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FACULDADE DE MEDICINA DENTÁRIA
VISEU

Assessment of maximum torque application in dental implantology: factors influencing practitioner performance

Dissertation submitted to the *Universidade Católica Portuguesa* to obtain the Master’s Degree in Dental Medicine.

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The sky was never promised to us; we were meant to build wings and take flight.

-Forough Farrokhzad

DEDICATIONS

To all Iranian women around the world, may our strength, courage, and determination shape a future where we can thrive freely. To "*women, life, and freedom*".

To my mother and father, my whole family, and in loving memory of my grandmother, who may not be here to witness this, but whose spirit has never left my side; Thank you for never stopping believing in me, no matter what.

To all of my friends in Iran, Ukraine, Portugal, and around the world, to Farzad, Yousef, Arash, and Zar, who stood by my side through every fight and helped me win each battle.

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And last but not least, to everyone who supported and inspired me along the way, you helped me keep going, inch by inch.

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ABSTRACT

Introduction: The application of optimal torque is critical for the mechanical stability and long-term success of implant-supported prostheses. However, manual torque tightening is susceptible to variability due to operator experience, glove material, hand moisture, and instrument design. Inadequate torque delivery can lead to complications such as screw loosening, prosthetic instability, and eventual failure of the rehabilitation. This study aimed to investigate how these clinical and practitioner-related factors influence the maximum torque value (MTV) in implant dentistry.

Materials and Methods: A pre-clinical laboratory study was conducted with 30 participants: 10 professors familiar with the area of implantology and 20 dental students of 4th and 5th year from FMD-UCP. Participants manually tightened prosthetic screws using Straumann® medium (21 mm) and long (27 mm) screwdrivers under six different glove and moisture combinations: nitrile gloves, latex gloves, and bare hands, each tested in both dry and wet environments. All torque values were measured using a calibrated bench torque meter. Descriptive statistics were used to summarize the data, followed by inferential analysis through ANOVA, Mann-Whitney, and Kruskal-Wallis tests to evaluate the effects of experience level, glove type, screwdriver length, and hand moisture on MTV, as well as to explore possible interaction effects between variables.

Results: Professors achieved significantly higher torque values than students (mean = 16.92 Ncm Vs 15.03 Ncm; p = 0.01), confirming the influence of clinical experience. Glove type also significantly affected torque values (p = 0.01), with nitrile gloves yielding higher values (mean = 17.11 Ncm) than bare hands (mean = 14.20 Ncm; p = 0.008). This effect was significant among professors (p = 0.02) but not among students (p = 0.16). Although medium screwdrivers produced slightly higher torque values (16.33 Ncm) compared to long ones (14.99 Ncm), the difference was not statistically significant (p = 0.12). Dry hand conditions resulted in a higher mean torque (16.21 Ncm) than wet conditions (15.11 Ncm), but this was also not significant (p = 0.07).

Conclusion: Clinical experience and glove type significantly influence the maximum torque applied in implant-supported prosthetic rehabilitation. Screwdriver length and hand moisture did not show statistically significant effects. Further studies should use calibrated torque devices with different mechanisms and assess how repeated use and time affect torque reliability and stability.

Keywords: dental prosthesis, implant-supported, dental prosthesis retention, torque, biomechanics, dental implants.

RESUMO

Introdução: a aplicação de um torque correto é essencial para a estabilidade mecânica e o sucesso a longo prazo das próteses suportadas por implantes. No entanto, o aperto manual do torque está sujeito a variabilidade devido à experiência do operador, ao tipo de luvas utilizadas, à presença de humidade nas mãos e ao *design* do instrumento. Uma aplicação inadequada de torque pode levar a complicações como afrouxamento do parafuso, instabilidade protética e eventual falha da reabilitação. Este estudo teve como objetivo investigar como estes fatores clínicos e relacionados com o profissional influenciam o valor máximo de torque na reabilitação protética com implantes.

Materiais e Métodos: foi realizado um estudo laboratorial pré-clínico com 30 participantes: 10 professores familiarizados com a área da implantologia e 20 estudantes do 4º e 5º anos do curso de Medicina Dentária da FMD-UCP. Os participantes apertaram manualmente parafusos protéticos utilizando chaves protéticas Straumann® de comprimento médio (21 mm) e longo (27 mm) sob seis combinações diferentes de luvas e condições de humidade: luvas de nitrilo, luvas de látex e mãos descobertas (sem luvas), cada uma testada em ambiente seco e húmido. Todos os valores de torque foram medidos com um torquímetro de bancada calibrado. Utilizaram-se estatísticas descritivas, seguidas de análises inferenciais através dos testes ANOVA, Mann-Whitney e Kruskal-Wallis para avaliar os efeitos do nível de experiência, tipo de luva, comprimento da chave protética e humidade das mãos no valor máximo de torque, bem como para explorar possíveis efeitos de interação entre variáveis.

Resultados: os professores atingiram valores de torque significativamente superiores aos estudantes (média = 16,92 Ncm vs. 15,03 Ncm; p = 0,01), confirmando a influência da experiência clínica. O tipo de luva também influenciou significativamente os valores de torque (p = 0,01), com as luvas de nitrilo a gerar valores superiores (média = 17,11 Ncm) em comparação com as mãos descobertas (média = 14,20 Ncm; p = 0,008). Este efeito foi significativo entre os professores (p = 0,02), mas não entre os estudantes (p = 0,16)**.** Embora as chaves médias tenham produzido valores de torque ligeiramente superiores (16,33 Ncm) face às chaves longas (14,99 Ncm), a diferença não foi estatisticamente significativa (p = 0,12)**.** As condições com mãos secas resultaram numa média de torque superior (16,21 Ncm) comparativamente às mãos húmidas (15,11 Ncm), mas também sem significância estatística (p = 0,07)**.**

Conclusão: a experiência clínica e o tipo de luva influenciam significativamente o valor máximo de torque aplicado em reabilitações protéticas suportadas por implantes. O comprimento da chave e a humidade das mãos não demonstraram efeitos estatisticamente significativos. Estudos futuros devem utilizar dispositivos de torque calibrados com diferentes mecanismos e avaliar como o uso repetido e o tempo afetam a estabilidade e fiabilidade do torque aplicado.

Palavras-chave: prótese dentária, suportada por implantes, retenção de prótese dentária, torque, biomecânica, implantes dentários.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA – Analysis of Variance

BMI – Body Mass Index

CES – Ethics Committee for Health

CHE – Catastrophic Health Expenditures

MIMD-FMDUCP – Integrated Master in Dental Medicine - Faculty of Dental Medicine, Universidade Católica Portuguesa

MTV – Maximum Torque Value

Ncm – Newton centimeters

RT – Regular-Tapered

SCS – Screw Carrying System

1. INTRODUCTION

Oral health plays an important role in an individual's overall well-being, influencing the proper functioning of the stomatognathic system. Poor oral health, particularly involving the teeth, can disturb essential functions such as chewing and speaking, and diminish facial aesthetics. This not only causes discomfort but can also affect a person's self-esteem and quality of life. As a result, oral health has become a key factor in assessing population health and overall quality of life.(1)

1.1. Implant Dentistry

In recent years, the field of implant dentistry has undergone a profound transformation, offering patients innovative solutions for durable, functional, and aesthetically pleasing tooth replacement.

The last two decades have seen a rapid expansion of implant therapy in general dental practice. Osseo-integrated dental implants have become a cornerstone in the oral rehabilitation of single, partially, and fully edentulous patients, with numerous studies documenting their successful long-term outcomes.(2-4)

The concept of osseointegration, pioneered by Per-Ingvar Brånemark in the 1960s, revolutionized the field of modern dental implants. Osseointegration refers to the direct, stable bond that forms between living bone and the surface of an implant, enabling it to bear weight effectively. This innovation transformed implantology by providing a reliable, long-term solution for tooth replacement. (5)

Over the past two decades, implant dentistry has seen remarkable advancements, with implant placement becoming a routine procedure for general practitioners, largely due to enhanced training, refined techniques, and superior materials.

Advancements in dental implant design and materials have significantly improved the long-term stability of implants, even in challenging conditions. Research specifically examining osseointegrated implants in augmented bone has shown favorable outcomes. In a five-year prospective study with partially edentulous patients, Buser et al. (2002) reported that implants placed in augmented bone demonstrate high stability and survival rates, emphasizing the effectiveness of augmentation techniques in supporting durable, functional prosthetic restorations.(6)

The advancement of new biomaterials has played a crucial role in the success of contemporary dental implants. Titanium and its alloys have been the gold standard for many years due to their excellent biocompatibility, strength, and ability to fuse with bone. More recently, zirconia implants have gained attention as a viable alternative, offering improved aesthetic results in certain cases. Zirconia's white color closely mimics natural teeth, making it particularly beneficial for patients with thin or receding gum tissue, where aesthetics is a key concern.(7)

Additionally, innovations in implant surface modification techniques such as sandblasting and acid etching have notably improved the rate and quality of osseointegration. These methods increase the surface roughness of implants, enhancing bone contact and facilitating faster and more stable integration.(8)

A major innovation in implantology is the immediate loading protocol, which allows for implants to be placed and restored with a temporary crown or prosthesis on the same day or within a few days. This contrasts with traditional methods, where several months of healing were needed between implant placement and final restoration. Research indicates that immediate loading can achieve success rates similar to those of delayed loading as long as primary stability is established at the time of implant placement.(9)

Immediate loading has significantly enhanced patient satisfaction by shortening the overall treatment duration and enabling quicker functional and aesthetic restoration. This approach allows patients to enjoy faster recovery and improved outcomes in a shorter time frame.

Additionally, the adoption of minimally invasive techniques, like computer-guided implant surgery, has minimized surgical trauma, resulting in quicker recovery and better overall outcomes. Through the use of 3D imaging and advanced planning software, clinicians can place implants with higher accuracy, reducing the likelihood of complications and ensuring optimal implant positioning concerning the patient's anatomy.(10)

Long-term research indicates that dental implants can achieve high success rates, with studies showing that immediate or early loading protocols can be successfully implemented in selected patients. Success is more likely when factors such as primary implant stability are optimized, although outcomes may vary depending on individual patient conditions.(11)

Patient satisfaction with dental implants is exceptionally high due to several factors. Improvements in implant design and the use of esthetic materials, such as zirconia, contribute significantly to better visual outcomes, particularly in the anterior (front) regions where the appearance of natural teeth is crucial. Modern techniques ensure that the soft tissues, including the gums, around the implant are well-preserved, which is key to achieving a natural-looking gum line and maintaining long-term esthetics.(12, 13)

1.2. Prosthetic Oral Rehabilitation

Prosthetic rehabilitation with dental implants can be carried out using fixed options (such as screw or cement-retained prostheses) or removable solutions, incorporating components like abutments and prosthetic screws. The decision will be made collaboratively by the dentist and the patient, following a thorough explanation of the indications, benefits, and drawbacks of each approach, considering the different materials and components involved.(14, 15)

In cases where the prosthetic element is cemented to the implant abutment, the forces applied to the structures are reduced, as there is no need for a tightening screw. This approach offers superior aesthetic outcomes. However, the inability to remove the prosthesis can complicate any necessary interventions, whether for hygiene maintenance or addressing potential prosthetic complications.(16)

As a result, there is a significant likelihood that the crown may be damaged during its removal, leading to additional costs and extended chair time. Nevertheless, the most common complication arises from residual cement in the peri-implant sulcus, which is difficult to eliminate and can cause serious biological issues if it remains.(17-19)

In screw-retained restorations, the screw plays a key role by attaching the abutment to the implant, connecting all the prosthetic parts. What makes this approach stand out is how easy it is to insert and remove the screw, making the process more efficient and reliable. This simplifies the procedure and makes it much easier to clean, maintain, and repair the prosthesis over time if needed.(20-22) In such cases, there is a risk that the prosthetic screw may loosen or even fracture, potentially jeopardizing the prosthesis.(23)

Multiple factors, including the applied torque, the design of the screw head, the metal composition, and the diameter of the screw can influence the loosening of prosthetic screws.

Additionally, parafunctional habits, implant positioning, and improper seating of the prosthesis are also closely associated with an increased risk of screw loosening and potential fracture.(24, 25)

The literature suggests that crowns and abutments screwed directly onto implants should be tightened with a torque of approximately 35 Ncm, whereas crowns attached to prosthetic (or "intermediate") abutments should be tightened with a torque of around 15 Ncm. Although these values are commonly recommended, it is important to consult the manufacturer's instructions, as the maximum permissible torque for the screw can vary depending on several factors, which will be discussed in the following sections.(26, 27)

1.2.1. Prosthetic Components and Accessories

For fixed screw-retained rehabilitations, the screw is used to secure the abutment to the implant body, thereby connecting all the prosthetic components. Its ease of insertion and removal, efficiency, and predictability provide significant advantages, facilitating the prosthesis's cleaning, maintenance, and repairs.(14, 21, 22)

The force applied to the abutment by the tightening screw is referred to as preload, which ensures a secure connection between the prosthetic components.(28)

Jaarda et al. (29) demonstrated that less experienced operators tend to apply a torque value lower than the recommended level, whereas more experienced operators sometimes exceed the recommended torque. It was further shown that the manual torque operators applied vary significantly depending on experience.

Dentists using a manual screwdriver with a larger diameter and longer handle can achieve a much higher torque than with a screwdriver of smaller dimensions. Therefore, it is not advisable to perform the final tightening of prosthetic components using only hand-tightening screwdrivers; a manual torque wrench should be employed to control the applied torque accurately.(25, 30)

A manual torque wrench (or dynamometric wrench) acts as a lever to apply force. Depending on the length of the wrench's lever arm, it can increase the torque by over 100 Ncm on the screw, surpassing the material's elastic limit. To address this, the wrench is equipped with a safety valve that keeps the torque within a consistent limit. This feature appears to reduce the risk of screw loosening to below 16% within the first year of use.(31)

Most implant manufacturers recommend a torque force of 20 to 35 Ncm for abutment screws. However, the literature(29, 32) reports a considerable variation in the optimal torque values applied to screws and their components, which depends on the material and design of the screw.

It is essential to note that because the torque applied during preloading is lower than the material's permanent deformation threshold, the bolt slightly shortens, and the clamping force diminishes. Consequently, it is recommended to tighten the screw to 75% of its deformation limit (around 30 Ncm), then loosen and retighten it. After a 10-minute interval, the screw should be tightened once more (without loosening it again). This torque technique helps to reduce the tension on the bolt.(33)

1.2.2. Torque Wrenches

Due to the various reasons described in the previous section, torque wrenches are essential for measuring torque values as accurately and reliably as possible.

There are two types of torque wrenches: *friction-style* and *spring-style.*(34, 35) Friction-style devices are hexagon wrenches with a handle that releases when a desired torque value is reached. Spring-style devices have torque levels marked on an incremental scale, and the operator applies a force on the spring until the appropriate torque level is reached.(36) Studies have shown that spring-style devices are considerably more accurate than friction-style devices.(37)

The impact of autoclave sterilization on the accuracy of these instruments has been studied and analyzed. However, the published studies are not entirely conclusive. Similar results have been observed between torque wrenches that have undergone multiple autoclave cycles and those that are brand new.(38)

A recent study by Jiries et al. (39) examined the aging effects on torque wrenches, reporting notable differences between new and aged torque wrenches. The study found that regular use over time reduces the accuracy of torque wrenches, highlighting the impact of aging on their performance.

1.2.3. The Relationship Between Torque and Implant-Supported Prostheses

Dentists routinely involved in placing and removing implant components and restorations should possess a precise awareness of their capacity to generate torque force.(30)

Historically, torque application in implant dentistry has been guided primarily by empirical knowledge and clinical experience.(29) As an example, the insertion torque value (ITV) has been extensively used as an indicator for implant primary stability, which is considered a determining parameter for the implants' success.(40) It quantifies the rotational resistance encountered when inserting an implant into the bone, typically measured in Newton-centimeters (Ncm), and serves as a crucial parameter in this process.(41) Thus, a comprehensive understanding of torque application complexities, encompassing practitioner proficiency and instrument accuracy, is indispensable for achieving optimal treatment outcomes.

However, as technology continues to evolve and evidence-based practice gains prominence, there is a growing imperative to elucidate the multifaceted factors influencing torque application and to establish standardized protocols for its implementation. This comprehensive assessment seeks to address this evolving landscape by delving into the intricacies of torque application from various perspectives, including practitioner training, instrument design, and clinical implementation.

Practitioner proficiency in torque application is influenced by a myriad of factors, ranging from education and training to clinical experience and technique. The ability of a practitioner to accurately apply torque is not only essential for ensuring implant stability and longevity but also for minimizing the risk of complications such as implant fracture, screw loosening, and bone resorption.(42)

Ensuring the optimal torsional moment is applied to the implant-abutment complex is paramount for the long-term success of prosthetic implant restoration. Over time, the connection between the implant and abutment can loosen, creating micro gaps that foster bacterial colonization and may lead to mucositis/peri-implantitis. These micro gaps can progress to macro gaps, disrupting the surface connection and subjecting the screw to abnormal forces, potentially resulting in soft tissue inflammation/infection and screw fracture. To mitigate these risks, applying the ideal torsional force to the implant-abutment connection is essential, preferably utilizing a torque-calibrated ratchet wrench.(43-45)

Conversely, overtightening the abutment screw can lead to exceeding its yield strength, resulting in plastic deformation and loss of mechanical properties,(44) which usually causes loosening or fracture of the implant component.(46)

In addition to practitioner proficiency, the accuracy and reliability of torque-measuring instruments are crucial determinants of successful implant treatment.(29, 47)

With the proliferation of digital technology and computer-assisted implantology, clinicians now have access to a wide array of torque-measuring devices, ranging from mechanical torque wrenches to electronic torque meters. These innovations allow dental professionals to better control the torque applied during implant placement, making procedures smoother and more accurate.(48) This not only enhances efficiency but also helps to minimize the risks associated with over- or under-tightening of screws, leading to safer and more predictable outcomes for patients.

However, the accuracy of these instruments can vary significantly depending on factors such as calibration methods, manufacturing tolerances, and environmental conditions.(49)

Therefore, it is imperative to evaluate the performance characteristics of torque-measuring devices and to establish standardized protocols for their calibration and usage in clinical practice.

Furthermore, this comprehensive assessment aims to explore the interplay between practitioner proficiency and instrument accuracy, recognizing that these factors are inherently interconnected and mutually reinforcing.(50)

1.3. Justification

Despite the torque values proposed by manufacturers, they should more precisely instruct clinicians as to maximum torque, as opposed to "finger tighten only".(30) This study acknowledges the need to measure the maximum capabilities of practitioners to apply torque using different screwdrivers and considers other clinical variables that may affect torque application.

Earlier research (25) has revealed substantial variations in the torque values applied depending on the screwdriver used. However, a gap in the literature remains regarding whether clinical variables, such as the use of gloves, the presence of saliva, or the hand of the practitioner, affect these results. Understanding the influence of these clinical variables is essential for optimizing torque application protocols and enhancing treatment outcomes in implant dentistry.

Additionally, previous studies such as Parnia et al. (51) have provided valuable insights into the maximum torque generated by professors and post-graduate students, with no notable variances between the mean maximum torques produced by both groups. However, their study did not delve into whether this maximum provided torque was affected by the expertise, or simply their strength, or had been affected by clinical variables. This highlights the need for further research to fill this gap and advance our knowledge in the field.

Ultimately, this comprehensive assessment aims to advance our understanding of torque application in the prosthetic rehabilitation of dental implants and provide clinicians with evidence-based guidelines and best practices for achieving predictable and successful treatment outcomes. This study aims to foster innovation, standardization, and excellence in torque application by synthesizing current knowledge, empirical research, and clinical insights, thereby enhancing the quality of care provided to patients undergoing dental implant treatment.

1.4. Objectives

The primary goal of this preliminary study is to deepen our understanding of the complexities involved in torque application and to contribute to the development of standardized protocols that ensure predictable and successful outcomes in dental implant treatment. This objective is pursued through a comprehensive synthesis of empirical research, statistical analysis, and clinical insights. Specifically, this research seeks to:

- Assess the impact of practitioner education, training, and clinical experience on torque application proficiency.
- Investigate the influence of clinical variables, such as “Glove Types” and the “Presence of Saliva”, on torque outcomes.
- Identify whether variations in maximum torque application are influenced by practitioner expertise, physical strength, or other clinical factors.

1.5. Hypothesis

To address the objectives outlined in section 1.4, this study establishes null hypotheses (H_0), which presume no significant differences or effects between the variables under investigation. These hypotheses will undergo statistical testing, where a p-value below 0,05 will denote significance, prompting the rejection of the null hypothesis.

The null hypotheses defined are as follows:

H_{01}: No significant difference exists in the maximum torque values measured between professors and students.

This hypothesis examines whether the level of expertise and experience affects torque application.

H_{02}: No significant difference exists in the maximum torque values measured when using medium or long screwdrivers.

This hypothesis investigates whether screwdriver lengths impact torque application capabilities.

H_{03}: No significant difference exists in the maximum torque values measured when using nitrile gloves, latex gloves, or bare hands.

This hypothesis evaluates the influence of different glove materials on grip and torque application.

H_{04}: No significant difference exists in the maximum torque values measured under dry or wet hand conditions.

This hypothesis assesses the effect of moisture on torque application during tightening tasks.

H_{05}: No significant interaction effect exists between glove types, screwdriver lengths, and moisture conditions on maximum torque values.

This hypothesis investigates whether combinations of variables interact to influence torque application.

These hypotheses underpin the statistical analysis conducted in this study, providing a structured and data-driven framework for evaluating the factors affecting maximum torque application in implant dentistry.

By testing these assumptions, the study seeks to deliver actionable insights that will refine clinical protocols and enhance outcomes in dental practice.

2. MATERIALS AND METHODS

2.1. Study Characterization

This pre-clinical laboratory research was conducted to evaluate the maximum torque that can be applied under various conditions and identify the factors affecting its application, using different "screwdrivers" and torque wrenches with various "types of gloves" and "bare hands," aiming to provide insights into torque application that will inform best practices and improve clinical outcomes in implant dentistry rehabilitations.

2.2. Materials

2.2.1. Model Base

The implant analogs were incorporated into structures crafted in a dental prosthetics laboratory using an aluminum alloy and type III plaster (Pro-Solid Super®, Whip Mix Corporation, Louisville, United States).

This material was chosen for its excellent mechanical properties, including compressive strength (the ability to withstand pressure without deforming or breaking), hardness (the capacity to resist external forces that could change its shape or cause surface damage), and dimensional stability. This model, developed in previous research,(52) was used to securely fix implant analogs, providing a stable platform for torque application testing (Figure 1).

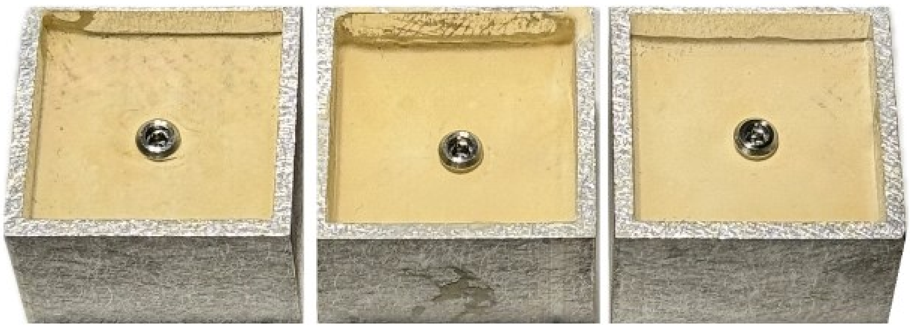

Figure 1 - Work tables with analogs included in type III plaster.

2.2.2. Screwdrivers

Medium Straumann® screwdriver: is shorter in length (21 mm) and is suitable for the posterior region where limited mouth opening restricts access, making it ideal for areas that require a more compact tool (Figure 2).

Long Straumann® screwdriver: designed for use in the anterior region, where there is more space for access, and the screwdriver's length (27 mm) allows for precise torque application (Figure 2).

Although Straumann® also offers a short screwdriver with a length of 15 mm, this option was not selected because its smaller size would likely result in contact between the operator's hand and the bench torque meter. Given the high sensitivity of the measuring device to external movements and pressure, such contact could introduce bias and compromise the reliability of the study's results.

Figure 2 - Long and Medium Straumann® Manual screwdrivers, respectively.

2.2.3. Prosthetic Components

Standardized Straumann® abutment and screw components were used in the study to replicate clinical conditions, allowing for the assessment of torque application efficiency (Figure 3 and Figure 4).

Figure 3- Straumann® Abutment and Screw Component, left and right, respectively

Figure 4 - Work table with analog, abutment and tightening screw.

2.2.4. Gloves

Nitrile gloves: used to stimulate a clinical setting that allows practitioners to maintain grip and control during torque application. Tested in both “dry” and “wet” conditions to observe its effect on torque efficiency.

Latex gloves: used to replicate clinical scenarios, allowing for flexibility and tactile sensitivity. Also tested in both fry and wet conditions to asses any differences in torque application compared to nitrile gloves.

2.2.5. Simulated Conditions

Dry environment: a standard condition to represent a typical clinical scenario with no moisture interference.

Wet environment: simulated by applying water to mimic moisture present in a real clinical setting, impacting torque application.

2.2.6. Bench Torque Meter

A bench-mounted, calibrated torque-measuring device (PCE Instruments™, PCE-CTT 2, Spain) is used to record the precise torque values applied under different conditions. This tool ensured accuracy and consistency in the measurement of torque across all test variables (Figure 5).

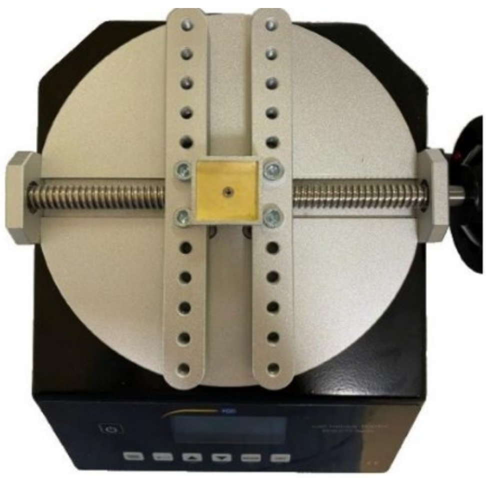

Figure 5 - Calibrated bench torque meter

2.3. Methods

2.3.1. Sample Set-Up

Based on a presumed population of 4th- and 5th-year dental students and professors with some experience in implant dentistry, within Portugal's dental schools (an eventual number of 400), a minimum sample size of 29 participants was calculated using an online sample size calculator.(53) This ensured a 95% confidence level with a 5% margin of error, assuming a population proportion of 2% in a universe of 400 eligible individuals. This calculation guaranteed that the real value of the data would be within ±5% of the measured or surveyed value. The number of participants in this study was similar to this minimum requirement, thus meeting the statistical sampling needs for reliability and accuracy.

As such, a convenience sample was selected from the population of professors and students from the MIMD, FMD-UCP. Professors were chosen based on their teaching areas and experience in the field of oral Implantology, while students were selected from the 4th and 5th years, as these years mark their first exposure to dental implant rehabilitation. Participant demographics, including gender/age, body mass index (BMI), profession, and years of experience, were documented to provide a comprehensive profile of the sample.

While convenience sampling can limit generalizability and may introduce selection biases(54), it is a widely accepted approach in research when random sampling is not possible.(55)

2.3.2. Experimental Set-Up

The experimental setup used dental implant analogs (RT Implant analog, Straumann® Basel, Switzerland. Ref. 036.0102), a straight standard abutment (RT Vario base, Straumann® for the crown, Ref. 037.1201), and a tightening screw (RT Basal Screw – TAN Straumann®, Ref. 036.3110)

Participants were provided with both medium (SCS screwdriver, length 21,0 mm, stainless steel, Ref. 046.401) and long (SCS screwdriver, length 27,0 mm, stainless steel, Ref. 046.402) Straumann® screwdrivers commonly used in dental implantology, to perform torque application tasks under three different conditions (Figure 6):

- **Nitrile Gloves**: simulating clinical conditions in both "Dry" and "Wet" environments.
- **Latex Gloves**: simulating both "Dry" and "Wet" environments.
- **Bare Hands**: both "Dry" and "Wet" environments.

Simulation conditions included both Dry and Wet environments, with wet conditions achieved using water to mimic some moisture and clinical settings.

Torque application was tested across different “Tool Lengths”, configurations, and “Glove Types”, ensuring a comprehensive examination of how these factors influenced torque proficiency in dental implantology.

A calibrated torque-measuring device (PCE Instruments™, PCE-CTT 2, Spain) was used to accurately measure the applied torque in each experimental condition, facilitating a thorough analysis of the results.

Figure 6: Hand condition in the experiment

2.3.3. Procedure

Participants underwent a brief training session by an Oral Rehabilitation Professor on proper torque application techniques using the provided screwdrivers. The training included instructions on consistent grip, angle of application, and duration of torque application to ensure uniformity across participants.

Participants were divided into groups and subgroups based on predetermined conditions, with a randomized application of “Medium” and “Long Screwdrivers” under varying “Gloves” and “Moisture Conditions” (Figure 7):

- **Group 1:** Medium Straumann screwdriver
    - **Subgroup 1.1:** with nitrile gloves (1-wet and 2-dry)
    - **Subgroup 1.2:** with latex gloves (1-wet and 2-dry)
    - **Subgroup 1.3:** bare-hand (without gloves) (1-wet and 2-dry)
- **Group 2:** Long Straumann screwdriver
    - **Subgroup 2.1:** with nitrile gloves (1-wet and 2-dry)
    - **Subgroup 2.2:** with latex gloves (1-wet and 2-dry)
    - **Subgroup 2.3:** bare-hand (without gloves) (1-wet and 2-dry)

Although clinical procedures without gloves should never occur in dental medicine due to the risk of cross-infections, it is a common belief that some professionals performing dental implant rehabilitations occasionally work without gloves to achieve a better grip. This rationale led to the inclusion of this variable in the study.

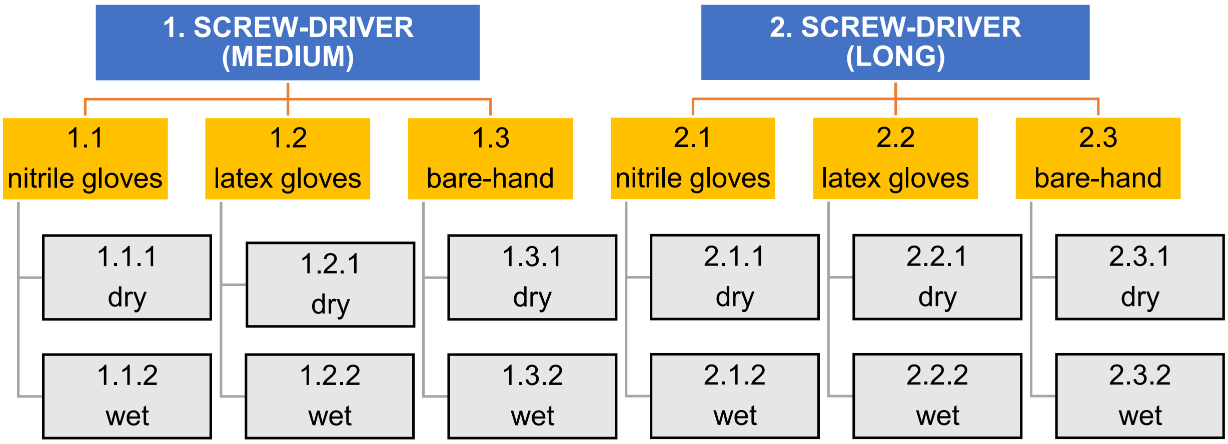

Figure 7- Distribution of the “Users” into groups and subgroups among the various conditions

Participants applied maximum torque to the implant analogs using the assigned screwdriver in a randomized order within their respective groups. Torque values were recorded for each application to ensure consistency across all conditions and to control for potentially confounding variables such as fatigue. Torque values were measured in Newton-centimeters (Ncm) using calibrated torque-measuring devices.

2.3.4. Data Analysis and Statistical Interpretation

Descriptive statistics were applied to summarize participant demographics and torque application data, capturing mean values, standard deviations, and data distribution across variables such as participant group (professors or students), "Glove Types" (nitrile, latex, bare hands), "Screwdriver Lengths" (medium or long), and "Moisture Conditions" (dry or wet).

To assess the influence of these factors on torque application, a combination of inferential statistical methods was employed.

ANOVA was applied to identify the main effects and potential interactions among variables, with careful verification of assumptions such as normality and homogeneity of variances. In instances where these assumptions were not met, non-parametric tests, including the Mann-Whitney and Kruskal-Wallis tests, were conducted to ensure reliable and accurate comparisons.

Furthermore, pairwise comparisons were performed to explore differences between specific conditions, such as "Glove Types" and "Screwdriver Lengths". This comprehensive analytical approach allowed for a nuanced understanding of how individual and combined factors influenced torque application. The methodology ensured that variations in participant experience, environmental conditions, and tool characteristics were thoroughly examined, providing a robust foundation for subsequent interpretation and clinical implications.

These recommendations aim to enhance torque application efficiency by identifying the most effective tools, glove types, and environmental conditions for dental professionals, ultimately improving treatment outcomes in dental implantology.

2.3.5. Ethical Considerations

Informed consent was obtained from all participants, ensuring they understood the study's objectives and procedures. Participant confidentiality and anonymity were strictly maintained throughout the study. This research was approved by the Ethics Committee for Health (CES) of the Universidade Católica Portuguesa.

Participation was entirely voluntary, and participants were free to withdraw at any time without consequences.

3. RESULTS

The sample of this research was composed of 10 professors and 20 undergraduate dental students from the 4th and 5th years of the Integrated Master in Dental Medicine (MIMD) program at FMD-UCP.

Participants were characterized according to several variables, and results are presented in Table 1 and Table 2:

- **Professors:** the group included 7 men and 3 women, with an average age of 39.3 years and a BMI of 23.85 kg/m². This group consisted of oral rehabilitation and oral surgery/periodontology professionals with experience in implant-related procedures (Table 1).
- **Students:** the group consisted of 12 women and 8 men, with an average age of 24 years and a BMI of 22.03 kg/m². This sample was evenly distributed, with 10 participants from the 4th year and 10 from the 5th year. The 5th year students had prior practical experience using screwdrivers for implant-related procedures, whereas the 4th year students possessed only theoretical knowledge of such techniques. (Table 2)

Following the participant characterization, the maximum torque values applied by each group- professors and students- were analyzed across different conditions. Torque measurements were taken under two distinct screwdriver types (medium and long) and with three different hand conditions (nitrile gloves, latex gloves, and bare hands), both in dry and wet environments.

This analysis provides insight into each group's torque performance based on their experience levels and the influence of external factors such as "Glove Types" and "Environmental Conditions". The following section presents a descriptive overview of the torque data for both the professors and students, highlighting the differences and similarities observed within the study

Table 1- Maximum torque values achieved by professors during manual tightening procedures.

The table compares results for" Long" and "Medium" screwdrivers under various conditions (nitrile gloves, latex gloves, and bare hands, both dry and wet). Additional parameters include age, height (H), weight (W), body mass index (BMI), area of dedication, prior experience in years (Exper.), and dominant hand (D-hand).

PROFESSORS							MEDIUM SCREWDRIVER						LONG SCREWDRIVER					
							Nitrile		Latex		Bare Hand		Nitrile		Latex		Bare Hand	
	Age	H-W	BMI	Area	Exper.	D-hand	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet
Prof-1	43	175-85	27.4	**Oral-Rehab**	30	R	12.9	20.0	18.8	10.9	11.4	10.2	14.8	11.0	11.1	11.7	8.2	11.8
Prof-2	41	185-90	26.3	**Oral-Rehab**	17	R	14.6	15.3	21.2	12.1	15.8	16.0	22.5	19.2	17.6	19.4	13.8	13.3
Prof-3	43	170-55	19.0	**Oral-Rehab**	19	R	36.0	27.8	18.7	10.7	20.8	19.7	32.3	21.3	8.2	8.6	10.9	8.9
Prof-4	47	160-50	19.2	**Oral-Rehab**	23	R	7.3	6.6	22.4	14.8	9.6	11.7	12.3	9.7	29.3	20.8	15.3	21.8
Prof-5	26	173-75	25.1	**Oral-Rehab**	3	R	14.6	10.7	7.4	9.6	6.4	5.6	14.1	10.8	7.3	7.4	7.9	6.0
Prof-6	42	187-80	22.9	**Oral-Surgery**	18	R	11.7	15.8	18.3	30.1	10.9	10.1	13.5	15.6	18.3	21.4	12.3	11.4
Prof-7	41	178-83	26.2	**Oral-Surgery**	15	R	27.0	18.4	17.8	18.0	20.2	18.4	24.1	21.2	15.0	17.5	11.1	10.4
Prof-8	43	190.84	23.2	**Oral-Surgery**	16	R	34.5	38.2	41.0	28.9	30.5	23.1	30.5	31.1	25.0	26.4	29.8	19.6
Prof-9	27	177-85	27.1	**Oral-Surgery**	5	R	20.1	15.7	18.1	12.6	13.5	16.3	22.0	10.8	13.6	14.5	12.7	7.8
Prof-10	40	180-71	21.8	**Oral-Surgery**	17	R	29.4	29.4	13.6	11.7	28.7	24.5	23.5	16.1	11.3	13.8	14.0	14.1

Table 2- Maximum torque values achieved by dental students during manual tightening procedures.

The table presents torque comparisons for "Long" and "Medium" screwdrivers under multiple conditions (nitrile gloves, latex gloves, and bare hands, both dry and wet). Additional parameters include age (yy), height (cm), weight (Kg), body mass index (BMI), academic year (A-y), prior experience (P-exper.), and dominant hand (D-hand, left or right).

STUDENTS							MEDIUM SCREWDRIVER						LONG SCREWDRIVER					
							Nitrile		Latex		Bare Hand		Nitrile		Latex		Bare Hand	
	Age	H-W	BMI	A-y	P-exper.	D-hand	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Stud-1	24	190-93	25.8	4	No	R	16.4	14.0	24.5	16.9	12.2	9.5	16.1	19.6	13.7	24.0	11.3	10.0
Stud-2	25	180-83	25.6	4	No	R	18.5	19.3	30.4	29.5	16.1	15.6	17.2	15.2	25.3	28.2	11.9	10.0
Stud-3	24	171-73	25.0	4	No	R	15.6	10.1	13.8	14.8	20.0	9.9	11.8	12.3	11.1	11.9	9.4	7.5
Stud-4	24	174-66	21.8	4	No	R	18.5	20.6	18.6	16.2	13.6	8.1	28.5	23.8	15.6	18.6	14.1	11.7
Stud-5	46	164-81	30.1	4	No	R	16.2	11.6	21.5	18.0	9.2	5.7	17.1	14.9	21.6	15.5	13.2	8.5
Stud-6	25	164-70	26.0	4	No	R	8.3	13.3	13.7	14.8	8.1	17.3	10.8	9.4	9.5	14.4	12.6	14.8
Stud-7	21	174-55	18.1	4	No	R	9.8	10.8	12.1	10.8	7.6	6.5	9.7	11.0	10.8	12.1	4.6	7.0
Stud-8	24	170-61	20.9	4	No	R	16.6	9.1	9.1	8.6	8.1	15.5	24.2	11.5	14.8	7.3	11.9	6.7
Stud-9	25	171-74	25.0	4	No	R	21.2	35.0	17.2	17.7	24.1	25.3	22.4	28.2	14.9	25.3	15.3	27.6
Stud-10	32	180-98	30.2	4	No	R	14.6	20.1	15.6	17.4	11.4	9.9	26.0	13.9	17.5	11.3	19.9	15.1
Stud-11	24	168-54	19.1	5	Yes	R	14.8	12.9	22.1	14.0	17.4	13.2	6.9	9.8	12.2	10.6	11.6	10.2
Stud-12	23	169-56	19.6	5	Yes	R	13.3	10.2	18.8	11.6	6.7	6.8	11.6	6.1	8.8	8.3	7.4	9.2
Stud-13	28	174-58	19.1	5	Yes	R	12.6	10.9	11.4	7.5	4.4	14.3	5.4	7.0	9.3	5.8	5.7	5.6
Stud-14	23	176-56	18.0	5	Yes	R	10.1	13.8	6.8	12.4	7.6	5.6	12.2	11.3	5.8	6.2	13.2	15.4
Stud-15	26	187-71	20.3	5	Yes	R	11.8	14.1	15.3	16.1	18.3	18.9	14.2	11.8	12.4	6.9	18.9	15.2
Stud-16	23	170-73	25.2	5	Yes	R	6.3	8.7	5.1	6.8	11.4	5.4	14.6	8.0	4.4	8.0	11.2	7.5
Stud-17	23	165-58	21.0	5	Yes	R	10.8	6.9	13.2	5.9	22.9	15.0	15.3	9.1	16.1	11.3	18.5	15.5
Stud-18	24	171-66	22.3	5	Yes	R	23.5	39.3	11.1	37.8	28.9	28.3	24.4	26.0	10.4	20.5	22.3	40.9
Stud-19	32	184-90	26.5	5	Yes	R	43.5	28.7	16.9	23.0	24.8	23.2	40.5	24.3	18.4	23.9	16.4	16.1
Stud-20	29	175-88	28.4	5	Yes	R	16.6	13.2	23.9	23.0	40.8	12.3	19.6	19.7	28.7	10.3	20.8	14.6

Table 3- Mean MTV achieved by "Users" using different "Screwdrivers", "Glove Types", and "Moisture Conditions".

	MEDIUM SCREWDRIVER						LONG SCREWDRIVER					
	NITRILE		LATEX		BARE HAND		NITRILE		LATEX		BARE HAND	
Hand condition	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet
Professors	19.67	19.79	19.73	15.94	16.78	15.56	20.96	16.68	15.67	16.15	13.60	12.51
Students	15.94	16.12	16.05	16.14	15.68	13.31	17.42	14.64	14.06	14.02	13.51	13.45

A detailed descriptive analysis of the maximum torque values was conducted to further understand the data obtained. This analysis examines the influence of various factors, including "Screwdriver Types", "Glove Types", and "Environmental Conditions" (dry or wet), on the torque values achieved.

The results are presented separately for the professors and students, enabling a clear comparison between the two groups. This section aims to provide a comprehensive overview of the range, mean, and variability of the torque values across all tested conditions. (**Erro! A origem da referência não foi encontrada.**)

In the **professor's group**, using the **medium screwdriver**:

- With "Nitrile Gloves", the maximum torque values ranged between 19.67 N/cm and 19.79 N/cm, with a mean of 19.73 N/cm (Dry: 19.67 N/cm; Wet: 19.79 N/cm).
- With "Latex Gloves", the maximum torque values ranged between 15.94 N/cm and 19.73 N/cm, with a mean of 17.83 N/cm (Dry: 19.73 N/cm; Wet: 15.94 N/cm).
- With "Bare Hands", the maximum torque values ranged between 15.57 N/cm and 16.78 N/cm, with a mean of 16.17 N/cm (Dry: 16.78 N/cm; Wet: 15.57 N/cm).
- Overall, the medium screwdriver showed a total mean torque of 17.91 N/cm (Dry: 18.72 N/cm; Wet: 17.10 N/cm).

In the **professor's group**, using the **long screwdriver**:

- With "Nitrile Gloves", the maximum torque values ranged between 16.68 N/cm and 20.96 N/cm, with a mean of 18.82 N/cm (Dry: 20.96 N/cm; Wet: 16.68 N/cm).
- With "Latex Gloves", the maximum torque values ranged between 15.67 N/cm and 16.15 N/cm, with a mean of 15.91 N/cm (Dry: 15.67 N/cm; Wet: 16.15 N/cm).
- With "Bare Hands", the maximum torque values ranged between 12.51 N/cm and 13.60 N/cm, with a mean of 13.05 N/cm (Dry: 13.60 N/cm; Wet: 12.51 N/cm).
- Overall, the long screwdriver showed a total mean torque of 15.92 N/cm (Dry: 16.74 N/cm; Wet: 15.11 N/cm).

For professors, the total mean torque values across all screwdriver types, gloves, and conditions were 16.92 N/cm (Dry: 17.73 N/cm; Wet: 16.10 N/cm).

In the **student's group**, with a **medium screwdriver**:

- With "Nitrile Gloves", the maximum torque values ranged between 15.94 N/cm and 16.12 N/cm, with a mean of 16.03 N/cm (Dry: 15.94 N/cm; Wet: 16.12 N/cm).
- With "Latex Gloves", the maximum torque values ranged between 16.05 N/cm and 16.14 N/cm, with a mean of 16.09 N/cm (Dry: 16.05 N/cm; Wet: 16.14 N/cm).
- With "Bare Hands", the maximum torque values ranged between 13.31 N/cm and 15.68 N/cm, with a mean of 14.49 N/cm (Dry: 15.68 N/cm; Wet: 13.31 N/cm).
- Overall, the medium screwdriver showed a total mean torque of 15.54 N/cm (Dry: 15.89 N/cm; Wet: 15.19 N/cm).

In the **student's group**, with a **long screwdriver**:

- With "Nitrile Gloves", the maximum torque values ranged between 14.64 N/cm and 17.42 N/cm, with a mean of 16.03 N/cm (Dry: 17.42 N/cm; Wet: 14.64 N/cm).
- With "Latex Gloves", the maximum torque values ranged between 14.02 N/cm and 14.06 N/cm, with a mean of 14.04 N/cm (Dry: 14.06 N/cm; Wet: 14.02 N/cm).
- With "Bare Hands", the maximum torque values ranged between 13.45 N/cm and 13.51 N/cm, with a mean of 13.48 N/cm (Dry: 13.51 N/cm; Wet: 13.45 N/cm).
- Overall, the long screwdriver showed a total mean torque of 14.52 N/cm (Dry: 15.00 N/cm; Wet: 14.04 N/cm).

For students, the total mean torque values across all screwdriver types, gloves, and conditions were 15.03 N/cm (Dry: 15.45 N/cm; Wet: 14.62 N/cm).

A structured statistical approach was adopted to evaluate the factors affecting the Maximum Torque Value (MTV) in prosthetic screw-tightening tasks.

Initially, parametric methods, such as one-way and two-way ANOVA, were used to analyze the main effects of factors, including "User Types", "Screwdriver Lengths", "Glove Types", and "Hand Conditions" (Dry/Wet), and their interactions. These tests were appropriate for datasets with a normal distribution and homogeneity of variances.

Following this, non-parametric methods, including the Mann-Whitney and Kruskal-Wallis tests, were employed to explore MTV differences in user groups and conditions, particularly when the data exhibited outliers and non-normal distributions. These methods were particularly effective in comparing variations within subgroups, such as differences between "Glove Types" (nitrile, latex, and bare hands), “Screwdriver Lengths” (medium vs. long), and “Hand Conditions” (dry vs. wet), ensuring valid conclusions for both parametric and non-parametric datasets.

Additionally, further analyses were conducted to investigate the impact of experience level (students vs. professors) on MTV, as well as the influence of glove types and other factors within each user group. This approach provided a deeper understanding of how various factors individually and collectively influence torque application during manual prosthetic screw-tightening tasks.

The following sections detail these findings, starting with an overview of the general trends established through ANOVA, followed by specific insights obtained through post-hoc analyses.

3.1. Evaluation of Factor Interactions Affecting Maximum Torque Value

Before data analysis, it was essential to evaluate whether the factors - “User”, “Gloves”, “Moisture Condition”, and “Screwdriver” - exhibited any interactions affecting the Maximum Torque Value (MTV).

This assessment was conducted through ANOVA. Results revealed no statistically significant interactions among the factors ($p>0.05$), indicating that combinations of variables such as “User*Screwdriver” or “Screwdriver*DryWet” did not significantly impact MTV under the tested conditions. Nevertheless, the analysis identified “Users” and “Gloves” as the primary factors influencing MTV.

The results of the between-subject effects test for MTV are detailed in Table 4.

Two factors demonstrated statistically significant main effects:

- **User**: the “User” factor significantly influenced MTV ($p = 0.02$). Professors achieved a higher mean MTV (16.92 N/cm) compared to students (15,66 N/cm), reflecting the impact of professional experience and skill level on torque application.
- **Gloves**: the “Gloves” factor also had a significant effect on MTV ($p = 0.005$). Comparisons indicated that “Nitrile Gloves” resulted in higher MTV compared to “Bare Hands”. However, no statistically significant difference was observed between “Nitrile Gloves” and “Latex Gloves” when accounting for other factors.

Although the “Screwdriver” factor approached statistical significance ($p = 0.07$), suggesting a possible influence that warrants further exploration, the “Dry/Wet” factor and all interaction effects, including two-way, three-way, and four-way combinations, were not statistically significant ($p > 0.05$).

These findings underscore the critical role of the “User” experience and “Gloves” in influencing the maximum torque achieved during manual prosthetic screw tightening. In contrast, interactions among the tested factors were negligible under the experimental conditions.

3.2. Comparison of Maximum Torque Value: Students vs Professors

The role of the "User" (students vs. professors) was analyzed to further investigate the factors influencing Maximum Torque Value (MTV).

Differences in MTV between these two groups may provide insights into how experience and expertise affect torque application.

Table 5 presents the main descriptive statistics and the p-value from the Mann-Whitney test comparing the median MTV values of students and professors. Additionally, Figure 8 visually highlights the differences. Since the p-value is less than 0,05, it is concluded that professors have a significantly higher median MTV compared to students.

Table 4- The between-subject effects test results for the dependent variable MTV.

Factors	p-value
User	**0.02**
Screwdriver	0.07
Gloves	**0.005**
Dry Wet	0.13
Factors interactions	
User * Screw Driver	0.56
User * Gloves	0.43
User * Dry Wet	0.63
Screwdriver * Gloves	0.67
Screwdriver * Dry Wet	0.93
Gloves * Dry Wet	0.91
User * Screwdriver * Gloves	0.85
User * Screwdriver * DryWet	0.93
User * Gloves * DryWet	0.91
Screwdriver * Gloves * Dry Wet	0.31
User * Screwdriver * Gloves * Dry Wet	0.67

Table 5- Descriptive statistics for MTV in different "Users" and Mann-Whitney analysis.

	Mean	p-value
Students	15.03	0.01 (<0.05)
Professors	16.92	

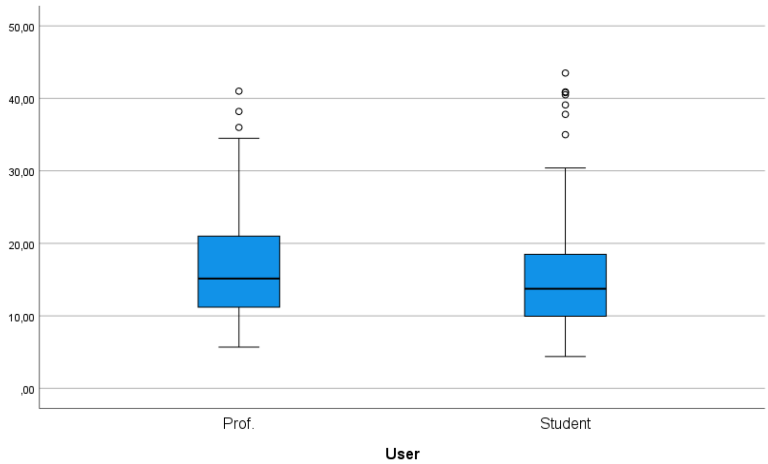

Figure 8-Boxplot illustrating the distribution of MTV between "Users".

3.3. Influence of "Glove Types" on Maximum Torque Value

After examining the influence of the "User Types" on MTV, attention was turned to another critical factor: the type of "Gloves" used during manual prosthetic screw tightening.

The gloves' material can impact grip and torque application, potentially influencing MTV.

Table 6 and

Table 7 present the main descriptive statistics and the p-value of the Kruskal-Wallis test. Figure 9 is for better visualization of the differences in Maximum Torque Value (MTV) among the three Glove types: "Nitrile", "Latex", and "Bare Hands".

"Nitrile Gloves" produced the highest mean MTV (17.11 N/cm), followed by "Latex Gloves" (15.67 N/cm) and "Bare Hands" (14.20 N/cm).

Pairwise comparisons further revealed that nitrile gloves result in a significantly higher MTV compared to bare hands (p = 0.008). However, no significant differences were observed between nitrile gloves and latex gloves (p = 0.85).

Table 6- Descriptive statistics for MTV in different "Glove Types" and Mann-Whitney analysis.

	Mean	p-value
Nitrile	17.11	**0.01 (<0.05)**
Latex	15.67	
Bare Hands	14.20	

Table 7- Pairwise comparison between different conditions for MTV.

Sample 1 - Sample 2	p-value
Bare Hands - Latex Gloves	0.16
Bare Hands - Nitrile Gloves	**0.008**
Latex Gloves - Nitrile Gloves	0.85

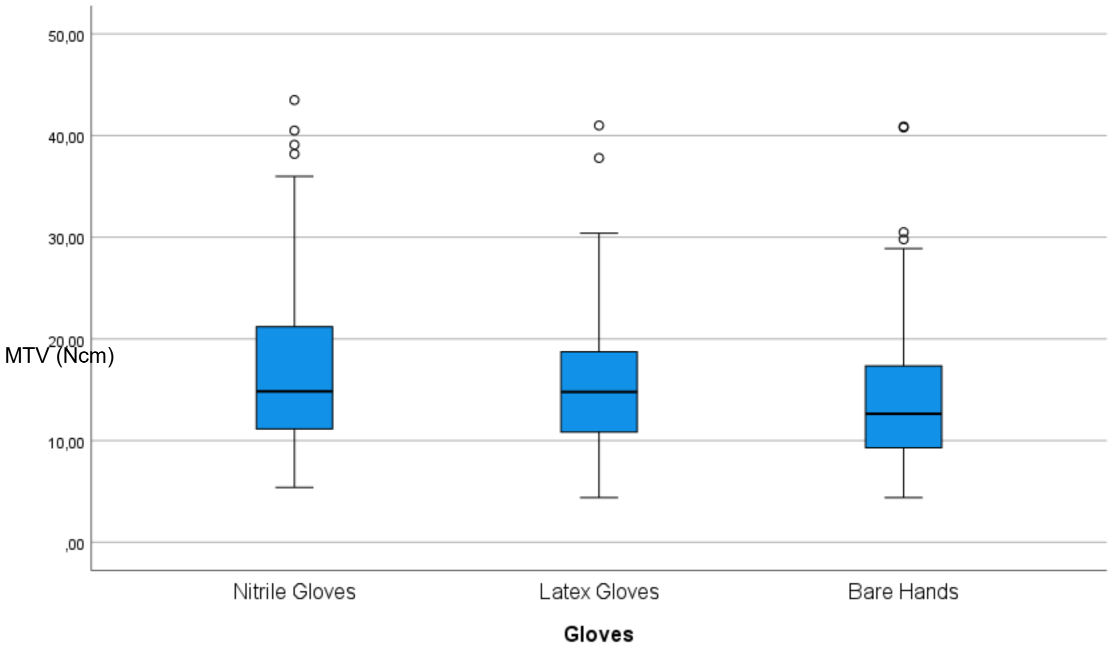

Figure 9- Boxplot illustrating the distribution of MTV for users using different "Glove Types".

3.4. Influence of "Screwdriver Lengths" on Maximum Torque Value

The effect of "Screwdriver Lengths" on Maximum Torque Value (MTV) was assessed by applying a Mann-Whitney test. While the mean MTV for "Medium Screwdrivers" (16.33 N/cm) is somewhat higher than that for "Long Screwdrivers" (14.99 N/cm), the p-value greater than 0.05 (0.12) indicates that the "Screwdriver Lengths" do not significantly affect the MTV. (Table 8)

Figure 10 further supports this finding, as it demonstrates the substantial overlap between the two groups' data distributions, reinforcing the conclusion that screwdriver length does not notably influence the torque applied.

Table 8- Descriptive statistics for MTV between "Screwdrivers" and Mann-Whitney analysis.

	Mean	p-value
Long	14.99	0.12 (>0.05)
Medium	16.33	

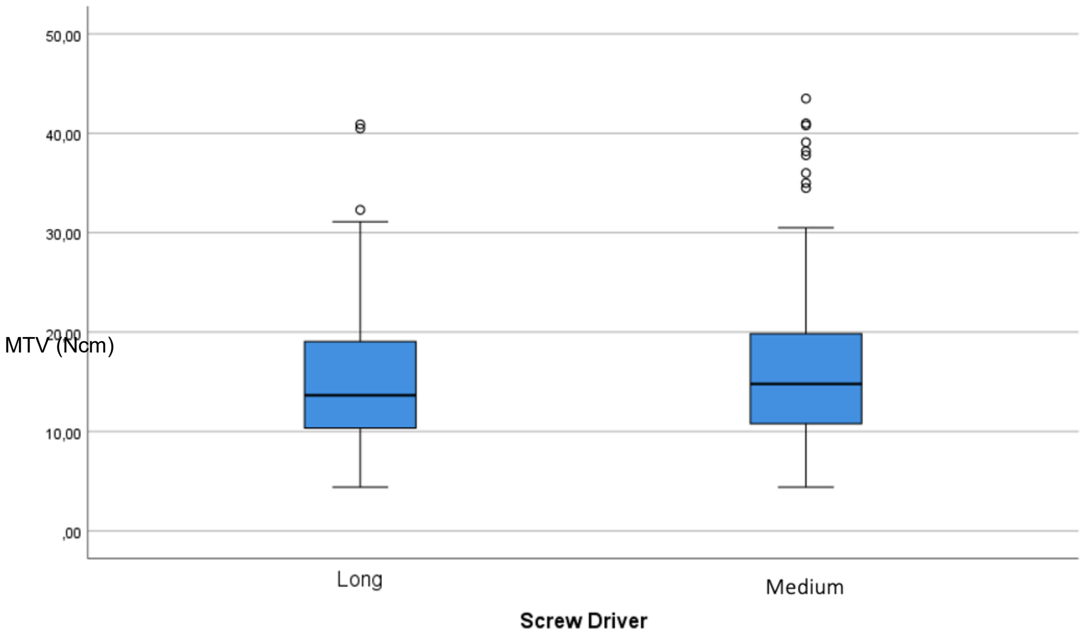

Figure 10- Boxplot illustrating the distribution of MTV between "Screwdrivers".

3.5. Influence of “Hand Conditions” (Dry vs. Wet) on Maximum Torque Value

The effect of “Hand Conditions” (dry vs. wet) on Maximum Torque Value (MTV) was evaluated using a Mann-Whitney test.

The mean MTV for “Dry” hands (16.21 N/cm) is slightly higher than that for “Wet” hands (15.11 N/cm), but the p-value of 0.07, which is greater than 0.05, indicates no statistically significant difference between the two conditions. (Table 9)

Figure 11 illustrates this finding, showing considerable overlap between the distributions of both “Dry” and “Wet” hand conditions, thus supporting the conclusion that the Moisture level of the hands does not significantly affect the MTV.

Table 9- Descriptive statistics comparing MTV between “Moisture Conditions” and Mann-Whitney analysis.

	Mean	**p-value**
Dry	16.21	0.07 (>0.05)
Wet	15.11	

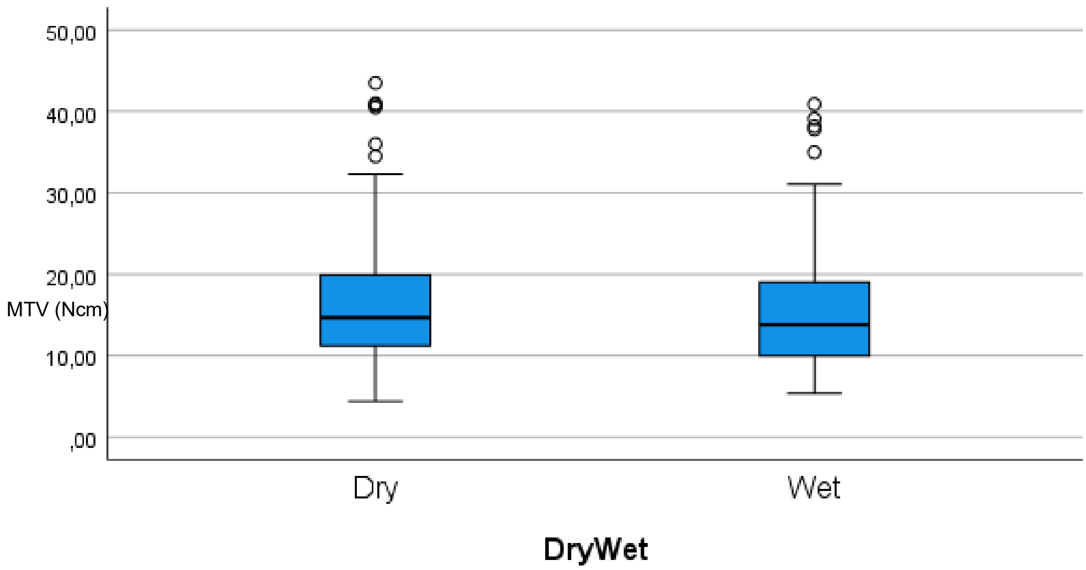

Figure 11- Boxplot comparing the MTV distributions for “Moisture Conditions”.

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3.6. Effect of "Gloves" on Maximum Torque Value: Students vs Professors

Given the significant differences observed between students and professors, it is valuable to further analyze the Maximum Torque Value (MTV) for each group separately. This will allow us to explore how various factors, such as the use of "Gloves", influence MTV within each group and determine if the effects differ between students and professors.

Table 10 presents the descriptive statistics and p-value from the Kruskal-Wallis test for students and professors. To enhance the understanding of the differences, box plots for both students and professors are also provided. (Figure 12 and Figure 13)

For students, the p-value exceeds 0.05, indicating that gloves do not significantly influence MTV. In contrast, for professors, the p-value is less than 0.05, which suggests that the type of gloves used significantly impacts MTV.

Table 10- Descriptive statistics for MTV in "Users" and "Glove Types" and Kruskal-Wallis analysis.

	Mean	**p-value**
Students		
Nitrile	16.03	0.16 (>0.05)
Latex	15.07	
Bare Hands	13.99	
Professors		
Nitrile	19.28	0.02 (<0.05)
Latex	16.87	
Bare Hands	14.62	

Pairwise comparisons (Table 11) for professors reveal that nitrile gloves result in a significantly higher MTV compared to bare hands, while no significant difference is observed between nitrile gloves and latex gloves.

Table 11- Pairwise comparison for MTV differences in professors using different "Glove Types".

Sample 1-Sample 2	**p-value**
Bare Hands-Latex Gloves	0.47
Bare Hands-Nitrile Gloves	0.01
Latex Gloves-Nitrile Gloves	0.54

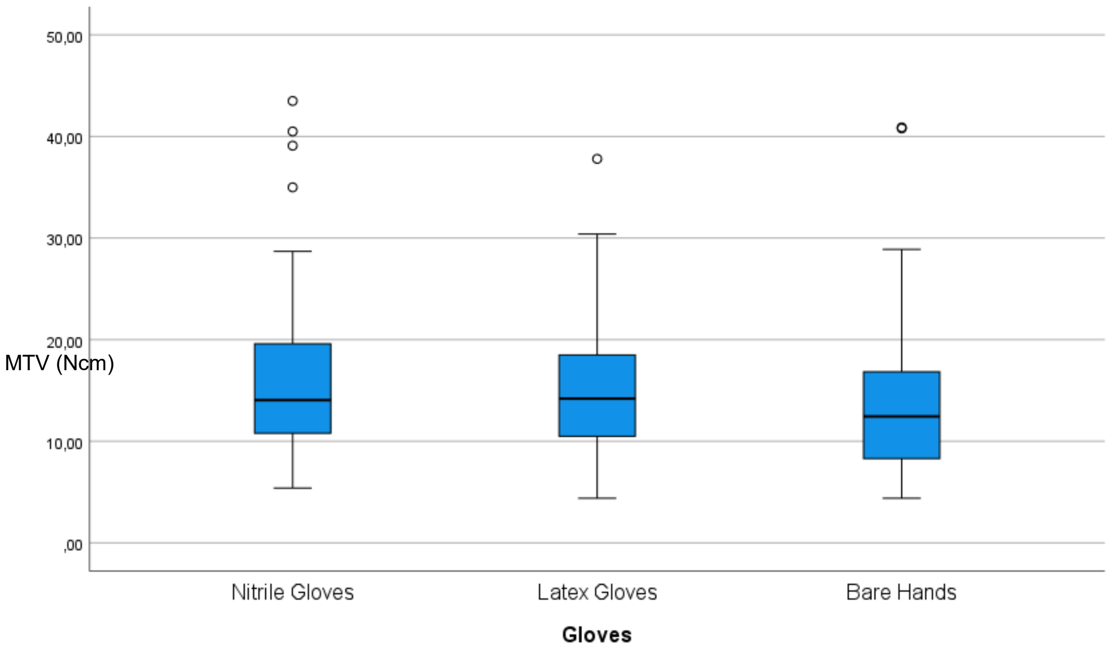

Figure 12- Boxplot illustrating the distribution of MTV for students using different “Glove Types”.

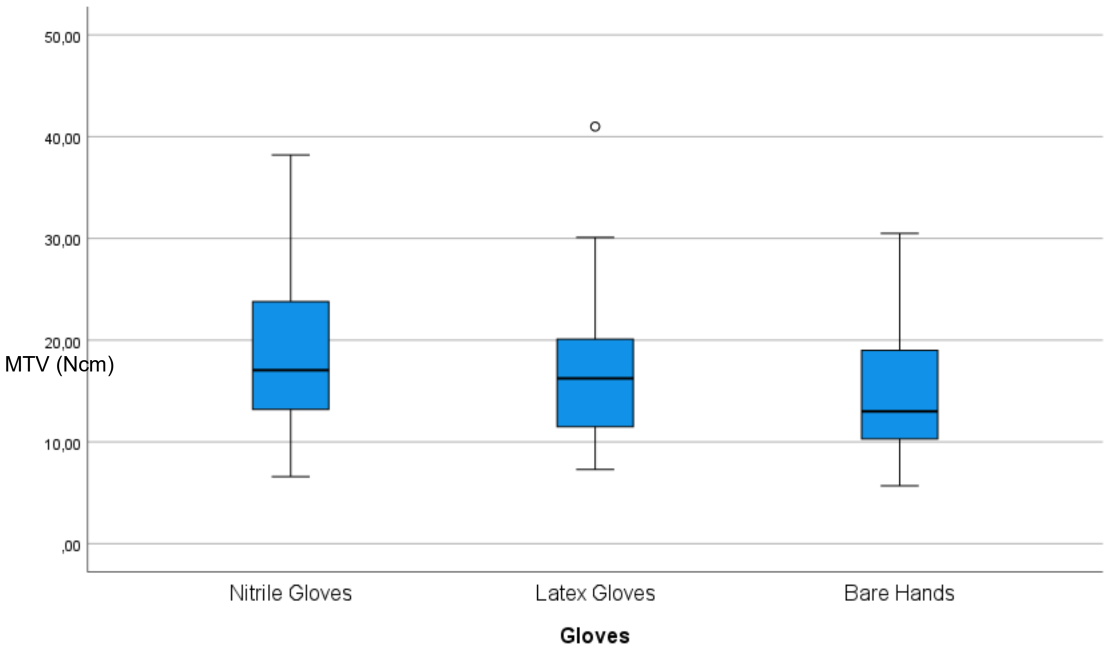

Figure 13- Boxplot illustrating the distribution of MTV for professors using different “Glove Types”.

3.7. Effect of "Screwdrivers" on Maximum Torque Values: Students vs Professors

The following table (Table 12) presents the descriptive statistics and the p-values obtained from the Mann-Whitney test, which was conducted separately for students and professors. The test was used to assess whether the types of "Screwdrivers" (medium or long) significantly affect the Maximum Torque Value (MTV) within each group. To aid in visualizing the distribution of MTV values, Figure 14 and Figure 15 are also provided for both students and professors.

The results indicate that for both students and professors, the p-values exceed 0.05 (0.29 for students and 0.23 for professors). This suggests that these types of screwdrivers (long or medium) do not have a statistically significant effect on the MTV in either group. In other words, the difference in MTV between the two screwdriver types is not large enough to be considered meaningful for either students or professors.

Table 12- Descriptive statistics for MTV in different "Screwdrivers" and "Users" and Mann-Whitney analysis.

	Mean	**p-value**
Students		
Long	14.52	0.29 (>0.05)
Medium	15.54	
Professors		
Long	15.93	0.23 (>0.05)
Medium	17.91	

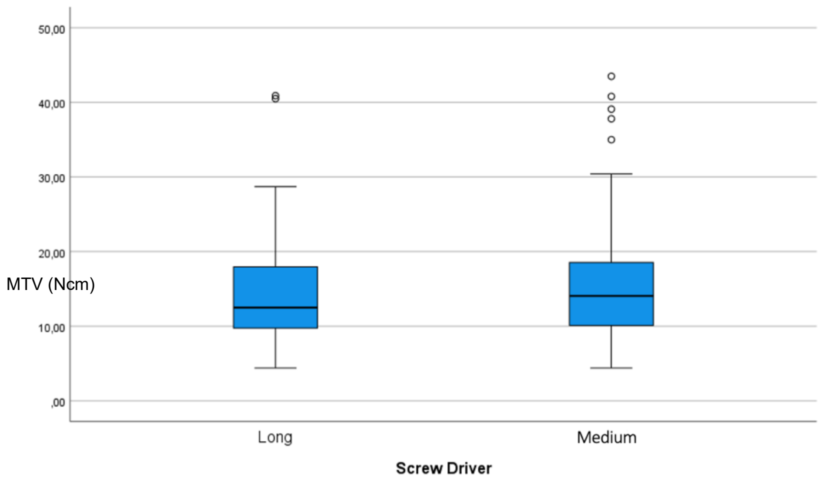

Figure 14- Distribution of MTV for students using different "Screwdriver Types".

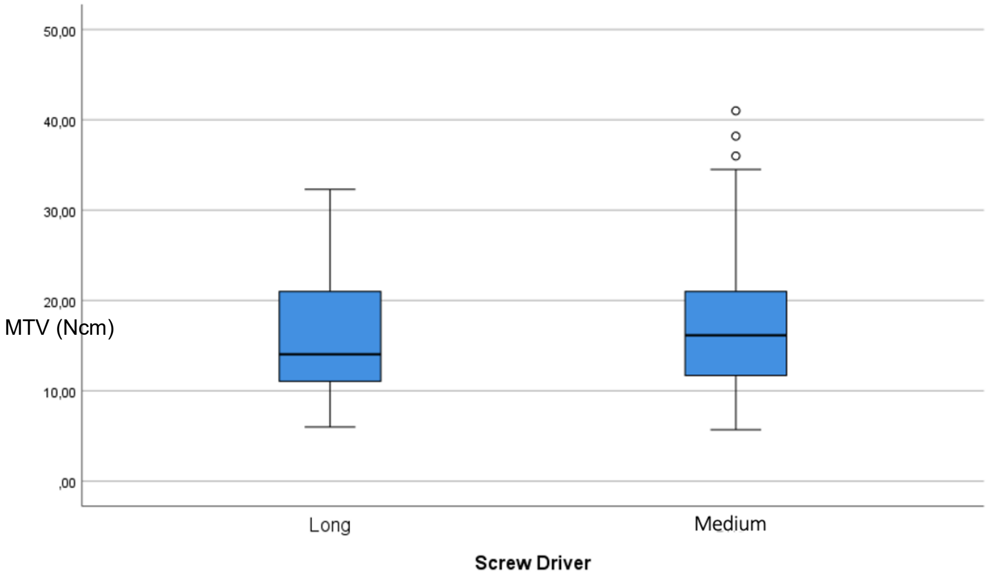

Figure 15- Distribution of MTV for professors using different "Screwdriver Types".

3.8. Effect of "Moisture Conditions" on Maximum Torque Value: Students vs Professors

The analysis of the influence of "Moisture Conditions" (wet or dry) on MTV was conducted separately for students and professors (Table 13). Boxplots for each group are included to provide a clear visualization of the results. (Figure 16 and Figure 17)

The p-values for both groups exceed 0.05, indicating that moisture conditions do not significantly affect MTV for either students or professors.

Table 13- Descriptive statistics for MTV in different "Moisture Conditions" and "Users" and Mann-Whitney analysis.

	Mean	p-value
Students		
Dry	15.45	0.14 (>0.05)
Wet	16.62	
Professors		
Dry	17.74	0.27 (>0.05)
Wet	16.11	

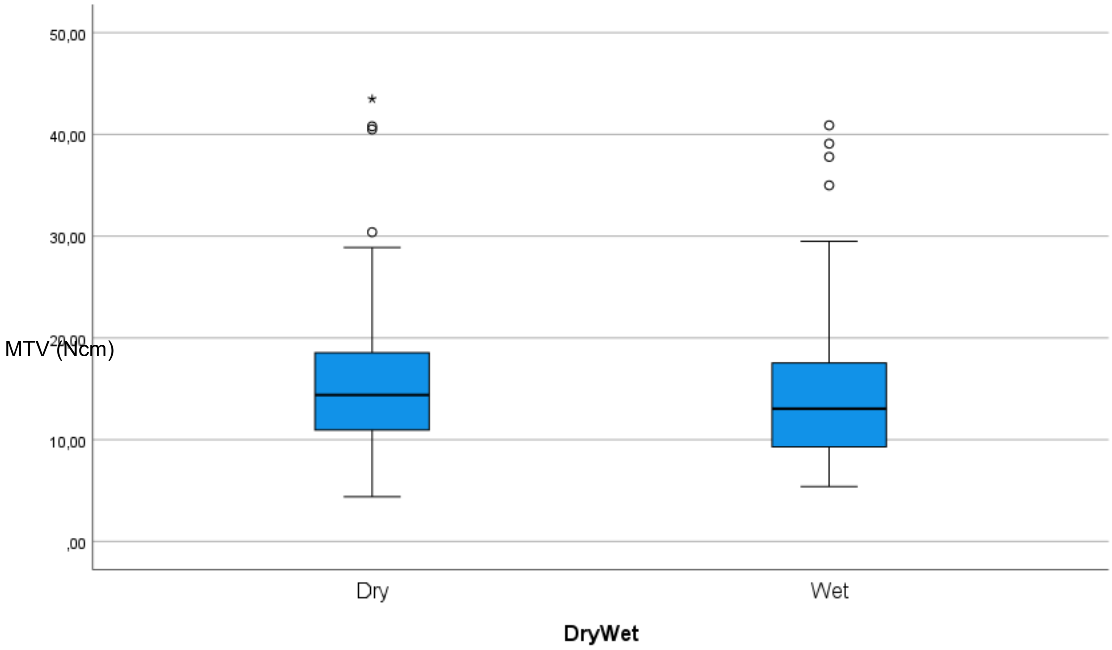

Figure 16- Distribution of MTV for students under different “Moisture Conditions”.

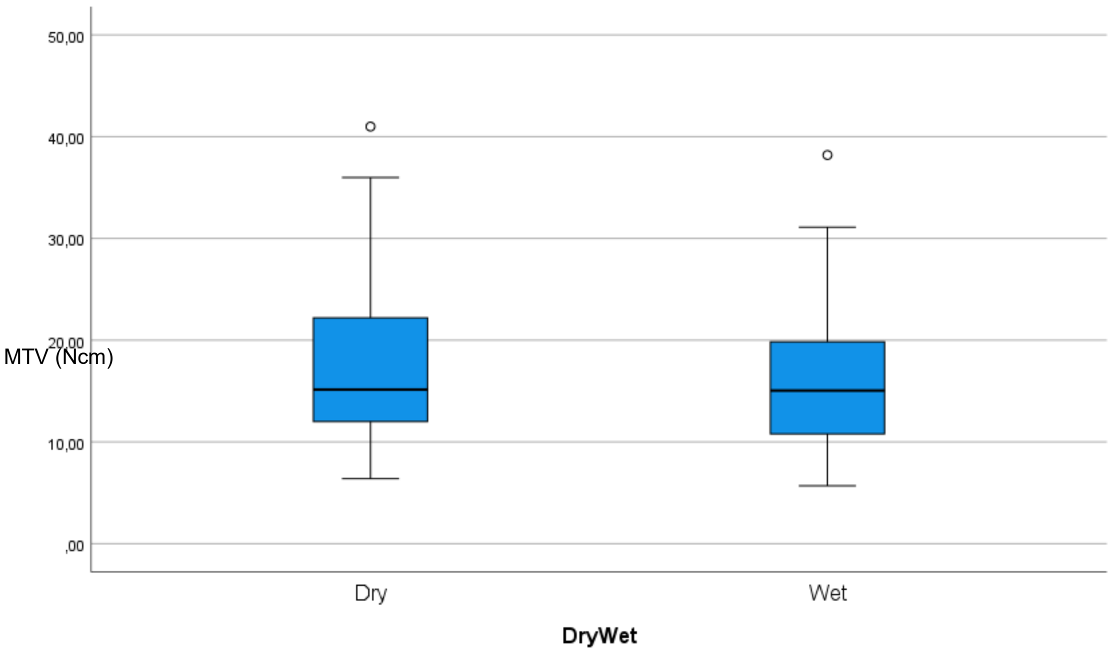

Figure 17- Distribution of MTV for professors under different “Moisture Conditions”.

4. DISCUSSION

The accurate application of torque in dental implantology is a fundamental factor ensuring the stability, durability, and long-term success of implant-supported prostheses. (25) This study aimed to assess the maximum torque applied during the manual tightening of prosthetic screws, with a particular focus on the impact of user experience and procedural conditions on torque application.

By analyzing variations in technique, familiarity with tools, and external factors, this research seeks to enhance clinical understanding and improve standardization in implant dentistry. The goal is to generate reliable data that informs clinical protocols, ensuring greater precision and uniformity in practice.

Achieving optimal torque during screw tightening is critical in prosthetic rehabilitation, as improper application can lead to screw loosening, prosthetic instability, or mechanical failure.(30, 56)

Such complications not only affect patient satisfaction but may also necessitate costly and time-consuming corrective procedures. The significance of this research lies in its potential to refine clinical protocols by providing a scientific foundation for best practices in prosthetic rehabilitation.

This study also intends to bridge the gap between theoretical knowledge and real-world implementation by addressing practical challenges faced by clinicians. The findings contribute to evidence-based strategies that advance implant dentistry, improving both scientific understanding and clinical outcomes.

While manufacturers provide recommended torque values, clinical application can vary significantly due to multiple variables, including operator expertise, tool selection, environmental conditions, and individual technique. This study examined how practitioner experience, glove types, screwdriver lengths, and moisture conditions influence maximum torque values (MTV).

By comparing these findings with existing literature, it can better identify where manual application aligns with research-based recommendations and where inconsistencies emerge, highlighting areas that require further refinement.

4.1. Maximum torque value vs Experience (Students vs. Professors)

A notable difference in torque application was observed between students and professors. Professors consistently applied higher and more stable torque values (mean MTV = 16.92 Ncm), whereas students achieved lower values (mean MTV = 15.03 Ncm). These findings support the notion that clinical experience enhances torque control and precision. Considering the observed differences, $\mathbf{H_{01}}$ **is rejected**, confirming that clinical experience significantly influences torque application in implant procedures.

Similar trends have been documented in prior research. Parnia et al. (51) reported that postgraduate students applied lower torque compared to experienced clinicians, demonstrating a direct correlation between clinical training and manual torque efficiency.

Alikhasi et al. (25) Also found that less experienced practitioners exhibited greater inconsistencies in torque application, reinforcing the idea that manual tightening alone remains unreliable without standardized procedural measures.

Furthermore, Adaobi (57) observed that even among skilled clinicians, manufacturer-recommended torque values (30 Ncm) were not always consistently met, highlighting the necessity of calibrated torque wrenches to enhance procedural reliability.

In addition to experience, individual physical attributes such as grip strength and dexterity may contribute to torque variability. Jaarda et al. (29) discovered that clinicians with greater grip strength achieved higher torque values, irrespective of their professional experience. This may explain some of the variations seen in this study, as students may not yet possess the same level of muscular endurance and refined motor control as experienced practitioners.

Taken together, these findings indicate that while clinical experience improves torque application, it does not eliminate variability.

This underscores the importance of incorporating/using mechanical torque calibration devices in clinical practice to enhance precision and consistency.(30)

4.2. Influence of Glove Types on Maximum Torque Values

This study revealed that the types of gloves worn had a notable impact on torque application. Nitrile gloves resulted in the highest maximum torque values (MTV) at 17.11 Ncm, followed by latex gloves at 15,67 Ncm, while bare hands produced the lowest values at 14.20 Ncm.

The difference between nitrile gloves and bare hands was statistically significant ($p = 0.008$), suggesting that wearing gloves enhances grip efficiency and improves force transmission. These findings indicate that nitrile gloves provide a distinct advantage in torque application over bare hands. while the differences between the other glove conditions are not statistically significant.

These findings underscore the importance of nitrile gloves in achieving higher torque values, suggesting they offer an advantage in manual prosthetic screw-tightening tasks.

Given the differences identified between glove types, particularly nitrile gloves and bare hands, **H_{03} is rejected**, indicating that glove material plays a role in torque performance.

These results align with findings from Nishiuchi et al. (50), who reported that gloves with higher friction coefficients improve grip stability, leading to more effective torque application**.**

Similarly, Bulaqi et al. (56) demonstrated that gloves enhance force transmission by increasing friction, thereby improving manual control.

However, there is debate regarding whether gloves enhance or hinder fine motor control and tactile sensitivity. Zare et al. (58) found that latex gloves reduced proprioceptive feedback, potentially leading to over-tightening. Similarly, Sung (59) observed that gloves altered grip mechanics but did not significantly impact torque precision, suggesting that glove material selection should balance friction enhancement and tactile feedback.

These findings indicate that glove selection should be tailored based on procedural requirements, particularly in torque-sensitive applications.

4.3. Effect of Screwdriver Lengths on Torque Application

Unlike previous studies, this research found no statistically significant difference between medium (16.33 Ncm) and long (14.99 Ncm) screwdrivers ($p = 0.12$), suggesting that the screwdriver lengths used in this research do not directly affect torque application.

As no substantial variation was observed between medium (21mm) and long screwdrivers (27mm), **H_{02} is not rejected**, suggesting that screwdriver length alone does not critically affect torque delivery.

These findings contrast with Alikhasi et al. (25) those and Kanawati et al. (30), who reported that longer screwdrivers enhanced torque efficiency due to leverage advantages. However, Alikhasi et al. (25) only measured the handle lengths, 12.47 mm for the long and 8.01 mm for the short screwdriver, while Jaarda et al. (29) , for comparison, used significantly longer instruments (37 mm and 20 mm, respectively). Kanawati et al. (30) did not disclose specific length measurements differences, and their classification included screwdrivers from different brands, potentially affecting consistency.

However, Mylon et al. (60) proposed that grip adaptability compensates for screwdriver length variations, leading to neutralized effects on torque output.

Additionally, Dianat et al. (61) found that torque accuracy depends more on wrist stability and hand positioning than on tool length, further explaining why the expected mechanical advantage of longer screwdrivers did not manifest in this study.

These results suggest that screwdriver selection should prioritize ergonomics and accessibility rather than torque optimization.

4.4. Impact of Moisture Conditions on Torque Values

This study found no statistically significant effect of moisture conditions on torque application ($p = 0.07$). While dry hands achieved slightly higher MTV (16.21 Ncm) compared to wet hands (15.11 Ncm), the difference was not clinically relevant.

Since no significant impact was attributed to moisture presence on torque values, **H_{04} is not rejected**, implying that dry or wet conditions may not be a decisive factor under the tested circumstances.

These results contrast with Bulaqi et al. (56) those who found that moisture reduced torque efficiency by up to 15%. However, Mylon et al. (60) suggested that practitioners unconsciously adjust grip force in response to wet conditions, minimizing its impact on torque accuracy.

Given these findings, moisture levels may not substantially affect torque application in controlled environments, but further investigation is needed to assess real-world clinical conditions.

4.5. Interaction Effects Between Glove Type, Screwdriver Length and Hand Moisture

The ANOVA analysis revealed no statistically significant interaction effects among glove type, screwdriver length, hand moisture, or user experience. For example, combinations such as "*User × Glove Type*" ($p = 0.43$) and "*Glove Type × moisture condition*" ($p = 0.91$) did not influence maximum torque values in a combined manner. These findings suggest that the tested variables acted independently, with no amplifying or modifying effects between them.

As a result, **H_{05} is not rejected**, supporting the interpretation that these procedural factors do not interact in a way that significantly alters torque application outcomes.

This observation is in line with studies such as Parnia et al. (51) and Alikhasi et al. (25), both of which found that while individual variables like user characteristics or tool design affected torque, no significant interaction effects were identified.

These findings reinforce the idea that improving individual conditions, such as operator training or glove material, may have a greater clinical impact than attempting to optimize variable combinations.

The findings of this study reinforce the complexity of manual torque application in implant dentistry, highlighting the interplay between operator skill, tool selection, and procedural conditions. While certain factors contribute to torque precision, the inherent variability in manual application underscores the need for improved standardization and calibration techniques.

These results emphasize that achieving consistent and reliable torque values requires both technical expertise and procedural refinement. Moving forward, integrating evidence-based calibration methods alongside clinical expertise will be essential in minimizing variability and improving long-term implant stability.

4.6. Limitations of this research

Although all the results obtained, it is important to acknowledge certain limitations related to the controlled nature of this experimental setup, which differs from real-world clinical practice.

The Type III plaster model used in this experiment provided a standardized platform for torque measurements, but it does not fully replicate the complexities of actual patient cases. In a clinical environment, additional factors such as patient movement and restricted intraoral access can further influence torque application (62, 63), elements that were not accounted for in this study's design.

Additionally, despite efforts to standardize participant training, variations in technique, grip strength, and tool handling may have introduced inconsistencies in the recorded torque values.

This limitation is particularly relevant when comparing groups with differing levels of clinical experience, such as students and experienced clinicians, where variations in manual dexterity, tool familiarity, and physical endurance could have influenced torque precision.

Furthermore, participant characteristics, including hand size, muscle fatigue, and overall strength, were not controlled in this study, potentially contributing to data variability.

The generalizability of these findings may also be limited due to the specific sample population, as participants were drawn from a single academic institution, which may not fully represent the broader dental professional community.

Additionally, this study focused on a limited range of tools, namely, long and medium Straumann® screwdrivers (27mm Vs 21mm), which may restrict the applicability of these findings to other instrument brands or clinical variations.

Lastly, while this research examined four key variables (tool types, glove materials, moisture conditions, and experience level), other factors such as implant system variations, prosthetic design, and clinical environment conditions were not considered but could play a significant role in torque application in practical settings.

4.7. Future perspectives

Further studies should be conducted using calibrated torque devices with different mechanisms, and should also evaluate how repeated use and time affect the stability and reliability of the applied torque.

5. CONCLUSION

This study provides valuable insights into the factors affecting maximum torque application in implant dentistry. Within the limitations of this research, it can be concluded that:

- Experience level significantly influenced performance, with professors achieving higher torque values than students, highlighting the role of clinical proficiency in torque application.
- Among the tested variables, glove type had a notable impact, with nitrile gloves producing higher torque values than bare hands, reinforcing their advantage in clinical practice.
- However, screwdriver length and hand moisture conditions showed no significant effect, suggesting that these factors may not be as critical as previously assumed.

These findings emphasize the importance of structured training and evidence-based guidelines to improve torque precision and minimize risks such as screw loosening and prosthetic failure. Incorporating these insights into clinical education and practice can enhance manual dexterity, procedural consistency, and long-term implant success.

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7. APPENDICES

Table 14 - Descriptive statistics for the MTV across groups categorized by "User Types", "Glove Types", "Screwdriver Lengths", and "Hand Conditions".

User	Screwdriver	Gloves	Dry/ Wet	Média	Estatística do teste Padrão	N
Professors	Long	Nitrile Gloves	Dry	20.9600	7.11043	10
			Wet	16.6800	6.73049	10
			Total	18.8200	7.08710	20
		Latex Gloves	Dry	15.6700	7.10275	10
			Wet	16.1500	6.03918	10
			Total	15.9100	6.42134	20
		Bare Hands	Dry	13.6000	6.17540	10
			Wet	12.5100	4.98341	10
			Total	13.0550	5.49004	20
		Total	Dry	16.7433	7.28819	30
			Wet	15.1133	6.05297	30
			Total	15.9283	6.69275	60
	Medium	Nitrile Gloves	Dry	19.6700	9.75865	10
			Wet	19.7900	9.46825	10
			Total	19.7300	9.35831	20
		Latex Gloves	Dry	19.7300	8.57426	10
			Wet	15.9400	7.53469	10
			Total	17.8350	8.09296	20
		Bare Hands	Dry	16.7800	8.11525	10
			Wet	15.5700	6.08624	10
			Total	16.1750	7.00908	20
		Total	Dry	18.7267	8.64694	30
			Wet	17.1000	7.79120	30
			Total	17.9133	8.20127	60
	Total	Nitrile Gloves	Dry	20.3150	8.33643	20
			Wet	18.2350	8.15277	20
			Total	19.2750	8.20659	40
		Latex Gloves	Dry	17.7000	7.94097	20
			Wet	16.0450	6.64676	20
			Total	16.8725	7.27645	40
		Bare Hands	Dry	15.1900	7.20562	20
			Wet	14.0400	5.63685	20
			Total	14.6150	6.41199	40
		Total	Dry	17.7350	7.99124	60
			Wet	16.1067	6.98921	60
			Total	16.9208	7.51993	120
Student	Long	Nitrile Gloves	Dry	17.4250	8.36439	20
			Wet	14.6450	6.67300	20
			Total	16.0350	7.59998	40
		Latex Gloves	Dry	14.0650	6.10334	20
			Wet	14.0200	7.00703	20
			Total	14.0425	6.48600	40
		Bare Hands	Dry	13.5100	4.87625	20
			Wet	13.4550	8.19907	20
			Total	13.4825	6.65848	40
		Total	Dry	15.0000	6.72504	60
			Wet	14.0400	7.21388	60

			Total	14.5200	6.96109	120
	Medium	Nitrile Gloves	Dry	15.9450	7.76832	20
			Wet	16.1200	8.78465	20
			Total	16.0325	8.18555	40
		Latex Gloves	Dry	16.0550	6.30926	20
			Wet	16.1400	7.76194	20
			Total	16.0975	6.98186	40
		Bare Hands	Dry	15.6800	9.14524	20
			Wet	13.3150	6.73540	20
			Total	14.4975	8.01753	40
		Total	Dry	15.8933	7.69490	60
			Wet	15.1917	7.78802	60
			Total	15.5425	7.71705	120
	Total	Nitrile Gloves	Dry	16.6850	8.00287	40
			Wet	15.3825	7.73609	40
			Total	16.0338	7.84805	80
		Latex Gloves	Dry	15.0600	6.20937	40
			Wet	15.0800	7.37724	40
			Total	15.0700	6.77507	80
		Bare Hands	Dry	14.5950	7.31689	40
			Wet	13.3850	7.40653	40
			Total	13.9900	7.34040	80
		Total	Dry	15.4467	7.20980	120
			Wet	14.6158	7.49717	120
			Total	15.0312	7.35128	240
Total	Long	Nitrile Gloves	Dry	18.6033	8.02502	30
			Wet	15.3233	6.64715	30
			Total	16.9633	7.49051	60
		Latex Gloves	Dry	14.6000	6.37609	30
			Wet	14.7300	6.67306	30
			Total	14.6650	6.47105	60
		Bare Hands	Dry	13.5400	5.23599	30
			Wet	13.1400	7.20807	30
			Total	13.3400	6.24932	60
		Total	Dry	15.5811	6.92621	90
			Wet	14.3978	6.83343	90
			Total	14.9894	6.88634	180
	Medium	Nitrile Gloves	Dry	17.1867	8.50188	30
			Wet	17.3433	9.02650	30
			Total	17.2650	8.69385	60
		Latex Gloves	Dry	17.2800	7.21117	30
			Wet	16.0733	7.55650	30
			Total	16.6767	7.34822	60
		Bare Hands	Dry	16.0467	8.68978	30
			Wet	14.0667	6.51054	30
			Total	15.0567	7.67771	60
		Total	Dry	16.8378	8.08824	90
			Wet	15.8278	7.79784	90
			Total	16.3328	7.93832	180
	Total	Nitrile Gloves	Dry	17.8950	8.22760	60
			Wet	16.3333	7.92487	60
			Total	17.1142	8.08177	120

		Latex Gloves	Dry	15.9400	6.88248	60
			Wet	15.4017	7.10019	60
			Total	15.6708	6.96799	120
		Bare Hands	Dry	14.7933	7.22420	60
			Wet	13.6033	6.82572	60
			Total	14.1983	7.02366	120
		Total	Dry	16.2094	7.53500	180
			Wet	15.1128	7.34607	180
			Total	15.6611	7.45103	360

Table 15-Descriptive statistics for MTV by "Users" and Mann-Whitney analysis.

	N	Mean	Std. Deviation	Min	Max	p-value
Student	240	15.03	7.35	4.4	43.5	0.014 (<0.05)
Professors	120	16.92	7.52	5.7	41	

Table 16- Descriptive statistics for MTV by "Glove Types", and Kruskal-Wallis analysis.

	N	Mean	Std. Deviation	Min	Max	p-value
Nitrile	120	17.11	8.08	5.4	43.5	0.01 (<0.05)
Latex	120	15.67	6.97	4.4	41	
Bare Hands	120	14.20	7.02	4.4	40.9	

Table 17- Descriptive statistics for MTV by "Screwdriver Lengths" and Mann-Whitney analysis.

	N	Mean	Std. Deviation	Min	Max	p-value
Long	180	14.99	6.89	4.4	40.9	0.120 (>0.05)
medium	180	16.33	7.94	4.4	43.5	

Table 18- Descriptive statistics for MTV by "Moisture Conditions" and Mann-Whitney analysis.

	N	Mean	Std. Deviation	Min	Max	p-value
Dry	180	16.21	7.54	4.4	43.5	0.079 (>0.05)
Wet	180	15.11	7.35	5.4	40.9	

Table 19-Descriptive statistics for MTV by "Glove Types" and "Users" and Kruskal-Wallis analysis.

	N	Mean	Std. Deviation	Min	Max	p-value
Students						
Nitrile	80	16.03	7.85	5.4	43.5	0.167 (>0.05)
Latex	80	15.07	6.78	4.4	37.8	
Bare Hands	80	13.99	7.34	4.4	40.9	
Professors						
Nitrile	40	19.28	8.21	6.6	38.2	0.023 (<0.05)
Latex	40	16.87	7.28	7.3	41	
Bare Hands	40	14.62	6.41	5.7	30.5	

Table 20- Descriptive statistics for MTV by "Screwdrivers" and "different Users" and Mann-Whitney analysis.

	N	Mean	Std. Deviation	Min	Max	p-value
Students						
Long	120	14.52	6.96	4.4	40.9	0.293 (>0.05)
medium	120	15.54	7.72	4.4	43.5	
Professors						
Long	60	15.93	6.69	6.0	32.3	0.236 (>0.05)
medium	60	17.91	8.20	5.7	41	

Table 21-Descriptive statistics for MTV by "Moisture Conditions" and different "Users" and Mann-Whitney analysis.

	N	Mean	Std. Deviation	Min	Max	p-value
Students						
Dry	120	15.45	7.21	4.4	43.5	0.147 (>0.05)
Wet	120	16.62	7.50	5.4	40.9	
Professors						
Dry	60	17.74	7.99	6.4	41	0.273 (>0.05)
Wet	60	16.11	6.99	5.7	38.2	