Primary Apical Stability of Tapered Implants Through Reduction of Final Drilling Dimensions in Different Bone Density Models: A Biomechanical Study

Alejandro Sierra-Rebolledo, DDS, MSc,* Marvis Allais-Leon, DDS, MSc, PhD,† Paul Maurette-O'Brien, DDS, MSc, PhD,‡ and Cosme Gay-Escoda, MD, DDS, MS, PhD§

Purpose: *A biomechanical study of the primary apical stability obtained in tapered implants through the reduction of final drilling dimensions in different bone density models.*

Material and Methods: An in vitro *study of maximum insertion torque and primary stability based on the resonance frequency analysis (RFA) of 24 conical implants measuring 13 mm in length and 3.75 and 4.20 mm in diameter, randomly inserted in 10-mm sockets prepared in 4 polyurethane blocks with a density of 15, 20, 30, and 40 pounds per cu ft, respectively, reducing the diameter of the final drill at constant speed (400 rpm) to obtain exclusive 4 mm anchoring of the apical third of each implant.*

Results: *The decrease in drilling diameter resulted in an increase in the insertion torque and implant stability quotient (ISQ) values in all implants, although without reaching statistical significance. In turn, a significant direct correlation was found between increasing bone analog block density and the insertion torque and ISQ values.*

Conclusions: *Under the conditions of this study, the primary apical stability obtained may be more dependent on bone density than on reduction of the final drilling diameter. (Implant Dent 2016;25:775–782)*
Key Words: primary stability, biomechanics, conical implants, resonance frequency analysis, insertion torque

Primary stability is a decisive factor for predicting dental implant success. It is the result of mechanical interaction between the bone and implant walls, conditioned by the discrepancy between the implant diameter and the dimensions of the recipient bone bed created by the drilling sequence during the surgical procedure. The factors influencing primary stability include bone quality and volume, the final surgical drilling diameter, and the percentage initial bone-to-implant contact (IBIC)—which must be sufficient to avoid micromovements during the osseointegration period. To secure primary stability, the usual discrepancy between the recipient bone and major diameter of the standard platform implant varies between 3% and 10%, which should allow insertion torque values of over 35 N·cm under normal bone quality and volume conditions.[1–3]

However, interest in avoiding degenerative gingival changes and crestal bone loss following extraction has led to modifications in the usual waiting time for implant insertion, with the adoption of immediate or early insertion.[4–9] Regardless of the treatment option chosen, insertion of 3 to 5 mm of the implant apex into the remaining bone below the apex of the tooth being extracted is needed to secure sufficient anchoring and the success of treatment. It is therefore essential to use a careful drilling protocol to ensure sufficient discrepancy between the apical diameter of the implant and the bone to secure mechanical stability without excessive compression of the bone walls.[10]

Campos et al[11] histologically evaluated the effect of reducing the final drilling diameter using 3.8, 3.5, and 3.2-mm drills with implants measuring

*Associate Professor of Oral Surgery and Implantology and Biotechnology Coordinator of Unit of Morphopathological Research, University of Carabobo Dental School, Valencia, Venezuela.
†Professor-in-Chief of Oral and Maxillofacial Surgery, Santa Maria University Dental School, Caracas, Venezuela.
‡Assistant Professor of Oral and Maxillofacial Surgery and Dental Research, Dr. Raul Vicentelli Institute, Central of Venezuela Dental School, Caracas, Venezuela.
§Cathedratic of Oral and Maxillofacial Surgical Pathology, Chairman of Oral and Maxillofacial Surgery, University of Barcelona Dental School; Coordinator of the Research Group of Maxillofacial Pathology and Dental Therapeutics, IDIBELL, Head of the Department of Oral Surgery, Implantology and Maxillofacial Surgery, TEKNON Medical Center, Barcelona, Spain.

Reprint requests and correspondence to: ***Alejandro Sierra-Rebolledo, DDS, MSc, Departamento de Estomatoquirurgica, Unidad de Investigaciones Morfo-Patologicas (UNIMPA) Pabellones 11-PB, Campus Barbula, Facultad de Odontología, Universidad de Carabobo, CP 2005, Valencia, Venezuela, Phone: (58) 243-2459898, Fax: (58) 243-2465803, E-mail: asierra4@uc.edu.ve***

ISSN 1056-6163/16/02506-775
Implant Dentistry
Volume 25 • Number 6

DOI: 10.1097/ID.0000000000000479

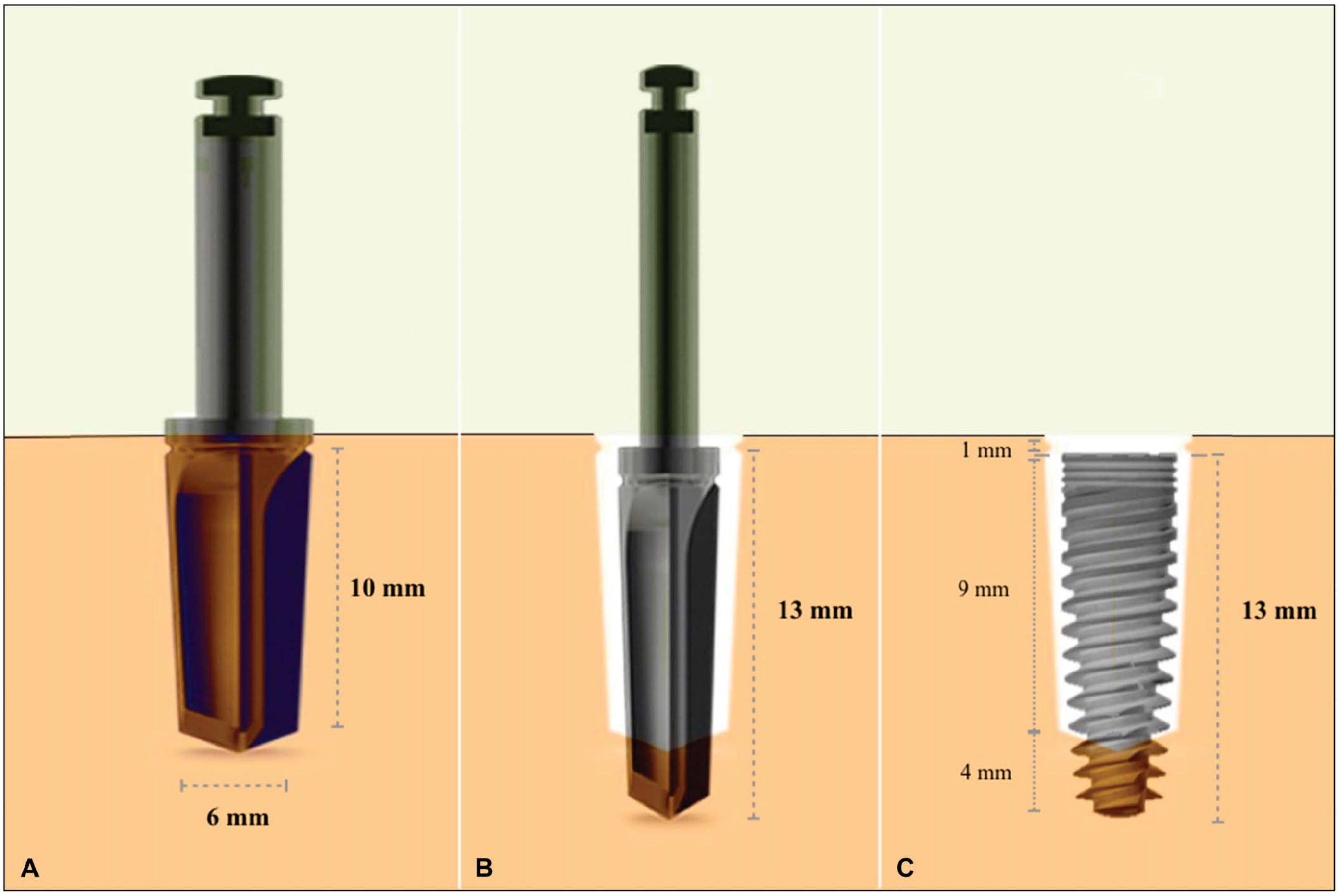

Fig. 1. Lateral view of the sequence of (**A**) socket preparation with 6 × 10 mm drill, (**B**) drilling with 13 mm length with different diameter final drill and (**C**) implant insertion, 1-mm subcrestal.

4 mm in diameter placed in animal models, resulting in a consequent increase in insertion torque. After 3 weeks, the authors concluded that although the percentage IBIC was similar in all 3 groups, an increased insertion torque was associated to greater compression necrosis—this in turn resulting in decreased stability during the first weeks of healing. In contrast, necrosis and bone remodeling were seen to be minimal when lesser insertion torque values were used. Furthermore, as a consequence of the lesser insertion of implant spires in the bone, the authors observed the formation of a so-called "healing chamber" in which bone neoformation was faster and could thus shorten the time needed to achieve secondary stability.[11] Based on these studies, some implant designs have incorporated the dual stability mechanism concept, based on coronoapical reduction of the discrepancy between the final drill and the diameter of a conical implant with the purpose of securing greater primary anchoring at the expense of the upper two thirds of the implant, whereas in the apical zone the lesser difference between the diameters and the geometrical conformation of the spires gives rise to healing chambers allowing faster secondary stability.[11,12]

However, to ensure stability under conditions of poor bone density, or when anchoring only of the apical third is intended, deliberate reduction of the bone bed diameter has been proposed, together with the adoption of an incomplete or undersized drilling protocol.[13] This would result in increased discrepancy between the implant and the recipient bed in the apical zone, with a consequent increase in insertion torque that would not necessarily serve as a predictor of treatment success.

Recently, González-Martin et al[14] conducted a descriptive study involving cone beam computed tomography to assess bone damage and response to a 28% decrease in final drilling diameter in conical implants. Although this percentage decrease is not reproducible in all implant designs, increased discrepancy was clearly seen to be associated to greater initial bone compression—thus again suggesting that greater insertion torque with excessive compression results in microfractures and damage to the periimplant bone. However, Trisi et al[15] found that implant insertion with a torque of more than 100 N·cm produces cortical bone microfractures at crestal level, with primary stability loss in the first 2 weeks that would be incompatible with immediate loading. The above observations confirm that reduction of the drilling diameter results in increased

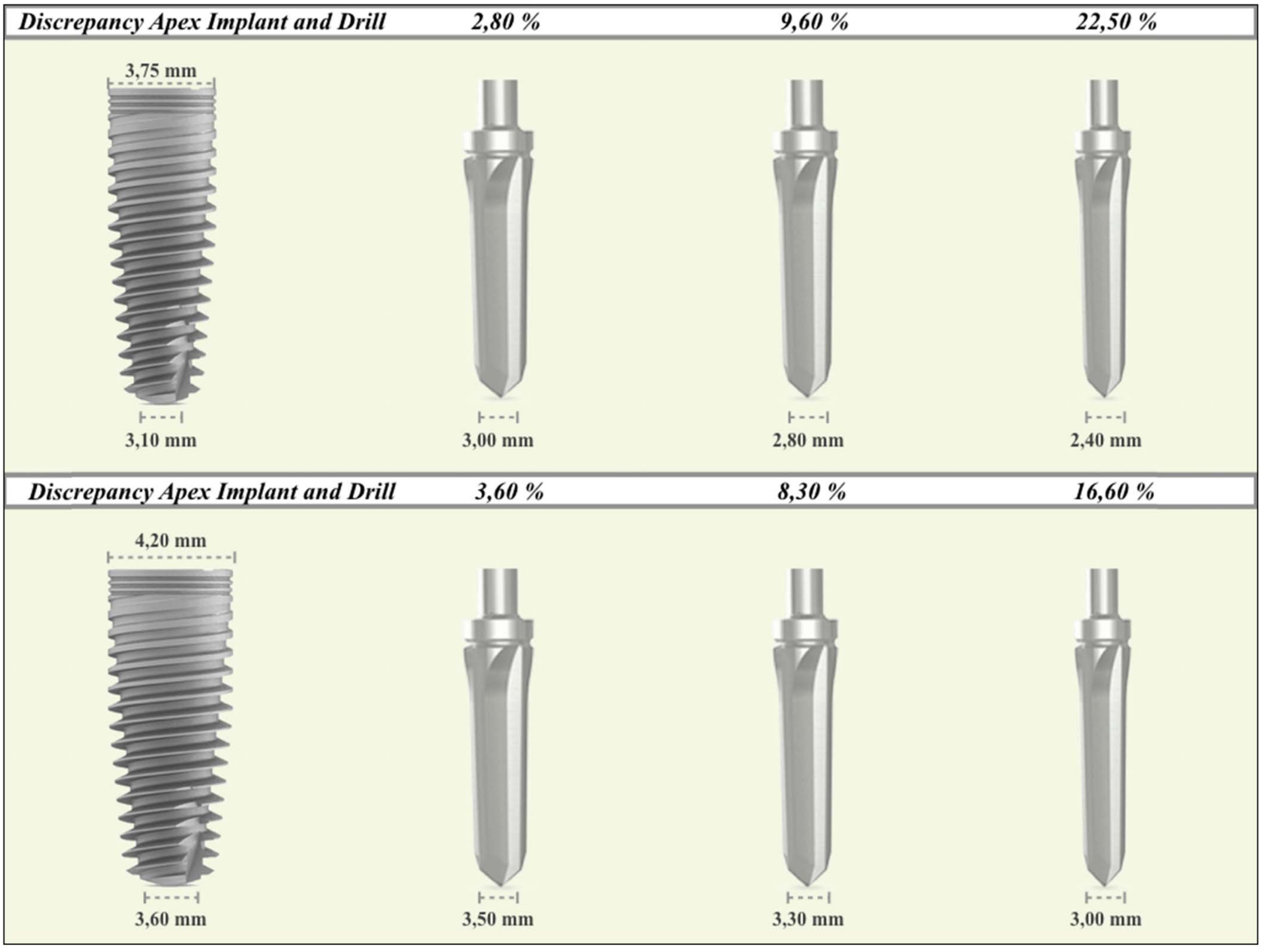

Fig. 2. Drilling sequence model and implant/drill-size discrepancy with each apex diameter.

insertion torque values, which in theory could improve implant stability in postextraction sockets. However, few data are available on the drilling protocol modifications required to secure initial mechanical stability or on the effects on the recipient bone.

The introduction of resonance frequency analysis (RFA) as a noninvasive and effective method for measuring implant stability complements the usefulness of insertion torque as a tool for measuring primary stability in implantology.[16–18] This widely used technique has been found to predict long-term implant success, and is very useful for deciding the ideal timing of loading in conventional implantology. However, little is known of the predictive capacity of RFA in immediate implantology, or of how reduction of drilling affects stability evaluated with this technique.

On the basis of the above, the authors ask themselves the following questions:

1. Is an incomplete drilling protocol needed to ensure initial mechanical stability of implants placed immediately after extraction?
2. If such a protocol is needed, what would be the minimum sufficient decrease in drilling to achieve apical anchoring with mechanical stability parameters similar to those obtained with conventional implant treatment?
3. What role does bone density play in determining the decrease in drilling as a method for increasing primary stability?

The present study, set within the research line "Biomechanics in osseointegrated implants," describes the stability parameters evaluated using insertion torque and the implant stability quotient (ISQ) obtained by deliberately reducing the final drilling diameter in different bone density models. At the same time, the study explores the relationship between the increase in torque and the resulting apical mechanical stability obtained, with a view to standardizing the drilling sequence in immediate or early implant placement and thus affording predictable results capable of guaranteeing the success of implant treatment—particularly in

Table 1. Insertion Torque and Implant Stability by RFA by Implant Diameter

Variable	N	Implant Diameter (mm)	Mean (m ± SD)	Range Low	Range High	*P*
Insertion torque (N·cm)	12	3.75	43.08 ± 34.00	5	120	0.931
	12	4.20	40.92 ± 37.91	3	120	
	24	Overall	42.00 ± 35.24	3	120	
RFA stability (ISQ)	12	3.75	37.41 ± 13.93	19	56	0.786
	12	4.20	39.16 ± 15.47	11	59	
	24	Overall	38.29 ± 14.42	11	59	

A similar behavior was observed in all implant diameters evaluated. The mean values of insertion torque above 40 cm.N in all groups evaluated; however, stability by RFA values were below the minimum 55 ISQ necessary to place the implants without risk of failure.

esthetically demanding sectors of the mouth.

MATERIAL AND METHODS

An *in vitro* study was conducted in which one same calibrated operator randomly inserted 24 Mis C1 implants (MIS Implant Technologies, Ltd., Bar Lev, Israel) measuring 13 mm in length in 10-mm sockets prepared in 4 polyurethane blocks (Sawbones BTM; Pacific Research Laboratories, Vashon Island, WA) with a density of 15, 20, 30, and 40 pounds/cu ft (pcf), respectively, reducing the diameter of the final drill at constant speed (400 rpm) to obtain exclusive 4 mm anchoring of the apical third of each implant.

Study Sample

The study sample consisted of 24-grade 5 titanium (Ti 6Al 4V) tapered implants with a rough sand blasted and acid-etched surface presenting a spiraled conical design with a distance of 1.5 mm between spires and an increase in the depth of the thread in the direction toward the apex. Twelve of the implants measured 4.2 mm in greater diameter in the region of the neck and 3.6 mm in minor diameter in the apical zone. The remaining 12 implants measured 3.75 mm in greater diameter in the region of the neck and 3.10 mm in minor diameter in the apical zone. The total length from the neck to the apex was 13 mm, and all implants corresponded to the standard platform of the manufacturer, with a conical connection design (Figure 1).

Methodology

The following variables were recorded:

Final insertion torque. A Tohnichi Model FTD200CN-S torque screwdriver (Tohnichi; America Corp., Buffalo Grove, IL) was used to measure the torque (in Newton centimeters) required to insert the implant in its indicated position.

Implant stability quotient. After implant placement, the ISQ was determined based on RFA using an Osstell ISQ device (SN 4669 Osstell AB, Goteborg, Sweden), following the instructions of the manufacturer.

Preparation of the Recipient Sockets in Bone Analog Blocks

An Mis Seven final conical implant drill measuring 6 mm in diameter in the cervical zone, 5.10 mm in diameter at the apical level, and 10 mm in length was used to perform 6 equidistant perforations in each of the 4 polyurethane blocks and thus conform the 24 recipient sockets.

The drilling protocol in each socket was as follows:

1. A rounded 1.9-mm drill at 1500 rpm;
2. A pilot drill measuring 10 mm in length at 1200 rpm;
3. An Mis Seven 6 × 10 mm drill at 800 rpm.

Drilling Protocols

Six different drilling protocols with different percentage discrepancies between the final drill and the implants were used, based on the speeds recommended by the manufacturer. The details of each sequence, the implant dimensions, and the last drill are shown in Figure 2.

Implant Insertion and Stability Measurement

The implant was inserted manually with the torque screwdriver until the specified position was reached 1 mm below the upper level of the bed in the polyurethane block, taking as reference the laser mark of the short insertion wrench of the implant. The maximum torque observed with the torque screwdriver during the insertion procedure was recorded.

Measurement of the Implant Stability Quotient by RFA

A Smart Pegs type 49 model 100480 device was fitted to each implant. The Osstell measurement probe was positioned perpendicular to the Smart Peg with a north-south orientation for a first ISQ measurement, and

Table 2. Correlation Between the Researched Variables

	Pearson Correlation					
	RFA Stability		Drill-Size Discrepancy		Bone Density	
	Pearson	Significance	Pearson	Significance	Pearson	Significance
Insertion torque	0.877	0.000	0.262	0.216	0.889	0.000
RFA stability	1		0.169	0.431	0.939	0.000

Positive correlation was observed between bone density and values of insertion torque and RFA. This suggests that the higher the bone density the greater the insertion torque and the greater the RFA values; regarding the discrepancy between the diameter of the drill and the implant diameter and despite the correlation between both remaining positive, there is no statistical evidence to confirm the theory that the greater the discrepancy the greater the stability, especially in the RFA values obtained.

Table 3. Insertion Torque and RFA Stability Values by Different Drill-Size Discrepancy

Variable	N	Drill-Size Discrepancies (%)	Mean (m ± SD)	Range Low	Range High	Significance
Insertion torque (N·cm)	4	2.80	26.75 ± 19.80	3	45	0.966
	4	3.20	34.75 ± 25.95	5	65	
	4	8.30	43.50 ± 46.17	4	110	
	4	9.60	40.00 ± 30.86	7	80	
	4	16.60	52.50 ± 47.87	10	120	
	4	22.50	54.50 ± 48.31	10	120	
RFA stability (ISQ)	4	2.80	36.25 ± 15.39	19	54	0.906
	4	3.20	33.75 ± 14.22	19	52	
	4	8.30	37.50 ± 20.22	11	59	
	4	9.60	38.75 ± 16.37	19	55	
	4	16.60	43.75 ± 13.76	26	59	
	4	22.50	39.75 ± 14.61	22	56	

The values obtained show that the higher percentage of drill-implant discrepancy, a greater insertion torque is expected, however, the similarities of the RFA values observed, suggests this increase of discrepancy does not necessarily imply a higher initial implant stability.

then the axis was moved 90 degrees to obtain a second measurement with an east-west orientation. The mean of the 2 ISQ values of each implant was taken to represent its stability quotient.

Statistical Analysis

The SPSS version 20.0 statistical package was used for determining differences between the study variables. The Student *t* test was applied to assess the 2 implant diameters, whereas analysis of variance was used to compare the values obtained in each model and contrast the drilling discrepancy and bone density variables according to the recorded torque and ISQ values. The Pearson correlation coefficient was used to determine the relationship between variables, with a confidence level of 95%.

RESULTS

A total of 24 implants (12 measuring 4.2 mm and 12 measuring 3.75 mm in major diameter) were inserted without complications in 4 polyurethane blocks of different densities, according to the study protocol. The mean insertion torques and primary stability quotients for each implant diameter and for the overall implants are given in Table 1. There were no statistically significant differences between the 2 implant diameters in relation to the study variables.

The Pearson correlation coefficient between variables showed a strong positive (+0.877) and statistically significant correlation ($P = 0.000$) between the insertion torque and RFA-based stability quotients—thus confirming that increased insertion torque is associated with greater primary stability. Likewise, a strong positive correlation was found on assessing both torque and ISQ with respect to bone density (Table 2).

On examining the effect of reducing the drilling diameter, which increased the percentage discrepancy between the recipient bed and implant, final drilling of the global Mis C1 implants (corresponding to discrepancies of 2.8% and 3.2%, respectively) was seen to generate a mean torque of more than 20 N·cm. Likewise, as the percentage discrepancy between the drill and implant increased, the insertion torque also increased, as confirmed by the greatest mean insertion torque (54.50 ± 24.15 N·cm) recorded for the highest discrepancy value. A positive correlation was found for this association ($r = +0.262$), although statistical significance was not reached (Table 3).

Although the torque values recorded in all the drilling protocols exceeded the minimum predictability values, RFA for each drilling protocol showed that the ISQ values did not exceed 39.75 on average. Likewise, in relation to the variable torque, the ISQ recorded with the Osstell device increased slightly with increasing discrepancies between the recipient bed and implant, although without reaching statistical significance (Table 3).

Four different polyurethane blocks with densities in pounds per cubic foot analog bone density classification receive 6 implants each. Evaluating the insertion torque values, implant insertion in the 15 pcf block analog to D4 bone was seen to yield a torque of no greater than 10 N·cm (mean, 6.50 ± 3.01 N·cm). In the clinical setting, this would not allow successful implant insertion in maxillary bone. On increasing the polyurethane block densities to 20 and 30 pcf, analog to D3 and D2 bone, the mean insertion torque values were found to be 25.50 and 46.00 N·cm, respectively—these values being clinically acceptable for implant placement. Last, in the case of the highest density studied (40 pcf), analog to D1 bone, the insertion torque values even exceeded 100

Table 4. Insertion Torque and RFA Stability Values by Different Bone Density Blocks

Variable	N	Bone Density Blocks	Mean (m ± SD)	Range Low	Range High	Significance
Insertion torque (N·cm)	6	15 pcf (D4)	6.50 ± 3.01	3	10	0.000
	6	20 pcf (D3)	25.50 ± 4.27	18	30	
	6	30 pcf (D2)	46.00 ± 8.48	35	60	
	6	40 pcf (D1)	90.00 ± 31.46	45	120	
RFA stability (ISQ)	6	15 pcf (D4)	19.33 ± 4.92	11	26	0.000
	6	20 pcf (D3)	33.33 ± 5.31	27	42	
	6	30 pcf (D2)	44.66 ± 4.32	37	49	
	6	40 pcf (D1)	55.83 ± 2.78	52	59	

Low insertion torque and RFA values obtained in the 15 pcf bone block analog to D4 bone do not suppose that sufficient initial stability for placement of immediate implants in this type of bone is obtained.

N·cm (mean, 90.00 ± 31.64 N·cm)—the differences being statistically significant ($P = 0.000$).

On examining stability based on RFA, a strong correlation was observed between the increase in polyurethane block density and the ISQ values (r = +0.939). Similar considerations apply to insertion torque, where implant placement in the lowest density bone (15 pcf) yielded a mean ISQ of 19.33 ± 4.92, which is clinically incompatible with successful implant placement. However, on increasing the density to 40 pcf, the mean ISQ was seen to reach 55.83 ± 2.76. These differences were statistically significant ($P = 0.000$) (Table 4).

DISCUSSION

Primary stability achieved at the time of implant insertion is decisive for treatment success, because implant immobility is needed to satisfactorily complete the osseointegration process. In conventional implant placement, stability is obtained thanks to IBIC over the entire length and diameter of the implant. However, in immediate or early implant placement, the geometrical differences between the implant and the socket have led different authors to postulate that anchoring of at least 3 to 5 mm of the apex of an implant measuring 10 mm in length is required.[19–21] In the present study, the implants were 13 mm in length and were all inserted 1 mm below the upper level of the 10-mm length socket fabricated in the polyurethane blocks to obtain 4-mm apex implant anchorage reproducing the ideal minimum conditions for immediate implant placement.

The measure most widely used to assess primary stability is insertion torque (in Newton centimeter). It is well known from the work of Testori et al[22] that the minimum torque required in conventional implant placement is 20 N·cm. However, Trisi et al,[15] in an animal model, found torque values above 100 N·cm to cause cortical bone microfractures that adversely affect primary stability during the first weeks of bone healing. Few data are found in the literature on the predictive usefulness of insertion torque in immediate implants. Atieh et al,[23] in a finite elements study in wide-diameter implants inserted in molar sockets, recorded high stress values in the bone walls with an insertion torque of 50 N·cm or more—a situation that could result in periimplant bone loss, which in turn would adversely affect the stability and treatment success. With the exception of the implants placed in polyurethane bone analog blocks with a density of 15 pcf (corresponding to D4 type density bone), all the insertion protocols in our study exceed torque values of 20 N·cm (mean, 42 N·cm)—thus suggesting that placement 4 mm above the apex suffices to secure implant immobilization.

Reduction of the final drilling diameter during implant placement has been proposed to increase insertion torque under conditions of deficient bone quality and/or volume, thanks to the increase in friction between the bone and the implant.[13] The effect of this decrease in drilling diameter has been studied by Coelho et al[12] in animal models. The authors confirmed that an increase in discrepancy between implant diameter and recipient bone increases the insertion torque. Values more than 80 N·cm were obtained on using the 3.2-mm drill diameter for placing implants measuring 4.0 mm in diameter. These values are similar to those obtained in our study on placing implants with percentage discrepancies of 16% and 22% in the 40 pcf polyurethane block, which would correspond to D1 density bone. However, the mentioned authors recorded loss of primary stability during the healing period due to bone necrosis secondary to overcompression. This could be regarded as contraindicating reductions in drilling diameter in D1 density bone even when the implant is placed immediately after extraction. Furthermore, in the abovementioned study, when drilling was performed with less discrepancy and the insertion torque values were between 40 and 60 N·cm, an increase in removal torque was observed after 3 weeks.[11,12] In the present study, it is important to note that use of the final drill proposed in the drilling sequence of the manufacturer yielded torque values between 26 and 34 N·cm, provided insertion was made under density conditions similar to those of D3 density bone or higher—thus confirming predictability of use even under conditions of immediate insertion with conventional or delayed loading. Insertion torque values between 40 and 43 N·cm were obtained on introducing a minimum reduction of the drilling dimensions equivalent to 8% and 9%, respectively, especially on placing the implants in the block of density 30 pcf (corresponding to D2 density bone). Although no statistically significant differences were recorded, this suggests that to guarantee predictable stability allowing early or immediate loading, we should use a decrease in drilling diameter corresponding to "no use of the final drill" in the drilling sequence of the manufacturer.

RFA has been proposed as an effective tool for assessing primary stability of the implant and for predicting the timing of loading in conventional implantology. A direct and proportional relationship between the insertion torque and ISQ has been reported by different authors.[11,13,16,18,24,25] These observations are supported by the present study, where significant Pearson correlation coefficients were found between these 2 variables on inserting implants measuring 13 mm in length in prefabricated sockets with only 4 mm apical anchoring. In an experimental study using the same density polyurethane blocks from the same manufacturer but with conventional drilling protocols, Kim et al[26] demonstrated the validity of these working models for assessing implant stability with RFA. The values obtained on inserting 10 and 13 mm implants in different bone densities indicate that bone density and the length of the inserted implant influence the stability parameters. The distance between the highest point of bone contact and the implant platform appears to be decisive in evaluations using RFA.[27] Confirmation of these results is provided by the values obtained by Turkyilmaz et al,[25] on comparing 11-mm implants inserted in postextraction sockets in fresh bone of cadavers with different vertical defect heights. It is true that the mean ISQ of 34 ± 14 obtained in this study could suggest that there is no guarantee that

4-mm insertion will afford enough implant immobility to secure secondary stability. However, the working model used for this experience ensures only an anchor of the apical third of the implant, which thus far has not been reproduced in other works and also does not accurately simulate clinical situations of immediate implantation, because it always seeks to obtain a contact between the implant body and some of the walls of the socket. It is worth mentioning that when implants were inserted, the drilling protocol used in the 40 pcf block density (corresponding to the bone density D1), values over 50 ISQ were reached in all cases.

Nevertheless, the aim of the study was to conduct an *in vitro* assessment of the need to reduce the diameter of the implant bed and of the effect of decreasing the drilling diameter under different bone conditions, with a view to determining the viability of the model in humans. In this regard, the following can be postulated:

1. Reduction of the final drilling diameter clearly results in an increase of the torque values; however, based on RFA values obtained in this experiment, this increase in torque does not necessary result in an increase of implant stability.
2. Concerning the minimum reduction of the final drilling diameter, the results of torque insertion suggest that a percentage reduction between 8% and 9% would be sufficient to obtaining values of initial stability in immediate implants similar to those obtained in conventional implantation; however, this assertion could not be confirmed by the stability values obtained by RFA.
3. Differences between torque and RFA values obtained in implants inserted in each type of the blocks of polyurethane density suggests the existence of a directly proportional relationship between bone density and initial stability of the implant immediately placed to tooth extraction. This will also be a determinant when deciding the final drilling diameter, because it is necessary to emphasize that the reduction of the final drilling diameter in D1 density bone would result in an increase in torque values to more than 90 N·cm, which could adversely affect secondary stability on applying the technique in human bone. Additionally, the insertion torque values obtained in poor bone density like D4 would contraindicate immediate implant placement with 4 mm of apical anchoring, regardless of the drilling sequence used.

CONCLUSIONS

Based on the results obtained, there is no evidence supporting an incomplete or undersized drilling protocol to increase the initial stability in immediate implant placement, probably because of the critical role that bone density would have in primary stability in implant placement under conditions similar to those of the present experimental *in vitro* study. However, further studies in human models are needed to assess the behavior of these variables and to investigate other aspects such as the evolution of stability over time, and its predictability.

DISCLOSURE

The authors claim to have no financial interest, either directly or indirectly, in the products or information listed in the article.

A. Sierra-Rebolledo performed the protocol, conducted the experiment in the research laboratory, and redacting this manuscript; M. Allais-Leon and P. Maurette-O'Brien reviewed the methodology and conducted the analysis and interpretation of the data; and C. Gay-Escoda led the workgroup, monitored and evaluated each phase of the protocol, advised on the correct use and interpretation of the RFA values obtained, and additionally critically reviewed and approved the manuscript.

REFERENCES

1. Novaes AB Jr, Novaes AB. Immediate implants placed into infected sites: A clinical report. *Int J Oral Maxillofac Implants.* 1995;10:609–613.
2. Potashnick SR, Marinello R. Root retention for immediate implant replacement: A case report. *Compendium*. 1994;15:570–578.
3. Schultz AJ. Guided tissue regeneration (GTR) of nonsubmerged implants in immediate extraction sites. *Pract Periodontics Aesthet Dent.* 1993; 5:59–65.
4. Chen ST, Buser D. Clinical and esthetic outcomes of implants placed in postextraction sites. *Int J Oral Maxillofac Implants.* 2009;(24 suppl): 186–217.
5. Chen ST, Wilson TG Jr, Hammerle CH. Immediate or early placement of implants following tooth extraction: Review of biologic basis, clinical procedures, and outcomes. *Int J Oral Maxillofac Implants.* 2004;(19 suppl):12–25.
6. Hämmerle CH, Chen ST, Wilson TG Jr. Consensus statements and recommended clinical procedures regarding the placement of implants in extraction sockets. *Int J Oral Maxillofac Implants.* 2004; (19 suppl):26–28.
7. Kan JY, Rungcharassaeng K, Lozada J. Immediate placement and provisionalization of maxillary anterior single implants: 1-year prospective study. *Int J Oral Maxillofac Implants.* 2003;18:31–39.
8. Lazzara RJ. Immediate implant placement into extraction sites: Surgical and restorative advantages. *Int J Periodontics Restorative Dent.* 1989;9:332–343.
9. Wöhrle PS. Single-tooth replacement in the aesthetic zone with immediate provisionalization: Fourteen consecutive case reports. *Pract Periodontics Aesthet Dent.* 1998;10:1107–1114.
10. Peñarrocha M, Uribe R, Balaguer R. Implantes inmediatos a la exodoncia. Situación actual [in Spanish]. *Med Oral.* 2004;9:234–242.
11. Campos FE, Gomes JB, Marin C, et al. Effect of drilling dimension on implant placement torque and early osseointegration stages: An experimental study in dogs. *J Oral Maxillofac Surg.* 2012;70:e43–e50.
12. Coelho PG, Marin C, Teixeira HS, et al. Biomechanical evaluation of undersized drilling on implant biomechanical stability at early implantation times. *J Oral Maxillofac Surg.* 2013;71:e69–e75.
13. O'Sullivan D, Sennerby L, Meredith N. Measurements comparing the initial stability of five designs of dental implants: A human cadaver study. *Clin Implant Dent Relat Res.* 2000;2:85–92.
14. González-Martin O, Lee EA, Veltri M. CBCT fractal dimension changes at the

apex of immediate implants placed using undersized drilling. *Clin Oral Implants Res.* 2012;23:954–957.

15. Trisi P, Todisco M, Consolo U, et al. High versus low implant insertion torque: A histologic, histomorphometric, and biomechanical study in the sheep mandible. *Int J Oral Maxillofac Implants.* 2011; 26:837–849.

16. Sennerby L, Meredith N. Implant stability measurements using resonance frequency analysis: Biological and biomechanical aspects and clinical implications. *Periodontol 2000.* 2008;47:51–66.

17. Sennerby L, Persson LG, Berglundh T, et al. Implant stability during initiation and resolution of experimental periimplantitis: An experimental study in the dog. *Clin Implant Dent Relat Res.* 2005;7:136–140.

18. Turkyilmaz I, Sennerby L, McGlumphy EA, et al. Biomechanical aspects of primary implant stability: A human cadaver study. *Clin Implant Dent Relat Res.* 2009;11:113–119.

19. Arlin M. Immediate placement of dental implants into extraction sockets: Surgically-related difficulties. *Oral Health.* 1993;83:23–31.

20. Bhola M, Neely AL, Kolhatkar S. Immediate implant placement: Clinical decisions, advantages, and disadvantages. *J Prosthodont.* 2008;17:576–581.

21. Buser D, Chen ST, Weber HP, et al. Early implant placement following single-tooth extraction in the esthetic zone: Biologic rationale and surgical procedures. *Int J Periodontics Restorative Dent.* 2008; 28:441–451.

22. Testori T, Del Fabbro M, Galli F, et al. Immediate occlusal loading the same day or the after implant placement: Comparison of 2 different time frames in total edentulous lower jaws. *J Oral Implantol.* 2004;30:307–313.

23. Atieh MA, Alsabeeha NH, Payne AG, et al. Insertion torque of immediate wide-diameter implants: A finite element analysis. *Quintessence Int.* 2012;43: e115–e126.

24. Turkyilmaz I, Sennerby L, Tumer C, et al. Stability and marginal bone level measurements of unsplinted implants used for mandibular overdentures: A 1-year randomized prospective clinical study comparing early and conventional loading protocols. *Clin Oral Implants Res.* 2006; 17:501–505.

25. Turkyilmaz I, Sennerby L, Yilmaz B, et al. Influence of defect depth on resonance frequency analysis and insertion torque values for implants placed in fresh extraction sockets: A human cadaver study. *Clin Implant Dent Relat Res.* 2009; 11:52–58.

26. Kim DS, Lee WJ, Choi SC, et al. Comparison of dental implant stabilities by impact response and resonance frequencies using artificial bone. *Med Eng Phys.* 2014;36:715–720.

27. Barikani H, Rashtak S, Akbari S, et al. The effect of implant length and diameter on the primary stability in different bone types. *J Dent (Tehran).* 2013;10: 449–455.