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The Effect of Threads Geometry on Insertion Torque (IT) and Periotest Implant Primary Stability: A High-Density Polyurethane Simulation for the Anterior Mandible

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Abstract: The implant geometry provides a key role in the osseointegration process and is able to improve the mechanical interaction and primary stability into the bone tissue. The aim of the present investigation was to compare different implant profiles to evaluate their influence on the primary stability on high-density polyurethane block. Methods: A total of 100 implants were used on 20 pcf polyurethane density in the present investigation, i.e., 20 implants for each of 5 groups (A, B, C, D, and E), characterized by different thread pitch and geometry. The insertion torque (IT), and Periotest mean values were recorded during the implant positioning. Results: Mean values for insertion torque values were higher for the group C and group E implant profiles when compared to all other groups ($p < 0.01$). No significant differences were detected between these two groups ($p < 0.05$). Lower IT (<20 Ncm^2) were presented by groups A, B, and D ($p < 0.05$). All groups showed negative Periotest values. Group C implants showed the lowest level of Periotest values ($p < 0.05$). No significant Periotest differences were found between group B and group D and between group A and group E ($p > 0.05$). Conclusions: Implants with a wider and V-thread profile and a round apex showed a higher stability in a standardized polyurethane foam. Their use could be suggested in high-density bone in clinical practice.

Keywords: insertion torque; Periotest; polyurethane block; primary stability; thread geometry; thread pitch

1. Introduction

The osseointegration of dental implants represents a multifaceted process that produces an intimate interface between the implant and the bone tissue without interposition of fibrous soft tissue [1–3]. The defect generated during the implant site drilling is able to produce a healing process similar to a primary fracture [4–6]. The dental implant healing process could be categorized in two different phases known as primary stability and secondary stability. The primary stability is determined by the mechanical contact and retention with the cortical bone around the implant. This intimate relationship between the interfaces plays a fundamental importance because an insufficient primary stability could generate an early failure of the implant, and the persistence of micromovements over 150 microns could determine the formation of connective, fibrous tissue at the interface [7–10]. The secondary stability is followed by a sequelae of physiological events that produce a woven bone formation, adaptation, and remodeling of the structures under masticatory loading [11–16]. Some of the most important factors for primary stability are determined by:

(1) the bone density around the implant [17–19], that is determined by the medullary/cortical bone ratio of the jaw's local anatomy [20,21];
(2) the quantity of bone-to-implant interface generated during the implant positioning that could be influenced by several factors such as the surgical preparation technique (standard drilling protocol [22,23], osteocondensation [24,25], and piezoelectric device procedure [26–28]);
(3) the macro and micro geometry of the implant screw.

Periotest and insertion torque (IT) are noninvasive, quantitative, and reproducible methods clinically used for determining primary stability. Periotest could also be used to evaluate the degree of osseointegration during the healing period, and in the long-term follow-up of the implant [29,30].

The polyurethane study model represents a highly-standardized method to simulate the relationship between metal implants and bone [31–39]. The polyurethane model has been proposed to simulate the medical and implants devices on an artificial substrate with a microstructure, density, and physical and mechanical characteristics similar to the human bone [36,37,40]. Moreover, the polyurethane is chemically and thermally stable in wide environmental conditions, homogeneous and resistant to the desiccation which makes it optimal for in vitro testing [36,37,40]. The aim of the present study was to investigate the impact of five cylindrical-shaped implants, with different thread pitch, width, and depth, on primary stability in polyurethane bone models. The hypothesis that different insertion torque values and different Periotest measurements could be found between the different implant designs was tested.

2. Materials and Methods

2.1. Polyurethane Foam Blocks

Cellular rigid polyurethane blocks (models 1522-12; Sawbones; Pacific Research Laboratories Inc., Vashon, WA, USA) were used for the present study. The bone model has larger pores to mimic maxillary cancellous bone with cell size ranges from 0.5 to 2.0 mm diameter for this primarily closed cell foam. The density of the block resembled D2 bone type of the Lekholm classification, with a thick layer of cortical bone surrounding a core of dense trabecular bone, and was 0.32 g/cm^3 (20 PCF) with an elastic modulus of 137 MPa and compressive strength of 5.4 MPa [41]. The cortical bone was simulated by short e-glass fibers filler in a structure model.

In total three bone blocks were used for this study, and the dimensions of each experimental specimen were 13 cm × 18 cm × 4 cm.

2.2. Implants Characteristics

Specifically, 100 cylindrical-shaped implants were used (3.8 mm × 12 mm; FMD, Rome, Italy): group A (Figure 1), 20 Elisir cylindrical implants, with neck of Ø 3.5 mm; group B (Figure 2), 20 Elisir long-thread cylindrical implants with neck of Ø 3.5 mm; group C (Figure 3), 20 Shiner cylindrical implants with a large neck of Ø 4.8 mm in diameter; group D (Figure 4), 20 Storm cylindrical implants with neck of Ø 4.1 mm and an external hexagon connection; Group E (Figure 5), 20 Crystal one-stage implants, large thread. All implant surfaces were sandblasted with large grit and acid etching.

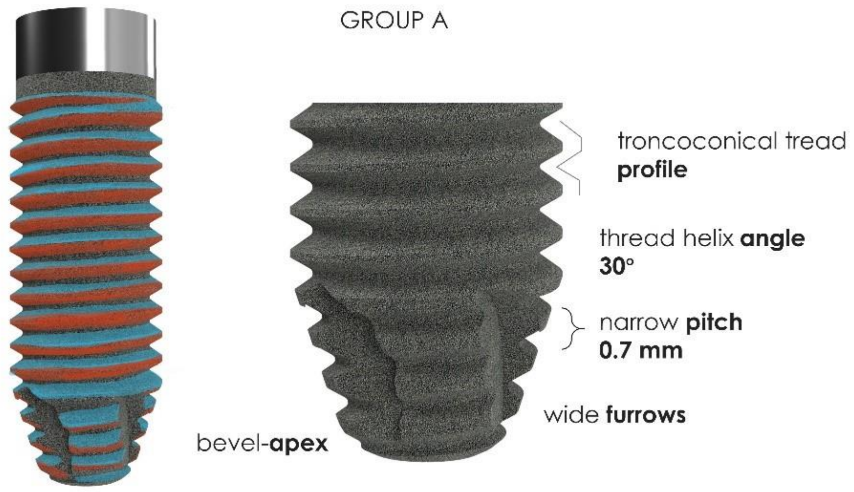

Figure 1. Group A: in detail, the morphology and thread geometry of the cylindrical implants.

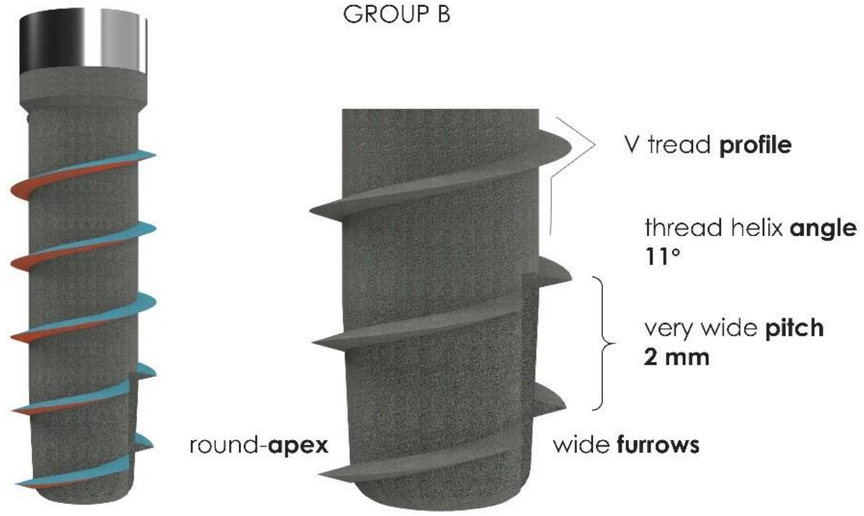

Figure 2. Group B: in detail, the morphology and long-thread geometry of the cylindrical implants.

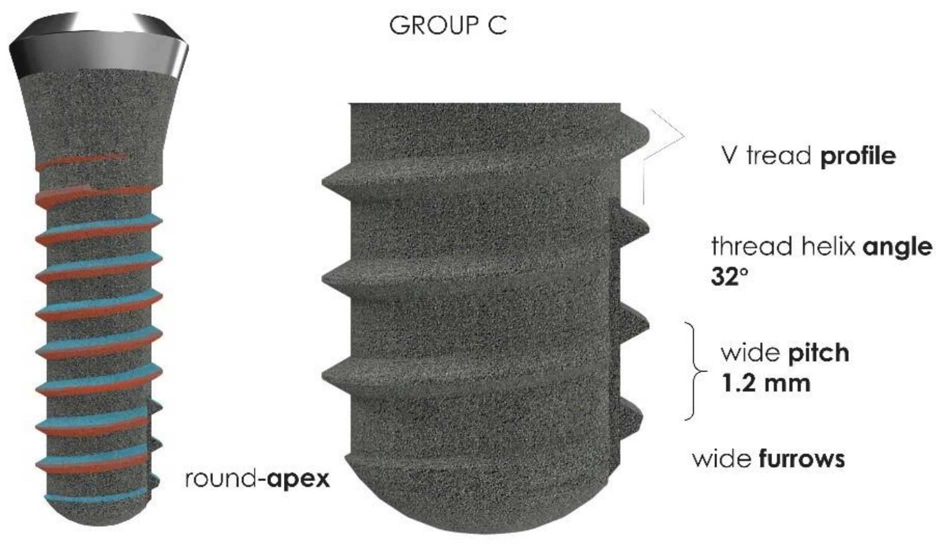

Figure 3. Group C: in detail, the morphology and thread geometry of the cylindrical implants.

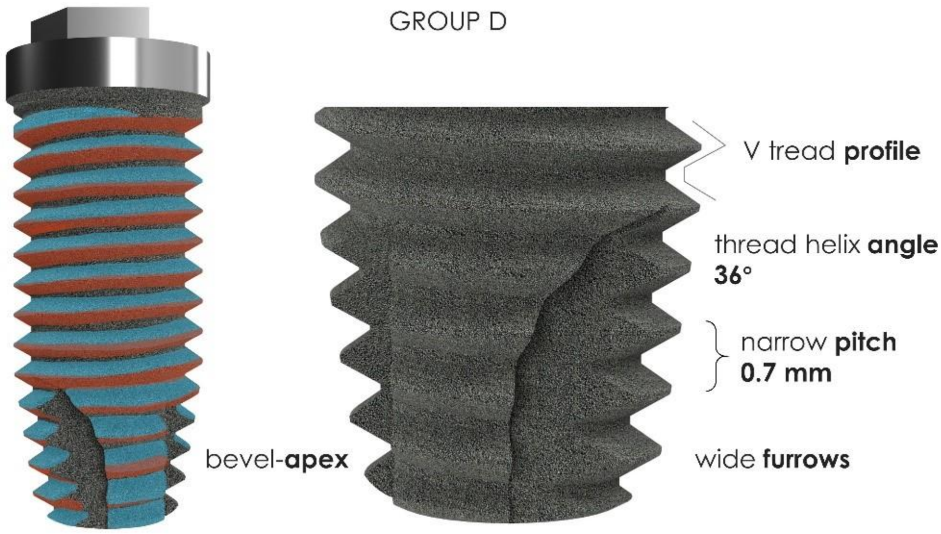

Figure 4. Group D: in detail, the morphology and thread geometry of the external hexagon cylindrical implants.

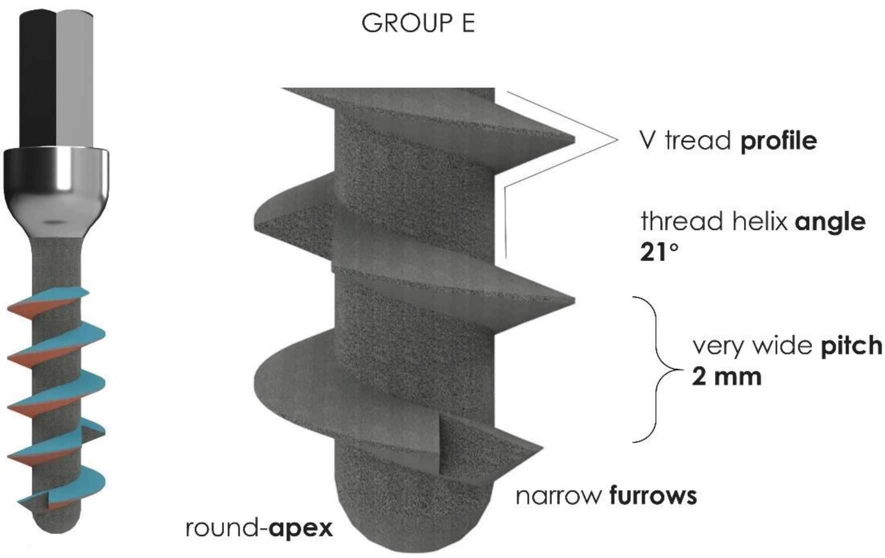

Figure 5. Group E: in detail, the morphology and thread geometry of the one-stage screw implants.

2.3. Preparation of Implant Insertion Site

The polyurethane bone blocks were fixed with a fastener (Figure 6). Osteotomy was prepared at a 4 cm distance between implants, with a gentle surgical technique using a surgical drill at a rotational speed of 800 rpm. A total of 100 drilling sites were performed into the polyurethane blocks. The drilling was performed according to the manufacturer's instructions. The succession of drills was: pilot drill, three intermediate drills (Ø 2.3 mm, Ø 2.5 mm, and Ø 2.8 mm in diameter), and final drill (Ø 3.2 mm in diameter) for groups A, B and C, drill diameters Ø 2.3 mm and Ø 2.8 mm for group D, and Ø 2 mm and Ø 2.3 mm for group E. All implants were placed according to the manufacturers' standard protocol and the minimum distance between implants was at least 3 mm according to the literature. After implant placement, implant primary stability was measured by means of insertion torque (ITv) and Periotest values (PTV).

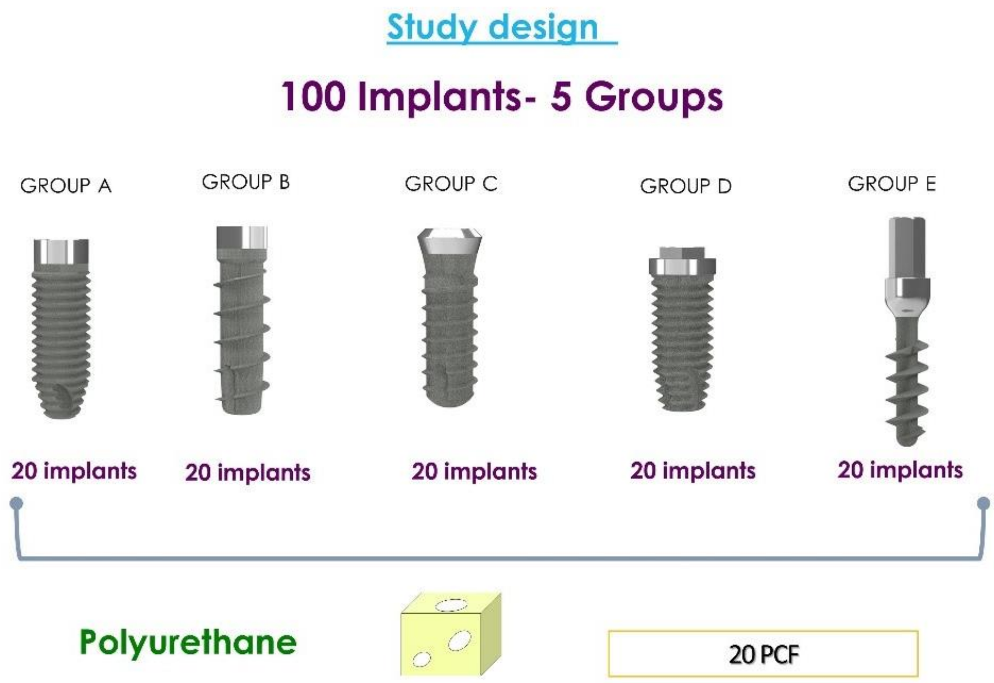

Figure 6. A graphical representation of the study design model.

2.4. Measurement of Insertion Torque

When inserting the implant, the peak insertion torque values were measured to the final 1 mm with a digital torque gauge instrument (Torque Meter PCE-TM 80; PCE Instruments, PCE Holding GmbH, Meschede, Germany) with a measurement range of 0–147 Ncm (Figure 7).

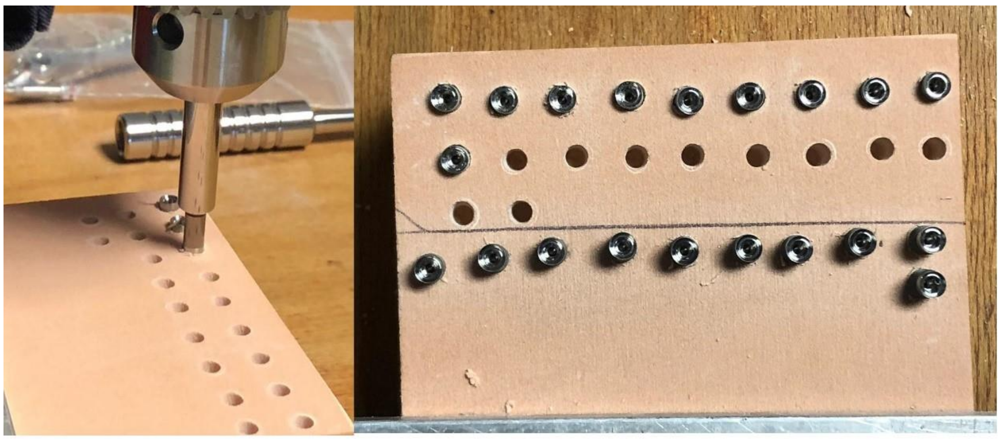

Figure 7. In detail, the phases of implant positioning into the polyurethane block.

2.5. Periotest Analysis

Periotest (Siemens, Bensheim, Germany), an electronically controlled rod weighting 8 g, tapped each implant 4 times/s for 4 s at a constant speed of 0.2 m/s. The rod decelerated when it touched the implant. The values ranged from –8 to +50 (PTV) by measuring the deceleration of the tapping instrument. The ranges of PTV reportedly have different meaning: –8 to 0, good osseointegration; 1–9, a borderline implant requiring clinical examination; and $\geq$10, insufficient osseointegration.

The handpiece sleeve was set at a fixed distance from a flat surface of the hexagon and centered perpendicularly to the long axis of the implant. Three measurements were recorded for each sample in 4 directions. For the statistical consideration, the mean value of the Periotest measurement for each implant was considered in order to reduce the bias associated to the viscoelastic properties of polyurethane block polymers and the resilience forces settling around the fixture positioned.

The Periotest measurements were performed through a dedicated abutment adapted in the chamber of the implant. The measurement of the one-stage implants (group E) was performed directly on the transmucosal portion of the fixture.

2.6. Statistical Analysis

The insertion torque and Periotest micromovement values were statistically evaluated. The normality was evaluated by Shapiro–Wilk test, and the one-way ANOVA followed the Sidak multiple comparisons test for heterogeneous variances. The data were analyzed by the software package GraphPad 6.0 statistical package (Prism San Diego, CA, USA). The level of significance was set at $p < 0.05$.

3. Results

Mean values for insertion torque measurements are presented in Table 1 and Figure 8. The IT means were higher for the groups C and E when compared to all other groups ($p < 0.01$) (Table 2). No significant difference was detected between these two groups ($p < 0.05$). Lower IT values (<20 Ncm^2) were evidenced for groups A, B, and D ($p < 0.05$). The Periotest analysis is reported in Tables 3 and 4 and Figure 8. All groups showed negative Periotest values. Group C implants showed the lowest Periotest values ($p < 0.05$). No significant Periotest differences were present between groups B and D and between groups A and E ($p > 0.05$).

Table 1. Insertion torque means of the study groups.

Insertion Torque (Ncm^2)	Mean	SD
GROUP A	17.75	3.354
GROUP B	15.15	5.383
GROUP C	27.95	5.68
GROUP D	15.7	3.42
GROUP E	32.3	8.298

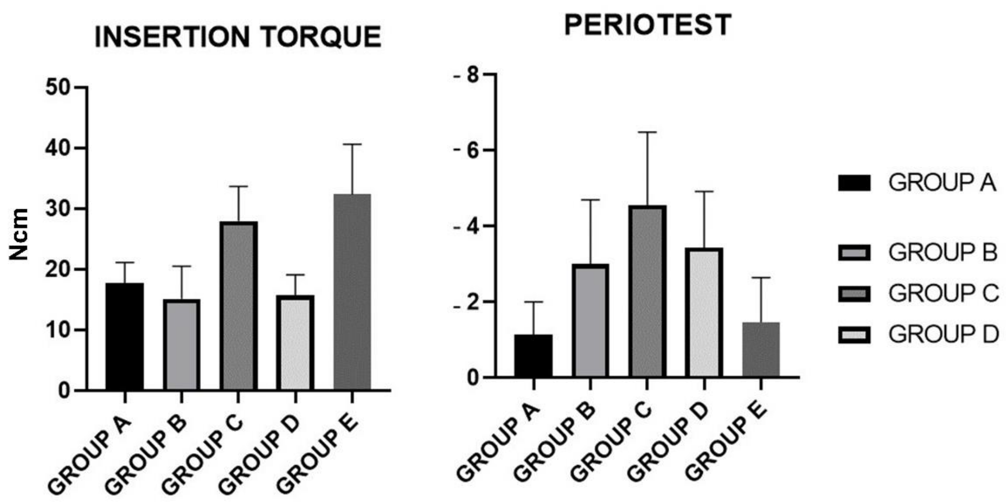

Figure 8. Insertion torque and Periotest means of the study groups.

Table 2. Insertion torque comparison between the study groups (ANOVA, Sidak post hoc test).

Insertion Torque	Mean Difference	95.00% CI	*p*-Value
GROUP A vs. GROUP B	2.600	−2.414 to 7.614	0.7801
GROUP A vs. GROUP C	−10.20	−15.21 to −5.186	<0.0001
GROUP A vs. GROUP D	2.050	−2.964 to 7.064	0.9392
GROUP A vs. GROUP E	−14.55	−19.56 to −9.536	<0.0001
GROUP B vs. GROUP C	−12.80	−17.81 to −7.786	<0.0001
GROUP B vs. GROUP D	−0.5500	−5.564 to 4.464	>0.9999
GROUP B vs. GROUP E	−17.15	−22.16 to −12.14	<0.0001
GROUP C vs. GROUP D	12.25	7.236 to 17.26	<0.0001
GROUP C vs. GROUP E	−4.350	−9.364 to 0.6643	0.1372

Table 3. Periotest means of the study groups.

Periotest	Mean	SD
GROUP A	−1.143	0.8603
GROUP B	−2.998	1.703
GROUP C	−4.563	1.93
GROUP D	−3.438	1.486
GROUP E	−1.463	1.183

Table 4. Periotest comparison between the study groups (ANOVA, Sidak post hoc test).

Periotest	Mean Difference	95.00% CI	*p*-Value
GROUP A vs. GROUP B	1.855	3.158 to 0.5523	0.0013
GROUP A vs. GROUP C	3.420	4.723 to 2.117	<0.0001
GROUP A vs. GROUP D	2.295	3.598 to 0.9923	<0.0001
GROUP A vs. GROUP E	0.3200	1.623 to −0.9827	0.9597
GROUP B vs. GROUP C	1.565	2.868 to −0.2623	0.0103
GROUP B vs. GROUP D	0.4400	1.743 to −0.8627	0.8808
GROUP B vs. GROUP E	−1.535	−0.2323 to −2.838	0.0125
GROUP C vs. GROUP D	−1.125	0.1777 to −2.428	0.1239
GROUP C vs. GROUP E	−3.100	−1.797 to −4.403	<0.0001

4. Discussion

Alveolar bone density could vary significantly between maxilla and mandible. Quantitative data provided evidence that maxillary anterior areas are significantly denser than posterior ones. In maxilla, the highest bone density was observed in the canine and premolar areas, with no differences about the amount of cancellous bone present [42]. On the other hand, cortical bone increased in thickness from anterior to posterior maxilla [43].

Primary stability may be difficult to achieve in low bone density regions. Primary stability is a prerequisite for osteointegration resulting from the mechanical interaction between bone tissue and the implant immediately after placement [44–46]. Implant micromovement below the 50–150 µm threshold promotes proliferation and differentiation of the osteoblast cells and inhibits fibrous tissue invasion and encapsulation [44]. Moreover, also the osteotomy preparation technique represents a key factor to achieve implant primary stability. In fact, the undersize preparation drilling represent one of the most widespread protocol for very low-density bone (D4–D5) [47]. The disadvantage of this technique is quite operator dependent and clinically not reproducible, while other techniques such as osteocondensation and ultrasonic preparation are standardized approaches [47]. Stacchi et al. reported in vivo a significant difference of the stability ultrasonic device group after 90 days of implant healing compared to the standard drilling protocol [48]. Moreover, a significant increase in the operative time was associated to the ultrasonic preparation protocol [48]. In another study, Scarano et al. reported no significant difference of crestal resorption between the two techniques after the implant osseointegration process with a significant decrease in the clinical pain and symptoms associated to the ultrasonic technique [22].

In the present investigation, different diameters and implant macrogeometries were tested on polyurethane bone blocks. Moreover, the comparation of the micromovement between one-stage and two-stage implants could represent a weak point for Periotest measurement. In fact, this aspect could introduce an increased risk of measurement bias and a sensible increase in the Periotest value for one-stage implant that could represent a potential limit of the present investigation.

According to the rationale of the present study, also the identification of the more appropriate implant fixture diameter is effective to obtain an higher implant primary stability in low-density regions due to residual thickness of the alveolar ridge [9].

The others clinical factors that affect primary stability were bone quantity and quality [49–51], surgical technique [52], surface treatment [32,53–56], microtopography [57,58], and implant macro-geometry (shape, length, diameter, and thread design) [53,59,60].

In the present study, the higher stability on 20 PCF polyurethane was obtained with a 1.2 mm thread pitch, 32° helix angle, and a round apex implant, while the other geometries showed insertion torque values of less than 20 Ncm^2. The choice of the optimal implant geometry for the local anatomy and bone density represents a priority in the daily clinical practice. The presence or absence of threads, additional macro-irregularities, and the shape/outline of the implant are considered some of the most significant aspects for a successful implant primary stability. Thread shape (e.g., square, V-shaped, and buttress) affects the direction of load from the prosthesis to bone. Moreover, the presence of surface irregularities represent an important characteristic of the implant textures that is generally associated to a macrogeometry with larger threads profiles and internal angles [61,62]. These aspects are histologically and clinically associated to an increase in the mechanical friction between the implant irregularities and the surrounding bone and an higher long-term stability of the fixture [61,62].

This reduces the development of shear at the dental implant–tissue interface so as to improve long-term success [37,63,64]. In the same way, implant design is important especially in cases of poor bone quality and immediate post-extractive implant. According to Ao and colleagues, the optimal thread width and depth for the immediately loaded cylinder implants were 0.18–0.3 mm and 0.35–0.5 mm, respectively. In addition, the stress concentration of the bone in the direction of depth was found to be a more sensitive factor in respect to the direction of width [65]. It has been suggested that smaller pitch presented better load resistance and lesser effective stress in three-dimensional FEA models, but the optimal pitch values could be found in different thread shapes [66]. A thread pitch of 0.8 mm was found to be optimal for achieving primary stability and optimum stress production on cylindrical implants with V-shaped threads [67]. Several studies suggested that insertion torque values in the range of 25–45 Ncm were desirable for improved implant integration. The IT is fundamental also for evaluating the possibility of immediate loading protocols: Calandriello et al. in 2003 indicated a minimum IT of 60 Ncm for single teeth, 45 Ncm for implants supporting partial-arch restorations, and 32 Ncm for implants supporting full-arch restorations [68]. However, Del Giudice et al. in a retrospective study, published in 2019, suggested that these values could be lowered, thanks to the technological improvements of implant surfaces and the surgical tools and the refinements of the surgical protocols, according to the recent literature [69].

However, the correlation between high IT and high implant primary stability may not hold true for all implant designs and associated surgical drilling techniques [70].

5. Conclusions

According to the effectiveness of the present study, implants with wider V-thread pitch and a round apex showed a higher primary stability in a simulated D2 model, and their use could be suggested in bone regions such as the anterior lower jaw.

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