EVALUTION OF THE EFFECT OF TORQUE ON AN IMPLANT ABUTMENT SCREW LOOSENING UNDER SIMULATED OCCLUSAL LOAD USING HAND HELD DRIVER AND TORQUE CONTROLLED WRENCH: AN IN VITRO STUDY

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ABSTRACT

Background: Implant-supported prostheses are valued for retrievability and function, yet screw loosening remains a frequent complication. Connection stability depends on preload from screw tightening, which varies with torque delivery. Hand drivers create inconsistent torque, whereas torque-controlled wrenches deliver more accurate and standardized values.

Aim: To evaluate the effect of torque application on abutment screw loosening under simulated occlusal loading using a handheld driver and a torque-controlled wrench.

Materials and Methods: Twenty acrylic blocks with implant analogs and abutments were fabricated and randomly divided into two groups ($n = 10$). Group A screws were tightened using a handheld driver, and Group B screws with a torque-controlled ratchet (RS-6111). Torque was verified with a digital torque gauge (WISRETEC, Taiwan). All samples were subjected to cyclic loading of 600 N for 500,000 cycles in a universal testing machine (Instron, USA) to simulate one year of mastication. Reverse torque values were recorded, and data analyzed with one-way ANOVA and Pearson correlation (SPSS v26.0, $p < 0.05$).

Results: Before loading, the handheld driver and torque wrench groups showed mean torque values of 31.21 ± 1.8556 Ncm and 31.28 ± 1.3373 Ncm, respectively. After cyclic loading, mean torque decreased to 27.01 ± 2.1799 Ncm in the handheld group and 29.5 ± 1.4079 Ncm in the torque wrench group. Torque loss was significant in both groups ($p = 0.002366$ and $p =$

0.009571, respectively), with between-group comparison showing higher retained torque in the torque wrench group (p = 0.007133).

Conclusion: Both groups exhibited torque loss after cyclic loading; however, torque-controlled wrenches maintained significantly greater residual torque and reduced variability compared with handheld drivers. Mechanical torque-limiting devices should be considered mandatory for minimizing abutment screw loosening.

Key words: Abutment screws, Dental torque wrench, Implant abutment design, Implantation, endosseous, Mechanical loading, Torque

INTRODUCTION

Dental implants are widely used to replace missing teeth because they preserve esthetics and function [1]. Implant therapy is considered a safe and predictable treatment option for both partially dentulous and edentulous patients [2]. Despite high success rates, biological and mechanical complications may occur during or after treatment [3].

Screw-retained, implant-supported prostheses are often preferred because they allow retrievability and facilitate repair. This approach provides distinct advantages but also presents limitations. Screw loosening is one of the most frequent complications. It compromises patient comfort, creates instability of the prosthesis, and reduces masticatory efficiency. For clinicians, it is time-consuming to manage, often requiring repeated interventions that increase treatment costs.

Screw loosening is also the most widely reported mechanical failure in implant dentistry [4]. A systematic review indicated that 5.8% of patients experienced screw loosening within five years of function [5]. Several factors influence this complication. Reported contributors include non-passive frameworks, contamination within the screw channel, insufficient or inconsistent torque application, occlusal overload, restoration design, implant–abutment connection geometry, material properties, the settling effect, and metal fatigue [6–12]. These factors interact to undermine preload stability, highlighting the importance of precise screw tightening protocols and appropriate prosthesis design.

The load created when the abutment screw is tightened is known as preload. Preload is critical for maintaining the stability of the screw joint. If functional or parafunctional forces exceed the established preload, screw loosening occurs [13,14]. The preload should be high enough to resist separating forces within the oral cavity to reduce this risk [15,16]. However the applied preload must remain below the yield strength of the screw material, as exceeding this threshold can cause permanent deformation or fracture [17].

Achieving the recommended preload depends on the torque applied to the abutment screw. Manufacturers specify torque values for each system, and adherence to these values is essential for long-term clinical success. Since torque application is under direct control of the clinician, the delivery method influences the preload achieved. Torque-limiting devices, like calibrated torque wrenches, have been emphasized for clinical use to provide consistent torque application. However, some clinicians rely on hand-held screwdrivers instead of torque wrenches, which often results in lower and undefined torque delivery [18–20]. Consequently, a discrepancy exists between the torque suggested by manufacturers and the torque actually applied in practice. This gap underscores the importance of evaluating torque values achieved by torque wrenches and hand-held drivers under controlled conditions [21,22].

In implant-supported restorations, the abutment-implant interface is stabilized by axial compressive forces created during screw tightening. When subjected to functional loading, prostheses encounter complex forces, including axial compression, bending moments, and microstrains. These forces can accelerate screw loosening, particularly during repeated masticatory cycles [23]. Laboratory and clinical studies have shown that repeated tightening, screw design, and loading conditions affect torque loss [24]. Limited data exist on how cyclic loading combined with torque application method influences the stability of implant–abutment screws. Prevention of screw loosening requires a thorough understanding of both biomechanical factors and clinical practice variables. Since torque values delivered by hand-held drivers vary widely among clinicians [18,20], and torque loss may occur under cyclic loading [23,24], it is necessary to investigate how these factors interact. A controlled comparison of torque loss between screws tightened with a torque wrench and those tightened with a hand driver under simulated loading conditions may provide clinically relevant insights.

Studies have shown that several factors contribute to loosening of the screw, including preload, screw design, connection geometry, and repeated tightening. Studies have examined torque values delivered by clinicians using hand drivers and torque wrenches, while others have assessed torque loss after repeated cycles of tightening and loosening [17–24].

However, most investigations have evaluated these aspects separately, and very few have compared torque loss after cyclic loading when the initial tightening was performed with different torque application methods. This gap indicates that the available knowledge does not clearly establish whether screws tightened with a torque wrench retained preload more effectively than screws tightened with a hand driver once subjected to simulated functional loading. The present in vitro study evaluated implant abutment screws tightened with a hand- held driver and a torque-controlled ratchet. It measured the torque generated by each method, compared the values, and examined screw loosening after simulated occlusal loading. The study aimed to determine how torque application affects abutment screw loosening under cyclic loading. The objectives were to measure and compare torque delivered by both methods, analyze screw loosening after loading, and assess whether the torque-controlled ratchet provides greater resistance to loosening than the hand driver.

MATERIALS AND METHODS

Materials: The study used commercially available clear acrylic cubes measuring 2.5 × 2.5 cm, RS straight titanium abutments (1 mm), RS internal hex implant analogs, an implant hex driver (1.25 small), and a prosthetic torque wrench (RS-6111) (all from ADIN Dental Implants, Sys Ltd., Israel). Self-cure acrylic resin (DPI Heat Cure, Denture Base Material, Dental Products of India, Mumbai) was used to embed the implant analogs into the acrylic blocks.

Equipment: The equipment included a parallelometer (MARATHON Surveyor 103), a digital torque gauge with adapter (WISRETEC, EWK3-060AN, Taiwan), and a universal testing machine (Instron, USA). The parallelometer was used to align the implant analogs perpendicularly within the acrylic blocks. The digital torque gauge measured torque between 3 and 60 Ncm, with a resolution of 0.1 Ncm, and was manually calibrated. It measured torque values from both the handheld driver and the torque wrench using a custom-made adapter to fit the 1.27 mm hex head of the ADIN system. The universal testing machine was used to simulate cyclic occlusal loading. The Instron 8800MT retrofit, equipped with WaveMatrix2™ software, applied dynamic fatigue testing loads in the range of 50 N to 1000 kN.

Specimen Preparation: Clear acrylic blocks (2.5 × 2.5 cm) were fabricated and polished with pumice and rouge. The center of each block was marked, and mock osteotomies (4 × 15 mm) were drilled to receive implant analogs (3.5 × 13 mm, ADIN Dental Implants) **(Figure 1).** Implant analogs were then positioned centrally and embedded with self-cure acrylic resin.

A parallelometer ensured perpendicular alignment to the horizontal plane, standardizing placement across all specimens.

Specimen Grouping and Torque Application: 20 specimens were prepared and randomly divided into two groups of 10 each.

- Group A (n = 10): Abutments were tightened with a handheld driver.
- Group B (n = 10): Abutments were tightened with a torque-controlled ratchet (prosthetic torque wrench, RS-6111).

The torque applied in both groups was measured and recorded using the digital torque gauge (WISRETEC, Taiwan) **(Figure 2).** All tightening procedures were performed by a single operator to eliminate inter-operator variability.

Cyclic Loading and Torque Measurement: All specimens were loaded in a universal testing machine (Instron, USA) with 600 N vertical occlusal force for 500,000 cycles, simulating one year of mastication [25] **(Figure 3).** After loading, samples were stored for 24 hours to account for the settling effect [12]. Reverse torque values were then recorded in both groups using a digital torque gauge, representing the degree of abutment screw loosening following cyclic loading **(Figure 4).**

Statistical Analysis: The data were analyzed using SPSS (version 26.0, IBM Corp., USA). One-way ANOVA compared mean torque values between groups, and Pearson correlation assessed relationships among variables. A p-value < 0.05 was considered statistically significant.

RESULTS

Descriptive Analysis: Before loading, the mean torque produced by the handheld driver was 31.21 Ncm with a standard deviation of 1.8556, while the torque wrench produced a mean of 31.28 Ncm with a standard deviation of 1.3373. These baseline values showed minimal difference between the two groups. After cyclic loading, the handheld driver group demonstrated a mean torque of 27.01 Ncm with a standard deviation of 2.1799, whereas the torque wrench group showed a mean of 29.5 Ncm with a standard deviation of 1.4079. The greater torque loss and higher variability observed in the handheld driver group indicated reduced consistency compared with the torque wrench.

One-Way ANOVA: Statistical analysis using one-way ANOVA confirmed these findings. The comparison of torque values between the two groups before loading revealed no significant difference at $p < 0.05$ (Table 2, Graph 1). Within-group analysis demonstrated a significant reduction in torque after loading in both groups, with $p = 0.002366$ for the handheld driver group (Table 3, Graph 2) and $p = 0.009571$ for the torque wrench group (Table 4, Graph 3). The between-group comparison after cyclic loading revealed a significant difference at $p = 0.007133$, with the torque wrench group maintaining higher torque values (Table 5, Graph 4).

Pearson Correlation Coefficient: Pearson correlation analysis indicated a statistically significant relationship between torque values of the two tightening methods ($p < 0.01$). The correlation was positive but weak, highlighting variability among operators using the handheld driver. Post-loading, torque values in the handheld driver group showed greater variability (SD = 2.1799) compared with the torque wrench group (SD = 1.4079), indicating less consistent preload maintenance. Both methods experienced torque loss after cyclic loading; however, screws tightened with a torque-controlled ratchet retained higher torque values and showed lower variability. This demonstrates that torque wrenches provide more stable preload and reduce the risk of screw loosening under simulated function.

Table 1: Descriptive statistics of the torque generated by hand held driver and torque controlled rachet before and after application of simulated occlusal load

S no	VARIABLES	HAND HELD DRIVER TORQUE		TORQUE CONTROL RACHET	
		Before	After	Before	After
1.	MEAN	31.21	27.01	31.28	29.5
2.	SD	1.8556	2.1799	1.3373	1.4079
3.	MEAN +-SD	33.0656	29.1899	32.6173	30.9079
4.	VARIANCE	3.4432	4.7521	1.7884	1.9822

Table 2: Torque generated by hand held driver and torque controlled rachet before application of simulated occlusal load

Summary of data Before load	Hand held driver	Torque control rachet	Total

N	10	10	20
∑X	302.1	312.8	614.9
Mean	30.21	31.28	30.745
∑X2	9157.43	9800.48	18957.91
Std.Dev.	1.8556	1.3373	1.6672
Source	SS	df	MS
Between-treatments	5.7245	1	5.7245
Within-treatments	47.085	18	2.6158
Total	52.8095	19	**F = 2.1884**
f-ratio value is 2.1884. p-value is .156342; not significant at p < .05.			

Graph 1: Torque values generated by hand held driver and torque controlled rachet

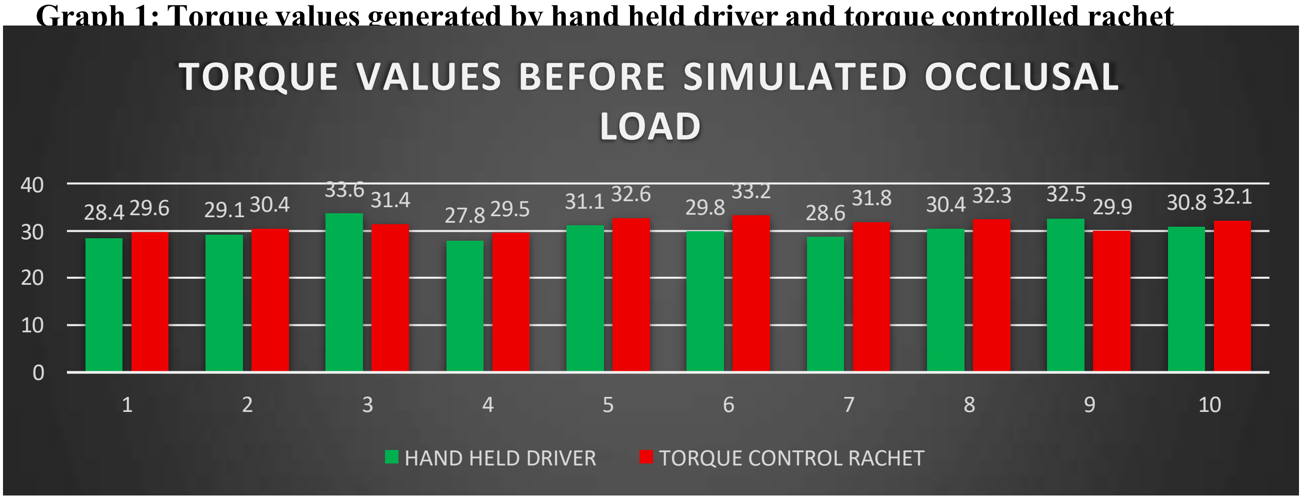


Table 3: Torque generated by hand held driver before and after application of simulated occlusal load

Summary Of Data Hand Held Driver	Before Load	After Load	Total
N	10	10	20
∑X	302.1	270.1	572.2
Mean	30.21	27.01	28.61

∑X2	9157.43	7338.17	16495.6
Std.Dev.	1.8556	2.1799	2.5645
Source	SS	df	MS
Between-treatments	51.2	1	51.2
Within-treatments	73.758	18	4.0977
Total	124.958	19	**F = 12.49492**
f-ratio value is 12.49492. p-value is .002366; significant at p < .05.			

Graph 2: Torque values generated by hand held driver before and after application of simulated occlusal load

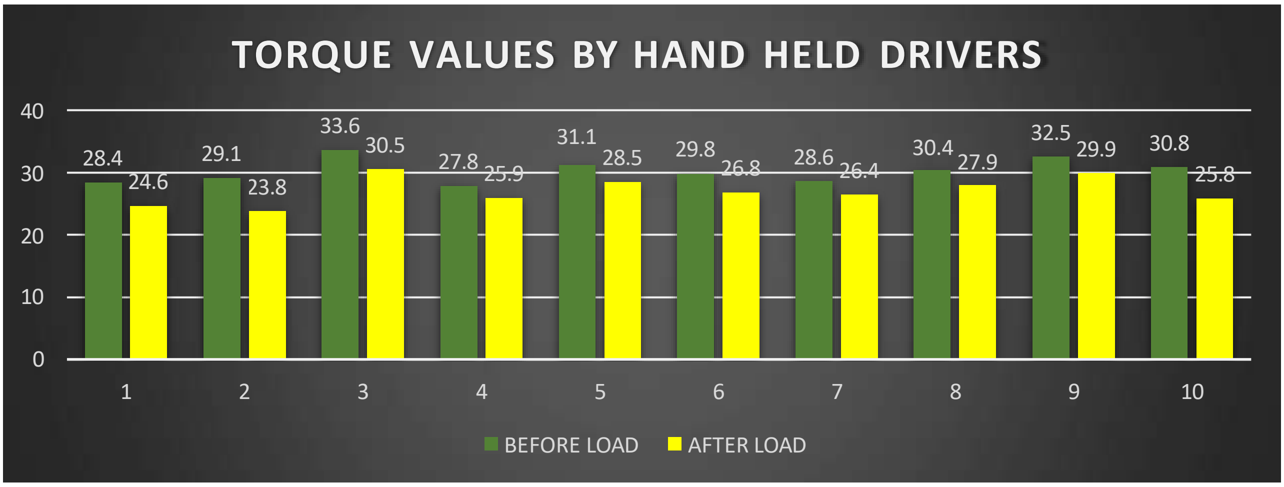


Table 4: Torque generated by torque controlled rachet before and after application of simulated occlusal load

Summary Of Data Torque Control Rachet	**Before Load**	**After Load**	**Total**
N	10	10	20
∑X	312.8	295	607.8
Mean	31.28	29.5	30.39
∑X2	9800.48	8720.34	18520.82
Std.Dev.	1.3373	1.4079	1.6186
Source	SS	df	MS
Between-treatments	15.842	1	15.842
Within-treatments	33.936	18	1.8853
Total	49.778	19	**F = 8.40276**

f-ratio value is 8.40276; p-value is .009571; result is significant at $p < .05$.

Graph 3: Torque values generated by torque controlled rachet before and after application of simulated occlusal load

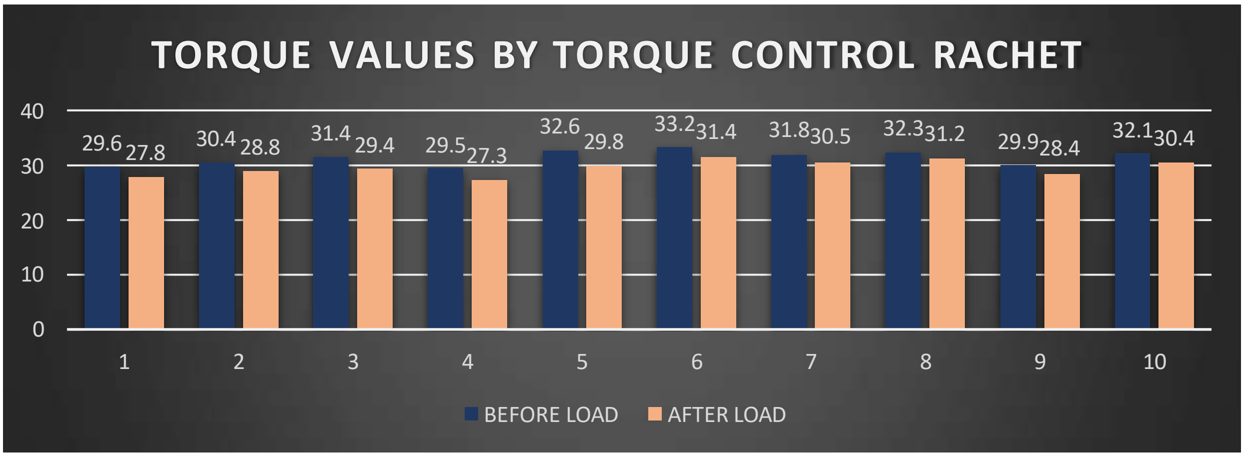
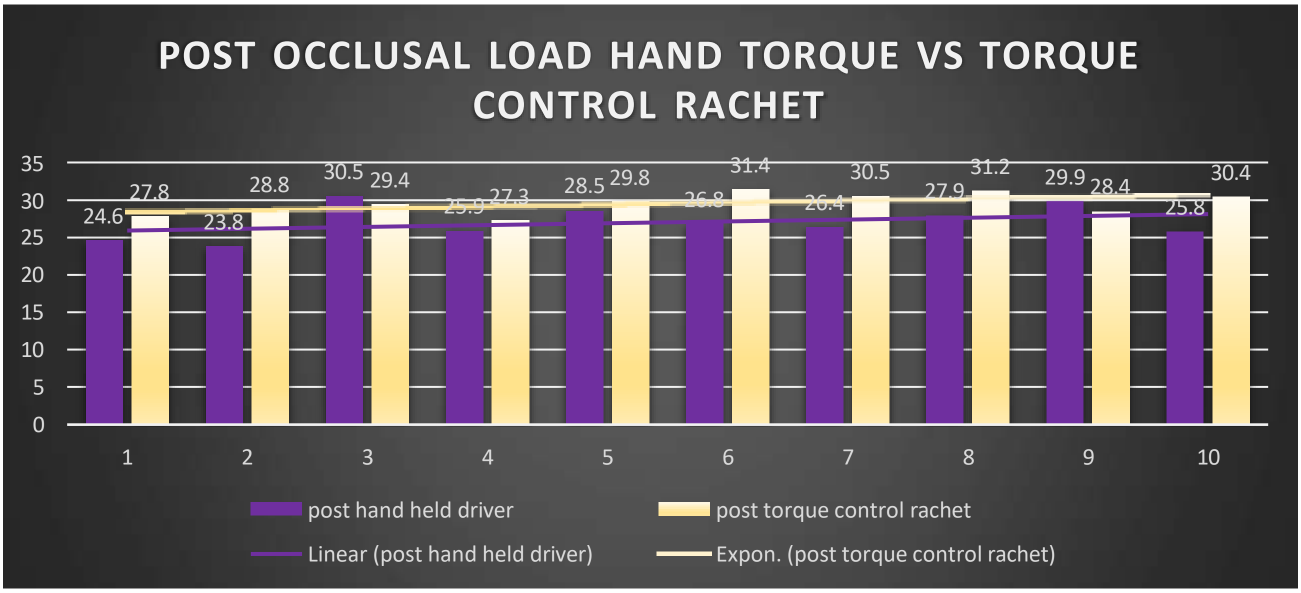


Table 5: Torque generated by hand held driver and torque controlled rachet after application of simulated occlusal load

Summary Of Data After Load	Hand Held Driver	Torque Control Rachet	Total
N	10	10	20
∑X	270.1	295	565.1
Mean	27.01	29.5	28.255
∑X2	7338.17	8720.34	16058.51
Std Dev	2.1799	1.4079	2.1958
Source	SS	df	MS
Between-treatments	31.0005	1	31.0005
Within-treatments	60.609	18	3.3672
Total	91.6095	19	**F = 9.2067**

f-ratio value is 9.2067; p-value is .007133; result is significant at $p < .05$.

Graph 4: Torque values generated by hand held driver and torque controlled rachet after application of simulated occlusal load



Result:	
X Values	**Y Values**
∑ = 270.1	∑ = 295
Mean = 27.01	Mean = 29.5
∑(X - Mx)2 = SSx = 42.769	∑(Y - My)2 = SSy = 17.84
X and Y Combined	
∑(X - Mx)(Y - My) = 5.12	
R value: r = 5.12 / √((42.769)(17.84)) = 0.1854	

r = 0.1854
value of R2, coefficient of determination = 0.0344

DISCUSSION

Implant-supported prostheses are considered a reliable treatment for restoring missing teeth, yet mechanical complications remain common even when biological outcomes are favorable. Long-term follow-up studies have shown survival rates above 95%, but complications such as screw loosening occur frequently and can significantly affect patient comfort and clinical workload. Screw loosening is a mechanical failure reported with an annual incidence of 2–3% and a cumulative rate that can exceed 20% over ten years [26]. This complication is primarily linked to inadequate preload, settling of screw threads, repeated functional loading, and variable tightening techniques [6,10,12,27].

Influence of Torque Application on Preload: The preload generated during abutment screw tightening is central to long-term stability, as it must withstand functional forces without surpassing the yield strength of the material. The accuracy of applied torque largely depends on the method of tightening. Manual tightening is unpredictable, often resulting in torque levels that are either too low to ensure stability or too high, risking screw deformation. Rajatihaghi et al. [27] showed that torque wrenches deliver more consistent and accurate values than hand drivers. Fahad Aziz et al. [28] reported that inconsistencies in closing torque reduce the integrity of the implant–abutment seal, underscoring the clinical impact of operator variability. Research has also indicated that factors such as screw length and the influence of cyclic loading play an important role in torque loss [29]. The way torque is applied affects preload retention [30], and marked inter-clinician variation has been observed when manual drivers are used [31]. Evidence from more recent work confirms that calibrated torque devices are more reliable in maintaining preload than hand tightening [32]. These findings support the use of torque-limiting devices to achieve predictable screw stability in implant-supported prostheses.

Effect of Cyclic Loading on Screw Stability: Cyclic occlusal loading reduces preload over time, regardless of how accurately it is applied at baseline. In this study, both groups showed measurable torque loss after 500,000 cycles, mirroring earlier experimental data. There are consistent decrease in removal torque for both internal and external hex implants subjected to repeated loading. It has also been confirmed that dimensional and preload changes in abutment screws of cantilever prostheses under function [33]. Bone anatomy has also been identified as a factor; variations in socket wall dimensions of the maxilla influence implant anchorage and load transfer. Implant configuration plays a part as well, with Bhumpattarachai et al. [34] reporting greater torque loss in narrow implants with angled screw channels. Other studies associated cyclic forces to accelerated torque reduction and showed that different abutment connection designs exhibit distinct preload loss patterns [35]. The present results follow a similar pattern, with torque wrenches maintaining preload more effectively than hand drivers after simulated functional loading.

Clinical Implications and Recommendations: Precise torque control is essential for maintaining preload and long-term stability of implant-supported prostheses. Rajatihaghi et al. [27] demonstrated that torque wrenches deliver more consistent values than hand drivers, while Saleh Saber et al. [28] examined different internal implant–abutment connections and showed that repeated torque application leads to measurable vertical displacement due to the settling effect. Among the tested designs, the octagon connection demonstrated the least settling, suggesting it provides more stable adaptation under functional torque. The role of screw length and the effect of cyclic loading, as described by Mohammed et al. [29], emphasize that preload stability depends on multiple biomechanical factors. Other investigations have confirmed that manual tightening is unpredictable, whereas torque-limiting devices ensure better preload retention [30,31]. Evidence also indicates that prosthesis design, bone morphology, and implant connection geometry influence how effectively preload is maintained over time [33-35]. These findings justify the present results, where screws tightened with torque wrenches demonstrated more consistent torque values both before and after cyclic loading. Hand drivers, in contrast, produced variable torque at baseline and showed greater torque loss following simulated occlusal function. This was in accordance with previous reports showing that hand tightening introduces both under- and over-torque, increasing the risk of screw loosening or deformation. The observation that torque-controlled devices better preserved preload under cyclic loading further supports their clinical use, since functional forces inevitably reduce torque values over time. The present study therefore highlihghts the view that torque wrenches not only achieve manufacturer-recommended torque levels more reliably but also maintain screw stability under functional loading conditions.

The data indicate that torque-limiting devices should be used routinely. Retightening after initial function helps counter the settling effect [29,33,35], and regular calibration is necessary to maintain the accuracy of torque wrenches [27,30]. This study was conducted in vitro and cannot fully reproduce intraoral conditions like saliva, temperature changes, or patient-related forces yet the evidence shows that torque-controlled application reduces screw loosening and improves the service life of implant-supported prostheses. In this study, torque wrenches achieved values closer to manufacturer recommendations and maintained preload more effectively after cyclic loading compared with hand drivers. Manual tightening produced greater variability, sometimes exceeding safe limits, and showed more pronounced torque loss during simulated function. These findings depicts the clinical value of torque-limiting devices for maintaining joint stability and reducing the risk of loosening. The results also highlight the need for continued research on different implant systems, abutment connections, and screw materials to confirm these outcomes in clinical settings.

Strengths and Limitations: The main strength of this study is the controlled in-vitro design, which eliminated patient-related factors and allowed precise measurement of torque using a digital torque gauge. The study provided clinically relevant data on screw stability by directly comparing hand drivers with torque wrenches under simulated occlusal loading. The use of cyclic loading enhanced the reliability of results by mimicking functional conditions. However, limitations include the inability to replicate all intraoral variables, such as saliva, temperature fluctuations, and complex occlusal forces. Only one implant system and one type of torque device were evaluated, which may restrict generalizability. Long-term clinical trials across different implant systems and torque devices are needed to confirm these laboratory findings and establish broader clinical recommendations.

CONCLUSION

Within the limits of this in-vitro study, it can be concluded that torque values achieved with hand-held drivers were inconsistent, reflecting the variability in individual operator technique. Although baseline torque values did not differ significantly from those achieved with torque wrenches, the effect of cyclic loading resulted in greater torque loss in manually tightened screws. Torque-limiting devices produced torque values closer to the manufacturer's recommendations and demonstrated more predictable stability under simulated function. These results signify the importance of mechanical torque application for minimizing screw loosening. While hand drivers remain widely used, their variability makes them less reliable for long-term prosthesis stability. Regular use of torque-limiting devices should be considered standard practice, and further studies should explore their impact on screw fracture resistance.

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