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Effect of material type, torque value, and sterilization on linear displacements of a scan body: An in vitro study

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Abstract

Background: There is limited knowledge on the effect of scan body (SB) material type, torque value, and sterilization on linear displacements of implant SBs.

Purpose: To evaluate the effect of material type, torque value, and sterilization on linear displacements of SBs during screw tightening by using digital image correlation (DIC) analysis.

Materials and Methods: One polyetheretherketone (PEEK, Zfx Intraoral Scan Body) and one titanium SB (Ti, MPS Zimmer Scanbody R1410) were tightened with 5 Ncm torque on two implants (Zimmer TSV ⌀4.7 mm) by using a digital torque limiting device. SBs' initial spatial positions relative to the implants were recorded by using 3D DIC technique. Measurements were repeated after initially increasing torque value to 10 Ncm and then to 15 Ncm, and these steps were repeated for a total of 10 PEEK and 10 Ti SBs on both implants ($n = 20$). All SBs were then sterilized 25 times by using an autoclave (STATIM 5000 S G4) according to manufacturer's recommendations and all measurements were repeated. Linear displacements on three axes were calculated for each SB with increasing torque values (from 5 to 10 Ncm and from 10 to 15 Ncm) before and after sterilization. SB displacements within each torque value–sterilization pair were compared by using Mann–Whitney *U* test, whereas Wilcoxon signed-rank test was used to compare SB displacements within each material–torque value pair between conditions and within each material–sterilization pair between torque values ($\alpha = 0.05$).

Results: On x-axis, PEEK SBs had higher displacements than Ti SBs ($p < 0.001$), whereas sterilization ($p \le 0.028$) and 15 Ncm torque application ($p \le 0.006$) led to higher displacements of PEEK SBs. On y-axis, PEEK SBs had higher displacements than Ti SBs with 15 Ncm torque application ($p \le 0.033$). A total of 15 Ncm torque-applied PEEK SBs and 10 Ncm torque-applied Ti SBs had higher displacements after sterilization ($p \le 0.028$). Application of 15 Ncm torque led to higher displacements regardless of the material ($p \le 0.002$). On z-axis, PEEK SBs had higher displacements ($p \le 0.015$), except for 10 Ncm torque-applied sterilized SBs ($p = 0.102$). With

10 Ncm torque application, sterilization decreased the displacement values of PEEK SBs ($p = 0.044$). Greater displacements were observed with 10 Ncm torque-applied Ti SBs before sterilization and 15 Ncm torque-applied PEEK SBs after sterilization ($p \leq 0.033$).

Conclusions: Axial displacement of SBs was affected by material type, torque value, and sterilization. Ti SBs mostly had lower displacements than PEEK SBs. Application of 15 Ncm torque to tested PEEK SBs should be refrained from and a calibrated tightening tool may enable the application of 10 Ncm or lower torque values for lower displacements. Sterilization generally increased PEEK SB displacements.

KEYWORDS

linear displacement, polyetheretherketone, scan body, sterilization, titanium, torque value

Summary Box

What is known

Commercially available intraoral scan bodies (SBs) are provided by many original equipment and third-party manufacturers; thus, they differ in certain properties such as the material they are fabricated in or the amount of torque value needed for tightening. In addition, some manufacturers claim that their SBs can be used repeatedly after sterilization. However, the knowledge on the effect of material type, torque value, and sterilization process on linear displacement of SBs is limited.

What this study adds

Ti SBs mostly had lower displacements than polyetheretherketone (PEEK) SBs. Sterilization and 15 Ncm torque value increased the displacements of PEEK SBs. Using 10 Ncm or lower torque application, and avoiding multiple-time sterilization may lead to more accurate implant scans with tested one-piece PEEK SB.

1 | INTRODUCTION

Integration of computer-aided design and computer-aided manufacturing technologies into dentistry has facilitated the use of intraoral scanners (IOSs) for implant prosthodontics.[1] By using scan bodies (SBs), IOSs can digitize implants[2] without the involvement of factors related to conventional impressions.[3,4] Currently available SBs generally have a common anatomy that consists of a scan region, a body, and a base. Scan region and body of a SB are generally of the same material. The base, however, may or may not be manufactured from the same material as the body.[3] Polyetheretherketone (PEEK) and titanium (Ti) are among the materials that can be used to fabricate SBs.[3] PEEK is advantageous in terms of light reflection, which is a shortcoming of Ti[3,5,6]; yet it may undergo changes when exposed to thermal processes.[7–9] In addition, possible alterations of the base due to repeated use or sterilization might affect a scan's accuracy due to displacement of the SB.[5,10]

Regardless of the material it is fabricated from, a SB needs to be tightened onto the implant before data acquisition.[3] However, tightening of the screw leads to settling effect, which approximates the base and the implant due to the wear on rough surfaces during compression[11] and causes displacement. A previous study has reported that an increase of 5 Ncm in torque value had led at least 7 μm of axial displacement while placing abutments,[12] and another study reported mean displacement of 18 μm towards mesial and 43 μm towards the implant when screw-retained crowns were tightened with 20 Ncm torque.[13] In a recent study, Rebeeah et al.[14] have reported that zirconia screw-retained crowns had a maximum of 13.2 μm displacement when prosthetic screw was tightened as recommended by the manufacturer. Effect of different torque values on buccolingual displacement has also been reported.[15]

Considering that torque values are not commonly provided by the manufacturers[7] and hand tightening is inconsistent,[16,17] clinicians may benefit from studies on potential linear displacements of SBs when tightened under different torque values. The authors are aware of only two studies that investigated the effect of SB displacement depending on torque value.[5,7] However, those studies[5,7] were only based on the effect of torque value on displacement and did not investigate other parameters that may affect a SB's displacement such as material type and possible material deterioration due to sterilization. Therefore, the aim of this study was to evaluate linear displacements of SBs during screw tightening when SBs in different materials

(Ti and PEEK) were tightened varying torque values (10 and 15 Ncm),[5] and after sterilization, by using digital image correlation (DIC) analysis. The null hypothesis was that material type, torque value, and sterilization would not affect linear dimensional displacements of SBs.

2 | MATERIALS AND METHODS

Two dental implants (Zimmer TSV; Zimmer Dental), Ø4.7 × 10 mm, were inserted into prefabricated epoxy resin polymeric sleeves (G10; McMaster-CARR) with an elastic modulus of 1800 MPa.[18] These assemblies were then fixed to a table by using C-clamps. One PEEK (Zfx Intraoral Scan Body; Zfx-dental GmbH) and one Ti SB (MPS Zimmer Scanbody R1410; Medentika) were consecutively fixed to these implants by using a digital torque limiting device (Chatillon DFS II R ND; AMETEK Test & Calibration Instruments). A SB was initially tightened with 5 Ncm and its initial spatial position relative to the implant was simultaneously recorded by using 3D DIC technique.[18] DIC system comprised of two cameras that have a resolution of 1624 × 1224 pixels (GRAS-20S4 M; Point Gray Research) equipped with 35 mm lenses (Schneider-Kreuznach; Jos. Schneider Optische Werke). Cameras were fixed on a tripod by using a custom fixation device and calibrated individually by using 1-inch glass calibration grid that had 81 dots (9 × 9) of known spacing to establish a common world coordinate system. Then, a 3D algorithm used images from both cameras to generate a model of 3D world space and an associated set of axes. Basically, calibration converted cameras' sensor-based pixel space to 3D world space. An x-axis was aligned horizontal to the cameras, Y-axis aligned vertical to the cameras and z-axis was aligned out-of-plane (being closer to the cameras or further away; Figure 1).[19,20] A random dot-pattern with high contrast was applied to the surfaces of the SBs and the polymer sleeves by spraying the assembly with white paint and then splattering with black spray, to create measuring points for the image correlation software (Vic-3D, Digital Image Correlation v2009.1.0, build RC 2009.448; Correlated Solutions Inc). Two points were selected for measurements: one in the middle of the SB and the other on the polymeric sleeve ~10 mm below the first point.[14] Coordinates of the point on the SB were subtracted from the coordinates of the point on the polymeric sleeve to measure the relative displacement. After initial measurements, torque value was initially increased to 10 Ncm and then to 15 Ncm (values representing hand tightening)[21] by using the same torque limiting device, and measurements were repeated after each interval (Figure 2). These steps were randomly repeated by using 9 PEEK and 9 Ti SBs on both implants, resulting in a total of 20 measurements at each torque value for each type of SB.

After all measurements were completed, all SBs were sterilized according to PEEK SB's manufacturer's recommendations.[22] Each SB was initially cleaned in an ultrasonic bath (S 300 H; Elmasonic) using a mildly alkaline cleaner (1.5%) at a frequency of 40 kHz for 20 min and then rinsed thoroughly with demineralized water for 1 min. After cleaning, each SB was subjected to full cycle pre-vacuum steam sterilization at a temperature of 134°C for 3 min by using an autoclave (STATIM 5000 S G4; SciCan). This cycle was repeated 25 times for all SBs, which was stated as the product life time of a PEEK SB.[22] After sterilization, random dot pattern was applied again and spatial position of each SB was remeasured with the same methodology. By using image correlation software, linear displacement (on x-axis [right/left], y-axis [apical/coronal], and z-axis [front/back]) of each type of SB with increasing torque values (from 5 to 10 Ncm and from 10 to 15 Ncm) before and after sterilization was calculated in μm.

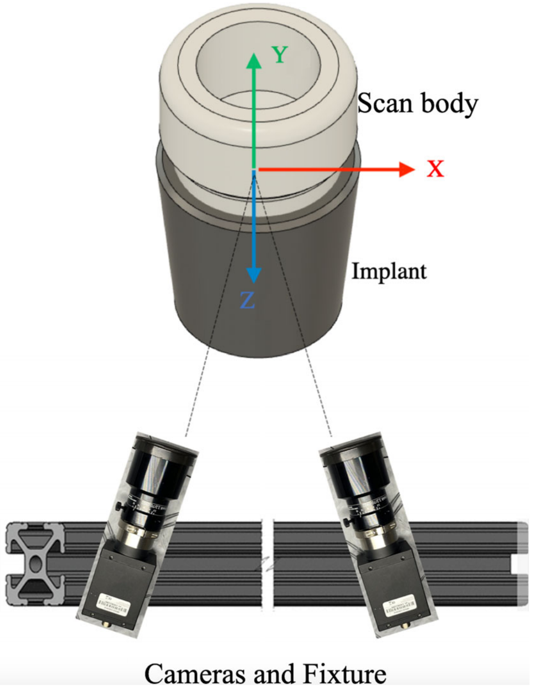

FIGURE 1 Schematic representation of the digital image correlation system.

Shapiro–Wilk test was used to evaluate the distribution of data, which yielded non-normal distribution. Therefore, nonparametric tests were used to evaluate the data. Mann–Whitney *U* test was used to compare the displacement values of SB materials within each torque value–sterilization pair. For the comparison between the displacement values of condition (before and after sterilization) within each material–torque value pair and torque values within each material–sterilization pair, Wilcoxon signed-rank test was used. A statistical analysis software for used for all analyses (SPSS v26; IBM Corp) at a significance level of $\alpha = 0.05$.

3 | RESULTS

Ti SBs had significantly lower displacements than PEEK SBs on x-axis, regardless of the torque value and condition ($p < 0.001$). PEEK SBs had higher displacement after sterilization regardless of the torque value ($p = 0.028$ for 10 Ncm and $p = 0.002$ for 15 Ncm); 15 Ncm torque value led to higher PEEK SB displacements regardless of the condition ($p < 0.001$ for before sterilization and $p = 0.006$ for after sterilization; Table 1).

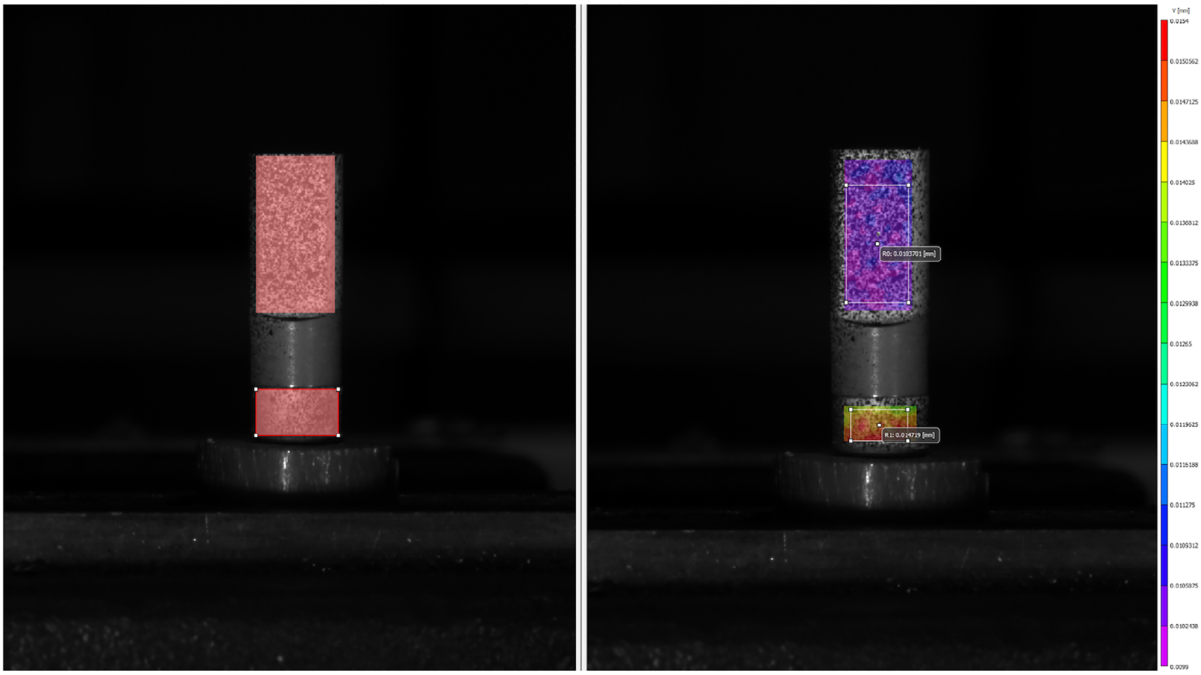

FIGURE 2 Representative images of digital image correlation technique. Image on left represents data sets on the scan body and implant defined for analysis, whereas image on right represents points selected for coordinate measurements.

TABLE 1 Descriptive statistics of displacement values (μm) of each SB type within each torque value–condition pair on x-axis.

		PEEK		Ti	
Torque value	Condition	Mean ± SD	Median (IQR)	Mean ± SD	Median (IQR)
10 Ncm	Before sterilization	−14.40 ± 22.72	-16.49^{bA*} (−25.30/−10.03)	−1.82 ± 1.79	-1.99^{aA} (−2.77/−0.75)
	After sterilization	−40.29 ± 34.65	-49.79^{bB*} (−66.22/−16.32)	−2.34 ± 4.51	-1.49^{aA} (−2.75/−0.19)
15 Ncm	Before sterilization	−39.58 ± 19.50	$-39.64^{bA\phi}$ (−46.72/−27.87)	−1.64 ± 2.50	-1.73^{aA} (−3.34/0.38)
	After sterilization	−70.62 ± 33.04	$-67.60^{bB\phi}$ (−97.64/−44.11)	−2.17 ± 5.10	-0.62^{aA} (−3.37/0.67)

Note: Different lowercase letters in same row show significant differences between material types for each torque value–condition pair, whereas different superscript letters in same column indicate significant differences between different conditions (before and after sterilization) for each material–torque value pair. Different symbols in same column show significant differences between torque values for each material–condition pair. Negative values indicate displacement towards right and positive values indicate displacement towards left.
Abbreviations: IQR, interquartile range; PEEK, polyetheretherketone; Ti, titanium; SB, scan body.

TABLE 2 Descriptive statistics of displacement values (μm) of each SB type within each torque value–condition pair on y-axis.

		PEEK		Ti	
Torque value	Condition	Mean ± SD	Median (IQR)	Mean ± SD	Median (IQR)
10 Ncm	Before sterilization	−2.45 ± 1.83	-2.29^{aA*} (−3.91/−0.94)	−2.12 ± 0.56	-2.17^{aA*} (−2.43/−1.80)
	After sterilization	−3.14 ± 2.75	-3.23^{aA*} (−4.43/−1.87)	−2.87 ± 1.15	-2.85^{aB*} (−3.64/−2.23)
15 Ncm	Before sterilization	−5.30 ± 1.56	$-4.77^{bA\phi}$ (−6.63/−3.94)	−4.16 ± 0.67	$-4.14^{aA\phi}$ (−4.59/−3.91)
	After sterilization	−8.46 ± 7.87	$-7.41^{bB\phi}$ (−10.34/−5.97)	−4.57 ± 1.53	$-4.99^{aA\phi}$ (−5.89/−3.55)

Note: Different lowercase letters in same row show significant differences between material types for each torque value–condition pair, whereas different superscript letters in same column indicate significant differences between different conditions (before and after sterilization) for each material–torque value pair. Different symbols in same column show significant differences between torque values for each material–condition pair. Negative values indicate displacement towards apical and positive values indicate displacement towards coronal.
Abbreviations: IQR, interquartile range; PEEK, polyetheretherketone; Ti, titanium; SB, scan body.

TABLE 3 Descriptive statistics of displacement values (μm) of each SB type within each torque value–condition pair on z-axis.

		PEEK		Ti	
Torque value	Condition	Mean ± SD	Median (IQR)	Mean ± SD	Median (IQR)
10 Ncm	Before sterilization	−2.99 ± 2.21	-2.90^{bB} (−4.22/−1.49)	−0.42 ± 1.94	$-0.29^{aA\phi}$ (−1.43/0.65)
	After sterilization	−0.91 ± 4.32	-1.43^{aA*} (−3.78/1.08)	0.48 ± 2.88	0.43^{aA} (−0.62/2.56)
15 Ncm	Before sterilization	−3.58 ± 4.54	-3.71^{bA} (−6.59/−2.05)	0.18 ± 1.98	0.05^{aA*} (−1.37/1.72)
	After sterilization	−3.14 ± 4.47	$-3.26^{bA\phi}$ (−5.51/0.58)	0.34 ± 4.73	1.45^{aA} (−1.85/3.70)

Note: Different lowercase letters in same row show significant differences between material types for each torque value–condition pair, whereas different superscript letters in same column indicate significant differences between different conditions (before and after sterilization) for each material–torque value pair. Different symbols in same column show significant differences between torque values for each material–condition pair. Negative values indicate displacement towards front and positive values indicate displacement towards back.
Abbreviations: IQR, interquartile range; PEEK, polyetheretherketone; Ti, titanium; SB, scan body.

Ti SBs had lower displacement than PEEK SBs on y-axis after 15 Ncm torque application ($p = 0.033$ for before sterilization and $p = 0.001$ for after sterilization). For each material–condition pair, 15 Ncm led to higher displacements than 10 Ncm ($p \leq 0.002$). Sterilization led to higher displacement for 10 Ncm torque-applied Ti SBs ($p = 0.019$) and 15 Ncm torque-applied PEEK SBs ($p = 0.028$; Table 2).

Ti SBs had lower displacements than PEEK SBs on z-axis for each torque value–condition pair ($p \leq 0.015$), except for when sterilized SBs were tightened with 10 Ncm ($p = 0.102$). Sterilization decreased the displacement of 10 Ncm torque-applied PEEK SBs ($p = 0.044$). In total, 10 Ncm torque-applied Ti SBs had higher displacements before sterilization ($p = 0.033$) and 15 Ncm torque-applied PEEK SBs had higher displacements after sterilization ($p = 0.008$; Table 3).

4 | DISCUSSION

Ti SBs mostly had lower displacement than PEEK SBs, whereas sterilization mostly led to higher PEEK SB displacements of. In addition, 15 Ncm torque application generally led to higher displacements compared with 10 Ncm. Therefore, the null hypothesis of this study was rejected.

Before sterilization, Ti SBs mostly had lower displacements than PEEK SBs (except for displacements on y-axis with 10 Ncm torque application), which may be related to the fact that they had a metal-to-metal fit that led to lower displacement values even with increased torque.[7] Lower displacements with Ti SBs after sterilization (on x-axis with 10 and 15 Ncm torque application and on y-axis and z-axis with 15 Ncm torque application) may be related to susceptibility of PEEK to high temperature and pressure compared with Ti. In a recent study on the effect of artificial aging on mechanical properties of various PEEK materials, Pretchel et al.[9] have shown that autoclave sterilization had detrimental effects, while one of the tested PEEK materials was not affected by autoclave sterilization. Therefore, the results of this study cannot be completely extrapolated to other PEEK SBs from different manufacturers. In another study, PEEK was reported to decrease in size when subjected to repetitive autoclave sterilization cycles.[8] Even though this study did not investigate the dimensional stability of SBs, potential dimensional instability limits the repetitive use of PEEK SBs. Such dimensional issues can jeopardize the congruence between the SB mesh and SB's proprietary CAD library file, which may affect positional accuracy of definitive prostheses.[23] It should also be noted that, when displacement values of tested SBs were similar (on y-axis with 10 Ncm torque application and on z-axis with 10 Ncm torque application and after sterilization), Ti still had nonsignificantly lower values. Based on these results, it can be speculated that tested Ti SBs may lead to more accurate scans than those performed by using tested PEEK SBs, regardless of sterilization and torque values used. However, this hypothesis needs further support.

To the authors' knowledge, only two other studies have investigated the displacement of SBs as a function of torque value.[5,7] Kim et al.[5] compared 3D, vertical, and horizontal displacement of one-piece PEEK SBs from three different manufacturers to those of a PEEK SB with a Ti base, after different torque applications (5, 10, and 15 Ncm). Kim et al.[5] have concluded that increased torque value resulted in increased displacement for all SBs tested, PEEK SB with Ti base had lower displacements than two of the one-piece SBs, and the one-piece SB that had similar values with PEEK SB with Ti base had a base shape that acted as a stop for vertical movement, which highlighted the effect of the geometry of the base region. In another study, Tan et al.[7] have concluded that higher torque values increased the movement in vertical axis towards the implant for one-piece PEEK SBs, which is parallel to the results of this study and can be attributed to the compression of SBs at mating surfaces.

In this study, displacement of SBs was evaluated on three axes to better interpret its possible effects on definitive prostheses. Displacements on x-axis may result in interproximal contacts issues, particularly for those prostheses fabricated from scans acquired by using tested PEEK SBs. Regardless of the torque value or the condition, PEEK SBs had mean displacements that were higher than 8 μm, which is the thickness of one type of commercially available tin foil shims used for interproximal and occlusal adjustments.[14,15,24] However, for those displacements on y-axis, only PEEK SBs had higher mean values than 8 μm when tightened under 15 Ncm torque after sterilization (8.46 μm). When displacement values on z-axis were evaluated, Ti

SBs mostly deviated backwards, whereas PEEK SBs deviated forward. Other than possible esthetic issues due to over and undercontouring of the prosthesis, displacements on z-axis might also result in occlusal interferences of both functional and nonfunctional cusps. In addition, displacements on x-axis and z-axis may affect the location of the screw access hole and alter occlusal surface configuration when a screw-retained implant-supported prosthesis is fabricated. However, considering that implant scan deviations >100 μm might lead to inaccurate fit of the definitive prosthesis,[25,26] the prosthesis fabricated by using the scans of tested SB may have acceptable clinical fit.

Even though statistically significant differences were detected in this study, the sample size is a limitation. Nevertheless, statistical significances for median values as low as 0.34 μm (−0.29 vs. 0.05 μm for Ti SBs on z axis when testing the effect of applied torque) were detected with the sample size and design, and such a value can be considered clinically low, which confirms high statistical power. The SBs were sterilized for 25 times to simulate a worst case clinical situation. However, lower number of sterilization cycles may lead to different results. The torque values were only limited to 10 and 15 Ncm and different SB manufacturers may recommend higher torque values, which may affect the results. All SBs were one-piece and different SB designs may affect the results. DIC has been previously used in dental research studies on displacement evaluation.[13–15,19,24] Another limitation is that only two implants were used in this study. Even though both implants were used for all SBs in a randomized manner to standardize the possible effect of torque and detorque values on measured displacements, a different test set up with individual implants for each SB may have led to lower displacements. Only one type of implant-abutment connection was tested in this study and the effect of connection on axial displacement has been reported, and different results may be obtained for SBs on implants with different connection designs.[27] However, the use of other measurement methods such as coordinate measuring machine[7] or 3D inspection software[5,27] have been reported. Finally, even though measured displacement values can be used to speculate on possible clinical effects, in vivo studies are needed to corroborate the results of this study when different types of implant-supported prostheses are used in different clinical situations.

5 | CONCLUSIONS

Within the limitations of this study, the following conclusions can be drawn:

1. Scan body (SB) material and sterilization affected axial displacements of tested SBs. Tested one-piece Ti SBs can be preferred over one-piece PEEK SBs for lower displacements.
2. A tightening torque of 15 Ncm increased the displacements of tested PEEK SBs and should not be applied. To reduce the displacement of tested PEEK SBs, a calibrated tightening tool can be used, instead of recommended hand tightening, to better control the torque value and 10 Ncm or lower torque values can be considered. Nevertheless, PEEK SB displacements in mesiodistal direction may still be expected when 10 Ncm torque is reached.
3. Sterilization process generally increased PEEK SB displacements. Therefore, disposal of tested PEEK SBs can be considered after sterilization, particularly when multiple-time sterilization is implemented as performed in this study.

AUTHOR CONTRIBUTIONS

Emre Diker: Concept/design, methodology, and investigation. **Hakan Terzioğlu:** Concept/design, data collection, critical revision of the article, and approval of the submitted and final versions. **Diogo N. M. Gouveia:** Methodology and investigation. **Mustafa Borga Donmez:** Drafting article and critical revision of article. **Burak Yilmaz:** Concept/design, data interpretation, critical revision of the article, and approval of the submitted and final versions.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest. The authors do not have any financial interest in the companies whose materials are included in this article.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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