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RESEARCH AND EDUCATION

Effect of mechanical aging and steam autoclaving on the accuracy of different mechanical torque limiting devices

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ABSTRACT

Statement of problem. Evidence is lacking regarding the accuracy of the long-term torque delivery of mechanical torque-limiting devices (MTLDs) from different manufacturers after repeated mechanical aging and sterilization.

Purpose. The purpose of this in vitro study was to evaluate the accuracy of spring- and friction-style MTLDs from 6 implant manufacturers in delivering target torque values and to assess the effects of mechanical aging and steam autoclaving on their performance.

Material and methods. Sixty new MTLDs from 6 manufacturers (spring-style devices: Astra Tech, Nobel Biocare, Straumann, Bilimplant; and friction-style devices: Neoss and Meisinger) were included in the present study (n=10). After initial measurements (T1), all devices underwent 500 simulated clinical uses to assess the effect of mechanical aging, after which torque values were recorded again (T2). Subsequently, each device was subjected to 100 steam autoclaving cycles under standardized conditions (134 °C, 7 minutes), and final torque values were collected (T3). All torque measurements were performed using a custom-designed device. Two accuracy metrics, absolute difference (ABSDIFF) and percentage deviation (PERDEV), were used for comparison. Statistical analyses included 2-way robust ANOVA and Bonferroni-adjusted post hoc tests (α=.05).

Results. At baseline, spring-style MTLDs demonstrated significantly lower ABSDIFF values than friction-style devices (P=.001), indicating higher initial accuracy. No significant differences were found between device types after mechanical aging (P>.05). Following sterilization, torque deviation increased in spring-style devices, particularly Astra (P<.05). All devices maintained torque delivery within the clinically acceptable ±10% threshold.

Conclusions. Spring-style MTLDs provided more accurate torque delivery initially, while friction-style devices demonstrated greater stability after repeated mechanical aging and sterilization. Device type and manufacturer-specific factors influence long-term accuracy. (J Prosthet Dent xxxx;xxx:xxx-xxx)

Dental implants have emerged as a prominent approach to the rehabilitation of partial and complete edentulism, offering long-term functional and esthetic success.[1–3] Although implant-supported prostheses demonstrate long-term survival rates exceeding 90%, various complications may be encountered in clinical practice,[4] and mechanical complications have been regarded as a significant cause of prosthesis failure.[5] The deformation of prosthetic components, material wear, and loosening or fracture of abutment screws have often been reported to be the result of unfavorable mechanical conditions within the implant-prosthesis assembly.[4,6,7] Factors such as occlusal overload, material fatigue, and improper torque application can lead to mechanical complications by compromising the stability and integrity of the implant-abutment interface.[8–10]

Mechanical stability at the implant–abutment interface largely depends on the screw tightening process and the resulting preload. Preload, defined as the clamping force generated within the stem of the screw upon torque

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Clinical Implications

Delivering accurate screw torque is essential for ensuring the long-term success of implant-supported prostheses. Repeated clinical use and routine sterilization may compromise the accuracy of MTLDs, particularly spring-style devices.

application, plays a fundamental role in maintaining the mechanical performance of the prosthesis.[11,12] While inadequate preload may lead to micromovements in the joint, and screw loosening,[11,13] excessive preload may increase the risk of material fatigue, component deformation, and screw fracture.[11,14] To minimize potential risks and ensure optimum preload, manufacturers specify torque values for each implant system.[11]

Torque application can be performed with hand-held drivers, mechanical torque-limiting devices (MTLDs), and electronic torque-control devices (ETLDs).[15] Hand drivers have been widely used because of their simplicity, tactile feedback, and low cost,[16,17] but they yield inconsistent preload values and are often insufficient for tightening larger screws,[15,18] especially in posterior regions.[19–21] To achieve accurate torque values and minimize operator-related variability, manufacturers recommend MTLDs for final screw tightening.[15,22,23]

MTLDs have been classified as friction-style (toggle-type) and spring-style (beam-type) based on their torque delivery mechanism. Friction-style devices use a release mechanism that disengages or clicks once the preset torque value is reached, preventing overtightening. In contrast, spring-style devices rely on a calibrated spring-loaded beam that deflects under applied force, allowing the clinician to visually monitor the torque value during tightening.[16] During prosthetic screw tightening, accurate torque delivery of MTLDs is essential to maintain the integrity of the implant-prosthesis connection, and regular calibration is recommended to ensure consistent performance.[24]

The initial accuracy of MTLDs may vary depending on both the device mechanism[25–27] and the manufacturer.[16,28,29] It has been reported that spring-style devices tend to deliver more accurate torque values than friction-type devices.[25,26] Albayrak et al[28] reported no significant difference between spring- and friction-style devices in achieving target torque value. Similarly, other investigations also indicated that device mechanism may not be a determining factor for torque accuracy.[16,29] While each device type is designed to deliver standard torque values, their accuracy can be compromised by repeated mechanical use and sterilization procedures.[30–33] Stroosnijder et al[34] evaluated the effects of clinical use and cleaning procedures on the accuracy of MTLDs, reporting that repeated cycles of mechanical use and sterilization can cause statistically significant deviations but that torque values remained within a clinically acceptable range. However, another study[35] reported that multiple sterilization procedures did not significantly affect the torque accuracy of either spring- or friction-style MTLDs.

The accuracy of new and used MTLDs has been investigated, highlighting the potential impact of clinical service on device performance. However, in most of these studies, the number of clinical uses or cleaning procedures was not clearly specified.[24,36,37] Although some studies have evaluated the effects of mechanical aging and steam autoclaving separately,[31,32,35] comprehensive assessments involving both factors under standardized conditions remain limited. Furthermore, operator-related differences in torque application may introduce variability in comparative studies. Therefore, the aim of the present study was to evaluate the accuracy of spring- and friction-style MTLDs from 6 manufacturers and to assess the effects of mechanical aging and steam autoclaving in achieving target torque delivery using a standardized and controlled torque application protocol. The null hypotheses were that no significant difference would be found in the initial torque accuracy between spring- and friction-style MTLDs and that mechanical aging and steam autoclaving would not significantly affect the torque accuracy of MTLDs, regardless of device type (spring- and friction-style) and different manufacturers.

MATERIAL AND METHODS

The sample size per group was determined using a power analysis software program (G*Power v3.1.9.6; Heinrich Heine University Düsseldorf) with the effect size of f=0.65, α=.05 and test power =.95 based on a previous study.[16] A total of 60 MTLDs from 6 different manufacturers and their screwdrivers were included in the present study (n=10): 4 new spring-style MTLDs (torque wrench and screwdriver; Astra Tech, Nobel Biocare, Straumann and Bilimplant) and 2 new friction-style MTLDs (torque wrench and screwdriver; Neoss Implants and Meisinger Implants) (Fig. 1). Target torque values were determined for each MTLD in accordance with the manufacturer's recommendations for the abutment screws and are presented in Table 1.

Torque application procedure was performed through a special device (torque application device; Bahadır Tıbbi Aletler A.Ş.), which simulated manual torque application and was designed to eliminate possible operator errors and ensure the standardization of torque application. The device consisted of 2 main parts: the body, comprising the power adapter, the digital

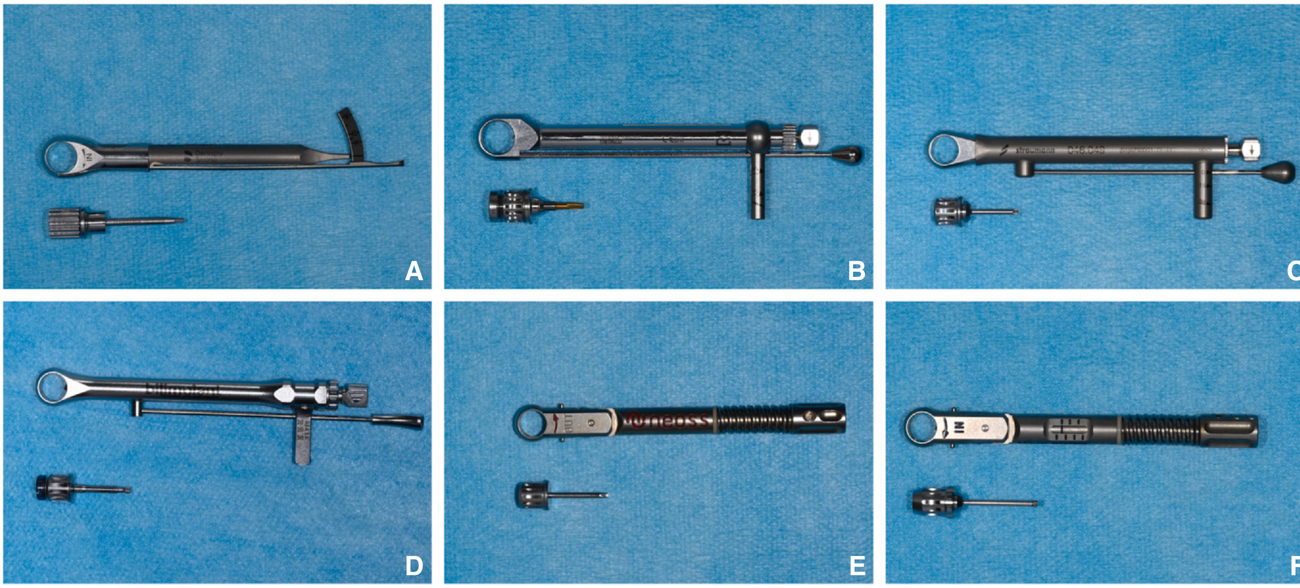

Figure 1. Mechanical torque limiting devices. A, Astra. B, Nobel. C, Straumann. D, Bilimplant. E, Neoss. F, Meisinger.

Table 1. Manufacturer-recommended target torque values for mechanical torque limiting devices

Device Type	Manufacturer	n	Target Torque Value (Ncm)
Spring-style	Astra Tech	10	25
	Nobel Biocare	10	35
	Straumann	10	35
	Bilimplant	10	30
Friction-style	Neoss	10	32
	Meisinger	10	35

counter, the position adjustment plane with the elliptical component (cam), and the pushing bar (Fig. 2) and the bottom plate designed to allow the digital torque gauge (Cap Torque Tester Series TT01; Mark10) to be inserted directly in it.

Before the measurements, the digital gauge was calibrated according to the manufacturer's instructions with an accuracy level of ±0.3% of full scale. After the device and the digital torque gauge had been connected

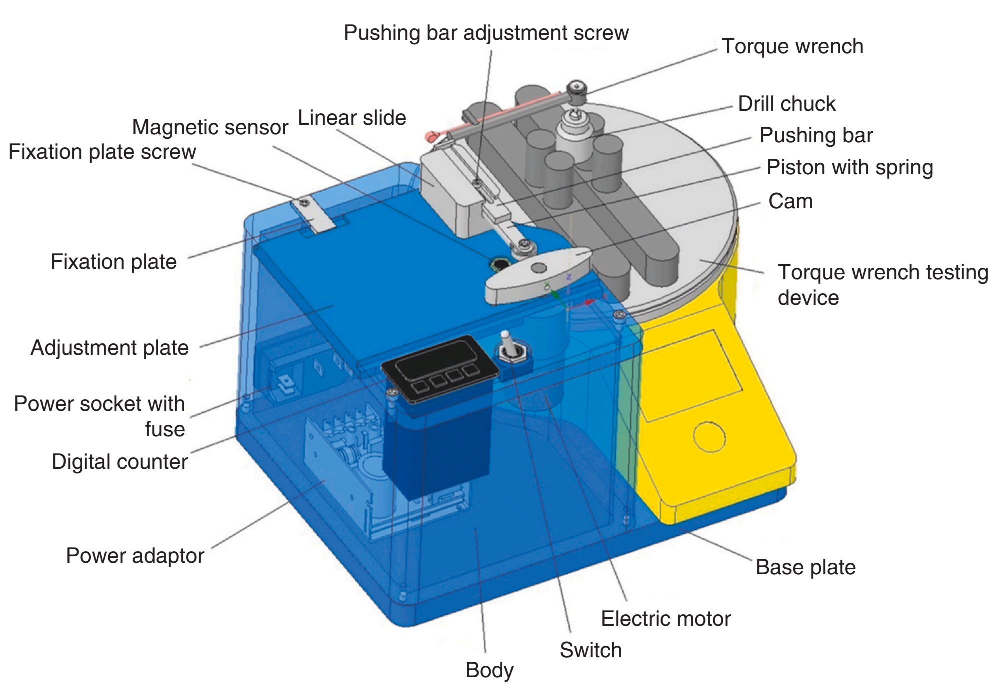

Figure 2. Schematic illustration of custom-made torque application device.

Table 2. Two-way robust ANOVA results of device type and manufacturer

Between and Within Groups	PERDEV (%)			ABSDIFF (Ncm)		
	Q	P	η²	Q	P	η²
Device type	9.422	.009*	0.486	14.146	.001*	0.539
Manufacturer	42.72	<.001*	0.996	44.26	<.001*	0.898

ABSDIFF, absolute difference; PERDEV, percentage of deviation; Q, robust ANOVA test statistic; η^2, effect size estimate; *statistically significant (P<.05).

to each other, the torque application procedure was initiated. A setup was generated for applying torque to the MTLDs by rotating the elliptical component through 1 complete rotation and thereby activating the push bar. Each rotation was completed in 4 seconds, and, before the torque application, the screwdrivers of each MTLD were inserted into the chuck and locked. Then, the locked system was fixed on the torque gauge and MTLDs were connected to the screwdrivers. The pushing bar was positioned to stop tightening at the center of the target scale line for spring-type MTLDs and to release at the target torque value for friction-type MTLDs. After setting the number of torque applications in the digital counter, a clockwise driving force was implemented for each MTLD from 0 to the target value. Initial target torque values were recorded 10 times for each torque wrench (T1). Afterward, all groups were tested 500 times to determine the effect of mechanical aging on the devices. Then, the target torque values of each group were again recorded 10 times (T2).

After mechanical aging, all MTLDs were prepared for the sterilization procedure by following the manufacturers' recommendations and then subjected to steam autoclaving cycles (Steam Sterilizer, Model STR 4407; Eryiğit A.Ş.). The procedure was carried out at 134 °C for a sterilization time of 7 minutes and a drying time of 20 minutes. This procedure was repeated for a total of 100 cycles. Afterward, the target torque values of all MTLDs were retested with 10 consecutive measurements and recorded (T3). The data obtained at 3 separate time points (T1, T2, and T3) were compared based on device types (spring- and friction-style) and different manufacturers.

Statistical analyses were performed using a statistical software program (R programming Language, 4.3.1. version; The R Project for Statistical Computing). Two primary dependent variables were defined to assess the accuracy outcomes of the MTLDs: the absolute difference (ABSDIFF) between the measured torque value and the target torque value, and the percentage deviation (PERDEV= [ABSDIFF/target torque] × 100). The normality of the data distribution was assessed using the Shapiro-Wilk test. As both sets of data failed to meet the assumption of normality (P<.05), nonparametric methods were used for subsequent analyses. A 2-way robust ANOVA was used to evaluate the torque accuracy outcomes depending on the manufacturer, testing time point, and their interaction. Post hoc pairwise comparisons were carried out using the Bonferroni correction to adjust for multiple testing. Effect sizes were calculated for the tested variables using a bootstrap approach based on the Cohen d formula (α=.05).

RESULTS

Table 2 summarizes the results of 2-way robust ANOVA assessing the effects of device type (spring and friction) and manufacturer on torque accuracy outcomes according to different time points between and within groups. Statistically significant differences were observed in both PERDEV (P=.009) and ABSDIFF (P=.001) values for device types among manufacturers (P<.001). Effect size values (η^2), demonstrating the magnitude of observed differences, are also listed in Table 2. Table 3 presents the post hoc pairwise comparisons of median PERDEV and ABSDIFF values.

Within-group comparisons for spring-style devices demonstrated significant differences in PERDEV values between T1 and T3 (P=.001), with no significant changes between T1 and T2 or between T2 and T3 (P=.208). In contrast, ABSDIFF values for spring-style devices showed a significantly higher deviation at T3 compared with both T1 (P<.001) and T2 (P=.047); however, there was no significant difference between T1 and T2 (P=.064). Friction-style devices exhibited no statistically significant differences in either PERDEV or ABSDIFF values across all time points (P>.05).

Between-group comparisons for PERDEV values showed no significant difference between the spring- and friction-style devices at T1 (P=.208), indicating comparable initial accuracy. However, spring-style devices at T3 exhibited significantly higher deviation than friction-style devices at T1 (P=.03) and T2 (P=.004). Regarding ABSDIFF values, a significant difference was observed between the 2 device types at T1 (P=.048) with friction-style devices showing higher deviation. Conversely, the torque deviation of spring-style devices at T3 was significantly greater than that of friction-style devices at both T1 (P=.023) and T2 (P=.002). No significant differences were found between the 2 device types at T2 and T3 for both PERDEV and ABSDIFF values (P>.05).

Table 3. Post hoc pairwise comparisons in groups of device type and manufacturers

Between and Within Groups	PERDEV (%)			ABSDIFF (Ncm)		
	T1	T2	T3	T1	T2	T3
Device Type						
Spring-style	0.6 (0 - 8)[A]	1.9 (0 - 8.8)[AB]	2.8 (0 - 9.6)[B]	0.2 (0 - 2)[A]	0.6 (0 - 2.4)[AB]	1 (0 - 2.4)[C]
Friction-style	1.7 (0 - 3.13)[A]	1.1 (0 - 5.3)[A]	2.5 (0 - 11.4)[AB]	0.6 (0 - 1)[B]	0.4 (0 - 1.7)[AB]	0.9 (0 - 4)[ABC]
Manufacturer						
Astra	4.2 (1.9 - 8)[ABCD]	3.6 (0.8 - 8.8)[ABCD]	7.6 (2 - 9.6)[A]	1 (0.5 - 2)[ABCD]	0.9 (0.2 - 2.2)[ABCD]	1.9 (0.5 - 2.4)[A]
Nobel Biocare	0.1 (0 - 0.9)[B]	1.1 (0.2 - 2.3)[BCD]	1.6 (0 - 2.3)[BCD]	0 (0 - 0.3)[B]	0.4 (0 - 0.8)[BCD]	0.6 (0 - 0.8)[BCD]
Straumann	0.2 (0 - 0.6)[BC]	0.6 (0 - 2.3)[BCD]	2.6 (0.9 - 3.4)[CD]	0.1 (0 - 0.2)[BC]	0.2 (0 - 0.8)[BCD]	0.9 (0.3 - 1.2)[CD]
Bilimplant	1 (0 - 4)[BCD]	2.7 (0.7 - 8)[ABCD]	3.8 (2.3 - 5.3)[BCD]	0.3 (0 - 1.2)[BCD]	0.8 (0.2 - 2.4)[ABCD]	1.2 (0.7 - 1.6)[ACD]
Neoss	1.9 (1.3 - 3.1)[D]	1.7 (0 - 5.3)[BCD]	1.6 (1.3 - 3.1)[BCD]	0.6 (0.4 - 1)[D]	0.6 (0 - 1.7)[ABCD]	0.5 (0.4 - 1)[BCD]
Meisinger	1.4 (0 - 2.3)[BCD]	0.9 (0 - 4)[BCD]	4.7 (0 - 11.4)[ABCD]	0.5 (0 - 0.8)[BCD]	0.3 (0 - 1.4)[BCD]	1.7 (0 - 4)[ABCD]

ABSDIFF, absolute difference; PERDEV, percentage of deviation; *statistically significant ($P<.05$). Values are presented as median (minimum-maximum). No statistically significant difference among groups with same letter. Superscript letters indicate statistical differences within each result (PERDEV and ABSDIFF) across groups, independently.

When assessing both between- and within-group comparisons among different manufacturers, Astra devices exhibited the highest torque deviation at T3 with PERDEV of 7.6% and ABSDIFF of 1.9 Ncm. These values were significantly higher than those of most other groups ($P<.05$), except for Astra at T1 ($P=.388$) and T2 ($P=.303$), Bilimplant at T2 ($P=.081$), and Meisinger at T3 ($P=.098$). The pairwise comparisons also revealed that ABSDIFF values for Astra at T3 were not significantly different than those of Bilimplant at T3 ($P=.310$) and Neoss at T2 ($P=.061$). However, Nobel Biocare (PERDEV: 0.1%; ABSDIFF: 0 Ncm) and Straumann (PERDEV: 0.2%; ABSDIFF: 0.1 Ncm) demonstrated higher accuracy at T1 compared with the other manufacturers. At T3, the lowest deviation values were observed in Neoss and Nobel Biocare devices, followed by Straumann, Meisinger, Bilimplant, and Astra.

DISCUSSION

The null hypothesis that no significant difference would be found in the initial torque accuracy between spring- and friction-style MTLDs was partially rejected. Although there was no significant difference between spring- and friction-style MTLDs in PERDEV values at T1 ($P=.208$), ABSDIFF values at T1 were significantly higher for friction-style devices ($P=.048$). The hypothesis that mechanical aging and steam autoclaving would not significantly affect the torque accuracy of MTLDs, regardless of device type (spring- and friction-style) and different manufacturers was also partially rejected. Although no significant difference was found between the device types after mechanical aging (T2) and following steam autoclaving (T3) ($P>.05$), spring-style devices showed a significant increase in their torque deviation at T3 ($P=.001$), while friction-style devices maintained their torque accuracy without significant changes over time ($P>.05$). Astra exhibited significantly higher deviation at T3 compared with most other devices ($P<.05$). These findings suggest that both mechanical aging and sterilization can compromise torque delivery accuracy, depending on device type and manufacturer.

The influence of the device mechanism on torque delivery accuracy has been investigated in previous studies,[16,25,29,36] and different findings were reported. Vallee et al[25] reported that friction-style MTLDs exhibited significantly greater deviations in achieving the target torque values compared with spring-style devices, consistent with the findings of the present study. Although PERDEV values at T1 did not differ significantly between device types, ABSDIFF values revealed higher accuracy in the delivered torque of spring-style MTLDs. However, Britton-Vidal et al[16] reported that the device mechanism was not a contributing factor affecting torque accuracy. In their study, however, torque was applied manually over approximately 1 second, whereas in the present study, torque applications were performed using a custom-designed device with a standardized 4-second interval, potentially minimizing operator-related variability; this methodological difference may explain the contrasting results.

The impact of repeated use and sterilization on the torque accuracy of MTLDs has also been evaluated.[24,27,33,38] Cha et al[30] reported that after 100 sterilization cycles and 2000 uses, spring-style MTLDs remained within acceptable limits, whereas friction-style MTLDs deviated significantly from their target values, with several devices exceeding the ±10% threshold. These findings were not consistent with the present study. This discrepancy may be because of the differences in the extended number of mechanical uses and manufacturers tested. In contrast, Yılmaz et al[35] reported no statistically significant effects of 100 steam autoclaving cycles on the accuracy of either spring- or friction-style devices. However, in their study, mechanical aging was not included, which limits comparability with the findings of the present study, and their results may not fully simulate clinical conditions. In the present study, after 500 simulated clinical uses, no significant difference was found between the 2 device types compared with their initial torque accuracies. However, following 100 cycles of steam autoclaving, torque deviation significantly increased, particularly in spring-style devices. These findings were not consistent with a previous report[24] suggesting lower accuracy in friction-style MTLDs than in spring-style MTLDs after clinical service. However, the number of clinical uses and sterilization cycles was not clearly defined in that study. Variations in the number of clinical uses and sterilization cycles may lead to different outcomes in the torque accuracy of MTLDs.

Torque delivery accuracy may also vary across different manufacturers' MTLDs with aging procedures.[16,25,28] Sadr et al[31] reported that Astra Tech devices showed the greatest deviation among the devices tested in their study after 100 cycles of steam autoclaving. Goldstein et al[37] evaluated both new and clinically used Nobel Biocare MTLDs and reported that neither repeated clinical use nor autoclaving had a significant effect on their torque accuracy. Similarly, in the present study, Nobel Biocare devices exhibited lower deviation at all time points, maintaining stable torque delivery after both mechanical aging and steam autoclaving. Neoss devices also showed lower deviation values, indicating better long-term torque stability with aging procedures, followed by Straumann, Meisinger, Bilimplant, and Astra devices, respectively. All recorded PERDEV values remained below the clinically accepted threshold of 10%, a deviation range that has been defined as clinically acceptable for screw-tightening procedures.[32,36,39]

Various approaches have been used to assess the accuracy of MTLDs, including comparisons based on mean torque value,[28,40] ABSDIFF and PERDEV,[24,25,28,29,35] and confidence intervals.[16] In this study, both ABSDIFF and PERDEV values were used to provide a comprehensive evaluation of torque accuracy. Although confidence intervals can also be useful in determining whether the mean torque remains within an acceptable range of the target value,[16] this method was not preferred because of the differing target values among tested devices which would reduce comparability.

In the present study, a custom-designed torque application device was used to standardize torque application with consistent speed and magnitude. This arrangement aimed to eliminate variability associated with manual torque application, such as beam alignment, viewing angle, and torque application speed, determinants which have been previously identified as affecting the torque accuracy of MTDLs.[36,41] McCracken et al[36] reported that torque application for approximately 4 seconds provided torque outputs more consistent with the target torque value compared with faster application (1 second). Accordingly, in the present design, the beam scale was centrally aligned, viewed perpendicularly (90 degrees), and torque applications were performed over 4 seconds. When designing the methodology of the present study, the number of mechanical aging and sterilization cycles had been determined based on previous reports,[27,33–35,42] given the lack of consensus regarding the clinical lifespan of MTLDs. For sterilization, 100 steam autoclaving cycles were applied in accordance with previous studies[33,35] which used similar protocol to simulate long-term clinical service. The number of mechanical uses reported in the previous studies varied widely,[27,34,42] ranging from 500 to over 1000 cycles. In the present study, 500 mechanical cycles had been selected as a conservative yet clinically relevant simulation of aging. This approach was intended to enable a balanced investigation of the combined effects of mechanical use and sterilization, while preserving device integrity throughout the experimental protocol. Nevertheless, the variability in clinical use and sterilization across institutions and clinicians should be considered when interpreting the results of the present study.

Limitations of this in vitro study included operator-related variability and that real-time patient factors were not reflected, which may have influenced the final torque values. Additionally, the number of use and sterilization cycles were limited; extended testing protocols may yield different results. The inclusion of ETLDs in future studies may also offer a more comprehensive understanding of the torque delivery of MTLDs. Further investigations under actual clinical conditions with long-term simulation are recommended to confirm the clinical relevance of the study.

CONCLUSIONS

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

1. All mechanical torque-limiting devices (MTLDs) delivered torque values within the clinically acceptable ±10% threshold under all test conditions.
2. Spring-style MTLDs showed higher initial torque accuracy than friction-style devices; however, after mechanical aging and steam autoclaving, no significant difference was found between the 2 device types.
3. The Astra device exhibited the highest torque deviation following mechanical aging and steam autoclaving.

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