quantitatively controlled. Finally, the relatively small sample size (n = 7 per group), although determined by power analysis, may limit the external validity of this study.

Future studies should evaluate different implant systems, connection designs, and a broader range of digital materials. Quantitative assessment of contaminant thickness, detailed surface characterization, and incorporation of dynamic loading conditions would provide further insight into the mechanisms affecting preload. Additionally, a comparative evaluation of advanced cleaning methods for resin-based contaminants is warranted.

Conclusions

Within the limitations of this in vitro study

1- Digital workflow contaminants affected reverse torque values in a material-dependent manner. Before steam cleaning, scanning lacquer (SL) and scanning spray (SS) were associated with greater initial preload loss, whereas 3D-printing resin (PR) caused minimal effect.
2- After steam cleaning, RTV values increased in the SL and SS groups, whereas the PR group showed a marked decrease in RTV.
3- The PR group showed significantly lower RTV than the control, SL, and SS groups after steam cleaning.
4- Steam cleaning is effective for particulate (SS) and film-forming (SL) contaminants but may be inadequate for resin-based materials.

Author contributions

AN contributed to conceptualization, methodology, investigation, formal analysis, and manuscript drafting and revision; AT to methodology, investigation, data curation, and manuscript revision; FP to formal analysis, visualization, and manuscript revision; and FB to supervision, project administration, resources, and manuscript revision. All authors approved the final manuscript and take responsibility for its content.

Conflict of interest

The authors declare that they have no competing interests.

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Ethical considerations

The protocol was approved by the ethics committee of Tabriz University of Medical Sciences under the IR.TBZMED.VCR.REC.1399.104.

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