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GRADUATION PROJECT

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TORQUE VALUES IN DENTAL IMPLANT PLACEMENT: A REVIEW OF MANUFACTURER RECOMMENDATIONS

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ABSTRACT

Introduction: Insertion torque is a key intraoperative parameter influencing the primary stability of dental implants and osseointegration. While sufficient torque is required to achieve adequate mechanical fixation, excessive compression of the bone may affect the tissue response. Despite its clinical importance, the optimal insertion torque range remains debated, and manufacturer recommendations vary among implant systems. **Objective**: The aim was to analyze the effect of different insertion torque values on primary stability and osseointegration of dental implants and to compare clinical outcomes with manufacturer-recommended torque ranges. **Material and methods:** A structured literature search was performed across multiple platforms. Clinical studies published between 2015 and January 2026 investigating insertion torque and implant stability were included. Data extracted from the selected studies included insertion torque values, implant stability quotient, marginal bone level changes, and implant survival rates. Manufacturer instructions for use from major implant systems were also reviewed. **Results**: Nine clinical studies met the inclusion criteria. Lower insertion torque values generally resulted in more micromotion, while higher insertion torque values resulted in increased primary stability at placement. However, implant survival rates were comparable across different torque ranges. Several studies reported greater marginal bone loss when torque exceeded approximately 50-60 N·cm, particularly when manufacturer recommendations were surpassed. **Conclusion**: The available clinical evidence supported the existence of a physiological torque window in implant placement. Moderate torque values, generally between 30-50 N·cm, appeared to provide an optimal balance between mechanical stability and preservation of peri-implant bone. Insertion torque should therefore be optimized according to clinical conditions and manufacturer guidelines rather than maximized.

KEYWORDS

Dentistry, Implantology, Insertion torque, Osseointegration, Primary stability.

ABSTRACT

Introducción: El torque de inserción es un parámetro intraoperatorio clave que influye en la estabilidad primaria de los implantes dentales y en el proceso de osteointegración. Aunque es necesario aplicar un torque suficiente para lograr una adecuada fijación mecánica, una compresión excesiva del hueso puede afectar la respuesta tisular. Además, el rango óptimo de torque sigue siendo objeto de debate y recomendaciones de los fabricantes varían entre los distintos sistemas de implantes. **Objetivo**: Analizar el efecto de diferentes valores de torque de inserción sobre la estabilidad primaria y la osteointegración de los implantes dentales, y comparar los resultados clínicos con recomendaciones de fabricantes. **Material y métodos**: Se realizó una búsqueda bibliográfica estructurada en varias bases de datos. Se incluyeron estudios clínicos publicados entre 2015 y enero de 2026 que evaluaran el torque de inserción y la estabilidad de implantes. Se analizaron los valores de torque, el índice de estabilidad del implante, los cambios en el nivel óseo marginal y la supervivencia de los implantes. También se evaluaron las Instrucciones de Uso de los principales sistemas de implantes. **Resultados**: Nueve estudios clínicos cumplieron los criterios de inclusión. Los valores más altos de torque se asociaron con mayor estabilidad primaria, pero no con mayores tasas de supervivencia. Algunos estudios observaron mayor pérdida ósea marginal cuando el torque superaba aproximadamente los 50–60 N·cm. **Conclusión**: Los resultados sugirieron la existencia de una ventana fisiológica de torque, donde valores moderados (30–50 N·cm) ofrecieron un equilibrio entre estabilidad mecánica y preservación del hueso periimplantario. En consecuencia, el torque debe optimizarse según las condiciones clínicas y las recomendaciones del fabricante.

KEYWORDS

Odontología, Estabilidad primaria, Implantología, Osteointegración, Torque de inserción.

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ABBREVIATIONS

N·cm: Newton Centimeter

BIC: Bone-to-implant Contact

ISQ: Implant Stability Quotient

MBL: Marginal Bone Loss / Marginal Bone Level

IFU: Instructions For Use

IT: Insertion Torque

RCT: Randomized Clinical Trial

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

PICO: Population, Intervention, Comparison, Outcomes

1. INTRODUCTION

1.1. Definition and General concepts

1.1.1. Dental implant

A dental implant is a titanium screw-like device that functions as an artificial tooth root designed to support a dental prosthesis (Figure 1). Over the years, dental implants have become one of the most reliable and esthetic options for tooth replacement (1–3).

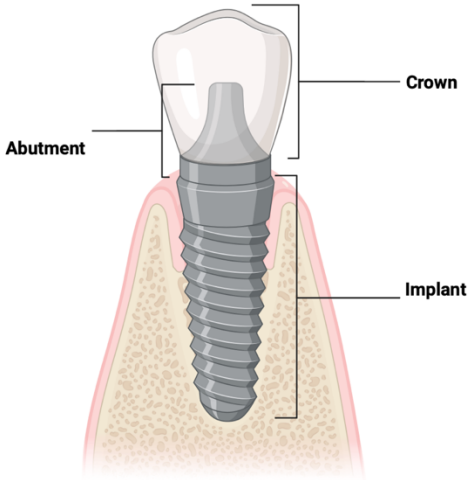


Figure 1. Example of a dental implant

However, the long-term success of a dental implant does not rely on a single factor. The long-term outcome depends on three interrelated aspects: the surgical technique used, the initial mechanical engagement at placement, and the subsequent biological process of osseointegration (2,4,5).

Clinically, these parameters are connected through one key concept: the insertion torque. Following the manufacturer's recommendations for torque application is essential to ensure optimal primary stability and promote successful bone integration (5).

1.1.2. Insertion torque

Insertion torque corresponds to the specific amount of rotational force, expressed in N·cm (Newton-centimeter), applied to a dental implant as it is screwed into the prepared osteotomy. This parameter serves as a practical intraoperative indicator of the implant’s mechanical stability at placement (5).

Achieving adequate torque during placement ensures secure anchorage in the bone while preventing over-compression of the surrounding tissues, which could compromise vascularity and healing (6).

Although all dental implants share the same fundamental objective, stable integration within the alveolar bone, manufacturers have developed distinct systems. Variations in thread shape, surface roughness, taper, and connection design all influence how the implant engages with the bone (6–8). As a result of these design variations, the optimal torque value differs among implant systems. Manufacturers aim to balance mechanical stability with biological safety (4).

Excessive or insufficient torque may lead to biological complications, for this reason, controlled torque application is essential for predictable clinical outcomes (2,4,5).

1.1.3. Primary stability

Beyond torque itself, another crucial concept emerges: primary stability. While insertion torque quantifies the immediate resistance during placement, primary stability reflects the overall mechanical fixation that allows successful healing to begin.

Primary stability is the immediate mechanical fixation of the implant in bone and serves as the foundation for predictable osseointegration. Achieving an appropriate level of stability at the time of placement is therefore critical to ensure predictable healing and long-term clinical success. This mechanical fixation provides immediate resistance to any micromotion prior to biological healing and bone remodeling (5,8–11).

Primary stability describes how firmly the implant mechanically engages the surrounding bone. It mainly depends on bone quality, implant design and the surgical protocol applied (10,11). Adequate stability reduces micromovements at the bone-implant interface. This prevents fibrous tissue formation and lowers the risk of early implant failure. Generally, micromovements exceeding 50–100 µm are considered detrimental (4,5).

Several factors influence primary stability (Table 1). Dense cortical bone ensures stronger retention than soft trabecular bone. Additionally, thread geometry, pitch, depth, and taper play a crucial role in achieving firm initial engagement (8).

Table 1. Factors influencing primary stability

Category	Factors	Influence on stability	
Bone-related	Bone quality (D1-D4)	Primary stability increases with bone density. Dense cortical bone (D1-D2) provides greater resistance and friction, while low-density trabecular bone (D3-D4) leads to reduced mechanical retention.	(8–11)
	Cortical thickness	Thicker cortical plates offer a larger contact area for implant thread, enhancing mechanical fixation and insertion torque.	(8,9)
Implant-related	Thread design	Deeper and more aggressive threads enlarge the bone-implant contact area, increasing frictional resistance and stability, particularly in softer bone.	(8,12)
	Implant shape (tapered vs cylindrical)	Tapered implants compress surrounding bone and achieve higher torque, whereas cylindrical designs distribute forces more evenly, reducing stress concentration.	(6,13)
	Surface roughness	Micro-roughened or hydrophilic surfaces promote better interlocking with bone at the microscopic level, indirectly enhancing primary stability.	(7,14)
Surgical	Drilling protocol	Undersized drilling increases bone compression and torque values, while standard or oversized preparation may reduce stability.	(10,11)
	Insertion torque control	Proper torque adjustment prevents over-compression and microfractures, maintaining optimal balance between mechanical and biological stability.	(2,4,15)
Patient-related	Bone density variation by site	Posterior maxilla often exhibits lower bone density than the anterior mandible, requiring adapted torque and implant design.	(9,16)
	Systemic conditions	Alter bone metabolism and remodeling capacity, reducing mechanical engagement and delaying osseointegration.	(16–18)

1.1.4. Osseointegration

Osseointegration is the biological process by which a direct structural and functional connection is established between living bone and the surface of a dental implant. It represents the biological foundation of implant success, ensuring stability and the ability of the implant to support functional loads without movement or discomfort (4,19,20).

After placement, a cascade of biological events begins. A blood clot forms around the implant and serves as a scaffold for new tissue formation. Osteogenic cells then differentiate into osteoblasts and begin depositing bone matrix directly onto the implant surface.

Over time, the early woven bone gradually remodels into mature lamellar bone, establishing a strong bone-implant interface (21). This process provides the biological basis for the implant's secondary stability.

Secondary stability refers to the mechanical retention of the implant resulting from osseointegration, arising from new bone formation and maturation at the implant-surface interface (4,5). Achieving sufficient initial stability is therefore a critical prerequisite for predictable healing, particularly in early or immediate loading protocols (11,22).

1.1.5. Importance of primary stability and osseointegration

Long-term implant success depends on several factors: implant design, surgical technique, and the balance between mechanical stability and biological response. Once the implant is placed, optimal fixation allows bone remodeling to occur under stable conditions (2,4). If movement occurs during this phase, it may disturb the healing cascade, while optimal mechanical conditions favor direct bone apposition and early maturation of the bone-implant interface (5).

Ultimately, osseointegration ensures not only physical anchorage but also the functional integration of the implant within the masticatory system (12,13). The quality of this biological bond determines the implant's capacity to withstand long-term occlusal loads and maintain peri-implant bone health.

For this reason, achieving a balance between mechanical engagement and biological response is considered one of the key objectives in modern implantology (23). The interaction

between insertion torque, primary stability, and osseointegration determines implant longevity, which makes the understanding of these parameters essential for clinical success (4).

1.2. Background and relevance of torque control

1.2.1. History of research about primary stability

The concept of primary stability was introduced through Brånemark's pioneering work in the 1960s. He first introduced the notion of osseointegration as a direct structural and functional connection between living bone and the surface of a load-bearing implant.

This discovery laid the foundation for modern implant dentistry, emphasizing that a stable mechanical fixation at the time of placement is essential for long-term clinical success (24). In the following decades, researchers studied how implant geometry, surgical technique and bone density affect both the mechanical fixation and initial stability of implants.

By the 1980s and 1990s, researchers began differentiating primary stability, the initial mechanical anchorage, and secondary stability, the biological fixation achieved through osseointegration (25–27). This distinction provided a clearer understanding of the time-dependent nature of implant stability and its relationship with healing dynamics.

In the mid 1990s, a major breakthrough occurred: Meredith *et al.* introduced resonance frequency analysis (RFA) as a non-invasive method to quantify implant stability through the implant stability quotient (ISQ) (3,26). Since then, numerous studies have examined the correlation between insertion torque and other factors such as ISQ values, bone density, implant macro-design, and surgical protocols like undersized drilling (3,19,26).

Today, achieving optimal primary stability is recognized as essential for immediate or early loading and is one of the strongest predictors of long-term osseointegration and implant success and survival rates.

1.2.2. Role of torque in short and long-term success

Insertion torque (IT) has become a critical intraoperative parameter to assess primary stability and predict implant prognosis. Clinically moderate torque values, around 25 to 35 N·cm, are

generally associated with reliable osseointegration and minimal complications. They are considered ideal for achieving sufficient mechanical retention while avoiding excessive bone stress.

During the early phase, controlled torque reduces micromotion at the bone-implant interface, creating favorable conditions for bone healing. Over time, this mechanical stability transforms into biological fixation, leading to long-term osseointegration (3,25,26). In this sense, torque control acts as a bridge between surgical technique and biological response, supporting both immediate and lasting success.

1.2.3. Consequences of insufficient or excessive torque

Both insufficient and excessive torque can compromise implant outcomes. If the insertion torque is too low, the implant may not be securely anchored, leading to micromotion or early mobility which may result in potential failure, and excessive torque can cause compression, microfractures, impaired blood flow, and subsequent marginal bone loss (15).

Finding the right balance ensures that the implant is stable enough to allow a proper healing process, while still preserving bone vitality. Proper torque control therefore plays a central role in achieving predictable osseointegration and maintaining long-term clinical success.

1.3. Theoretical framework: Mechanical and biological aspects

1.3.1. Mechanical aspect

From a clinical perspective, implant insertion usually starts with site preparation using a sequence of drills of increasing diameter, creating osteotomy slightly narrower than the implant. The implant is then introduced using a motorized handpiece for most of its depth, followed by manual tightening with a torque wrench to achieve the desired insertion torque (28).

As mentioned previously, torque represents the rotational resistance between the implant threads and the surrounding bone (29,30). As the implant advances in the osteotomy, frictional resistance increases with bone density and elastic modulus. This relationship directly improves primary stability while reducing micromotion (22,25–28).

The geometry and macro-design of the implant play a fundamental role in determining torque behavior (4,6). Cylindrical implants tend to distribute forces more evenly but usually generate

lower torque values. In contrast, tapered implants compress the surrounding bone, producing stronger fixation, especially with reduced bone density (13).

Thread characteristics, such as depth, pitch, and profile, also modulate mechanical performance. A deep and aggressive thread increases the contact area and friction, enhancing stability in softer bone, while shallower or finer threads are better suited for dense cortical regions to prevent excessive compression (12).

Bone quality is also a key factor influencing insertion torque. Dense cortical bone, types D1-D2, naturally generates higher torque values due to greater resistance, while low-density trabecular bone, types D3-D4, yields lower torque and a higher risk of micromotion (2,3,9). Mechanical success therefore depends on achieving sufficient torque for stability while avoiding excessive stress on the surrounding bone (15,31).

1.3.2. Biological aspect

Biologically, insertion torque is crucial in directing the early healing events at the bone-implant interface. In addition to providing immediate mechanical stability, the applied torque influences the biological cascade that determines the success or failure of osseointegration (32,33).

When an implant is inserted, the bone surrounding the threads experiences compressive and shear forces. When torque remains within physiological limits, it stimulates bone remodeling and increases bone-to-implant contact (BIC). This process involves higher osteoblastic activity and greater mineralized matrix deposition (34,35).

However, excessive torque can exceed the bone's adaptive capacity. This over-compression reduces blood flow, causes microfractures, and may even lead to peri-implant bone necrosis. This biological disturbance can hinder osseointegration and promote fibrous encapsulation instead of bone integration. While adequate torque is essential for initial stability, excessive torque can paradoxically reduce long-term biological stability (36,37).

Bone is not a passive structure. It responds dynamically to mechanical stimuli through a process called mechano-transduction. Osteocytes, the mechanosensitive cells embedded within the bone matrix, detect strain and regulate the balance between bone formation and resorption.

Optimal torque generates moderate mechanical strain, which promotes osteoblast differentiation and new bone formation along the implant surface (38). In contrast, excessive micromovement, typically between 50–100 µm, can disrupt healing. Instead of bone formation, fibrous tissue develops at the interface (35).

Several factors modulate the biological response to torque, including bone density, implant surface texture, and patient-related conditions. For example, roughened and hydrophilic surfaces enhance osteogenic cell attachment and improve osseointegration even under low insertion torque (39,40).

In low-density bone, where primary mechanical retention is limited, the biological phase of healing becomes the main contributor to long-term stability (40,41). Ultimately, successful osseointegration depends on a delicate balance between mechanical compression and biological vitality. The applied torque must stabilize the implant while preserving the bone's regenerative capacity (39-42).

1.3.3. Factors influencing torque and stability

The interaction between mechanical and biological parameters during implant placement is governed by multiple factors related to bone, implant design, surgical technique, and patient characteristics (3,7). Understanding how these variables influence insertion torque and primary stability is essential for achieving predictable osseointegration (37).

Bone-related factors play a decisive role in torque behavior. Bone density, typically following Misch's classification from D1 (very dense) to D4 (very soft), directly affects the resistance encountered during implant insertion (2,9,41). Dense cortical bone, with its limited elasticity, generates higher torque values. In contrast, trabecular bone offers less resistance and therefore lower stability (11,33). Additionally, cortical thickness and trabecular organization influence how forces are distributed along the implant surface.

Implant-related factors include both macro-design and surface characteristics. Tapered implants tend to produce higher insertion torque by compressing the bone laterally, whereas cylindrical designs distribute stress more uniformly. Thread geometry, pitch, depth, and profile determine how efficiently the implant engages with the surrounding bone (7,39).

At the microscopic level, surface roughness and hydrophilic surface treatments enhance osteoblastic attachment and bone formation, supporting secondary stability even when initial torque is moderate (7,42).

Surgical and clinical factors further modulate these interactions. The drilling protocol, standard, undersized, or osteotome-assisted, directly affects bone compression and the resulting insertion torque (10,17). Controlled insertion speed and the use of a torque-limiting device help prevent excessive tightening. Operator experience also affects the precision of torque application and the final seating of the implant (14,36,43).

Finally, several patient-related factors can influence bone density and healing capacity. These include age, metabolic bone disorders, systemic diseases and the use of certain medications (16,41). Conditions like osteoporosis or diabetes may reduce primary stability and delay osseointegration (3,18).

All these factors interact dynamically to determine both the optimal torque value and the resulting implant stability. A comprehensive understanding of their combined influence is essential for clinicians to adapt their surgical technique and achieve consistent long-term outcomes (44).

1.4. Current state of the literature

Recent in-vitro and clinical studies have improved our understanding of the relationship between insertion torque, primary stability and early osseointegration. However, the available evidence remains heterogeneous and highlights several key research gaps.

In vitro studies consistently demonstrate a clear relationship between insertion torque, micromotion and bone density. For example, Brizuela-Velasco *et al.* (2015) found that torque and micromotion were inversely related up to 34 N·cm, after which the relationship became exponential (45). Similarly, biomechanical analyses have shown that implant macro-geometry and bone density significantly influence the relationship between torque and stability in controlled bone models (46). While these findings provide valuable mechanistic insight, their clinical applicability remains limited, as *in vitro* conditions cannot fully reproduce the biological and patient-related variability encountered *in vivo*.

In contrast, clinical studies report more variable outcomes. Randomized trials comparing different insertion torque values have shown that higher torque is generally associated with increased primary stability. For instance, a 2018 study reported a mean insertion torque value of 58 N·cm for tapered implants versus 29 N·cm for cylindrical ones, although the differences in ISQ values were less pronounced (19). This suggests that higher torque does not necessarily translate into proportionally greater clinical stability, highlighting a potential dissociation between mechanical measurements and biological outcomes.

Moreover, some clinical studies have associated higher insertion torque values (≥50 N·cm) with increased marginal bone loss (47), whereas others report comparable implant survival rates across different torque ranges. This apparent contradiction indicates that the relationship between insertion torque and implant success is not linear, but rather dependent on a balance between mechanical fixation and biological response.

Several factors may explain these inconsistencies. First, there is considerable heterogeneity in study design, including differences in implant systems, surgical protocols, bone quality, and outcome measures. Second, the use of *in vitro* versus clinical models limits direct comparability between studies. Third, the lack of standardized torque thresholds across manufacturers further complicates the interpretation of results. This methodological variability reduces the generalizability of findings and may explain the absence of a universally accepted optimal torque range.

Furthermore, only a limited number of longitudinal studies have systematically compared manufacturer-recommended torque values with long-term clinical outcomes, such as marginal bone loss and implant survival beyond the early healing phase. This lack of long-term evidence represents a significant gap in the literature.

Overall, while current evidence confirms the importance of insertion torque as a key factor in implant stability, it also suggests that torque should not be considered in isolation. Instead, its clinical relevance appears to be context-dependent, influenced by biomechanical, biological, and patient-related factors. Therefore, more standardized, long-term, and multi-system, clinical studies are needed to establish reliable and clinically applicable guidelines. In this context, the present review focuses exclusively on clinical human studies in order to provide evidence that is directly relevant to practice.

1.5. Clinical implications and manufacturers recommendations

Manufacturer-recommended insertion torque values serve as practical guidelines for clinicians, aiming to achieve mechanical stability without compromising bone health. However, recent evidence shows that these recommendations cannot be universally applied to every clinical situation.

Experimental research has shown that both implant macro-geometry and drilling protocols strongly influence the achieved torque and resulting primary stability. Consequently, two implant systems or preparation techniques can produce very different insertion torque and ISQ values even within the same bone type (45).

Clinical and in-vivo studies confirm that local bone density is a key determinant of insertion torque and stability. Therefore, manufacturer guidelines should always be interpreted according to site-specific factors, including cortical and trabecular architecture. Moreover, a recent systematic review and meta-analysis found that implants placed with low insertion torque (≤ 35 N·cm) had similar survival rates after 24 months under immediate loading conditions. This finding challenges the idea of a universal “ideal” torque threshold (48).

Taken together, these findings support a personalized approach. Insertion torque should be adapted to bone density, implant design, and surgical protocol, rather than rigidly following manufacturer recommendations. Such an individualized strategy better preserves bone vitality while ensuring both mechanical stability and long-term osseointegration.

1.6. Justification and aim of the study

Despite extensive research on implant stability, there is still no clear consensus regarding the ideal insertion torque values applicable to different clinical conditions. Current evidence remains fragmented, with varying recommendations among manufacturers and inconsistent findings in the literature. Understanding how insertion torque influences both primary stability and the biological process of osseointegration is therefore essential to improve implant success and longevity.

The main objective of this study is to analyze the relationship between insertion torque, primary stability and osseointegration by integrating both mechanical and biological perspectives. By comparing experimental and clinical findings with manufacturer recommendations, this review

seeks to clarify the parameters that ensure optimal implant performance. Ultimately, the study aims to contribute to evidence-based clinical practice by establishing a more rational and individualized approach to torque selection, improving predictability and long-term outcomes in implant dentistry.

2. OBJECTIVE

To analyze the effect of different insertion torque values on primary stability, marginal bone remodeling, osseointegration and implant survival, while comparing clinical outcomes with manufacturer-recommended torque ranges.

3. MATERIAL AND METHODS

3.1. Formulation of research question

To guide the structure and focus of this review, a structured electronic literature search was performed in order to answer the following question: *"In patients receiving dental implants, how do different insertion torque values influence primary stability and subsequent osseointegration, compared with other torque values or manufacturer recommended torque threshold?"*

This was based on the PICO (Population, Intervention, Comparison, Outcome) framework:
P (Population): Patients receiving dental implants
I (Intervention): Placement of dental implants using different insertion torque values
C (Comparison): Comparison with alternative torque values, manufacturer-recommended torque ranges, or different implant macro-designs and drilling protocols.
O (Outcome): Primary stability (insertion torque and ISQ), osseointegration parameters, marginal bone level changes, and implant survival.

3.2. Eligibility criteria

A set of predefined inclusion and exclusion criteria was used to identify studies relevant to torque values, implant stability and osseointegration. Only clinical studies were considered to ensure a comprehensive review.

3.2.1. Inclusion criteria

Studies were included if they met the following requirements:

- Type of study: Clinical studies, including randomized controlled trials, cross-sectional observational studies, retrospective or prospective cohort studies, case series with > 5 patients, comparative studies.
- Publications in English, Spanish or French.
- Published between 2015 and January 2026.
- Focus of interest: Investigation of the relationship between insertion torque and primary stability, implant stability quotient (ISQ), osseointegration outcomes, marginal bone level changes, or implant survival.
- Implant characteristics: titanium dental implants of any system, design or surface treatment.

3.2.2. Exclusion criteria

Exclusion criteria consist of: Experimental studies *in vitro* and in animals, letters or comments to the editor, expert reports, case reports. Moreover, the studies published in languages other than English, Spanish or French and studies published earlier than 2015.

3.3. Data sources and search

A comprehensive literature search was performed across the following databases: PubMed, Medline, Google Scholar, Wiley Online Library, Cochrane Library, ScienceDirect, and Scopus.

The search strategy combined Medical Subject Headings (MeSH) terms and free-text keywords related to insertion torque and implant stability. Boolean operators (AND, OR) were used to refine the search.

An example of the search equation used in PubMed is as follows:
(“dental implant” AND “insertion torque”) AND (“primary stability” OR “implant stability quotient” OR “ISQ”) AND (“osseointegration” OR “marginal bone loss” OR “implant survival”) AND (“manufacturer” OR “recommendation”).
This search strategy was adapted as necessary for each database.

Additionally, the reference lists of relevant articles were manually screened to identify further eligible studies. Duplicate records were removed prior to screening.

3.4. Study selection

The study selection process was conducted in two stages. First, titles and abstracts were screened to identify potentially relevant articles. Subsequently, full-text articles were assessed according to the predefined eligibility criteria.

Only studies meeting all inclusion criteria were included in the final analysis. The selection process followed a structured approach in accordance with PRISMA guidelines.

3.5. Data extraction

For each included study, the following information was systematically extracted:

- Study characteristics: authors, year of publication, study design, sample size.
- Implant characteristics: implant system, macro-design, thread profile, surface treatment, and dimensions.
- Bone characteristics: bone type or density
- Intervention details: insertion torque values and drilling protocol, loading protocol
- Outcome measures:
    - Primary stability (Insertion torque and ISQ)
    - Histomorphometric data (BIC)
    - Marginal bone level changes
    - Osseointegration parameters
    - Implant survival or failure
- Main findings: correlation between torque values and stability or osseointegration.

Data extracted from each study were compared qualitatively due to heterogeneity in designs, implant systems, and measurement protocols. When available, findings were contrasted with manufacturer-recommended torque ranges. In addition to clinical studies, manufacturer Instructions for Use (IFU) from major implant systems (Straumann, Nobel Biocare, Dentsply Sirona and ZimVie) were consulted to compare recommended insertion torque limits with clinical evidence.

4. RESULTS

4.1. Study selection

The initial search identified 46 records. After removal of duplicates (n=2), 44 articles remained for title/abstract screening. 30 full-text articles were assessed for eligibility. Finally, 9 studies met the inclusion criteria and were included in the qualitative analysis.

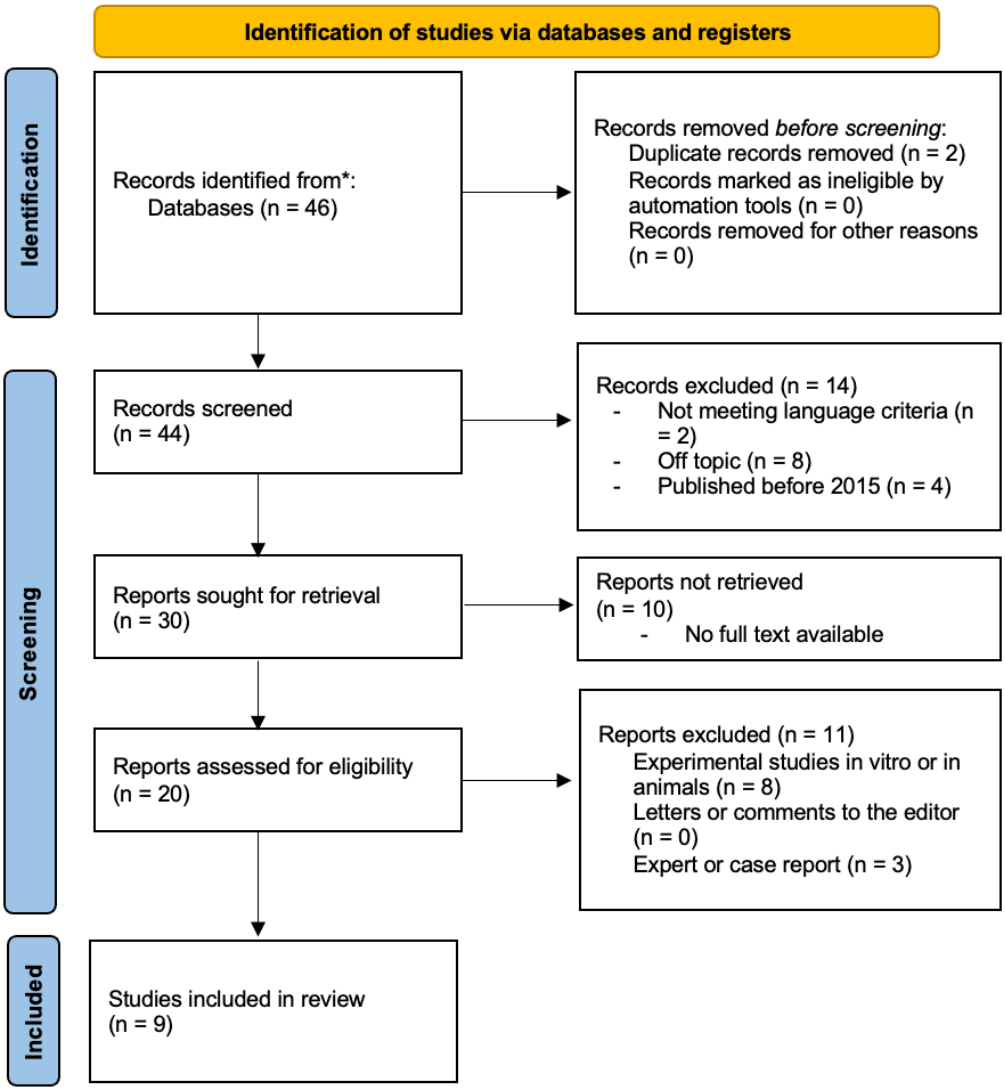


Figure 2. PRISMA flow diagram of the search flow and title selection process during the systematized review.

Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, *et al*. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi:10.1136/bmj.

4.2. Characteristics of included studies

Table 2. Study characteristics, insertion torque protocol and manufacturer recommendations

Study	Design	n Implants	Implant system	Insertion torque (N·cm)	Torque category*	IFU max. (N·cm)	IFU exceeded	Loading protocol	Follow up
Barone *et al.,* 2016 (49)	RCT	116	CT/Blossom (Intra-Lock)	Regular: 30.3 ± 7.5 High: 68.8 ± 9.0	Moderate vs High	60	High group: Yes	Delayed	12 months
Norton *et al*., 2017 (50)	Prospective	30	Nobel BioCare	≤20	Low	45	No	Immediate	12 months
Aldahlawi *et al*., 2018 (32)	Cohort	113	Multiple	≤55 vs >55	Moderate vs High	50-60	No	Immediate	12.9 months
Marconcini *et al*., 2018 (47)	RCT	116	CT/BLCT (Intra-lock)	Regular: 29-30 High: 68-70	Moderate vs High	60	Yes	Delayed	36 months
Amari *et al*. 2019 (17)	Split-mouth RCT	22	ZirTi mini-implants	< 10 vs 30	Low	NR	Within ranges	NR	8 weeks
Gehrke *et al.* 2023 (19)	RCT	100	Duo Cone/Maestro	DC: approx. 56 ± 6 MAE: 25-33	Moderate	60	NR	NR	45 days
Dkheel *et al*., 2024 (51)	Prospective	NR	Multiple	28 ± 11.7	Moderate	NR	NR	Immediate	NR

Sreerama *et al*., 2021 (2)	Clinical study	80	Multiple systems	Site dependent (higher in D1-D2)	NR	NR	NR	Delayed	NR
Do Vale Souza *et al.,* 2021 (3)	Prospective	60	Neodent	Mean IT: 32.7 ± SD	Moderate	NR	NR	Delayed	NR

*Torque categories were defined as: low (<30 N·cm), moderate (30-50 N·cm) and high (> 50 N·cm).

Table 3. Bone density context

Study	Study design	Jaw location	Bone density characterization	Standardized between torque groups	Mean IT (N·cm)	ISQ at placement
Barone *et al*., 2016 (49)	RCT	Maxilla / Mandible	Anatomical site (maxilla vs mandible)	Yes (randomized)	30 vs 69	Higher in high-IT
Marconcini *et al.,* 2018 (47)	RCT	Maxilla / Mandible	Anatomical site (maxilla vs mandible)	Yes (randomized)	29–30 vs 68–70	Higher at placement
Norton *et al*., 2017 (50)	Prospective	Mixed	Not stratified	No	≤20	NR
Aldahlawi *et al.,* 2018 (32)	Cohort	Mixed	Not stratified	No	≤55 vs >55	NR
Gehrke *et al*., 2023 (19)	RCT	Mandible / Maxilla	Not stratified	Yes (randomized)	56 ± 6 vs 25–33	approx. 61–62
Sreerama *et al*., 2021 (2)	Clinical	Site-dependent	D1–D4 (Misch)	Not comparison-based	Higher in D1–D2	Higher in D1–D2
Do Vale Souza *et al*., 2021 (3)	Prospective	Site-dependent	Site-dependent clinical assessment	Not comparison-based	32.7 ± SD	67 ± SD

4.3. Primary stability (IT and ISQ)

The relationship between insertion torque values and primary stability indicators reported in the included studies is summarized in Table 4.

Table 4. Insertion Torque and primary stability (ISQ)

Study	Torque groups (N·cm)	ISQ at placement	ISQ follow-up	Statistical result
Gehrke *et al*., 2023 (19)	56 ± 6 vs 25-33	Baseline: approx. 61-62	45 days: 69-73	No baseline difference ($p=0.49$); increase over time ($p<0.001$)
Dkheel *et al*. 2024 (51)	28 ± 11.74	63 ± 18.66	NR	$r = 0.5$; $p = 0.027$
Marconcini *et al*. 2018 (47)	29-30 vs 68-70	Higher ISQ in High-IT	No long-term difference	Early difference
Barone *et al*., 2016 (49)	30 vs 69	Higher ISQ in High-IT	NR	Higher initial stability

4.4. Osseointegration and marginal bone level (MBL)

Clinical outcomes related to osseointegration, including marginal bone level changes and histologic parameters, are summarized in Table 5.

Table 5. Insertion torque, marginal bone loss and histologic outcomes (osseointegration parameters)

Study	Follow-up	Torque groups (N·cm)	Outcome measure	Mean ± SD	p-value	Survival rates
Amari *et al*., 2019 (17)	8 weeks	<10 vs 30 approx.	New BIC (%)	39.3 ±18.5 vs 49.4 ± 9.4	0.114	NR
			Total mineralized bone (%)	46.8 ± 22.1 vs 57.0 ± 14.1	0.213	
Barone *et al*., 2016 (49)	12 months	30 vs 69	MBL maxilla (mm)	0.68 ± 0.46 vs 1.01 ± 0.57	0.024	97.4%
			MBL mandible (mm)	0.70 ± 0.28 vs 1.33 ± 0.33	<0.001	
Aldahlawi *et al*., 2018 (32)	12.9 months	≤55 vs >55	MBL (mm)	0.18 vs 0.95	NR	93.5% vs 96%
Marconcini *et al*., 2018 (47)	36 months	29-30 vs 68-70	MBL maxilla (mm)	0.96 ± 0.46 vs 1.16 ± 0.61	0.01	96.5%
			MBL mandible (mm)	1.03 ± 0.12 vs 1.53 ± 0.29	<0.001	
Norton *et al.,* (50)	12 months	≤20	MBL (mm)	0.21 ± 0.33		96.7%

4.5. Manufacturer IFU guidance

Manufacturer recommendations regarding insertion torque limits and surgical considerations extracted from implant system instructions for use are presented in Table 6 and 7.

Table 6. Manufacturer insertion torque guidance (IFU / surgical manual)

Company	Implants system / Document used	Recommended insertion torque (range/target)	Maximum insertion torque	Notes directly relevant (primary stability / osseointegration)
ZimVie	Trabecular Metal® & Tapered Screw-Vent® Implant Systems (52)	Not specified in N·cm in this manual	NR	Cortical bone taps may be used to reduce insertion torque in dense cortical bone. Warns that debris can increase insertion torque above acceptable limits.
Dentsply Sirona	Astra Tech Implant System® EV (53)	NR (only a ceiling provided)	45 N·cm	Explicit warning: do not exceed 45 N·cm during implant placement, if it's reached before final placement, remove implant and widen osteotomy appropriately.
Nobel Biocare	NobelActive® TiUnite™ (54)	Immediate function (final torque capacity): - 35 - 45 N·cm (NobelActive 3.0) - 35 - 70 N·cm (NobelActive 3.5 - 5.5).	45 N·cm (3.0) 70 N·cm (3.5 - 5.5)	Clear differentiation by diameter and state that exceeding maximum insertion torque value may damage implant or contribute to bone necrosis.
Straumann	Straumann® Bone Level Tapered (55)	Alert threshold: if >35 N·cm is reached before final position, verify site prep to avoid excessive bone compression.	NR for maximum	States Loxim™ has a predetermined break point at 80 N·cm to prevent damaging internal configuration.

Table 7. Manufacturer torque control strategies and recommended limits

Manufacturer	Torque decision point (as written in IFU/manuals)	Intended clinical meaning	Recommended action (manufacturer)
ZimVie (TSV/TM)	NR (no numeric torque maximum, only rpm, mention torque can exceed acceptable limits)	Primary stability/osteointegration indirectly managed through surgical technique rather than torque threshold.	Cortical bone taps may be used to reduce insertion torque in dense cortical bone. Warns that debris can increase insertion torque above acceptable limits.
Dentsply Sirona (Astra Tech EV)	45 N·cm (ceiling during installation)	Avoid excessive drilling, manage primary stability with good osteotomy preparation rather than with over-torquing	Explicit warning: do not exceed 45 N·cm during implant placement, if it's reached before final placement, remove implant and widen osteotomy appropriately.
Nobel Biocare (NobelActive® TiUnite™)	Max insertion torque: 45 N·cm (3.0) / 70 N·cm (3.5–5.5)	Protect implant / bone when pursuing high primary stability.	Clear differentiation by diameter and state that exceeding maximum insertion torque value may damage implant or contribute to bone necrosis.
Straumann (BLT)	>35 N·cm before final position: alert threshold.	Avoid excessive bone compression during insertion (protect osseointegration environment)	States Loxim™ has a predetermined break point at 80 N·cm to prevent damaging internal configuration.

4.6. Torque category comparative synthesis

A comparative synthesis of clinical outcomes according to insertion torque categories is presented in Table 8.

Table 8. Structured comparative summary by torque category

Torque category	Primary stability (ISQ)	Marginal bone loss	Survival	IFU compliance pattern
Low (< 30 N·cm)	Adequate	Low MBL reported in some RCTs	High	Within IFU
Moderate (30-50 N·cm)	Stable	Stable bone levels reported	High	Within IFU
High (> 50N·cm)	Higher initial	Higher MBL reported	Comparable	Frequently exceed IFU

5. DISCUSSION

5.1. Principal findings in the context of the study objective

The present review sought to clarify whether increasing insertion torque values improves implant primary stability and long-term osseointegration in patients receiving dental implants and whether torque values exceeding manufacturer-recommended limits confer measurable clinical advantages or if a biologically optimal torque window exists. By integrating randomized clinical evidence, prospective data, histological findings, and manufacturer guidance, this analysis allows insertion torque to be interpreted within a comprehensive biomechanical and biological framework. While the findings summarized in Tables 2-5 provide a coherent overview of the relationship between insertion torque, primary stability, and peri-implant remodeling, the findings summarized in Tables 6-8 provide a complementary regulatory and clinical perspective, illustrating how manufacturer safety thresholds align with, and are supported by, the biological evidence gathered across the included studies.

The collective evidence indicates that insertion torque functions as a threshold-dependent mechanical variable rather than a linear determinant of implant success. Randomized clinical trials by Barone *et al*., 2016 (49) and Marconcini *et al*., 2018 (47) consistently showed that higher torque values, typically more than 50 to 60 N·cm, generally enhance primary stability at placement, as reflected by elevated insertion resistance and ISQ measurements, and compared with moderate torque values (29-30 N·cm). Similarly, Gehrke *et al*., 2023 (19) reported greater insertion torque in tapered macro-designs compared with cylindrical implants.

On the contrary, this initial mechanical superiority does not persist proportionally during healing, and it does not translate into improved survival outcomes. More importantly, torque values exceeding approximately 60 N·cm are associated with significantly greater marginal bone loss (MBL), particularly when IFU limits were exceeded (Table 2 and Table 5). Survival rates remained comparable across torque categories (Table 5).

These findings directly address the PICO question. In patients receiving dental implants, insertion torque influences primary mechanical stability but increasing torque beyond moderate or manufacturer-recommended ranges does not enhance osseointegration or survival when compared with lower torque values. Instead, excessive torque appears to induce a measurable biological response at the crestal bone level.

This interpretation highlights a critical conceptual difference between three dimensions of implant success. First, the mechanical success, which is defined by immediate stiffness and resistance to micromotion. Second, the biological success defined by bone-to-implant contact, stable remodeling, and preservation of crestal bone. And finally, clinical success defined by survival, functional stability, esthetic integration and absence of complications. High insertion torque primarily enhances mechanical success. However, biological and clinical success appear to depend on maintaining an optimal strain environment rather than maximizing compression.

These findings carry significant clinical implications. The consistently high survival rates observed across torque categories suggest that moderate insertion torque values, generally between 30 and 50 N·cm, represent an effective and biologically safe target for most clinical situations. Clinicians should therefore prioritize torque optimization over torque maximization, adapting their surgical approach to bone density, implant design, and manufacturer guidance rather than pursuing the highest achievable torque value. Furthermore, the association between high torque and increased marginal bone loss underscores the importance of monitoring peri-implant bone levels over time, particularly in patients where torque exceeded manufacturer-recommended thresholds. These results support the development of more individualized, evidence-based torque protocols that integrate both mechanical and biological considerations into clinical decision-making.

5.2. Clinical implications of the findings

Beyond its biomechanical implications, the association between high insertion torque and increased marginal bone loss may be particularly relevant in esthetically sensitive regions. Even minor crestal bone remodeling can influence gingival contour, papilla height, and soft tissue thickness over time. Clinicians should therefore be especially cautious about pursuing high torque values in the anterior region, where peri-implant tissue stability is critical.

5.3. Primary stability as a dynamic process: confirmation of mechanical principles

From a mechanical standpoint, the association between higher insertion torque and increased primary stability is expected. Insertion torque reflects the rotational resistance encountered as the implant engages bone during placement, meaning that greater torque values indicate a stronger thread engagement and increased compressive interaction between implant and cortical bone, and correspond to increased frictional resistance and reduced micromotion at placement.

As shown in Table 3, Barone *et al*., 2016 (49) and Marconcini *et al*., 2018 (47) demonstrated higher ISQ values in high-torque groups at placement. Similarly, Gehrke *et al*., 2023 (19) confirmed that tapered implants generate higher insertion torque values due to lateral compression of bone.

This confirms that greater compressive engagement enhances initial stiffness. However, a critical observation emerges during follow-up: stability values in moderate torque groups progressively increase and often converge with those of high torque groups. In Gehrke *et al*., 2023 (19) ISQ values increased significantly over time ($p < 0.001$), regardless of initial torque magnitude.

This pattern supports the biphasic model of implant stability: primary stability is mechanical and dependent on interfacial friction and compression, while secondary stability is biological and results from new bone formation and remodeling around the implant surface.

Insertion torque primarily influences the first phase. Once biological healing begins and woven bone is replaced by lamellar bone, the contribution of mechanical compression becomes less dominant. As long as micromotion remains below the threshold associated with fibrous encapsulation, often cited as approximately 50-100 µm, osseointegration proceeds predictably. This observation is clinically relevant: achieving extremely high torque may offer immediate reassurance, but it does not appear to alter the biological trajectory of integration once sufficient stability has been reached. Mechanical superiority at placement therefore does not guarantee long-term biological superiority.

Implant microgeometry also plays a significant role in the relationship between insertion torque and primary stability. As illustrated in Table 4, Gehrke *et al.* (2023) (19) reported higher insertion torque values for tapered implants compared with cylindrical macro-designs. This difference can be explained by the lateral compressive effect generated by tapered implants during placement, which increases frictional resistance between the implant threads and the surrounding bone. While this mechanical behavior may enhance initial stability, it also means that identical drilling protocols may generate different torque values depending on implant design. Consequently, insertion torque cannot be interpreted as an isolated parameter but must be considered together with implant microgeometry, drilling preparation, and local bone density. This interaction further supports the concept that torque optimization should be individualized according to the biomechanical characteristics of the implant system used.

5.4. Biological response: crestal stress concentration and cortical bone physiology

The most consistent biological effect observed across randomized designs is increased marginal bone loss in high torque groups. Although the absolute difference in MBL (approximately 0.3-0.6 mm) may appear modest, their consistency across independent studies strengthens their biological plausibility.

As detailed in Table 5, Barone *et al*., 2016 (49) reported significantly greater MBL in implants placed with 69 N·cm compared with 30 N·cm, both in the maxilla and mandible. Similarly the 3-year RCT by Marconcini *et al*., 2018 (47) demonstrated greater crestal bone loss in the high-torque group. Importantly in both studies, high-torque protocols exceeded the manufacturer maximum of 60 N·cm, shown in Table 2.

The localization of remodeling at the crestal level is biomechanically meaningful. Finite element analyses consistently show that peak stresses concentrate at the crestal cortical region, particularly around the first implant threads. Elevated insertion torque disproportionately increases compressive stress in this zone.

Crestal cortical bone is particularly vulnerable because of its high elastic modulus and relatively limited vascular supply compared with trabecular bone. Consequently, it tolerates excessive compressive strain less effectively. When compressive forces exceed physiological tolerance, microdamage and transient vascular compromise may occur, triggering osteoclastic activation and remodeling. Bone remodeling may occur as a protective adaptation rather than as a sign of failure. Therefore, the increased MBL observed in high torque groups likely reflects an adaptive response to excessive crestal strain rather than enhanced osseointegration.

5.5. Mechanotransduction and biological ceiling effect

Bone is a mechanosensitive tissue that is regulated through mechano-transduction. When osteocytes detect mechanical deformation, they coordinate remodeling through signaling pathways that balance bone formation and resorption.

Within a physiological strain window, moderate compressive strain stimulates adaptive bone formation and stable bone-to-implant contact. However, excessive compressive strain may exceed this adaptive capacity and therefore induce localized remodeling and microdamage. High insertion torque may produce excessive compressive strain in cortical crestal bone, leading to localized microfractures, reduced microvascular perfusion, transient ischemia, and subsequent osteoclastic activation.

The histomorphometric randomized clinical trial by Amari *et al*., 2019 (17) did not demonstrate significant differences in new bone-to-implant contact between low (< 10 N·cm) and moderate (30 N·cm) torque groups. This suggests that once micromotion is adequately controlled, increasing compression does not proportionally increase bone formation.

These findings are consistent with the systematic review and meta-analysis by Roca-Millan *et al*., 2020 (35), which concluded that higher insertion torque values were significantly associated with increased marginal bone loss without improving implant survival. The convergence between individual randomized clinical trials (Table 5) and meta-analytic evidence supports the concept of a biological ceiling effect: beyond moderate torque levels, additional compression does not enhance integration and may instead promote adaptive crestal remodeling.

5.6. Clinical interpretation of Marginal Bone Loss

While the magnitude of marginal bone loss (MBL) differences may not exceed widely accepted first-year remodeling thresholds (1.0-1.5 mm), consistent incremental differences between torque groups should not be dismissed. As summarized in Table 5, randomized clinical trials by Barone *et al*., 2016 (49) and Marconcini *et al*., 2018 (47) demonstrated significantly greater crestal bone loss in implants placed with higher insertion torque values compared with moderate torque protocols.

Even small early variations in crestal bone levels may influence long-term soft tissue stability and esthetic outcomes. In esthetically demanding regions, minimal bone loss can alter gingival contour and papilla support. Furthermore, early remodeling may interact with additional risk factors such as peri-implant inflammation, prosthetic overload, or systemic conditions. Therefore, even in the absence of survival differences in Table 5, increased MBL associated with high torque may have clinically relevant implications over extended follow-up. This reinforces the importance of evaluating biological parameters rather than relying exclusively on survival rates as indicators of implant success.

An additional aspect that merits consideration is the temporal dimension of bone remodeling. Early marginal bone changes observed in high torque groups, in Table 5, may represent an adaptive response to initial mechanical overload. However, whether these early differences stabilize, progress or interact with functional loading over longer follow-up remains incompletely clarified. It is plausible that early crestal remodeling reflects the bone's attempt to re-establish a mechanically favorable configuration around the implant. If compressive forces are excessive at placement, the bone may resorb marginally to redistribute

strain more evenly. In this context, marginal bone loss should not be interpreted solely as a complication, but as a potential adaptive phenomenon. Nevertheless, even adaptive remodeling may carry esthetic or long-term biomechanical consequences.

Importantly, early crestal remodeling may also influence peri-implant soft tissue behavior. Bone level stability is intimately linked to soft tissue attachment and mucosal architecture. Even sub-millimetric differences in crestal bone levels may alter biologic width establishment, papilla height, and tissue thickness. Thus, while survival remains unaffected, tissue-level outcomes may be subtly modulated by torque strategy.

5.7. Implant survival and the multifactorial nature of immediate loading

Despite differences in MBL, survival rates across torque categories remained high and clinically comparable in Table 5. Barone *et al*., 2016 (49) reported 97.4% survival at 12 months and Marconcini *et al*., 2018 (47) reported 96.5% at 36 months. Notably, Norton *et al*. 2017 (50) demonstrated successful immediate loading with insertion torque values at ≤ 20 N·cm and stable marginal bone level at 12 months. Similarly, Aldahlawi *et al*. 2018 (32) observed comparable survival between ≤ 55 and > 55 N·cm groups.

This indicates that implants can successfully integrate under a wide range of torque conditions, provided that micromotion is adequately controlled. The traditional belief that high torque is necessary for immediate loading is increasingly challenged by clinical evidence. Successful immediate protocols have been reported with moderate or even low torque values when implant design, bone quality, and occlusal management are appropriately controlled.

Immediate loading success is multifactorial and depends on implant macro-geometry and surface roughness, bone density, and cortical thickness, drilling protocol and osteotomy preparation, prosthetic design and occlusal force distribution. Torque is only one element within this complex stability network. Excessive torque should therefore not be pursued solely to satisfy a perceived mechanical threshold for immediate function.

5.8. Manufacturer IFU: Clinical and biomechanical interpretation

The integration of manufacturer Instructions for Use (IFU) in Table 2 into this analysis provides additional context. In both Barone *et al.,* 2016 (49) and Marconcini *et al.,* 2018 (47), high-torque protocols

frequently approached or exceeded manufacturer-defined maximum values of 60 N·cm. These same protocols were associated with increased MBL.

The concordance suggests that manufacturer torque ceilings likely represent biomechanical safety boundaries intended to prevent excessive cortical compression, structural overload of internal implant components, deformation of the implant-abutment connection, bone necrosis due to vascular compromise. Importantly, IFU maximum values should not be interpreted as targets to reach but as boundaries to respect.

Clinical evidence does not support intentional exceedance of manufacturer ceilings as a strategy to enhance stability. Torque optimization must therefore be individualized and system-specific, integrating IFU recommendations with biological considerations.

5.9. Contextual clinical decision-making

Insertion torque must always be interpreted within its clinical context. The biological tolerance to compressive strain likely varies between patients according to cortical thickness, trabecular density, metabolic bone turnover, and systemic factors such as osteoporosis or smoking. Anatomical site also plays a major role: dense mandibular cortical bone may generate high torque values even with moderate drilling, whereas posterior maxillary bone may produce lower torque despite under-preparation. Implant macro-design further influences torque magnitude, with tapered implants generally producing higher values than cylindrical designs.

Therefore, torque should not be interpreted in isolation but rather in conjunction with bone density, implant design, drilling protocol, and patient-related factors. The clinical objective should not be to achieve the highest possible torque, but rather to obtain sufficient primary stability within a biologically safe range.

5.10. Integrative interpretation: the physiological torque window

When mechanical stability, marginal bone outcomes, survival rates from Table 5, and manufacturer recommendations from Table 2 are considered together a coherent physiological torque window emerges. Low torque (<30 N·cm) can be adequate if micromotion is controlled and there is sufficient stability. Moderate torque (30-50 N·cm) falls within a physiological strain window that supports adaptive remodeling and predictable osseointegration. There is an optimal balance between mechanical stability

and biological preservation. High torque (> 50-60 N·cm) may create an increased stiffness but also a higher crestal remodeling without any survival benefit, while frequently exceeding IFU limits.

Insertion torque should therefore be optimized, not maximized in order to balance mechanical stability and biological preservation while respecting manufacturer safety guidance and patient-specific anatomical conditions. This concept is summarized in Figure 3, which illustrates the three-zone torque model and highlights the physiological window within which the clinical outcomes are optimized.

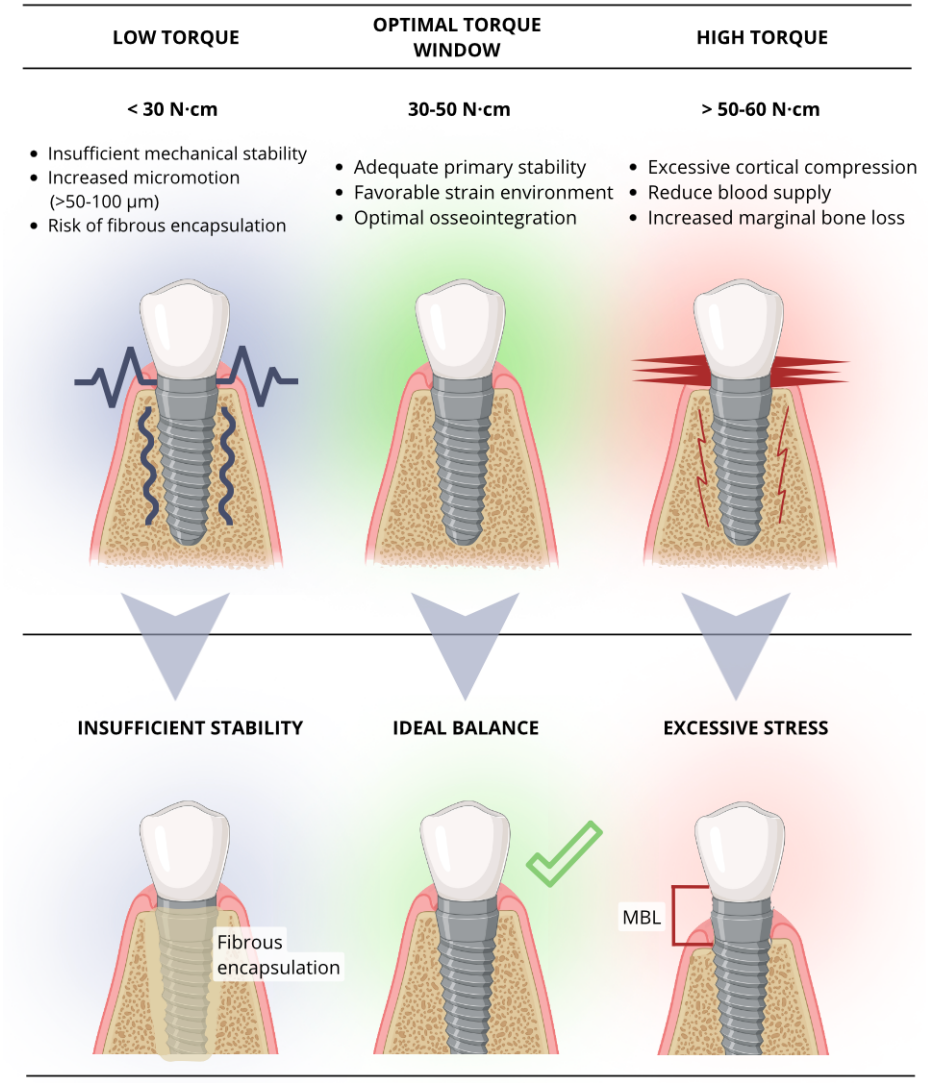


Figure 3. Conceptual model illustrating the physiological insertion torque window for dental implant placement.

In a broader perspective, minimizing unnecessary biological trauma during implant placement may contribute to long-term treatment sustainability. Crestal bone preservation reduces the likelihood of prosthetic complications, soft tissue recession, and potential need for secondary regenerative procedures.

From both a biological and healthcare resource standpoint, strategies that optimize rather than maximize mechanical compression may enhance long-term predictability and reduce cumulative intervention burden. Therefore, torque calibration may be considered not only a biomechanical parameter but also a component of responsible and sustainable clinical practice.

5.11. Methodological considerations and future directions

Several methodological limitations should be acknowledged. Heterogeneity in implant macro-design, drilling protocols, and bone density stratification limits direct comparison across studies. Torque reporting varied across studies, and target torque may not always reflect achieved torque due to operator variability, and radiographic assessment of marginal bone levels may underestimate microstructural cortical changes.

In addition, potential sources of bias across the included studies, such as selection bias, variability in operator technique, and heterogeneity in surgical protocols and torque application strategies, may have influenced the reported outcomes and limit the direct comparability of results.

Furthermore, long-term follow-up beyond three to five years remains limited, and standardized stratification by bone quality is inconsistently reported. Future prospective studies should integrate controlled torque categories with standardized bone density assessment and long-term radiographic and clinical endpoints. Despite these limitations, the consistency of findings across independent randomized trials and their alignment with meta-analytic evidence strengthens the validity of the observed association between high torque and increased crestal remodeling.

The development of digital surgical systems and torque-controlled motors may further refine intraoperative decision-making. Future implant systems may incorporate real-time torque monitoring and feedback technologies, allowing clinicians to dynamically adjust osteotomy preparation or insertion parameters in order to remain within biologically optimal biomechanical thresholds during implant placement.

5.12. Overall conclusion of the discussion

Insertion torque is a critical intraoperative parameter for achieving primary stability. However, it behaves as a threshold-dependent variable rather than a linear determinant of success. Higher torque enhances immediate mechanical stiffness but does not improve long-term survival or osseointegration and

may induce increased marginal bone remodeling, particularly when manufacturer safety limits are exceeded.

The available clinical and meta-analytic evidence supports the existence of a physiological torque window that balances mechanical engagement with biological preservation. Respecting manufacturer IFU guidance and adapting torque to bone density, implant design, and surgical context represent a rational, evidence-based approach to implant placement. Insertion torque should therefore be calibrated within a biologically safe range rather than maximized indiscriminately.

This perspective shifts the clinical mindset from “achieving the highest possible torque” to “achieving sufficient torque within a biologically safe window”. Such an approach aligns with precision medicine principles in implantology, where treatment parameters are adapted to individual anatomical and systemic context rather than standardized to rigid mechanical goals. These findings support the concept that insertion torque influences not only mechanical fixation but also early peri-implant tissue dynamics, highlighting the need to consider biological outcomes in addition to implant survival.

6. CONCLUSION

Insertion torque is a key intraoperative parameter influencing the primary stability of dental implants. The clinical evidence analyzed in this review indicates that higher insertion torque values can increase initial mechanical stability at placement. However, this mechanical advantage does not translate into improved implant survival or long-term clinical outcomes. Implant success rates remain high across a wide range of torque values. Several studies reported greater marginal bone loss when torque values exceeded approximately 50-60 N·cm, suggesting that excessive compressive stress at the crestal bone level may induce adaptive bone remodeling.

Overall, the available evidence supports the existence of a physiological torque window in dental implant placement. Moderate torque values, generally between 30-50 N·cm, provide an optimal balance between primary mechanical stability and preservation of peri-implant bone, without improving implant survival when exceeded.

This review therefore answers the initial objective by demonstrating that insertion torque should not be maximized but rather adapted to clinical conditions and aligned with manufacturer recommendations. However, the heterogeneity of study designs, implant systems and clinical protocols limits direct comparability of results. Future well-designed clinical studies with standardized torque protocols and longer follow-up periods, are required to further refine evidence-based torque guidelines.

7. SUSTAINABILITY

The sustainability of this study lies in its contribution to promoting more efficient, ethical, and patient-centered dental practices. By analyzing the relationship between insertion torque, primary stability, and osseointegration, this research supports evidence-based decision-making that can optimize clinical outcomes while reducing unnecessary material use and surgical interventions. Economically, improving implant predictability helps decrease the need for retreatments and the management of complications, which reduces costs for both patients and healthcare systems. This directly contributes to the long-term sustainability of dental care delivery. Environmentally, inappropriate torque application may lead to implant failure, increase marginal bone loss, and the need for additional surgical procedures, which in turn increases the consumption of biomaterials, energy, and clinical resources. Therefore, rational torque selection may minimize the consumption of implant materials and surgical resources, aligning with the principles of resource efficiency and waste reduction promoted by the United Nations Sustainable Development Goal 12 (Responsible Consumption and Production). Socially, the implementation of standardized, evidence-based torque protocols enhances treatment safety and predictability, contributing to improved patient outcomes and quality of life. This aligns with Sustainability Development Goal 3 (Good Health and Well-being), by promoting safer and more effective healthcare practices. Importantly, this study highlights the need for personalized torque application strategies based on bone quality, implant design, and clinical conditions. The adoption of such strategies, together with adherence to manufacturer recommendations and avoidance of excessive compression, represents a practical approach to integrate sustainability into daily practice. Overall, this research integrates sustainability by critically addressing the ethical, economic, and environmental implications of implant dentistry, while proposing clinically applicable strategies to support more responsible and efficient healthcare.

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