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The impact of everyday usage of different dental implant torque wrenches on their performance accuracy and repeatability: an *in vitro* study

Uticaj svakodnevnog korišćenja različitih moment-ključeva za dentalne implantate na tačnost i ponovljivost njihovog učinka: *in vitro* studija

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Abstract

Background/Aim. The clinical success of prosthetic rehabilitation that commences after the attained implant osseointegration is dependent on the influence of several factors, of which screw loosening is a frequent one, and it is highly related to inadequate tightening (torquing) using torque wrenches. Although the wrenches are initially calibrated by the manufacturer, it is of great importance to evaluate their function after usage for a certain period of time. The aim of this study was to evaluate the accuracy and repeatability of the performance of implant torque wrenches in delivering necessary torque values before and after one year of usage. **Methods.** Two types of wrenches were used in the study: the beam-type and the toggle-type. Four various brands of beam-type wrench were marked as Beam 1 – Beam 4, and three various brands of toggle-type wrench were marked as Toggle 1 – Toggle 3, according to their design. Torque values delivered by wrenches were measured and analyzed using the One-Sample *t*-test, Independent-Samples *t*-test, and Mann-Whitney *U* test. The Bland-Altman bias test was used as an index of accuracy, whereas Forkman's comparison of datasets coefficients of variation (CV) served as an index of repeatability. **Results.** All wrenches except new Beam 2 and Beam 3 showed differences between the average measured torque value and target torque value. Differences were found in the average measured values between all used and new wrenches. Higher bias was observed in Toggle 1, Toggle 2, and Toggle 3 brands, whereas lower bias was recorded between used and new Beam 1 and Beam 3 wrenches. When comparing the CV for used and new wrenches, Beam 1, Beam 4, Toggle 1, and Toggle 2 revealed differences, whereas the CV for Beam 2, Beam 3, and Toggle 3 did not differ significantly. **Conclusion.** Compared to toggle-type, the beam-type wrenches offer greater accuracy in achieving the target torque value. The torque deteriorates in all wrenches after aging/usage and is more prominent in toggle-type devices.

Key words:
biomechanical phenomena; dental implantology; dental instruments; in vitro techniques; torque.

Apstrakt

Uvod/Cilj. Klinički uspeh protetske rehabilitacije nakon postignute oseointegracije implantata zavisi od uticaja nekoliko faktora, od kojih je razlabavljivanje šrafa čest faktor i u velikoj meri je povezano sa neadekvatnim zatezanjem upotrebom moment-ključeva. Iako je proizvođač inicijalno kalibrisao ključeve, veoma je važno proceniti njihovu funkciju nakon korišćenja tokom određenog vremenskog perioda. Cilj ove studije bio je da se proceni tačnost i ponovljivost učinka moment-ključeva za implantate u postizanju potrebnog stepena zatezanja, pre i posle njihovog korišćenja tokom godinu dana. **Metode.** Dva tipa moment- ključeva su korišćena u studiji: *beam*-tip i *toggle*-tip. Četiri različite marke *beam*-tipa ključeva koji su korišćeni u studiji su označeni kao *Beam* 1 – *Beam* 4, a tri različite marke *toggle*-tipa ključeva su označene kao *Toggle* 1 – *Toggle* 3 u skladu sa njihovim dizajnom. Vrednosti obrtnog momenta koje su postigli ključevi merene su i analizirane pomoću *One-Samples t*-testa, *Independent-Samples t*-testa i Mann-Whitney *U* testa. Bland-Altman-ov test odstupanja korišćen je kao indeks tačnosti, dok je Forkman-ov test poređenja koeficijenata varijacije (KV) skupova podataka korišćen kao indeks ponovljivosti. **Rezultati.** Svi moment-ključevi osim novih *Beam* 2 i *Beam* 3, pokazali su razlike između prosečne izmerene vrednosti i ciljne vrednosti obrtnog momenta. Utvrđene su razlike u prosečnim izmerenim vrednostima obrtnih momenata

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između svih korišćenih i novih ključeva. Veće odstupanje primećeno je kod *Toggle* 1, *Toggle* 2 i *Toggle* 3 modela, dok je manje odstupanje zabeleženo između korišćenih i novih ključeva *Beam* 1 i *Beam* 3. Kada su upoređivani KV korišćenih i novih ključeva, *Beam* 1, *Beam* 4, *Toggle* 1 i *Toggle* 2 su pokazali značajne razlike, dok se KV za *Beam* 2, *Beam* 3 i *Toggle* 3 nisu značajno razlikovali. **Zaključak.** U poređenju sa *toggle*-tipom, moment-ključevi *beam*-tipa nude veću tačnost u postizanju ciljne vrednosti obrtnog momenta. Vrednost obrtnog momenta se nakon starenja/korišćenja pogoršava kod svih ključeva i izraženiji je kod uređaja *toggle*-tipa.

Ključne reči:
biomehanika; stomatološka implantacija; stomatološka oprema; in vitro; obrtni moment.

Introduction

Prosthetic rehabilitation that commences after the attained implant osseointegration represents one of the milestones in implant therapy. Its long-term clinical success is highly dependent on the influence of distinctive mechanical and biological features. One of the most commonly reported in the literature that may have an impact on the clinical outcome is screw loosening [1–4]. Screw loosening is considered a substantial clinical problem caused by various factors. Most of them are related to inadequate tightening (torquing), incompatible screw alloy type or shape, dominant lateral occlusal loading and repeated bending, improper occlusal morphology, and misfit of implant-abutment components [5–11]. First, it is of crucial importance that the initial tightening force using the torque wrench (TW) applied to the screw is neither inadequate nor excessive but rather accurately applied as designated by the manufacturer. Hence, a proper fit of the abutment and implant without possible complications is achieved [12–14]. That consequently leads to a long-term integrity of the implant components assembly with functional loading [15, 16]. Different designs of TW are currently available on the market, classified as electrical and mechanical, whereas the latter are further divided into beam-type (BT) (spring) wrenches and toggle-type (TT) (friction) wrenches [15]. BT devices use the bending of an attached bar to the extent value readable on the scale, whereas the TT devices are designed to break away once the determined torque value (TV) is achieved [16, 17]. TWs are initially calibrated by the manufacturer and are ready to deliver an adequate torque value for specific implant components. Although the manufacturer calibration is undisputable, there are considerable differences between the target TV and achieved TV in brand-new TWs [18]. Moreover, each torque device is subjected to different clinical conditions in the oral environment and consequently requires proper maintenance [19]. Hence, various fluids such as saliva, blood, and saline solution or improper handling and dismantling are issues that are expected to have an impact on the accuracy of TWs. In support of this, a study implementing unused TWs and the used ones under normal clinical conditions showed significant fluctuations above and below the target TV [20]. According to previously published studies, BT TWs possess a more consistent range of TVs, whereas the variations are dependent on the wrench design and the obtained torque level [21, 22]. However, features like the accuracy and repeatability of mechanical oral TWs have not been fully evaluated, particularly considering the influence of aging deterioration due to metal fatigue, cleaning, and disinfection or wet conditions in the oral environment. Considering these issues, the present study aimed to evaluate the accuracy and repeatability of measurement of various TWs with different mechanical designs before and after annual clinical use. The null hypothesis was that regardless of the TWs' mechanical design (BT or TT) or condition (new or used), no significant difference would be found among them with regard to their measurement accuracy and repeatability while achieving the target TV proposed by the manufacturer.

Methods

Ethical standard

The procedures performed in the study were approved by the Ethics Committee of the Faculty of Dental Medicine, University of Belgrade, Serbia (No. 36/53), and were in line with the ethical standards of the 1964 Helsinki Declaration.

Selection of torque wrenches

The TWs selected for the study are representative of the two different torque mechanisms (BT and TT), as well as of various brands mostly presented in our country's market, designated for use with manufacturer-supplied implant component parts. Tested wrenches of seven brands, marked as Beam 1 (Straumann Group), Beam 2 (Neodent® Dental Implants System), Beam 3 (Nobel™ Biocare), Beam 4 (Bredent Group), Toggle 1 (Bredent Group), Toggle 2 (Astra Tech Implant System® – Dentsply Sirona), and Toggle 3 (Alpha-Bio Tec) according to their design, with their required target TVs adopted from the manufacturer's instructions, are presented in Table 1. TWs were divided into two groups. The first study group (new) consisted of new TWs in the "as-received" condition. The second study group (used) was comprised of TWs of the same brands that were used for one year in usual clinical practice (minimum 250 times a year) [23]. For each study group, one TW *per* brand was tested (n = 1).

Experimental procedure

The experimental procedure for this investigation was performed using a test assembly comprising a torque-measuring device (iSD900, NSK-Nakanishi International) operating at 230 V. Holding the torque-measuring device in one hand, the operator was able to apply the target TV using the tested TW in another one [24] (Figure 1).

Table 1

Brands of torque wrenches included in the study

Torque wrench	Manufacturer	Target torque value (Ncm)
Beam 1	Straumann Group	35
Beam 2	Neodent® Dental Implants System	20
Beam 3	Nobel™ Biocare	35
Beam 4	Bredent Group	25
Toggle 1	Bredent Group	25
Toggle 2	Astra Tech Implant System®, Dentsply Sirona	25
Toggle 3	Alpha-Bio Tec	30

Ncm – Newton x cm.

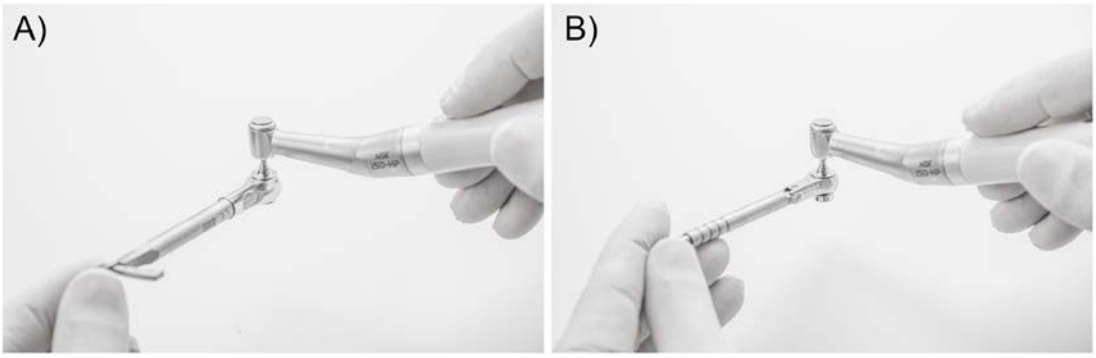

Fig. 1 – Measuring the applied target torque value by holding the torque-measuring device in one hand and the tested beam (A) or toggle (B) torque wrench in another hand.

The measurements were repeated 15 times for each TW and were performed by one investigator to avoid discrepancies resulting from the inclusion of multiple operators. The average measured TV of all the measurements was calculated and recorded accordingly.

The bias that represents the difference between the average measured TV and target TV divided by the target TV was used as the index of measurement accuracy. The coefficient of variation (CV) that represents the standard deviation (SD) of the measured TV divided by the average measured TV was used as an index of measurement repeatability.

Statistical analysis

All statistical analyses were performed using the Statistical Package for Social Sciences (SPSS version 26.0, SPSS) and Prism 9 for macOS version 9.5.1, GraphPad Software, LLC. The difference between the target TV and the average measured TVs of the used and new TWs was analyzed using the One-Sample *t*-test. A pairwise comparison of the average measured TVs of the used and new TWs was performed using the Independent-Samples *t*-test and Mann-Whitney *U* test, according to the results obtained by the One-Sample Kolmogorov-Smirnov test for normal distribution. Mean ± SD and median (minimum-maximum) were used to describe the numeric data. The bias was determined using the Bland-Altman plot method [25]. This method was used to quantify the agreement between two quantitative measurements within the limits of the agreement by calculating the mean and SD of the differences between the two measurements. Therefore, the mean difference between the used and new TW (within its 95% limits of agreement) vs. the average of the two datasets is used to depict and quantify bias. The Forkman test [26] was implemented to compare the CVs. Differences were considered significant when the *p*-value was < 0.05.

Results

The results from the present study revealed that the majority of the tested TWs showed a significant difference ($p < 0.05$) between the obtained average measured TV and the target TV. The only TWs that showed an absence of statistical significance with regard to the same parameters were Beam 2 ($p = 0.257$) and Beam 3 ($p = 0.065$) wrenches, both in the new "as-received" condition (Figure 2).

Furthermore, the obtained data revealed a significant difference ($p < 0.05$) in the average measured TV when comparing the used and new TWs of all brands included in the research (Figure 3). The detailed descriptive statistics are given in Table 2.

Regarding the measurement accuracy, according to the presented data, a certain degree of bias was noticed in all tested implant brands (Figure 4). Descriptive statistics (Table 2) revealed the highest bias in Toggle 2, followed by Toggle 1 and Toggle 3. On the other hand, Beam 1 and Beam 3 exhibited the lowest bias when comparing the used and new TWs. Considering the repeatability of the measured, CVs are listed in Table 2. When comparing the CVs of the datasets for used and new TWs, Beam 1, Beam 4, Toggle 1, and Toggle 2 revealed significant differences ($p < 0.05$), whereas the CVs of Beam 2, Beam 3, and Toggle3 did not differ significantly ($p > 0.05$) (Figure 5).

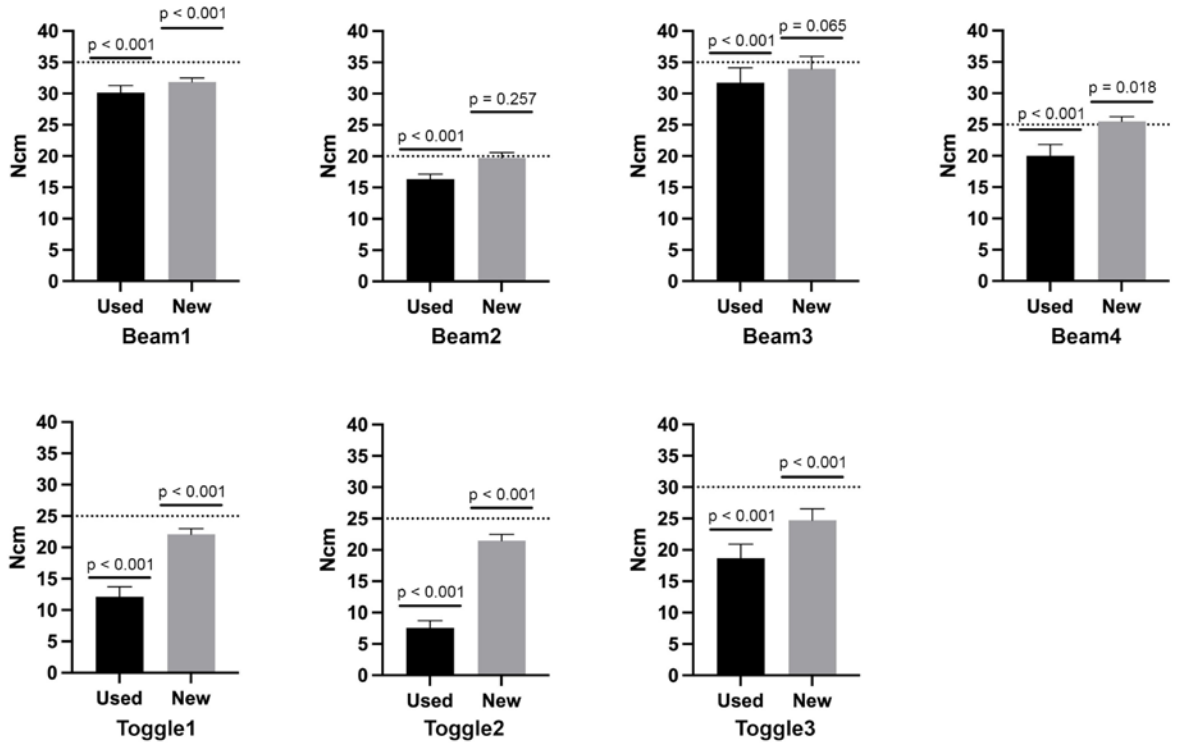

Fig. 2 – The difference between the target torque value (dotted line) and the average measured torque values of the used and new torque wrenches (One-Sample *t*-test).
Ncm – Newton x cm.

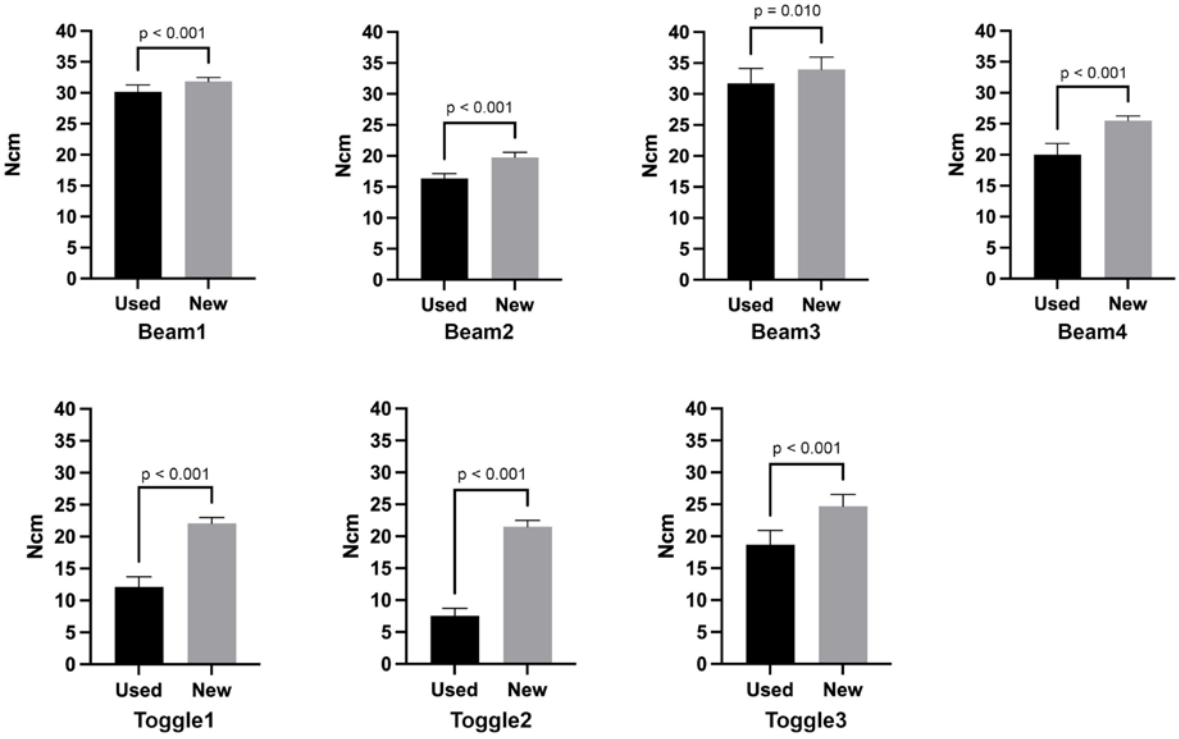

Fig. 3 – Pairwise comparisons of the average measured torque values of the used and new torque wrenches (Independent-Samples *t*-test and Mann-Whitney *U* test).
Ncm – Newton x cm.

Table 2

Descriptive statistics of datasets for torque values of various used and new torque wrenches

Torque wrench	Mean ± SD (Ncm)	Median (min–max) (Ncm)	CV (%)	Bias (Mean difference ± SD)
Beam 1				
used	30.14 ± 1.15	30.02 (28.26–32.67)	3.82	1.71 ± 0.71
new	31.85 ± 0.62	31.79 (30.91–32.67)	1.94	
Beam 2				
used	16.35 ± 0.80	16.68 (14.72–17.66)	4.89	3.40 ± 0.73
new	19.75 ± 0.82	19.62 (17.66–20.60)	4.14	
Beam 3				
used	31.73 ± 2.39	30.91 (28.26–35.32)	7.54	2.24 ± 1.24
new	33.97 ± 1.10	35.32 (30.91–36.20)	5.88	
Beam 4				
used	20.01 ± 1.81	19.62 (17.66–23.54)	9.03	5.50 ± 1.22
new	25.51 ± 0.74	25.51 (24.53–27.47)	2.90	
Toggle 1				
used	12.12 ± 1.59	12.6 (9.90–14.40)	13.12	9.96 ± 0.87
new	22.08 ± 0.89	21.6 (20.70–23.40)	4.04	
Toggle 2				
used	7.53 ± 1.20	7.95 (5.30–8.83)	15.90	13.95 ± 0.49
new	21.49 ± 0.98	21.19 (19.43–22.96)	4.58	
Toggle 3				
used	18.64 ± 2.23	17.66 (15.89–22.96)	11.96	6.08 ± 1.94
new	24.72 ± 1.83	24.72 (21.19–28.26)	7.40	

SD – standard deviation; CV – coefficient of variation; Ncm – Newton x cm; min – minimum; max – maximum.

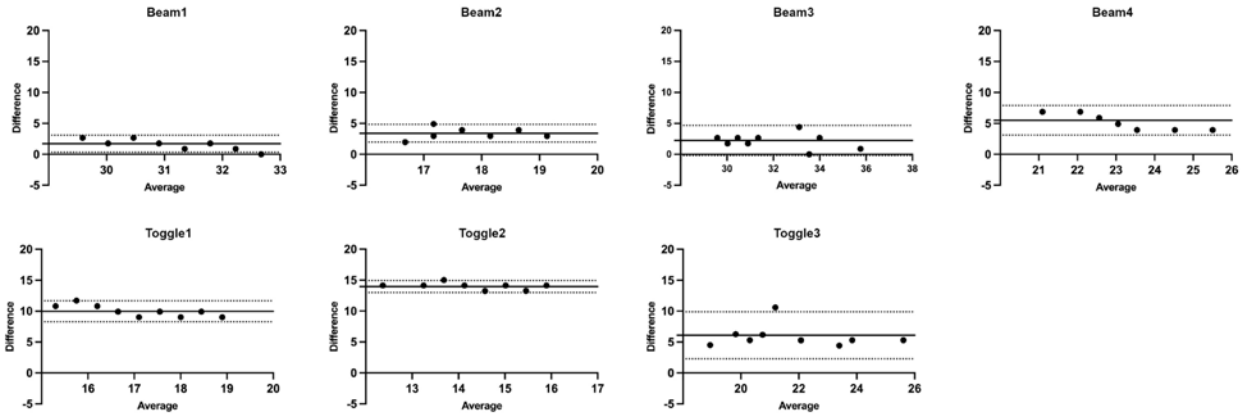

Fig. 4 – The bias (index of measurement accuracy) represents the difference between the average measured torque value and the target torque value, divided by the target torque value. The solid line represents the mean difference, and the dotted lines represent the 95% of limits of agreement (Bland-Altman plot method [25]).

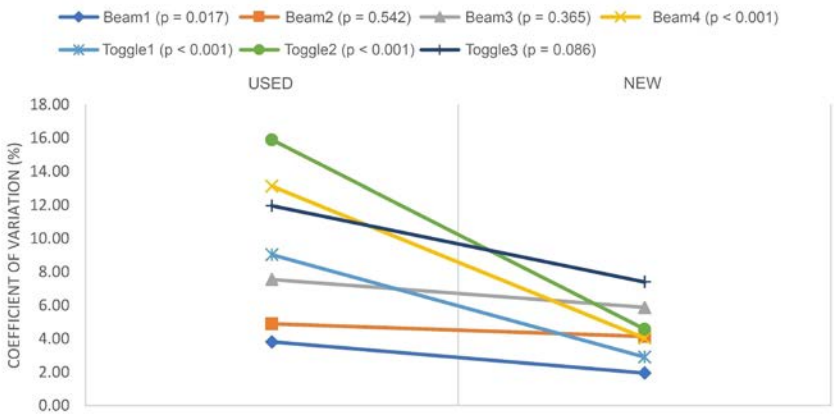

Fig. 5 – The coefficient of variation (CV) represents the standard deviation of the measured torque value, divided by the average measured torque value (Forkman test [26]). The CV was used as an index of measurement repeatability.

Discussion

It is of paramount importance to position and fix the implant-abutment complex in correct relation to the delivered manufacturer's recommended TV, obtaining in such a way specific stability and long-term functionality [27–30]. A prerequisite for achieving stability and screw preload is the clinician's knowledge of the amount of torque required for the specific implant brand employed. Each manufacturer provides its own recommendation of TV depending on various factors, including the type of implant, implant-abutment connection, abutment design, screw design, and screw material. Improper and inadequate screw torquing can result in various mechanical failures, including screw loosening or fracture, with consequent restoration loss [31]. On the other hand, overtorquing may initiate screw joint high preload with abutment screw complications such as screw fracture or flattening of the screw threads [32, 33]. Since hand-held screwdrivers do not deliver sufficient torque force and are not able to provide adequate abutment tightening [34], mechanical torque-limited devices are considered standard tools for precise and accurate torquing in everyday clinical practice. This study aimed to evaluate the measurement accuracy and repeatability of different used and new mechanical torque devices (wrenches) from implant brands that are most common in our country's market today.

The results from the present study are in agreement with the outcomes of previous research that revealed that even in the new, "as-delivered" condition, there is variation among TWs in their ability to deliver specific values of torque [35]. Discrepancies between the target and obtained TVs were found for the majority of the tested wrenches. These findings indicate that clinicians should be aware that each new wrench unwrapped from the factory package carries some torque errors. A possible explanation for this may be that new, "as-delivered" mechanical components of the wrenches are still stiffened and require some manipulation prior to everyday use. However, new, unused devices with BT (spring) mechanical design, such as Beam 2 and Beam 3 wrenches, delivered TVs without significant difference compared to the target value, whereas only a new Beam 4 wrench managed to achieve the exact target value. Furthermore, the highest bias, index of accuracy, was observed for all three representative wrenches of the TT.

In addition, after comparing wrenches with different mechanical designs (BT and TT) from the same manufacturer (Beam 4 and Toggle 1), a higher TV was obtained for the BT device. One may speculate that the ability of the oral implant TWs to deliver the target TV is most likely influenced by the design of the wrench components. Thus, the results of this study confirm that the BT (spring) wrenches offer greater accuracy regarding the target values compared to the TT (friction) wrenches, which is in agreement with previous findings [21]. The results suggest that the prerequisite for TW accuracy is BT mechanical construction.

In comparing the average measured TVs between the used and new TWs, a significant difference was observed within all tested wrenches. The results of the present research support that the observed TVs tended to be lower than the target values for both mechanical designs [35], which is the opposite of the studies where greater TVs in both used and new wrenches compared to the target values were found [17, 22]. Furthermore, the obtained TVs of the TT wrenches were less consistent compared to those of the BT, which were associated with a lower risk of disagreement between repeated measurement values, which is in favor of a previously reported statement [36]. However, some studies did not find that the design of the wrenches and their limiting mechanism had any impact on the repeatability and confidence interval [16]. According to our results, the CVs of the datasets for the used and new wrenches of Beam 2, Beam 3, and Toggle 3 did not differ significantly. On the other hand, a large discrepancy in the results of the average measure TVs between the used and new devices was observed for Toggle 1 and Toggle 2 wrenches, supporting the speculation that TT mechanical design is more susceptible to inaccurate values due to aging and reuse. Considering all the aforementioned, the results of the present study revealed some degree of error between the used and newly tested devices. However, Beam 1 and Beam 3 wrenches were the most consistent throughout all measurements. In other words, the reported data imply that TVs for used and new Beam 1 and Beam 3 wrenches can be expected to differ by no more than 3 Ncm or no more than 10%, which could be regarded as insignificant from a clinical point of view and still lead to accepted clinical target values [24].

Taking into consideration all of the results from the present study, the null hypothesis – regardless of the TWs' mechanical design (BT or TT) or condition (new or used), no significant difference would be found among them with regard to their accuracy and repeatability while achieving the target TV proposed by the manufacturer – was rejected.

The major limitation of the current study might be the fact that only one TW device from each manufacturer was used for the analyses. Therefore, any differences between individual wrenches were omitted. In order to strengthen the study, although a similar conceptualization was reported previously [15, 37], we incorporated a relatively large number of repeated measurements for each tested TW, thus indicating greater assurance of whether the device delivered its target TV. Despite the aforementioned limitations, the generalized applicability of the present study may be that the accuracy of wrenches deteriorates during use, which implies the importance of calibration of the wrenches from time to time, as recommended by the International Organization for Standardization (ISO) 6789-2 [38]. Moreover, clinicians must be aware that handling during clinical use and maintenance must be performed mindfully because TWs are prone to misfit owing to their regular use. The latter is of much more importance for TT devices since it has been shown that their accuracy loss is more expected after prolonged clinical use. Therefore, the results from the present study may be

beneficial for selecting implant and implant components assembly systems and achieving clinical functionality.

Conclusion

Based on the findings of the present study, two conclusions could be drawn. First, compared with the toggle-type (friction), the beam-type (spring) of torque wrenches offers greater accuracy while delivering the target torque value proposed by the manufacturer. Second, the ability to torque after aging and prolonged clinical use deteriorates in all tested torque wrenches and is more prominent in those with toggle-type mechanical design than beam-type devices.

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Conflict of interest

The authors declare no conflict of interest.

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