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Torque precision and deviation in mechanical TLDs: implications for implant-supported restorations

Abstract

Mechanical torque-limiting devices (TLDs) are widely used in implant dentistry to ensure accurate preload application to prosthetic screws, thereby enhancing the mechanical stability of implant-supported rehabilitations. However, variations in torque delivery remain a clinical concern. This systematic review aimed to evaluate the accuracy of mechanical TLDs by analyzing *In vitro* studies published between January 2000 and June 2025. Following PRISMA 2020 guidelines, eligible studies were identified across four databases and assessed for methodological quality using a modified Joanna Briggs Institute tool. Results revealed significant discrepancies between the torque values delivered by TLDs and those specified by manufacturers, with spring-type mechanisms demonstrating greater accuracy than beam or friction-based types. Factors such as repeated use, autoclave sterilization, and device brand significantly affected performance, with torque deviations exceeding ±10% in many cases. These findings underscore the importance of routine calibration and highlight the need for clinicians to consider both device type and usage history in clinical protocols. Further research is recommended to assess real-world performance and to support the development of advanced TLDs with integrated calibration features.

Keywords: dental implants, fixed prosthesis, prosthodontics, dental materials

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Introduction

Modern implant dentistry has advanced significantly in recent decades, achieving high clinical success rates and substantial patient satisfaction. However, one of the main causes of mechanical failure in implant-supported rehabilitations remains the loosening or fracture of prosthetic screws events that can compromise prosthesis stability, cause pain and inflammation, and, in more severe cases, lead to implant loss.[1,2]

These complications are often associated with improper torque application during the installation of prosthetic abutments. The torque applied to the abutment screw is responsible for generating the optimal preload necessary to keep the assembly firmly coupled to the implant, even under repeated masticatory loads. When torque is insufficient, preload is not adequately maintained, which can result in progressive loosening; conversely, excessive torque increases the risk of plastic deformation or fracture of the screw.[3,4]

Therefore, precise and controlled torque application is essential for the biomechanical success of implant-supported restorations. To address this need, torque-limiting devices (TLDs) have been developed. These instruments are designed to standardize the force applied to implant screws, reducing the variability observed with manual torque application. TLDs can be classified as either electronic or mechanical, with the latter being more commonly used in clinical practice due to their lower cost, ease of use, and independence from batteries or digital calibration.[5,6]

Mechanical TLDs are manufactured with different internal mechanismssuch as spring-type, beam-type, or friction-based systemseach with distinct performance characteristics. However, studies have shown that these devices are not immune to a loss of accuracy over time. Factors such as mechanical wear, repeated use, autoclave sterilization, and material quality can all compromise the torque output relative to the nominal setting.[7-9]

The *In vitro* literature reveals considerable variability among different TLD brands and models, even when calibrated for the same target torque. Many devices exhibit deviations exceeding ±10% from the manufacturer-recommended values, particularly after multiple cycles of use and sterilization.[10,11] This raises clinical concerns, as even small variations in applied torque may directly affect the stability of the implant–abutment connection, especially in high occlusal load areas.[12]

Given this evidence, it is essential to systematically evaluate the accuracy of mechanical torque-limiting devices used in implant dentistry. This systematic review aims to gather and critically analyze the available *In vitro* studies on the performance accuracy of these devices, focusing on influencing factors such as mechanism type, brand, repeated use, and sterilization ultimately supporting safer and more effective clinical decision-making.

Methodology

This systematic review was conducted in accordance with the PRISMA 2020 guidelines (Preferred Reporting Items for Systematic

Reviews and Meta-Analyses),[1] with the aim of identifying, critically appraising, and synthesizing the available evidence regarding the accuracy of mechanical torque-limiting devices (TLDs) used in implant dentistry.

a) **Research question**

The research question was structured based on the PICO framework:

a) **P (Population):** Mechanical torque-limiting devices used in implant dentistry;

b) **I (Intervention):** Torque application to implant screws;

c) **C (Comparison):** Actual torque applied versus the torque specified by the manufacturer;

d) **O (Outcome):** Accuracy (precision) of delivered torque.

b) **Information sources and search strategy**

A systematic search was performed in the following electronic databases:

a) PubMed/MEDLINE

b) Scopus

c) Web of Science

d) Embase

c) **Inclusion criteria**

Studies were included if they met the following criteria:

a) In vitro studies evaluating mechanical torque-limiting devices (TLDs) applied to dental implant screws;

b) Studies comparing the measured torque with the manufacturer's nominal torque specification;

c) Articles published in **English**, between **January 2000 and June 2025**;

d) Studies employing **objective torque measurement methods** (e.g., load cell, digital torque meter).

d) **Exclusion criteria**

The following were excluded:

a) Studies focusing exclusively on **electronic devices**;

b) **Review articles**, **case reports**, **letters to the editor**, **commentaries**, or **expert opinions**;

c) Clinical studies without standardized mechanical evaluation;

d) **Duplicate publications** or those with **insufficient data** for analysis.

e) **Study selection**

Study selection was performed in two stages by **two independent reviewers**:

1. **Title and abstract screening** to exclude clearly irrelevant studies;
2. **Full-text review** of potentially eligible articles.

Disagreements were resolved by **consensus** or by consulting a **third reviewer**.

f) **Data extraction**

Data were extracted using a **standardized form**, including the following variables:

a) Brand and type of TLD;

b) Target torque and measured torque;

c) Measurementmethod;

d) Numberofrepetitions;

e) Presenceofsterilizationcycles;

f) Mean deviations from nominal torque (expressed in N·cm or percentage).

Data extraction was conducted **independently** by two reviewers.

g) **Risk of bias assessment**

The risk of bias in the included studies was assessed independently by two reviewers using a **modified version** of the **Joanna Briggs Institute (JBI) tool** for ***In vitro*** **laboratory studies**.[2] Thefollowingcriteriawereevaluated:

a) Methodologicalclarity;

b) Standardizationofmeasurementprocedures;

c) Controlof experimental variables;

d) Disclosure of conflicts of interest.

Any discrepancies were resolved by **consensus**.

h) **Synthesis of results**

Due to methodological heterogeneity among the included studies-particularly regarding device brands, measurement protocols, and target torque values- a **narrative synthesis** of the findings was conducted. Resultsweregroupedaccording to:

a) Internal mechanism type (spring, beam, friction-based);

b) Effects of repeated use and sterilization;

c) Performance variations across different brands;

d) Clinical implications of observed torque deviations.

Study outcome of literature

Overall accuracy of mechanical devices

Several studies have shown that mechanical torque-limiting devices (TLDs) often deliver torque values that differ from those specified by the manufacturers. Among the various types, spring-based mechanisms generally exhibit greater accuracy compared to beam- or friction-type devices.[11-14]

In a study by Arshad et al.,[15] spring-type torque wrenches showed mean deviations of ±1.7 N cm from the target torque of 30 N cm, whereas beam-type devices presented deviations of up to ±4.5 N cm.

Similarly, Suzuki et al.,[16] reported systematic under-torquing associated with beam-type instruments.

Effect of sterilization and reuse

Autoclave sterilization cycles and repeated use significantly reduce the accuracy of mechanical TLDs. Squier et al.[17] observed torque losses of up to 15% after 20 sterilization cycles in spring-type torque

wrenches. Kim et al.[18] reported statistically significant reductions in delivered torque after 100 uses.

Sterilization affects the internal mechanisms—especially metal springs—leading to elasticity loss or deformation, particularly in lower-quality devices or those made with less durable materials.[19-21]

Variability among manufacturers

Torque delivery varies considerably among devices from different manufacturers. In a comparative study involving six brands, Mulla et al.[22] reported delivered torque values ranging from 28.4 to 37.1 N cm in devices calibrated for 35 N cm. Mendonça et al.,[23] showed that even devices certified according to ISO standards can exhibit significant discrepancies in torque output, suggesting inconsistencies in factory calibration processes.

Clinical implications

Deviations in applied torque can compromise the mechanical stability of implant-supported rehabilitations. Insufficient preload may lead to micromovement and screw loosening, while excessive torque increases the risk of component deformation or fracture.[24] Barbosa et al.[25] and Cavallaro et al.[26] emphasized that deviations as small as 5 N cm may negatively affect the longevity of implant-supported prostheses. For this reason, periodic calibration of TLDs is strongly recommended- ideally every 6 to 12 months or after approximately 100 uses.[27] Some manufacturers offer verification devices or calibration services, although these are still underutilized in routine clinical practice.[28]

Discussion

This systematic review highlights significant variability in the torque accuracy of mechanical torque-limiting devices (TLDs) used in implant dentistry. Although these devices are widely adopted in clinical practice for standardizing torque application, the findings demonstrate that many fail to deliver torque values that consistently match manufacturer specifications. These discrepancies raise important concerns regarding the long-term mechanical stability of implant-supported rehabilitations. Consistent with previous literature, spring-type TLDs were generally more accurate than beam- or friction-type mechanisms.[11-16]

The superior performance of spring-based devices may be attributed to their more consistent elastic response under load, which is less prone to operator-dependent variability. However, even among spring-type devices, accuracy can deteriorate over time, particularly following repeated use or sterilization cycles.[17-21] These findings emphasize that device longevity and maintenance should be factored into clinical protocols. The effects of sterilization and repeated use are especially critical. Studies have shown that torque loss can reach up to 15% after only 20 sterilization cycles, and statistically significant reductions can occur after as few as 100 uses.[17-19]

The internal components, particularly metallic springs, are susceptible to fatigue, deformation, and corrosion, which impair the device's ability to deliver the intended preload. Devices constructed with lower-grade materials or lacking protective coatings may be especially vulnerable to these effects. Inter-brand variability further complicates clinical decision-making. Even among ISO-certified devices, significant discrepancies in delivered torque were observed.[21-23]

These differences likely reflect inconsistencies in manufacturing tolerances, quality control, and calibration procedures. For clinicians, this underscores the importance of not relying solely on brand reputation or certification labels, but also seeking independent performance data when selecting TLDs. From a clinical perspective, deviations in applied torqueeven as small as 5 N cm can compromise the preload at the implant-abutment interface.[24-26]

This may lead to micromovements, screw loosening, and eventual component fracture, jeopardizing the longevity of the prosthetic restoration. Given these risks, routine calibration and verification of mechanical TLDs should be a standard part of clinical protocols. While some manufacturers offer verification tools or recalibration services, their use remains limited in practice.[27,28]

Despite the robust findings, this review has some limitations. First, it is based exclusively on *In vitro* studies, which may not fully replicate intraoral conditions such as temperature fluctuations, humidity, and operator technique variability. Second, the methodological heterogeneity across studiesparticularly in measurement protocols and torque targets precluded a quantitative meta-analysis.[29,30]

Third, the review did not assess economic factors, such as the cost-effectiveness of regular calibration or the impact of device replacement intervals. Future studies should investigate the clinical performance of mechanical TLDs under real-world conditions and explore the development of smart torque tools with integrated feedback or auto-calibration features. Research into material science may also improve the durability of internal mechanisms, reducing performance degradation over time..

Final considerations

Mechanical torque-limiting devices are essential tools in modern implant dentistry. However, their accuracy may be affected by factors such as mechanism type, manufacturer, frequency of use, and exposure to sterilization cycles. Spring-type devices tend to show superior performance in terms of torque accuracy compared to beam or friction-based models. Clinicians should remain aware of inter-brand variability and the aging of devices over time. Implementing calibration protocols and maintaining usage logs in clinical practice is crucial to ensure treatment predictability and the long-term success of implant rehabilitations. Future research should investigate the performance of these devices under real clinical conditions and explore the development of technologies with self-correction mechanisms or integrated torque validation systems.

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Data availability

All data analyzed during this study are available from the corresponding author upon reasonable request.

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None

Conflicts of interest

All data analyzed during this study are available from the corresponding author upon reasonable request. The authors report no conflicts of interest regarding any of the products or companies discussed in this article.

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