applied sciences

MDPI

Article

Primary and Secondary Stability Assessments of Dental Implants According to Their Macro-Design, Length, Width, Location, and Bone Quality

Norberto Quispe-López [1], Soraya Martín-Martín [1], Cristina Gómez-Polo [1], Oscar Figueras-Alvarez [1,*], María Isabel Sánchez-Jorge [2] and Javier Montero [1]

[1] Department of Surgery, Faculty of Medicine, Dental Clinic, University of Salamanca, Campus Miguel de Unamuno, 37007 Salamanca, Spain; norberto_quispe@usal.es (N.Q.-L.); sorayamm@usal.es (S.M.-M.); crisgodent@usal.es (C.G.-P.); javimont@usal.es (J.M.)

[2] Department of Surgery, Implants and Periodontics, Faculty of Health Sciences, Alfonso X El Sabio University, 28691 Madrid, Spain; msancjor@externos.uax.es

* Correspondence: ofigueras@uic.es

Abstract: Some evidence supports the influence of implant macro-design on primary stability. Additionally, tactile perception can be used to assess implant stability when placing the implant. This research aimed to quantify the primary and secondary stability of three implant systems with two different macro geometries (cylindrical and conical) determined based on the insertion torque and the implant stability quotient (ISQ) at the moment of implant placement as a function of implant-related factors (length, width, dental arch, and implant location in the arch), intraoperative factors (bone density determined subjectively by the clinician's tactile perception), and patient-related factors (age, gender, and bone density determined objectively based on cone beam computed tomography (CBCT). Methods: 102 implants from three implant systems with two different macro geometries (conical and cylindrical) were placed in 53 patients. The insertion torque, the ISQ at the implant placement (ISQ0), and the bone quality according to the clinician's tactile sensation were recorded on the day of the surgery. After a three-month healing period, the ISQ was re-evaluated (ISQ3). Results: The cylindrical implants exhibited significantly higher insertion torque and ISQ values at the moment of the surgery and after three months compared to the conical implants. The cylindrical implants also showed significantly lower indices of tactile evaluation of bone quality during the implant placement surgery. However, no differences were demonstrated in the bone density measured objectively using CBCT. (4) Conclusions: The cylindrical implants achieved the highest values for primary stability (Newtons × centimeter (Ncm) and ISQ) and secondary stability (ISQ after three months). The insertion torque was the variable that most influenced the ISQ on the day of the surgery. The implant location (incisors–canines, bicuspids–molars) and the implant macro geometry were the variables that most influenced the secondary stability (ISQ at three months).

Keywords: dental implants; bone density; macro-design; implant stability; computerized tomography; bone quality

Citation: Quispe-López, N.; Martín-Martín, S.; Gómez-Polo, C.; Figueras-Alvarez, O.; Sánchez-Jorge, M.I.; Montero, J. Primary and Secondary Stability Assessments of Dental Implants According to Their Macro-Design, Length, Width, Location, and Bone Quality. *Appl. Sci.* **2024**, *14*, 4841. https://doi.org/10.3390/app14114841

Academic Editor: Alessandro Scala

Received: 10 May 2024
Revised: 31 May 2024
Accepted: 1 June 2024
Published: 3 June 2024

1. Introduction

Dental implants are an option that provides satisfactory and esthetic results when treating edentulous areas or performing immediate implantology [1–3]. Consolidated technologies such as cone beam computed tomography (CBCT), specific planning software, and non-invasive tools for evaluating the primary and secondary stability of the implant (e.g., resonance frequency analysis, RFA) provide the means for clinicians to reach a correct diagnosis and treatment plan [4–6].

Research has demonstrated that implant stability, bone volume, and quality determination can contribute to dental implant surgery success [7,8]. Primary impact stability is one of the areas that has received the most attention, since failure rates have been observed to decrease when insertion torque increases [9,10] because of a reduction in implant micromotion [11]. Primary stability is obtained immediately after implant placement. It depends on bone quality, implant macro geometry (implant shape, length, and diameter), and the drilling sequence used to prepare the implant bed [12–14]. This last variable (drilling sequence) depends on the early evaluation of the bone quality, which is generally based on the operator's experience. Thus, if the surgeon categorizes the bone of the implantation site as soft, the implant bed preparation will be infra-prepared. Conversely, this preparation will have a larger diameter if the surgeon perceives the bone to be more compact. Therefore, knowing the bone quality enables the clinician to optimize the drilling sequence and select the best implant design (conical or cylindrical; self-tapping or non-self-tapping) to achieve optimal primary stability [11,15].

Several classification systems have been established for evaluating bone density. Lekholm and Zarb [16] divided bone density into four types: from the more compact type I bone to type IV, which is low-density trabecular bone surrounded by a thin layer of cortical bone. Misch [17] classified bone density according to the surgeon's tactile sensation, from D1, with a hardness analogous to oak or maple wood, to D4, approximately as hard as Styrofoam [17]. Objective methods have also been developed to quantitatively assess bone density based on the Hounsfield scale (Hounsfield units, HU) [18,19], where bone density ranges between 100 and 1900 HU, while soft tissues are close to or below 0 HU [18].

Subsequent maturation of the bone in direct contact with the implant surface results in secondary or biological stability [20,21], which depends mainly on the implant's macro design and physical properties [22]. Therefore, implant design is fundamental to achieving adequate primary and secondary stability, which is essential for successful osseointegration. However, several design factors can affect this primary implant stability, such as implant diameter and length, thread design, and implant shape [23,24].

Against this background, this clinical study aimed to compare the primary and secondary stability, determined based on the insertion torque and the ISQ at the moment of implant placement and after three months, of two different implant macro geometries (cylindrical and conical) as a function of patient-related factors (gender, age, and bone quality determined objectively in the CBCT), implant-related factors (width, length, dental arch, and implant location in the arch), and intraoperative factors (bone quality determined by the clinician's tactile sensation during implant placement). In addition, we also aimed to determine the correlation (overall and within each macro geometry) between the patient-related, implant-related, and intraoperative variables. The null hypothesis was that no variable could predict implant stability.

2. Materials and Methods

2.1. Study Design

In this prospective study, patients requiring implant surgery were consecutively recruited from December 2020 to September 2022. The trial protocol was registered on ClinicalTrials.gov (NCT05670340), developed under the Declaration of Helsinki on medical research involving human subjects, as revised in 2013 and authorized by the Bioethical Committee of the University of Salamanca (Registration number 473/2020). A sample size calculation determined a subsample size of 31 implants to achieve a power of 80% and a level of significance of 5% (two-sided) for detecting a true difference in means between implant groups of 5 ISQ units, assuming a pooled standard deviation of 7 ISQ units for the day of surgery and expected means between 70 and 75 ISQ among distinct implant subgroups.

The patients included in this study were partially or completely edentulous with healed bone crests. The exclusion criteria comprised patients with previous chemotherapy or radiotherapy histories, patients with any medical conditions (metabolic bone disorder and/or uncontrolled diabetes), and patients receiving bisphosphonates treatment. Similarly, to provide standardization of bone maturation, patients who had a recent tooth extraction at the implant sites (<3 months) or those treated with bone augmentation procedures were also excluded [25].

A preoperative CBCT scan was performed on all the patients, which was initially used for implant planning and evaluation of the bone quality at the expected implant site. Three types of implants with two different macro-designs were used. The Nobel Active® implant (Nobel Biocare AB, Gothenburg, Sweden) is a conical implant with a reverse neck, micro-threads in the coronal portion, a variable thread design (changing from a V-thread in the coronal portion to buttress threads in the apical portion), and a 1.2 mm thread pitch at the implant apex and body. The Nobel Parallel® implant (Nobel Biocare AB, Gothenburg, Sweden) is cylindrical with a conical apex and a V-thread design. It has a thread pitch of 0.6 mm for implants with diameters of 3.75 mm and 4.3 mm and 0.8 mm for implants with a 5 mm diameter, having a more significant number of threads. Finally, the 3i T3® implant (ZimVie, Westminster, CO, USA) is a conical implant with no micro-threads in the most coronal portion, a V-thread design, and a thread pitch of 0.8 mm. The implants were distributed randomly among the patients using closed envelopes as the randomization method.

2.2. Preoperative Radiographic Assessment

A CBCT scan was used to assess each patient's mandible and maxilla preoperative. Invivo™ 6 dental software was used for CBCT 3D scan image visualization and implant planning. This software enabled the surgeon to select the length and diameter of the implants placed in the patients. For the densitometric analysis, BTI Scan 4 software (BTI Biotechnology Institute) was used to evaluate the averaged bone density (in HU) of the implant area and 0.5 mm all-around of the bone to be occupied by the planned implant. The BTI scan uses an algorithm that traduces bone density through the gray scales in HU, as depicted in Figure 1. The surgeon was blinded to the bone density-related assessment before and during the implant surgery.

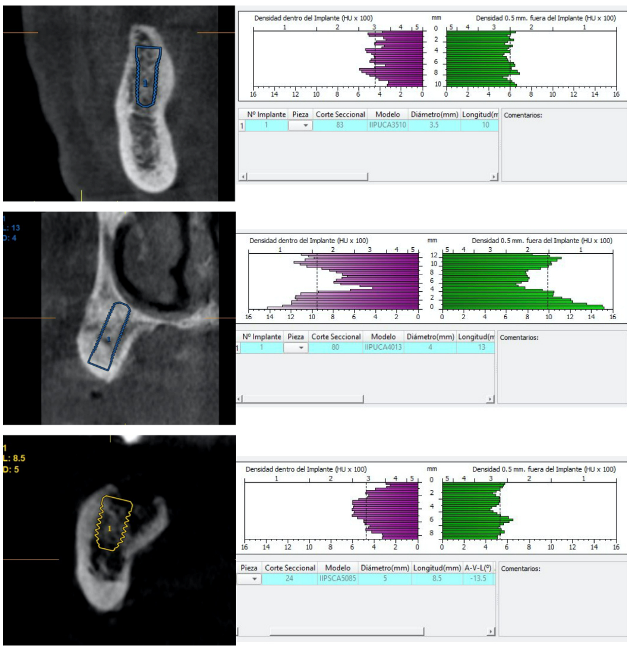

Figure 1. CBCT image used for implant planning, and image of bone-density evaluation (in HU) using BTI Scan software. The purple bar chart shows the bone density inside the implant, and the green bar chart shows the bone density 0.5 mm outside the implant.

2.3. Surgical Protocol

All the implants were placed by an experienced surgeon (NQ) and then left for transmucosal healing following a one-stage surgical procedure protocol. The surgeries were performed under local anesthesia, using articaine 2% mg/mL with epinephrine 1:100,000. After applying the local anesthesia, the mucoperiosteal flaps were elevated to expose the bone crest. The osteotomies were conducted following the manufacturers' instructions for each type of implant and bone quality, so the last step of the drilling sequence varied depending on the clinician's tactile evaluation of bone density while preparing the implant bed, because he was blinded regarding the bone density assessed using CBCT.

When the surgeon perceived a hardness analogous to Styrofoam (soft bone), undersized bone bed preparation was conducted. In contrast, the entire drilling sequence, including screw tap drills, was completed when the surgeon's tactile evaluation indicated that there was bone with a hardness analogous to oak or maple wood (hard bone).

The surgeon placed the implants sequentially once the needed drilling protocol had been performed. Sixty-five conical implants (thirty-two 3i T3 implants and thirty-three Nobel Active implants) and thirty-seven cylindrical implants (thirty-seven Nobel Parallel implants) were placed in fifty-three patients (Figure 2). The surgeon subjectively recorded bone density during bed preparation while drilling into one of the four bone-quality groups (D1–D4) following the Misch classification system [17]. The primary stability of each implant type was recorded using a manual torque wrench using the maximum insertion torque value (Ncm), rounded to the nearest 5 Ncm, obtained at the end of implant insertion into the recipient site. The values of the implant stability quotient (ISQ) were also recorded (ISQ0). The Smartpeg® (Perugia, Italy) was placed in direct contact with the implant, and three consecutive measurements were taken (vestibular, interproximal, and lingual/palatal) to obtain a mean value (Figure 2). After the primary stability assessment, healing abutments were placed, and the flap was sutured using 5/0 simple sutures. After three months of osseointegration, the secondary stability was again recorded using a resonance frequency analysis (ISQ3).

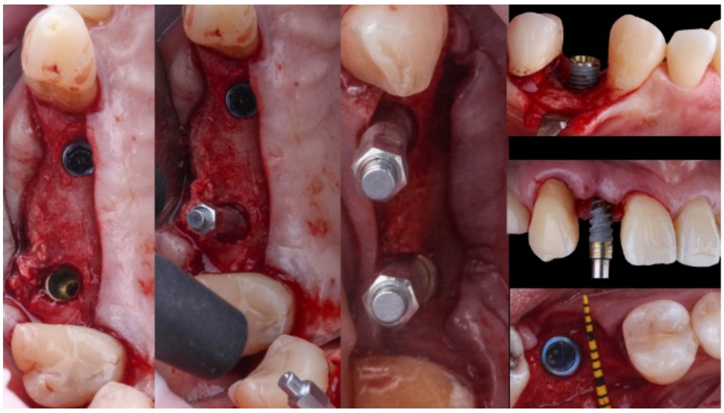

Figure 2. Implant placement and measurement of implant stability quotient (ISQ).

2.4. Statistical Analysis

The normal distribution of the data collected was assessed based on the Shapiro–Wilks statistic. The measured insertion torque, implant stability quotient at the moment of implant insertion (ISQ0), and implant stability after three months (ISQ3) failed to follow a normal distribution, so non-parametric statistics were used. In the statistical description of the sample, the mean and standard deviation were used for describing the objectively measured bone density, and the median and interquartile range were used for describing the insertion torque. The implant stability quotients (at implant placement and after three months) were the quantitative variables. The absolute frequency and percentage in categories were used for describing the nominal variables. Although some of the implants were placed in the same patients, all were considered independent because they were objectively or subjectively individually characterized during data collection. The collected data were considered paired when comparing the implant stability quotient measured at the time of implant insertion and after three months. Depending on the normal distribution assessment, Pearson's or Spearman's correlation coefficients and parametric tests (Student's *t*-test) or non-parametric tests (Mann–Whitney (M-W) test) were used to compare the effects on the studied variables (insertion torque, ISQ0, and ISQ3) of the implant-related factors (implant macro geometry (cylindrical or conical), implant location (incisor–canine, bicuspids–molars), dental arch (mandible or maxilla), implant dimensions (diameter and length), intraoperative variables (bone density and bone quality determined based on the clinician's tactile sensation), and patient-related factors (gender (male, female) and age (>55, <55)). Then, significant predictors for the ISQ0 and ISQ3 were identified through a stepwise linear regression analysis. Finally, a stepwise linear regression analysis was performed using ISQ0 and ISQ3 as the dependent variables and the significant predictors previously identified. SPSS 27 statistical software (SPSS Statistics, version 27, IBM Corp) was used. The significance was set at p-values of $\leq$0.05.

3. Results

Fifty-three patients (22 women and 31 men, with a mean age of 56.6 years ± 10.1) were included in this study (Table 1). One hundred and two implants were placed (43 in the mandible and 59 in the maxilla). Sixty-five conical implants (32 3i T3 implants (31.4%), 33 Nobel Active implants (32.4%)), and thirty-seven cylindrical implants (37 Nobel Parallel implants (36.3%)) were placed in 53 patients. The implants were also grouped according to their location in the arch: the incisor–canine group included 36 implants (21 conical and 15 cylindrical implants), and the bicuspid–molar group included 66 implants (44 conical and 22 cylindrical implants). The distributions of the implants in this study according to length and diameter are also shown in Table 1. The distribution, correlation, analysis of the insertion torque, ISQ0, ISQ3, clinician's tactile bone quality assessment, and bone density, together with their relationship for each studied macro geometry, are shown in Tables 2 and 3.

Table 1. Baseline demographic and clinical data of patients and implants (n = 53 patients, n = 102 implants).

Patient-Related Variables (n = 53)		**Groups**		**n (%)**	
Gender		Women		22 (41.1%)	
		Men		31 (58.5%)	
Age (years)		≤55 years		27 (50.9%)	
		>55 years		26 (49.1%)	
Average age in years (mean ± SD)		56.6 ±10.1			
Dental arch		Mandible		43 (42.2%)	
		Maxilla		59 (57.8%)	
Implant location in the arch		Incisors–canines		36 (35.3%)	
		Bicuspids–molars		66 (64.7%)	
Implant-related variables (n = 102)					
Implant macro-design		Conical		Cylindrical	
Variables		n	%	n	%
Macrogeometry design		65	63.7%	37	36.3%
Location in the arch	Incisors–canines	21	20.59%	15	14.70%
	Bicuspids–molars	44	43.14%	22	21.57%
Implant diameter	Standard (<4.5 mm)	55	53.92%	36	35.29%
	Wide (≥4.5 mm)	10	9.80%	1	0.98%
Implant length	Standard (≤10 mm)	30	29.41%	18	17.65%
	Long (>10 mm)	35	34.31%	19	18.63%

Table 2. Pearson's or Spearman's correlation coefficient (r) between the patient-related and intra-operative variables of stability and bone density in the two types of macro geometries of implants (n = 102 implants).

	Groups (n) Estimation of Initial Stability	Insertion Torque (Ncm)		ISQ Day of Surgery (ISQ Units)		ISQ 3 Months (ISQ Units)		Tactile Evaluation of Bone Quality (D1–D4 Range)		Bone Density (HU)	
		Rho-r-	*p*-Value	Rho-r-	*p*-Value	Rho-r-	*p*-Value	Rho-r-	*p*-Value	Rho-r-	*p*-Value
Insertion torque (Ncm)	Cylindrical (n = 37)	1		0.214	0.203	0.033	0.845	−0.366	0.026	−0.036	0.832
	Conical (n = 65)	1		0.554	<0.001 *	0.237	0.057	−0.403	<0.001 *	0.358	0.003 *
	Total (n = 102)	1		0.497	<0.001 *	0.258	0.009 *	−0.425	<0.001 *	0.294	0.003 *
ISQ day of surgery (ISQ units)	Cylindrical (n = 37)	0.214	0.203	1		0.429	0.008 *	0.132	0.438	−0.245	0.144
	Conical (n = 65)	0.554	<0.001 *	1		0.310	0.012	−0.236	0.059	−0.030	0.812
	Total (n = 102)	0.497	<0.001 *	1		0.417	<0.001 *	0.245	0.013 *	−0.038	0.705
ISQ 3 months (ISQ units)	Cylindrical (n = 37)	0.033	0.845	0.429	0.008 *	1		0.076	0.656	−0.332	0.045 *
	Conical (n = 65)	0.237	0.057	0.310	0.012 *	1		−0.041	0.745	−0.016	0.902
	Total (n = 102)	0.258	0.009 *	0.417	<0.001 *	1		−0.035	0.728	−0.068	0.496
Tactile evaluation of bone quality (D1–D4 range)	Cylindrical (n = 37)	−0.366	0.026 *	−0.132	0.438	0.076	0.656	1		0.062	0.716
	Conical (n = 65)	−0.403	<0.001 *	−0.236	0.059	0.041	0.745	1		−0.373	0.002 *
	Total (n = 102)	−0.425	<0.001 *	−0.245	0.013 *	−0.035	0.728	1		0.273	0.005 *
Bone density (HU)	Cylindrical (n = 37)	−0.036	0.832	−0.245	0.144	−0.332	0.045 *	0.062	0.716	1	
	Conical (n = 65)	0.358	0.003 *	−0.030	0.812	−0.016	0.902	−0.373	0.002 *	1	

* Statistically significant differences after Spearman or Pearson coefficient. Coefficients above r = 0.40 are highlighted in light grey.

Table 3. Student's *t*-test (*t*-test), Mann–Whitney test (U M-W test), or Pearson's Chi-square test between the patient-related and intraoperative variables of stability and bone density in the three types of implants (n = 102 implants).

	Groups (n) Estimations of Initial Stability	Mean ± SD Median (IR) n (%)	Range	U t CHI^2	*p*-Value
Insertion torque (Ncm)	Cylindrical (n = 37)	45 (10)	20–55	U 748	0.001 *
	Conical (n = 65)	40 (15)	15–70		
	Total (n = 102)	40 (15)	15–70		
ISQ day of surgery (ISQ units)	Cylindrical (n = 37)	79 (8.95)	61,60–88	U 766.50	0.002 *
	Conical (n = 65)	76 (10.35)	44.60–83		
	Total (n = 102)	77.5 (8.40)	44.60–83		
ISQ 3 months (ISQ units)	Cylindrical (n = 37)	84 (6.65)	53.30–89	U 689.50	<0.001 *
	Conical (n = 65)	78.60 (6.65)	55.30–86.60		
	Total (n = 102)	80 (7.95)	53.30–89		
Tactile evaluation of bone quality (D1–D4 Range)	Cylindrical (n = 37)	36 (35.29%)		CHI^2 22.2	0.001 *
	Conical (n = 65)	66 (64.71%)			
	Total (n = 102)	102 (100%)			
Bone density (HU)	Cylindrical (n = 37)	696.62 ± 158.95	375–950	T 1.481	0.142
	Conical (n = 65)	642.50 ± 205.94	225–1100		
	Total (n = 102)	662.13 ± 191.21	225–1100		

* Statistically significant differences after *t*-test, M-W, or Pearson's Chi-square tests ($p < 0.05$).

Without dividing the data based on the implant macro geometry group (n = 102 implants), a significant relationship was found between the clinician's tactile bone quality assessment and the bone density, insertion torque, and ISQ values on the day of the surgery (Table 2, Figure 3). An indirect significant correlation was found between the clinician's tactile bone quality assessment, the insertion torque values (rho = −0.425; $p < 0.001$), and the ISQ values on the day of the surgery (rho = −0.245; p = 0.013). In other words, higher insertion torque and ISQ values were recorded when the clinician perceived the bone as hard (D1-type bone). Additionally, a significant inverse association was identified between the clinician's tactile bone quality assessment and the bone density (in HU) (r = −0.273; p = 0.005). In contrast, no statistical significance was revealed between the clinician's tactile bone quality assessment and ISQ after 3 months (rho = −0.035; p = 0.728). When analyzing the relationship between the clinician's tactile bone quality assessment and the various patient-related and intraoperative variables in each of the implant macro geometry groups, an indirect significant association was found for the conical implant group in the insertion torque (rho = −0.403; p < 0.001) and the bone density (r = −3.73; p = 0.002). The cylindrical implants group also displayed an indirect significant association with the insertion torque (rho = −0.366; p = 0.026) but not for the bone density (r = 0.062; p = 0.716).

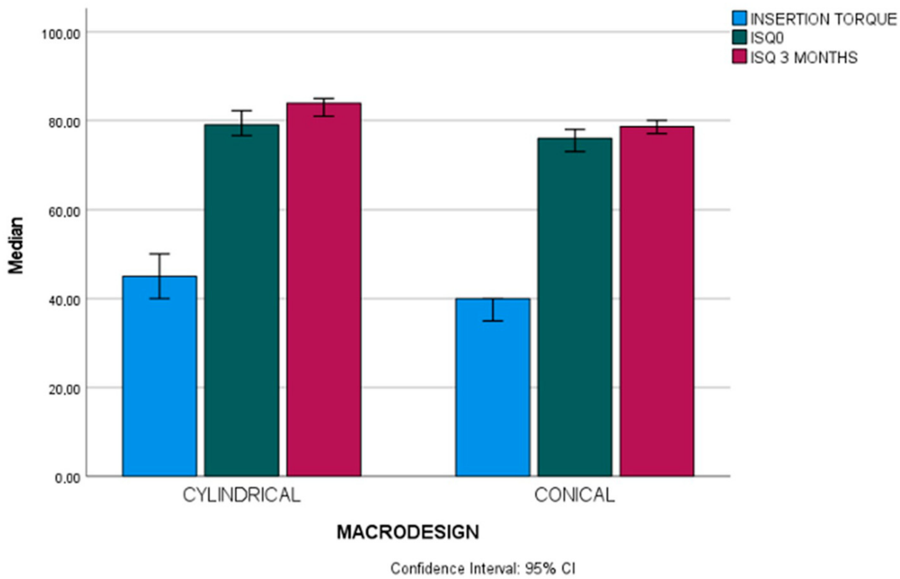

Figure 3. Bar chart representing medians of insertion torque (N × cm), implant stability quotient at the moment of the surgery, and implant stability after three months depending on the implant macro design. Confidence intervals were set at p = 0.05.

When analyzing the association between insertion torque and ISQ, a strong positive correlation was identified in the conical implant group (rho = 0.554; p < 0.001) but not with the cylindrical implants (rho = 0.214; p = 0.203). A Mann–Whitney test revealed that the cylindrical implant group displayed a significantly higher insertion torque than the conical implants (U = 748; p < 0.001) (Table 3).

The cylindrical implants showed a significantly higher ISQ on the day of the surgery (U = 766.50; p = 0.0002) and after three months (U = 689.50; p < 0.001). The clinician's tactile sensation revealed a significantly softer bone when using conical implants (CHI^2 = 22.2; p = 0.001). However, the bone density analysis did not confirm the difference in bone density when using cylindrical or conical implants (t = 1.481; p = 0.142).

The descriptive data and comparisons of the patient-related and intraoperative variables in the distinct implant locations (the incisor–canine and bicuspid–molar regions) are summarized in Table 4. No significant differences were found when comparing the insertion torque, the ISQ on the day of the surgery (Figure 4), and the clinician's tactile evaluation of bone density according to the implant location. In contrast, the ISQ values recorded after three months were significantly higher in the bicuspid–molar area in the cylindric implant group (U = 88.50; p = 0.002) (Figure 5). Significantly higher bone densities were found in the incisor–canine area for the conical and cylindrical implants (t = 3.00; p = 0.005 and t = 3.99; p < 0.001, respectively).

Table 4. Effects of the implant location in the arch (incisors–canines, bicuspids–molars) on the patient-related and intraoperative variables of stability and bone density, according to Student's *t*-tests, M-W non-parametric tests or Pearson's Chi-Square tests (n = 102 implants). * denotes significant differences ($p < 0.05$).

	Groups (*n*)	Cylindrical Mean ± SD Median (IR) *n* (%)	Conical Mean ± SD Median (IR) *n* (%)	U *t* CHI^2	*p*-Value
Insertion torque (Ncm)	Incisors–canines (n = 36)	45(5)	40 (15)	U 99.50	0.058
	Bicuspids–molars (n = 66)	45 (11.5)	35 (15)	U 303	0.013 *
U (*p*-value)		130 (0.267)	340.5 (0.085)		
ISQ day of surgery (ISQ units)	Incisors–canines (n = 36)	78 (23.40)	76 (9.95)	U 136.50	0.500
	Bicuspids–molars (n = 66)	81.15 (8.50)	75.65 (11.90)	U 240.50	<0.001 *
U (*p*-value)		108 (0.08)	452.50 (0.894)		
ISQ 3 months (ISQ units)	Incisors–canines (n = 36)	80.60 (6)	77.30 (4.85)	U 105	0.092
	Bicuspids–molars (n = 66)	85 (3)	79.65 (6.92)	U 215	<0.001 *
U (*p*-value)		68.50 (0.002 *)	330.50 (0.065)		
Tactile evaluation of bone quality (D1–D4 Range)	Incisors–anines (n = 36)	15 (14.70%)	21 (20.59%)	CHI^2 2.176	0.537
	Bicuspids–molars (n = 66)	22 (21.57%)	44 (20.59%)	CHI^2 7.986	0.092
CHI^2 (*p*-value)		2.256 (0.689)	4.340 (0.362)		
Bone density (HU)	Incisors–canine (n = 36)	782.50 ± 124.89	775.59 ± 170.59	*t* 0.133	0.895
	Bicuspids–molars (n = 66)	638.06 ± 155.09	578.98 ± 191.85	*t* 1.253	0.215
t (*p*-value)		3.00 (0.005 *)	3.99 (<0.001 *)		

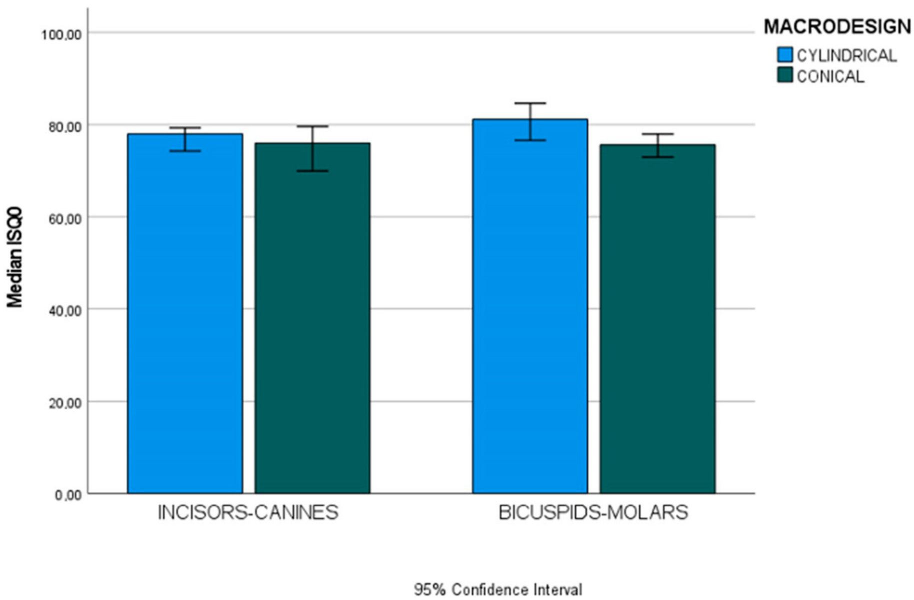

Figure 4. Bar chart representing medians of implant stability quotients at the moment of surgery according to macro-design and location. Confidence intervals were set at $p = 0.05$.

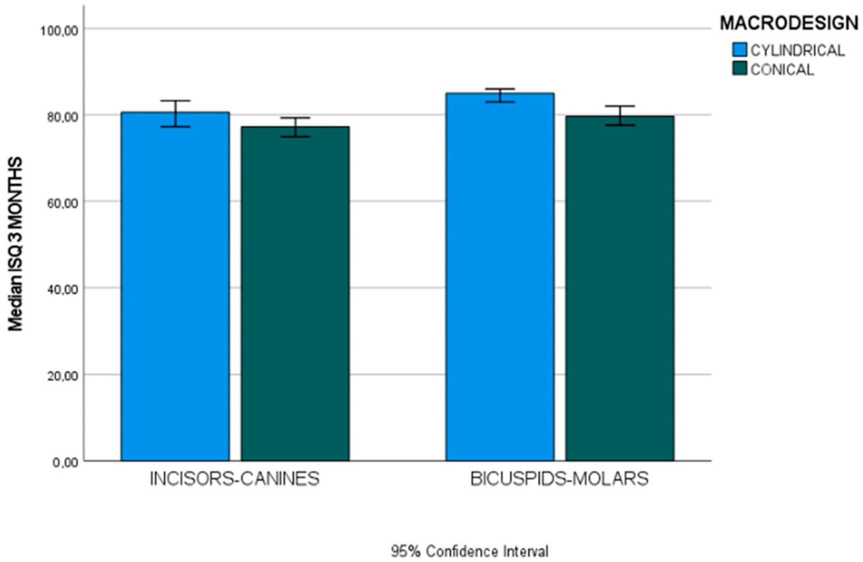

Figure 5. Bar chart representing medians of implant stabilities after three months according to macro-design and location. Confidence intervals were set at $p = 0.05$.

When studying the effects of arch location (maxilla or mandible) (Table 5), significantly higher ISQ values on the day of the surgery and greater bone densities were demonstrated for the mandible when using the conical implants (U < 0286; $p = 0.005$ and t = −2.578; $p = 0.012$, respectively). It is also remarkable that the insertion torque was higher in the maxilla when using the conical implants (U = 315; $p = 0.010$), the ISQ recorded on the day of the surgery and after three months was higher, and the bone density was higher in the maxilla when using the cylindrical implants (U = 131; $p < 0.001$, U = 202; $p = 0.006$, and t = 2.314; $p = 0.024$, respectively).

Table 5. Effects of the arch (maxilla or mandible) on the patient-related and intraoperative variables of stability and bone density according to the Student's *t*-test, Mann–Whitney's non-parametric test, or Pearson's Chi-square test ($n = 102$ implants). * denotes significant differences (p <0.05).

	Groups (n)	**Cylindrical Mean ± SD Median (IR) *n* (%)**	**Conical Mean ± SD Median (IR) *n* (%)**	**U *t* CHI^2**	***p*-Value**
Insertion torque (Ncm)	Maxilla ($n = 59$)	45 (11.25)	35 (12.50)	U 215.5	0.010 *
	Mandible ($n = 43$)	50 (10)	42.50 (20)	U 157	0.078
U (*p*-value)		144 (0.401)	427.5 (0.375)		
ISQ day of surgery (ISQ units)	Maxilla ($n = 59$)	80.80 (7.28)	73.30 (11.15)	U 131	<0.001 *
	Mandible ($n = 43$)	77 (7)	78.50 (17.40)	U 215	0.759
U (*p*-value)		101.50 (0.34)	286 (0.005 *)		
ISQ 3 months (ISQ units)	Maxilla ($n = 59$)	85 (7.78)	77.60 (5.65)	U 202.50	0.006 *
	Mandible ($n = 43$)	83 (6.60)	79.50 (8.97)	U 153	0.066
U (*p*-value)		161 (0.760)	399 (0.206)		
Tactile evaluation of bone quality (D1–D4 Range)	Maxilla ($n = 59$)	18 (17.64%)	41 (40.20%)	CHI^2 4.450	0.349
	Mandible ($n = 43$)	19 (18.63%)	24 (23.53%)	CHI^2 9.855	0.079
Chi^2 (*p*-value)		2.835 (0.586)	3.057 (0.547)		
Bone density (HU)	Maxilla ($n = 59$)	709.03 ± 148.08	594.21 ± 185.95	*t* 2.314	0.024 *
	Mandible ($n = 43$)	684.87 ± 171.82	725 ± 215.91	*t* 2.869	0.512
t (*p*-value)		0.457 (0.651)	−2.578 (0.012 *)		

Tables 6 and 7 display the descriptive data and the effects of the implant diameter (standard and wide) and the implant width (standard and long) for the various preoperative and intraoperative variables, respectively. Higher insertion torques and denser bones were detected for the standard-width conical implants compared to the wide implants (U = 126; $p = 0.006$, and t = 3.454; $p < 0.001$, respectively). Lower tactile bone quality indices were assessed for the standard-width conical implants ($CHI^2 = 20.93$; $p < 0.001$). A higher insertion torque and ISQ on the day of the surgery and after three months were assessed for standard-width cylindrical implants in comparison to conical implants (U = 665; $p = 0.008$, U = 667; $p = 0.009$, and U = 537; $p < 0.001$, respectively) (Table 6).

Table 6. Effects of implant diameter on the patient-related and intraoperative variables of stability and bone density according to the Student's *t*-test, Mann–Whitney's non-parametric test, or Pearson Chi-square test (*n* = 102 implants). * denotes significant differences ($p < 0.05$).

	Groups (n)	Cylindrical Mean ± SD Median (IR) *n* (%)	Conical Mean ± SD Median (IR) *n* (%)	U *t* CHI^2	*p*-Value
Insertion torque (Ncm)	Standard (<4.5 Ø); (*n* = 91)	45 (10)	40 (10)	U 665.50	0.008 *
	Wide (≥4.5 Ø); (*n* = 11)	35	27.5 (18.75)		
U (*p*-value)			126.5 (0.006 *)		
ISQ day of surgery (ISQ units)	Standard (<4.5 Ø); (*n* = 91)	78.80 (8.92)	76.3 (8.10)	U 667	0.009 *
	Wide (≥4.5 Ø); (*n* = 11)	82.30	68.95 (15.20)		
U (*p*-value)			264 (0.841)		
ISQ 3 months (ISQ units)	Standard (<4.5 Ø); (*n* = 91)	84(5.90)	79 (6)	U 537.50	<0.001 *
	Wide (≥4.5 Ø); (*n* = 11)	77.00	76.80 (9.17)		
U (*p*-value)			264 (0.841)		
Tactile evaluation of bone quality (D1–D4 range)	Standard (<4.5 Ø); (*n* = 91)	36 (35.29%)	55 (53.92%)	CHI^2 6.046	0.196
	Wide (≥4.5 Ø); (*n* = 11)	1 (0.98%)	10 (9.80%)		
Chi^2 (*p*-value)			20.93 (<0.001 *)		
Bone density (HU)	Standard (<4.5 Ø); (*n* = 91)	697.57 ± 161.10	677.27 ± 195.49	*t* 0.518	0.606
	Wide (≥4.5 Ø); (*n* = 11)	662.50	451.25 ± 155.73		
t (*p*-value)			3.454 (<0.001 *)		

When the cylindrical and conical implants were compared according to implant length (standard or long), no significant differences were identified ($p > 0.05$) in any of the variables examined. However, significantly higher insertion torques and ISQ values on the day of the surgery and after three months were assessed for the long implants when using the cylindrical implants (U = 218; $p = 0.036$, U = 194.50; $p = 0.012$, and U = 201.50; $p = 0.018$, respectively). The same effect was found for the ISQ after three months for the standard-length implants (U = 151.50; $p = 0.012$).

The ISQ values on the day of the surgery (ISQ0) and after 3 months (ISQ3) were considered as the dependent variables in the linear regression analysis. Implant-related factors (implant macro geometry, length, width, dental arch, and implant location in the arch), intraoperative factors (bone density determined subjectively based on the clinician's tactile perception, ISQ0, and insertion torque), and patient-related factors (age, gender, and bone density determined objectively based on the cone beam computed tomography (CBCT)) were firstly assessed as the independent variables. Still, only significant predictors were considered in the final linear regression analysis. The predictor variables used in the ISQ measured on the day of the surgery (ISQ0) in the linear regression analysis were the insertion torque, length, and implant macro design. For the ISQ measured after three months of osseointegration (ISQ3), the predictors were location, implant macro design, and age. (Table 8).

Table 7. Effects of implant length on the patient-related and intraoperative variables of stability and bone density according to the Student's *t*-test, Mann–Whitney's non-parametric test, or Pearson's Chi-square test (*n* = 102 implants). * denotes significant differences ($p < 0.05$).

	Groups (n)	Cylindrical Mean ± SD Median (IR) *n* (%)	Conical Mean ± SD Median (IR) *n* (%)	U *t* CHI^2	*p*-Value
Insertion torque (Ncm)	Standard (≤10 mm) (*n* = 48)	47.50 (11.25)	37.50 (20)	U 154.50	0.13
	Long (>10 mm) (*n* = 54)	45 (10)	40 (15)	U 218.50	0.036 *
U (*p*-value)		169 (0.950)	441.50 (0.266)		
ISQ day of surgery (ISQ units)	Standard (≤10 mm) (*n* = 48)	78 (11.85)	73.80 (38.40)	U 182	0.061
	Long (>10 mm) (*n* = 54)	79 (9)	77 (25)	U 194.50	0.012 *
U (*p*-value)		132 (0.235)	412.50 (0.138)		
ISQ 3 months (ISQ units)	Standard (≤10 mm) (*n* = 48)	84.50 (5.10)	78.80 (9)	U 151.50	0.012 *
	Long (>10 mm) (*n* = 54)	81.30 (7)	78.60 (5.30)	U 201.50	0.018 *
U (*p*-value)		130.50 (0.216)	500.50 (0.747)		
Tactile evaluation of bone quality (D1–D4 Range)	Standard (≤10 mm) (*n* = 48)	18 (17.65%)	30 (29.41%)	CHI^2 9.719	0.021 *
	Long (>10 mm) (*n* = 54)	19 (18.63%)	35 (34.31%)	CHI^2 2.746	0.601
CHI^2 (*p*-value)		2.835 (0.586)	8.954 (0.062)		
Bone density (HU)	Standard (≤10 mm) (*n* = 48)	663.19 ± 166.58	645.83 ± 217.66	*t* 0.291	0.773
	Long (>0 mm) (*n* = 54)	728.29 ± 148.83	639.64 ± 198.51	*t* 1.852	0.070
t (*p*-value)		−1.255 (0.218)	0.120 (0.905)		

Table 8. Linear regression model between the stability and bone-density variables.

Dependent Variables	Independent Variables	β	Error	*p*-Value	Lower CI 95%	Upper CI 95%
			Primary Stability			
ISQ day of the surgery [A]	Macrodesign	−0.200	1.410	0.028	−5.948	−0.350
	Length	0.175	1.315	0.046	0.049	5.269
	Insertion torque	0.387	0.064	<0.001	0.147	0.400
			Secondary stability			
ISQ 3 months [B]	Location	0.274	1.338	0.003	1.349	6.660
	Macrodesign	−0.277	1.333	0.003	−6.667	−1.375
	Age	0.190	1.284	0.041	0.112	5.208

[A]: **Coefficient of determination** $R^2 = 0.278$ $F = 12.589$; $p < 0.001$. [B]: **Coefficient of determination** $R^2 = 0.182$ $F = 7.258$; $p < 0.001$.

The primary stability linear regression model studied using the ISQ0 as the dependent variable produced very significant results ($F = 12.589$; $p < 0.001$), although it only predicted 27.8% of the results for the ISQ on the day of the surgery according to the coefficient of determination (R^2). Therefore, as a baseline, an average ISQ of 74.8 ± 7.79 was obtained on the day of the surgery at the incisor–canine area, and for each applied extra Ncm in the insertion torque, between 0.147 and 0.4 ISQ units were gained. Using longer implants resulted in a gain of 0.05–5.239 ISQ units, and utilizing conical-shaped implants resulted in a loss of 0.35–5.269 ISQ units (Table 7).

The secondary stability linear regression model, assessed based on the ISQ after three months (ISQ3), depended mainly on the location of the implant in the arch (incisor–canines, bicuspid–molars), the implant macro-design (cylindrical, conical), and the age of the patient ($\leq$55, >55). According to the significant regression model (F = 7.258; $p < 0.001$), which only predicted 18.2% of the results of the measured ISQ3 values, the average ISQ after three months at the incisor–canine area, 76.67 $\pm$ 7.13, will increase by 1.35–6.66 units when the implant is placed more posteriorly (bicuspids and molars), and by 0.11–5.21 units in older patients. If conical-shaped implants are used, the ISQ3 value will decrease by 1.375–6.660 (Table 7).

4. Discussion

Many factors can affect the success of implant therapy, but patient-related factors and implant-related factors are perhaps the two most important variables to consider [26,27]. Achieving primary stability in implant surgery is one of the many desired outcomes for clinicians [28,29], and it is reported to depend mainly on bone density and implant macro geometry [30]. Research relating to insertion torque and implant success is becoming increasingly frequent. In a randomized clinical trial lasting 12 months, Barone et al. [31] evaluated the influence of insertion torque and peri-implant bone stability. Their results showed that implants placed with a high insertion torque ($\geq$50 Ncm) showed greater peri-implant bone remodeling and greater recession of the buccal soft tissues. Following this trend, Marconcini et al. [32] observed similar results in terms of bone resorption (less marginal bone loss and less facial soft tissue recession) and implant success. They obtained a success rate of 98.2% in implants placed at a regular insertion torque (<50 Ncm) and 91.3% in implants placed at a high insertion torque ($\geq$50 Ncm).

The present study's first overall correlation analysis, i.e., before the data were divided into implant macro-geometry groups, showed a significant association between the tactile evaluation of bone density during the preparation of the osteotomy and the insertion torque, ISQ on the day of the surgery, and bone-density values attained using the CBCT. However, when the correlation analysis was conducted for each group of implants, the conical-shaped implants had an inverse significant correlation with the insertion torque and the bone density, and the cylindrical-shaped implants only produced significant results for the insertion torque, as mentioned earlier (Table 2). Several studies have analyzed the correlation between the surgeon's tactile sensation and variables such as insertion torque, ISQ, and bone density values derived from CBCT [7,33–35]. Fernandes Triches et al. [35] identified a moderate, negative association between the insertion torque and the bone type selected based on a tactile evaluation. The present study found a negative association between the insertion torque and tactile sensation for conical (rho = -0.403; $p < 0.001$) and parallel implants (rho = -0.366; $p = 0.026$). These differences may be influenced by the macro-geometry of the implants, since no prior studies have been found comparing all these variables and implant macro-designs.

The present study significantly demonstrated that the cylindrical implants provided higher primary stability values (insertion torque and ISQ values) than the conical implants. In contrast, Waechter et al. [36] showed that conical and cylindrical implants of the same length but different diameters placed in the posterior region of the mandible produced similar results for primary stability. Likewise, authors such as Cochran et al. [37] and Sakoh et al. [38] found no significant differences between the primary stability of conical and cylindrical implants. However, the literature suggests that implant macro geometries with hybrid and tapered designs provide greater primary stability [30,39,40].

Furthermore, several of the studies mentioned above were in vitro [38], animal-models [36,39], or retrospective clinical studies [7], and each study used different macro-designs (conical, cylindrical, and hybrid implants with different thread designs and pitches, with or without micro-spirals in the coronal portion), which makes it challenging to draw any conclusions on this issue. Thus, further clinical studies would be advisable to investigate the effects of macro geometry on primary stability, including patient-related clinical variables.

Another possible reason for the higher primary stability values for the cylindrical implants was the type of surgical procedure performed during the osteotomy. Most clinicians perform some drilling strategy depending on the perceived bone quality to achieve adequate primary stability. Thread-forming drills might be used whenever implants are placed in hard bone (Lekholm and Zarb type I and II) and to underdrill the implant bed whenever soft bone is felt (Lekholm and Zarb type III and IV) [41,42]. This high primary stability may be explained by the pressure setting generated by the underdrilling, which induces additional friction [25,34,35]. However, new bone preparation techniques, such as Osseodensification, are emerging, with significant results compared to the conventional technique [42,43].

Another notable finding was that the significantly lower ISQ obtained at the moment of the surgery for the conical implants was maintained at the ISQ after three months, which may imply that the implant's macro-geometry (thread design) may play a role in both primary and secondary stability.

Despite the subjective tactile evaluation of bone quality being used to assess softer bone when placing the conical implants, such differences did not correspond with the objective bone density assessment, which may indicate that implant macro-geometry may play a role in the tactile perception during implant placement.

This study also explored other factors, such as implant location in the arch (incisors–canines, bicuspids–molars) and whether the implants were placed in the maxilla or mandible. Our results showed that the more posterior the implant location, the lower the bone density. The values for the mean bone density according to implant location within the arch observed in the present study (Table 4) were similar to those reported by Fuster-Torres et al. [7]. These authors obtained a mean value of 684 ± 131 HU in the anterior region and 568.5 ± 170 HU in the posterior region. Therefore, in line with the results reported by Turkyilmaz et al. [44] in 2007, the highest values for bone density (HU) are found in the anterior region, and the lowest values (HU) occur in the posterior region.

This study found no statistically significant differences between the implants placed in the maxilla or mandible regarding primary stability, secondary stability, or bone density (Table 5), in contrast to the findings of other researchers [7,43,44]. This study also found that implant length (Table 7) did not significantly affect primary stability, secondary stability, or bone density. However, implant diameter was found to have significant effects (Table 6) on insertion torque and bone density variables. Wide-diameter implants achieved significantly lower insertion torque values than implants with a standard diameter. There are likely to be two main reasons for these results. Firstly, most implants (63.6%) were placed in the maxilla, where bone density is expected to be lower (reduced HU). Secondly, all the wide implants were placed in the molar region, where the mean bone density was the lowest.

In contrast, Farronato et al. [45] reported that a wider implant diameter was associated with a greater insertion torque. However, this was an in vitro study in which bone density would be difficult to control, given the challenge of reproducing human bone's macroscopic and microscopic characteristics in models. In a clinical study using a similar methodology, Da Rocha Ferreira et al. [46] compared cylindrical (Nobel Parallel) and conical (Nobel Active) implants and found no significant differences relating to implant diameter and insertion torque ($p = 0.57$). However, they did find that implant diameter had a significant effect ($p = 0.04$) on the ISQ on the day of the surgery. While the present research did not identify significant differences ($p = 0.162$) related to implant diameter and ISQ on the day of the surgery, lower ISQ scores were achieved for the wide implants compared to the standard-diameter implants. These results support those presented by Da Rocha Ferreira et al. [46].

In the present research, a linear regression analysis showed that the implant macro-design, the length, and the insertion torque were the most influential ISQ predictors at the moment of implant placement. The location, implant macro-design, and age of the patients were the most significant predictors for the ISQ after three months of healing.

Moreover, this study showed that although some implant macro-designs are specifically designed to achieve high primary stability values on the day of the surgery, after 3 months of osseointegration, some implant designs achieved greater secondary stability (Table 2). Clinicians should know that the implant design, site, and diameter will modulate the primary and secondary stability of implants placed in healed sites. The secondary stability also depends on other surface conditions of the implants, such as their surface topography or roughness [47–49].

A limitation of the present study was the sample size. The calculated minimum number of implants per group to achieve adequate statistical power (31 implants) was obtained for comparing the insertion torque and the implant stability quotient at implant placement and after three months for the cylindrical and the conical implants. However, lower frequencies were observed when comparing the different characteristics of the different microgeometries of the implants, such as the influence of the location in the arch or the implant diameter and length in the stability in the implant macro design groups. Even though only two subgroups of comparison were performed, anterior (incisors and canines) and posterior (bicuspids and molars) and standard and wide/long made the sample size reduction lower. A relatively small sample of wide-diameter implants (n = 11) was obtained, specifically for the cylindrical group, with only one implant. A 4.5 mm diameter was the limit for considering a standard or wide-diameter implant. The cylindrical implants used in this study had a standard width of 4.3 mm, so most of the implants placed were considered standard in this study, but they were used in many cases as wide-diameter implants clinically.

Future research should conduct clinical trials, maybe multicentric, on the main predictor variables affecting primary and secondary stability to obtain more conclusive statements with larger samples, a wider range of implant dimensions (diameter and length), and a longer follow-up period.

5. Conclusions

Bearing the limitations mentioned above in mind, the present study enables us to establish that:

1. On healed bone crests, higher values for primary stability (insertion torque and ISQ points) will be achieved with standard-diameter implants ($\varnothing \leq 4.5$).
2. After implant osseointegration (three months), the cylindrical implants yielded higher ISQ values than the conical implants. Further research is needed to assess factors that affect secondary stability.
3. The ISQ values after three months will be lower in implants placed in the incisor–canine region than those placed in the bicuspid–molar region.
4. Insertion torque is the variable that most influences ISQ on the day of the surgery, and the implant location and macro-design in the arch have the most significant effects on ISQ after three months.

Author Contributions: Conceptualization, resources, N.Q.-L. and J.M.; methodology, N.Q.-L., J.M. and S.M.-M.; software, S.M.-M.; validation N.Q.-L., M.I.S.-J., C.G.-P. and O.F.-A.; writing—original draft preparation, N.Q.-L., O.F.-A. and J.M.; writing (review and editing), N.Q.-L., C.G.-P. and J.M.; data interpretation, C.G.-P. and M.I.S.-J.; all statistical analyses, N.Q.-L., O.F.-A. and J.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: This study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the University of Salamanca (protocol code 473, 22 June 2020).

Informed Consent Statement: Informed consent was obtained from all the subjects involved in this study. Written informed consent was obtained from the patient(s) to publish this paper.

Data Availability Statement: The datasets analyzed during the current study are available from the corresponding author upon reasonable request.

Acknowledgments: This study was conducted within the Research Group "Avances en Salud Oral" (Advances in Oral Health) of the University of Salamanca. https://avancessaludoral.usal.es (accessed on 23 November 2021).

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

CBCT	Cone beam computed tomography.
HU	Hounsfield units.
DICOM	Digital imaging and communication in medicine
IT	Insertion torque
ISQ	Implant stability quotient

References

1. Gamborena, I.; Sasaki, Y.; Blatz, M.-B. Predictable immediate implant placement and restoration in the esthetic zone. *J. Esthet. Restor. Dent.* **2021**, *33*, 158–172. [CrossRef] [PubMed]
2. Papaspyridakos, P.; Chen, C.-J.; Singh, M.; Weber, H.-P.; Gallucci, G.-O. Success criteria in implant dentistry: A systematic review. *J. Dent. Res.* **2012**, *91*, 242–248. [CrossRef] [PubMed]
3. Carosi, P.; Lorenzi, C.; Laureti, M.; Ferrigno, N.; Arcuri, C. Short Dental Implants (≤6 mm) to Rehabilitate Severe Mandibular Atrophy: A Systematic Review. *Int. J. Oral Maxillofac. Implant.* **2021**, *36*, 30–37. [CrossRef] [PubMed]
4. Bornstein, M.-M.; Scarfe, W.-C.; Vaughn, V.-M.; Jacobs, R. Cone beam computed tomography in implant dentistry: A systematic review focusing on guidelines, indications, and radiation dose risks. *Int. J. Oral Maxillofac. Implant.* **2014**, *29*, 55–77. [CrossRef] [PubMed]
5. Jacobs, R.; Salmon, B.; Codari, M.; Hassan, B.; Bornstein, M.-M. Cone beam computed tomography in implant dentistry: Recommendations for clinical use. *BMC Oral Health* **2018**, *18*, 88. [CrossRef] [PubMed]
6. Marquezan, M.; Osório, A.; Sant′Anna, E.; Souza, M.M.; Maia, L. Does bone mineral density influence the primary stability of dental implants? A systematic review. *Clin. Oral Implant. Res.* **2012**, *23*, 767–774. [CrossRef] [PubMed]
7. Fuster-Torres, M.-Á.; Peñarrocha-Diago, M.; Peñarrocha-Oltra, D.; Peñarrocha-Diago, M. Relationships between bone density values from cone beam computed tomography, maximum insertion torque, and resonance frequency analysis at implant placement: A pilot study. *Int. J. Oral Maxillofac. Implant.* **2011**, *26*, 1051–1056.
8. Turkyilmaz, I.; Aksoy, U.; McGlumphy, E.-A. Two alternative surgical techniques for enhancing primary implant stability in the posterior maxilla: A clinical study including bone density, insertion torque, and resonance frequency analysis data. *Clin. Implant. Dent. Relat. Res.* **2008**, *10*, 231–237. [CrossRef] [PubMed]
9. Ottoni, J.-M.; Oliveira, Z.-F.; Mansini, R.; Cabral, A.-M. Correlation between placement torque and survival of single-tooth implants. *Int. J. Oral Maxillofac. Implant.* **2005**, *20*, 769–776.
10. Lages, F.-S.; Douglas-de Oliveira, D.-W.; Costa, F.-O. Relationship between implant stability measurements obtained by insertion torque and resonance frequency analysis: A systematic review. *Clin. Implant. Dent. Relat. Res.* **2018**, *20*, 26–33. [CrossRef]
11. Trisi, P.; Perfetti, G.; Baldoni, E.; Berardi, D.; Colagiovanni, M.; Scogna, G. Implant micromotion is related to peak insertion torque and bone density. *Clin. Oral Implant. Res.* **2009**, *20*, 467–471. [CrossRef] [PubMed]
12. Mikic, M.; Vlahovic, Z.; Stevanović, M.; Arsic, Z.; Mladenovic, R. The Importance of Correlation between CBCT Analysis of Bone Density and Primary Stability When Choosing the Design of Dental Implants-Ex Vivo Study. *Tomography* **2022**, *8*, 1293–1306. [CrossRef] [PubMed]
13. Falco, A.; Berardini, M.; Trisi, P. Correlation between Implant Geometry, Implant Surface, Insertion Torque, and Primary Stability: In Vitro Biomechanical Analysis. *Int. J. Oral Maxillofac. Implant.* **2018**, *33*, 824–830. [CrossRef] [PubMed]
14. Antonelli, A.; Barone, S.; Attanasio, F.; Salviati, M.; Cerra, M.G.; Calabria, E.; Bennardo, F.; Giudice, A. Effect of Implant Macro-Design and Magnetodynamic Surgical Preparation on Primary Implant Stability: An In Vitro Investigation. *Dent. J.* **2023**, *11*, 227. [CrossRef] [PubMed]
15. Pérez-Pevida, E.; Cherro, R.; Camps-Font, O.; Piqué, N. Effects of Drilling Protocol and Bone Density on the Stability of Implants According to Different Macrogeometries of the Implant Used: Results of an In Vitro Study. *Int. J. Oral Maxillofac. Implant.* **2020**, *35*, 955–964. [CrossRef] [PubMed]
16. Lekholm, U.; Zarb, G.-A. Patient selection and preparation. In *Tissue Integrated Prostheses. Osseointegration in Clinical Dentistry*; Brånemark, P.-I., Zarb, G.A., Albrektsson, T., Eds.; Quintessence Publishing Co.: Chicago, IL, USA, 1985; pp. 199–209.

17. Misch, C.-E. Density of bone: Effect on surgical approach, and healing. In *Contemporary Implant Dentistry*; Misch, C.E., Ed.; Mosby-Year Book: St. Louis, MO, USA, 1999; pp. 371–384.
18. Todisco, M.; Trisi, P. Bone mineral density and bone histomorphometry are statistically related. *Int. J. Oral Maxillofac. Implant.* **2005**, *20*, 898–904.
19. Sennerby, L.; Andersson, P.; Pagliani, L.; Giani, C.; Moretti, G.; Molinari, M.; Motroni, A. Evaluation of a Novel Cone Beam Computed Tomography Scanner for Bone Density Examinations in Preoperative 3D Reconstructions and Correlation with Primary Implant Stability. *Clin. Implant. Dent. Relat. Res.* **2015**, *17*, 844–853. [CrossRef] [PubMed]
20. Pandey, C.; Rokaya, D.; Bhattarai, B.P. Contemporary Concepts in Osseointegration of Dental Implants: A Review. *Biomed. Res. Int.* **2022**, *2022*, 6170452. [CrossRef] [PubMed]
21. Vallecillo-Rivas, M.; Reyes-Botella, C.; Vallecillo, C.; Lisbona-González, M.J.; Vallecillo-Capilla, M.; Olmedo-Gaya, M.V. Comparison of Implant Stability between Regenerated and Non-Regenerated Bone. A Prospective Cohort Study. *J. Clin. Med.* **2021**, *10*, 3220. [CrossRef]
22. Albrektsson, T.; Wennerberg, A. On osseointegration in relation to implant surfaces. *Clin. Implant. Dent. Relat. Res.* **2019**, *21* (Suppl. 1), 4–7. [CrossRef]
23. Kreve, S.; Ferreira, I.; da Costa Valente, M.L.; Dos Reis, A.C. Relationship between dental implant macro-design and osseointegration: A systematic review. *Oral Maxillofac. Surg.* **2024**, *28*, 1–14. [CrossRef] [PubMed]
24. Lozano-Carrascal, N.; Salomó-Coll, O.; Gilabert-Cerdà, M.; Farré-Pagés, N.; Gargallo-Albiol, J.; Hernández-Alfaro, F. Effect of implant macro-design on primary stability: A prospective clinical study. *Med. Oral Patol. Oral Cir. Bucal* **2016**, *21*, e214–e221. [CrossRef]
25. Walker, C.J.; Prihoda, T.J.; Mealey, B.L.; Lasho, D.J.; Noujeim, M.; Huynh-Ba, G. Evaluation of Healing at Molar Extraction Sites with and without Ridge Preservation: A Randomized Controlled Clinical Trial. *J. Periodontol.* **2017**, *88*, 241–249. [CrossRef]
26. Chrcanovic, B.-R.; Kisch, J.; Albrektsson, T.; Wennerberg, A. Factors Influencing Early Dental Implant Failures. *J. Dent. Res.* **2016**, *95*, 995–1002. [CrossRef]
27. Chatzopoulos, G.-S.; Wolff, L.-F. Retrospective analysis of 50,333 implants on implant failure and associated patient-related factors. *J. Stomatol. Oral Maxillofac. Surg.* **2023**, *124*, 101555. [CrossRef] [PubMed]
28. Griggs, J.-A. Dental Implants. *Dent. Clin. N. Am.* **2017**, *61*, 857–871. [CrossRef] [PubMed]
29. Heimes, D.; Becker, P.; Pabst, A. How does dental implant macrogeometry affect primary implant stability? A narrative review. *Int. J. Implant. Dent.* **2023**, *9*, 20. [CrossRef] [PubMed]
30. Torroella-Saura, G.; Mareque-Bueno, J.; Cabratosa-Termes, J.; Hernández-Alfaro, F.; Ferrés-Padró, E.; Calvo-Guirado, J.-L. Effect of implant design in immediate loading. A randomized, controlled, split-mouth, prospective clinical trial. *Clin. Oral Implant. Res.* **2015**, *26*, 240–244. [CrossRef] [PubMed]
31. Barone, A.; Alfonsi, F.; Derchi, G.; Tonelli, P.; Toti, P.; Marchionni, S.; Covani, U. The Effect of Insertion Torque on the Clinical Outcome of Single Implants: A Randomized Clinical Trial. *Clin. Implant. Dent. Relat. Res.* **2016**, *18*, 588–600. [CrossRef]
32. Marconcini, S.; Giammarinaro, E.; Toti, P.; Alfonsi, F.; Covani, U.; Barone, A. Longitudinal analysis on the effect of insertion torque on delayed single implants: A 3-year randomized clinical study. *Clin. Implant. Dent. Relat. Res.* **2018**, *20*, 322–332. [CrossRef]
33. Makary, C.; Rebaudi, A.; Mokbel, N.; Naaman, N. Peak insertion torque correlated to histologically and clinically evaluated bone density. *Implant. Dent.* **2011**, *20*, 182–191. [CrossRef]
34. Aksoy, U.; Eratalay, K.; Tözüm, T.-F. The possible association among bone density values, resonance frequency measurements, tactile sense, and histomorphometric evaluations of dental implant osteotomy sites: A preliminary study. *Implant. Dent.* **2009**, *18*, 316–325. [CrossRef]
35. Triches, D.-F.; Alonso, F.-R.; Mezzomo, L.-A. Relation between insertion torque and tactile, visual, and rescaled gray value measures of bone quality: A cross-sectional clinical study with short implants. *Int. J. Implant. Dent.* **2019**, *5*, 9. [CrossRef]
36. Waechter, J.; Madruga, M.-M.; Carmo Filho, L.-C.-D.; Leite, F.-R.-M.; Schinestsck, A.-R.; Faot, F. Comparison between tapered and cylindrical implants in the posterior regions of the mandible: A prospective, randomized, split-mouth clinical trial focusing on implant stability changes during early healing. *Clin. Implant. Dent. Relat. Res.* **2017**, *19*, 733–741. [CrossRef]
37. Cochran, D.; Stavropoulos, A.; Obrecht, M.; Pippenger, B.; Dard, M. A Comparison of Tapered and Nontapered Implants in the Minipig. *Int. J. Oral Maxillofac. Implant.* **2016**, *31*, 1341–1347. [CrossRef]
38. Sakoh, J.; Wahlmann, U.; Stender, E.; Nat, R.; Al-Nawas, B.; Wagner, W. Primary stability of a conical implant and a hybrid, cylindric screw-type implant in vitro. *Int. J. Oral Maxillofac. Implant.* **2006**, *21*, 560–566.
39. O'Sullivan, D.; Sennerby, L.; Meredith, N. Influence of implant taper on the primary and secondary stability of osseointegrated titanium implants. *Clin. Oral Implant. Res.* **2004**, *15*, 474–480. [CrossRef] [PubMed]
40. Toyoshima, T.; Wagner, W.; Klein, M.-O.; Stender, E.; Wieland, M.; Al-Nawas, B. Primary stability of a hybrid self-tapping implant compared to a cylindrical non-self-tapping implant with respect to drilling protocols in an ex vivo model. *Clin. Implant. Dent. Relat. Res.* **2011**, *13*, 71–78. [CrossRef] [PubMed]
41. Stacchi, C.; Troiano, G.; Montaruli, G.; Mozzati, M.; Lamazza, L.; Antonelli, A.; Giudice, A.; Lombardi, T. Changes in implant sability using different site preparation techniques: Osseodensification drills versus piezoelectric surgery. A multi-center prospective randomized controlled clinical trial. *Clin. Implant. Dent. Relat. Res.* **2023**, *25*, 133–140. [CrossRef]

42. Althobaiti, A.K.; Ashour, A.W.; Halteet, F.A.; Alghamdi, S.I.; AboShetaih, M.M.; Al-Hayazi, A.M.; Saaduddin, A.M. A Comparative Assessment of Primary Implant Stability Using Osseodensification vs. Conventional Drilling Methods: A Systematic Review. *Cureus* **2023**, *15*, e46841. [CrossRef]
43. Bhargava, N.; Perrotti, V.; Caponio, V.C.A.; Matsubara, V.H.; Patalwala, D.; Quaranta, A. Comparison of heat production and bone architecture changes in the implant site preparation with compressive osteotomes, osseodensification technique, piezoelectric devices, and standard drills: An ex vivo study on porcine ribs. *Odontology* **2023**, *111*, 142–153. [CrossRef]
44. Turkyilmaz, I.; Tumer, C.; Ozbek, E.-N.; Tözüm, T.-F. Relations between the bone density values from computerized tomography, and implant stability parameters: A clinical study of 230 regular platform implants. *J. Clin. Periodontol.* **2007**, *34*, 716–722. [CrossRef] [PubMed]
45. Farronato, D.; Manfredini, M.; Stocchero, M.; Caccia, M.; Azzi, L.; Farronato, M. Influence of Bone Quality, Drilling Protocol, Implant Diameter/Length on Primary Stability: An In Vitro Comparative Study on Insertion Torque and Resonance Frequency Analysis. *J. Oral Implantol.* **2020**, *46*, 182–189. [CrossRef]
46. Da Rocha-Ferreira, J.-J.; Machado, L.-F.-M. Insertion Torque Value and Implant Stability Quotient: Separate Evaluation and Correlation for Different Clinical Parameters. *Int. J. Oral Maxillofac. Implant.* **2022**, *37*, 812–822. [CrossRef] [PubMed]
47. Raghavendra, S.; Wood, M.-C.; Taylor, T.-D. Early wound healing around endosseous implants: A review of the literature. *Int. J. Oral Maxillofac. Implant.* **2005**, *20*, 425–431.
48. Gursoytrak, B.; Ataoglu, H. Use of resonance frequency analysis to evaluate the effects of surface properties on the stability of different implants. *Clin. Oral Implant. Res.* **2020**, *31*, 239–245. [CrossRef]
49. Neugebauer, J.; Weinländer, M.; Lekovic, V.; von Berg, K.-H.; Zoeller, J.-E. Mechanical stability of immediately loaded implants with various surfaces and designs: A pilot study in dogs. *Int. J. Oral Maxillofac. Implant.* **2009**, *24*, 1083–1092.