ARTIGO ORIGINAL
ISSN 1677-5090 impresso
ISSN 2236-5222 digital

DOI: 10.9771/cmbio.v23i3.57207

Influence of macrogeometry on primary stability and insertion torque in dental implants

Influência da macrogeometria dos implantes dentários na estabilidade primaria e torque de inserção

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Abstract
Introduction: *the primary stability and insertion torque of osseointegrated implants are fundamental to the success of osseointegration, especially in cases where a prosthesis with immediate load is installed.* ***Objective:*** *this study aimed to assess the influence of the macrogeometry of two implant types on insertion torque and primary stability.* ***Methodology:*** *this study utilised 40 implants, comprising 20 conical and 20 cylindrical, divided into four experimental groups. These implants were installed by a single operator in a synthetic bone block following the manufacturer's recommendations and the sub-instrumentation technique. Implant stability was immediately assessed post-installation using magnetic resonance frequency analysis, measured by Osstellâ. The insertion torque was determined using a surgical implant installation motor. The resulting data were subjected to statistical analysis using the Kruskal–Wallis test, with Dunn's post hoc test employed to determine any significant differences between the implant groups in terms of insertion torque and primary stability.* ***Results:*** *a significant difference was observed in the stability of buccolingual (p=0.002) and the average stability (p=0.008), with respective effect sizes of 0.197 and 0.335. The insertion torque also demonstrated significance (p=0.018). Notably, a decrease in the values of the 04×10 implants was observed when compared to the 3.5×10 implants.* ***Conclusions:*** *implants with a smaller diameter exhibited greater primary stability, whereas those with a larger diameter demonstrated higher insertion torque values.*
Keywords: *Dental implant; primary stability; insertion torque.*

Resumo
Introdução: a estabilidade primária e torque de inserção dos implantes osseointegrados é fundamental para o sucesso da osseointegração, principalmente nos casos em que é instalada uma prótese com carga imediata. **Objetivo:** este estudo teve como objetivo avaliar a influência da macrogeometria de dois tipos de implantes no torque de inserção e na estabilidade primária. **Metodologia:** este estudo utilizou 40 implantes, sendo 20 cônicos e 20 cilíndricos, divididos em quatro grupos experimentais. Os implantes foram instalados por um único operador, em bloco ósseo sintético seguindo as recomendações do fabricante e a técnica de subinstrumentação. A estabilidade do implante foi avaliada imediatamente após a instalação por meio de análise de frequência de ressonância magnética, medida pelo Osstell**â**. O torque de inserção foi determinado utilizando um motor cirúrgico de instalação de implante. Os dados resultantes foram submetidos à análise estatística utilizando o teste de Kruskal-Wallis, com o teste post hoc de Dunn empregado para determinar quaisquer diferenças significativas entre os grupos de implantes em termos de torque de inserção e estabilidade primária. **Resultados:** observou-se diferença significativa na estabilidade bucolingual (p=0,002) e na estabilidade média (p=0,008), com tamanhos de efeito respectivos de 0,197 e 0,335. O torque de inserção também mostrou significância (p=0,018). Foi observada uma diminuição nos valores dos implantes 04×10 quando comparados aos implantes 3,5×10. **Conclusões:** implantes com menor diâmetro tiveram maior estabilidade primária enquanto implantes de maior diâmetro mostraram maiores valores de torque de inserção.
Palavras-chave: Implante dentário; estabilidade primaria; torque de inserção.

INTRODUCTION

Osseointegration is a multifaceted process that leads to the formation of new bone between the surface of a titanium alloy and bone tissue[1-3]. A micromovement space of 50 to 150 mm between the implant and the

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bone structure is essential for successful osseointegration[4]. If this space is not maintained, fibrous tissue may form between the implant and bone tissue, potentially indicating a failure in osseointegration[5].

The significance of this point cannot be overstated, as contemporary implant dentistry frequently employs immediate activation and provisionalization protocols. These protocols are directly contingent on the initial or primary stability[1-3,6,7]. Achieving satisfactory primary stability necessitates carefully considering the available bone type, the surface, and the macrogeometry of the intended implant [7,8]. These factors are crucial in determining the success of osseointegration.

In the pursuit of primary stability, it is crucial to avoid excessive torque during implant installation. This is because it can lead to reduced blood circulation, microfractures, and tissue necrosis, which in turn cause tissue reabsorption and, consequently, osseointegration failure[1,2,6-8]. Implant insertion torque values exceeding 32N are deemed satisfactory for fulfilling the demands of immediate activation protocols[3].

Recognising the significance of implant insertion torque in bone [8,9], numerous studies[7-10] have been conducted to develop more accurate and practical methods for measuring the insertion torque of osseointegrated implants[3]. Currently, the most used measurement methods include resonance frequency analysis, impact analysis, and insertion torque analysis[10,11].

This study employed the Osstell Beaconâ for primary stability analysis. This device operates on resonance frequency analysis technology, a method that has been prevalent in dentistry for roughly 30 years. Numerous scientific publications have demonstrated its efficacy. Presently, it is recognised as a reliable tool for assessing the stability of osseointegrated implants [3,6,11,12].

The SmartPeg, a device that is attached to the implant, operates in conjunction with the Osstell Beacon. When the Osstell Beaconâ is positioned near the SmartPeg, it emits electromagnetic waves that induce vibrations in the SmartPeg. These vibrations enable an analysis of the implant's stability[8,10,11]. The most intense vibration detected is considered the implant's resonant frequency. A higher resonant frequency indicates a more stable implant[11].

The resonant frequency is converted into a numerical scale from 1 to 100, denoted as implant stability quotients (ISQ). According to the manufacturer, an ISQ value exceeding 65 signifies an implant with adequate stability, potentially allowing for early loading, contingent on the prosthetic conditions. Conversely, an ISQ value less than 50 indicates an implant with poor stability. An ISQ value of 70 or higher denotes exceptional primary stability, offering the potential for immediate prosthetic rehabilitation, even in the case of a single unit [3,6,8,10-13].

Currently, numerous macrogeometric forms of implants are generally categorised into two main groups: conical and cylindrical[14,15]. Each is designed for specific clinical situations and varying bone densities. The geometry of their threads may differ to facilitate and broaden the scope of implant therapy applications[11,14-16].

The thread geometry can vary across implants, presenting distinct characteristics. Some threads may be flat and deep with limited cutting areas, thus considered to facilitate bone compaction. Alternatively, implants may feature pyramidal threads with minimal depth and spacing, which are deemed to have cutting characteristics and a reduced capacity for bone compaction. Additionally, implants can incorporate micro threads in the cervical region near the prosthetic platform. This design ensures an increased contact area in this region[14,15].

The macro geometric designs of implants aim to accommodate diverse clinical needs based on the encountered bone conditions. In this study, we assessed the influence of the macrogeometry of two implant types on primary stability and insertion torque. We tested the hypothesis that, despite their macro geometric differences and installation in low-density bone, both implant groups could achieve satisfactory levels of insertion torque and primary stability.

Research plays a crucial role in advancing surgical protocols, fostering the creation of novel implant geometries, and enhancing the technologies employed for analysing and studying the interaction between bone tissue and osseointegrated implants.

METHODOLOGY

This in vitro study evaluated two distinct types of implants, each designed for unique clinical scenarios.

Sample selection

A total of forty implants, comprising twenty conical and twenty cylindrical, were utilised and divided into four experimental groups (Table 1). These implants were installed in a synthetic bone block (Nacional Oss, São Paulo, Brazil), adhering to the manufacturer's guidelines.

Table 1 – *Experimental groups*

Group	No.	Implant	Manufacturer	Settings
1	*10*	*CM 3.5×10 (Code: 106.325)*	*B- fix profile, Titaniumfix R (Batch: 399721)*	*Conical*
2	*10*	*CM 4.0×10 (Code: 106.330)*	*B- fix profile, Titaniumfix R (Batch: 384221)*	
3	*10*	*CM 3.5×10 (Code: 3510)*	*B-fix Blackfix, Titaniumfix R (Batch: 004422)*	*Cylindrical*
4	*10*	*CM 4.0×10 (Code: 4010)*	*B-fix Blackfix, Titaniumfix R (Batch: 356221)*	

Source: research data

Installation technique

The implants were installed in accordance with the manufacturer's established protocol, utilising the sub-instrumentation technique. This technique involves using a drill smaller than the one recommended by the manufacturer, a process known as under-drilling.

Primary stability assessment

The evaluation of implant stability was conducted immediately following the placement of the implant, utilising magnetic resonance frequency analysis. This was measured using Osstellâ (Integration Diagnostics, Göteborg, Sweden). The resonant frequency was rated on an ISQ scale of 1 to 100.

Primary stability was recorded using a transducer (Smarpeg) fitted to the implant. This device generated vibrations within the implant, which were then relayed back to the device, producing numerical values that classified the quality of stability. Measurements were taken in both the implants' buccolingual (BL) and mesiodistal (MD) directions. The average stability was considered the average of stability BL and MD.

Insertion torque evaluation

The torque during implant installation was gauged using an "NSK Surgical PRO" surgical motor during the procedure.

Statistical analysis

Upon confirming the data's non-normal distribution (Shapiro Wilk, p<0.05), the Kruskal–Wallis test, supplemented by Dunn's post hoc, was employed to ascertain any significant disparities among the implant groups concerning insertion torque and primary stability. If a significant difference was detected, the Eta squared test (η^2) was utilised to compute the effect size.

The statistical software utilised was SPSS 26.0 (IBM, Armonk, NY, USA), with a predetermined significance level of 5%.

RESULTS

Table 2 presents the mean and standard deviation values for BL and DM stability, along with the average stability values and the insertion torque. The results indicated a significant difference in BL stability (p=0.002) and average stability (p=0.008), with respective effect sizes of 0.197, 0.335, and 0.247.

Table 2 – *Mean values and standard deviation (SD) for stability BL, MD, mean stability, and insertion torque with their respective p values and effect size (η^2).*

	Implant		Average (SD)	P	η^2
Stability_BL	*BlackFix 3.5×10*	*a*	*64.90 (0.73)*	*0.002*	*0.335*
	Profile 3.5×10	*ab*	*64.10 (1.10)*		
	BlackFix 4.0×10	*b*	*63.00 (1.760*		
	Profile 4.0×10	*b*	*62.10 (2.42)*		
Stability_MD	*Profile 3.5×10*		*63.00 (1.70)*	*0.063*	
	BlackFix 3.5×10		*62.90 (1.72)*		
	BlackFix 4.0×10		*61.30 (2.35)*		
	Profile 4.0×10		*61.30 (2.31)*		
Average	*BlackFix 3.5×10*	*a*	*63.90 (1.04)*	*0.008*	*0.247*
Stability	*Profile 3.5×10*	*ab*	*63.55 (1.25)*		

	BlackFix 4.0×10	*b*	*62.15 (1.87)*		
	Profile 4.0×10	*b*	*61.70 (2.28)*		
Insertion torque	*Profile 4.0×10*	*a*	*33.00 (5.86)*	*0.018*	*0.197*
	BlackFix 4.0×10	*ab*	*29.50 (1.58)*		
	BlackFix 3.5×10	*ab*	*28.50 (4.11)*		
	Profile 3.5×10	*b*	*27.50 (3.53)*		

Different letters=significant statistical differences (p<0.05).

Source: research data

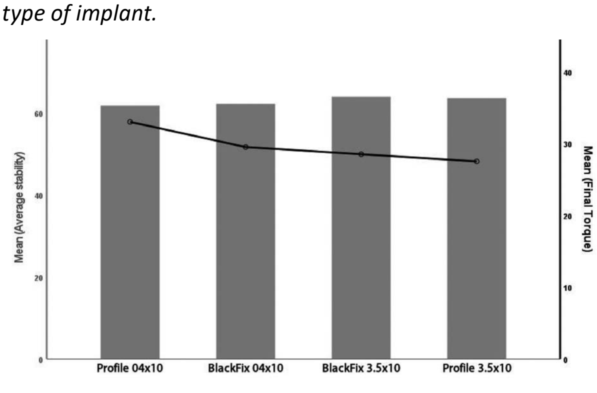
All effect sizes were considered significant, indicating that altering the implant type significantly impacted the insertion torque, BL stability, and average stability. The 3.5×10 implants were associated with the highest stability values.

For BL stability, the 3.5×10 cylindrical implants demonstrated equivalence to the 3.5×10 conical (p<0.05) but differed from the other types (p>0.05). Similarly, the average stability results showed comparable differences between groups, mirroring the findings for BL stability. The same pattern was observed for the average stability.

The insertion torque demonstrated significance (p=0.018). A notable decrease was observed in the values of the 04×10 implants compared to the 3.5×10 implants. A significant difference was identified between the Profile 04×10 and Profile 3.5×10 implants. However, no significant differences were found in the other comparisons.

Generally, as the size of the implant increased, the torque decreased. Conversely, stability increased with a decrease in implant size. Thus, smaller implants exhibited greater stability and lower torque (Figure 1).

Figure 1- *Relationship between the mean final torque value (black line) and the average stability value depending on the type of implant.*



Source: self-authored

DISCUSSION

Insertion torque and primary stability are considered important factors for osseointegration and implant success[11,17]. These parameters serve as references to assess the feasibility of early or immediate loading. Similarly, bone density and the implant recipient bed's preparation significantly influence the primary stability outcome.

The study's data revealed that the investigated implants, installed in low-density synthetic bone with merely 1 mm of cortical structure, attained satisfactory primary stability indexes exceeding 60 ISQ. This result confirms the hypothesis under test.

Literature indicates that the presence of cortical bone tissue facilitates the attainment of superior levels of primary stability, even in the context of low-density medullary bone tissue[18,19].

Implants placed in areas of low density, devoid of cortical bone, are more susceptible to unwanted trauma during milling. This is primarily due to the fragility of the medullary bone. Furthermore, the difficulty of implant insertion can cause deviation from the intended insertion line during installation[18,19].

The under-drilling protocol used yielded satisfactory rates of primary stability. This method, proposed by the manufacturer, is cited in the literature to enhance primary stability in low-density bones [18,19]. The conical and cylindrical implants tested were subject to two distinct milling protocols. These drilling methods aim to provide predictability in achieving primary stability in a variety of clinical situations for both implant types[18-20].

Conical implants are known to offer superior primary stability and insertion torque, particularly in regions of low bone density, compared to cylindrical ones[10,14,18,19]. This study found that larger-diameter conical implants had the highest average insertion torque, a finding that aligns with other research associating better insertion torques with larger-diameter conical implants [21,22]. This data supports the assertions of other researchers who have identified a direct relationship between an increase in diameter and an increase in the torque of the implants, regardless of whether they are conical or cylindrical, with the only variation being the milling protocol[14,15,17,21-23].

An additional significant factor that could explain the rise in torque in broader implants is the variation in the height of the micro-threads in the implant's cervical section. For 3.5 mm implants, the space allocated for these threads is 1.4 mm, while for 4 mm implants, this space expands to 1.5 mm. It is established that these micro-threads augment the bone/implant contact area, *leading to increased friction in the region. This results in enhanced imbrication and, consequently, a higher insertion torque[14,15,21].*

The conical implant utilised in this study features flat or square threads, which correlate with high insertion torque rates. Conversely, the cylindrical implants used possess pyramidal or triangular threads linked to lower insertion torques [21,24].

Implants featuring square or flat threads typically possess deeper threads than those with pyramidal threads. This increased thread depth not only enhances the contact area but also elevates the level of bone compaction. The literature highlights these attributes as crucial for augmenting bone compaction, leading to an increase in torque and primary stability[21-24].

Our analysis of primary stability measured using the Osstell[R] found that implants with smaller diameters achieved higher values. This indicates that stability is not directly proportional to the insertion torque. In fact, we observed an inverse relationship—the smaller the implant diameter, the lower the torque, yet the greater the stability as measured by magnetic resonance.

Certain authors have demonstrated a proportional relationship between insertion torque and magnetic resonance analysis[25,26]. Conversely, other authors argue that no such proportional relationship exists between these two forms of analysis[27,28]. They contend that resonance analysis provides a more reliable evaluation of the bone and implant resistance contact. This is attributed to its ability to measure the entire surface of the implants rather than concentrating solely on a specific tension area [27,28].

Thus, an increase in insertion torque might signify enhanced bone/implant contact in a specific region, but it does not necessarily imply an even distribution of contact throughout the implant. Nevertheless, a high torque does not always indicate an optimal contact relationship between the bone and the implant [28].

The quality of drilling plays a crucial role in achieving optimal primary stability [19]. In the case of more porous and low-density bones, it is essential to regulate the milling process to prevent damage to the bone tissue adjacent to the implant recipient bed. In this study, the synthetic bone used was designed to mimic a low-density bone with a 1 mm cortical layer. The heightened requirement for burs could potentially escalate the risk of bone damage, indicating a potentially higher risk during the milling process for implants of larger diameters[4,5,19,20].

The current study had certain limitations. It was primarily a laboratory investigation. Further research is required, encompassing various implant shapes (including differences in thickness, diameter, and macrogeometry), milling types, and bone classifications.

CONCLUSIONS

The methodology employed allows us to infer that larger-diameter implants yield higher insertion torque values. Conversely, implants with a smaller diameter demonstrated superior primary stability.

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