

# Macrogeometry and Bone Density Control Over the Primary Stability of 6-mm Implants: An In Vitro Study



Georgios Romanos, DDS, PhD<sup>1</sup>/Jessica Lau, BS<sup>1</sup>/Yun Zhang, BS<sup>2</sup>/Wei Hou, PhD<sup>2</sup>/Rafael Delgado-Ruiz, DDS, MS, PhD<sup>3</sup>



**Purpose:** Short implants are used in clinical conditions of insufficient vertical bone availability. This study aimed to compare the primary stability of short implants with different macrodesigns placed in different bone densities in vitro. **Materials and Methods:** One hundred twenty short (6-mm) implants (20/group) were placed at the bone level in commercially available polyurethane blocks representing type I and IV bone quality. The groups were as follows: test A group (4.6-mm diameter with tapered body), test B group (4.8-mm diameter/cylindric microthreaded neck), and test C group (4.8-mm diameter, cylindric body with polished collar, three threads at the intraosseous portion). Implant primary stability was assessed using insertion torque and implant stability quotient (ISQ) values. A blinded calibrated clinician recorded all measurements. Statistical comparisons were completed using a one-way analysis of variance (ANOVA) and Bonferroni posttests. **Results:** The insertion torque values (mean  $\pm$  SD) for groups A, B, and C in type I bone were  $52.50 \pm 5.25$ ,  $49.00 \pm 5.98$ , and  $46.25 \pm 3.93$ , and in type IV bone, the values were  $14.00 \pm 2.05$ ,  $15.50 \pm 2.76$ , and  $9.75 \pm 1.11$ , respectively. Also, the ISQ values were  $67.25 \pm 2.760$ ,  $69.25 \pm 1.67$ , and  $61.80 \pm 5.68$  (type I bone); and  $53.27 \pm 1.99$ ,  $60.65 \pm 2.11$ , and  $51.97 \pm 4.51$  (type IV bone), respectively. The comparison showed statistical differences in ISQ (Bonferroni adjusted  $P < .0001$ ) for the A and B groups but also for the A and C groups (type I bone), in soft bone between the A and B groups and between the B and C groups, and also for the insertion torque values for the A and C groups and between the B and C groups in type IV bone. **Conclusion:** Short implant macrogeometry defines primary stability. Short implants with 6-mm length and multiple threads can achieve good primary stability in vitro in type I and IV artificial bone. *Int J Oral Maxillofac Implants* 2021;36:322–326. doi: 10.11607/jomi.8804

**Keywords:** implant design, primary stability, short implants

In clinical cases with advanced bone resorption in the jaws, two main strategies can be used: (1) surgical modification of the future implant site (vertical bone augmentation, bone distraction, inferior alveolar nerve lateralization, or transposition or sinus elevation with or without sinus grafting) or (2) short-length implants.<sup>1</sup> Short dental implants are defined by the Glossary of Implant Dentistry III, edited by the International Congress of Oral Implantologists in 2017, as “implants with

normal diameters but decreased length.”<sup>2</sup> Specifically, dental implants with  $< 8$ -mm length are considered as “short” implants.<sup>3</sup>

The rationale that supports short implants is that they can reduce the complications, costs, and morbidity of advanced surgical procedures (usually completed to change the implant site to allow the placement of longer implants) with similar survival rates to those of standard-length implants.<sup>4</sup> With short implants having a less-demanding and noninvasive procedure, more predictable outcomes might be expected for the implant-supported restoration.<sup>5</sup>

It is logical to assume that the primary stability of short dental implants can be affected by multiple factors,<sup>6,7</sup> such as limited bone support (derived from the reduced implant length), variability of the implant bed, surgical technique, and lastly, the microgeometry of short implants.<sup>6–9</sup> Also, other factors should be highlighted, such as the implant-related (surface treatment), patient-related (metabolic bone changes), and operator-related factors (experience and obedience to strict surgical protocols).<sup>10,11</sup>

Regarding the primary stability and its relation to the macrogeometry of short implants, González-Serrano et

<sup>1</sup>Department of Periodontology, School of Dental Medicine, Stony Brook University, Stony Brook, New York, USA.

<sup>2</sup>Department of Family, Population and Preventive Medicine, Stony Brook University, Stony Brook, New York, USA.

<sup>3</sup>Department of Prosthodontics and Digital Technology, School of Dental Medicine, Stony Brook University, Stony Brook, New York, USA.

**Correspondence to:** Dr Georgios E. Romanos, Stony Brook University, School of Dental Medicine, Department of Periodontology, 106 Rockland Hall, Stony Brook, NY 11794-8700, USA. Fax: (631) 632-8670. Email: georgios.romanos@stonybrookmedicine.edu

Submitted July 1, 2020; accepted October 12, 2020.

©2021 by Quintessence Publishing Co Inc.



**Fig 1** 6-mm implants with different macrogeometries placed in the artificial bone block with type I bone quality.



**Fig 2** 6-mm implants with different macrogeometries placed in the artificial bone block with type IV bone quality.

al<sup>12</sup> tested short implants (from the same manufacturer) with double threads compared to short implants with a single thread. Short implants with double threads have higher primary stability compared with single-thread short implants inserted in type IV and type III bone.<sup>12</sup>

All the major dental implant manufacturers possess short dental implants within their implant catalogs with different lengths, diameters, and designs. However, there is a lack of information about these short implant designs and the implant primary stability (> 30 Ncm) that can be expected in different bone densities when using standardized implant bed preparations.

Therefore, the goal was to test the primary stability of 6-mm implants with various macrodesigns placed in different bone densities in vitro. The null hypothesis was as follows: There is no statistical difference in terms of primary stability of dental macrogeometries for implants with 6-mm length inserted in artificial bone type I and IV.

## MATERIALS AND METHODS

One hundred twenty short implants (6 mm long) were distributed into three experimental groups based on their geometry. Each group contained 40 short implants as follows: Test A (BioHorizons tapered, 4.6-mm diameter), Test B (Astra Tech OsseoSpeed EV 4.8 mm S, Dentsply Sirona), and Test C (Roxolid-SLA active, Tissue Level 4.8-mm diameter, Straumann). For the simulation of the implant insertion in different bone qualities, polyurethane composite blocks (Sawbones, Pacific Research Laboratories) with two different bone densities, type I (40 PCF; Fig 1) and IV (20 PCF; Fig 2), were used.

Solid resin (rigid polyurethane foam) was used as an alternative test medium for human cancellous bone. It does not replicate the structure of human bone; however, it provides consistent properties between human cancellous bone. This closed-cell resin block is most

commonly used for testing screw pullout, insertion, and stripping torque. The 40 PCF had a compressive strength of 31 MPa, tensile strength of 19 MPa, and shear strength of 11 MPa. Similarly, for the 20 PCF, these values were 8.4 MPa, 5.6 MPa, and 4.3 MPa, respectively. These foams meet the guidelines of the American Society for Testing and Materials (ASTM) F-1839-08. The uniformity and consistent properties of the rigid polyurethane foam make it an ideal material for comparative testing of bone screws and other medical devices and instruments.<sup>13</sup>

The drilling process was the same for all implants, following the exact drill sequence and protocol based on the manufacturer recommendations (800 rpm under copious water irrigation) to the bone level. The same experienced clinician (G.R.) performed all procedures. Twenty implants per group were inserted in each bone quality.

The implant primary stability was assessed using insertion torque (IT) and resonance frequency analysis (RFA) measurements. The same calibrated examiner (J.L.) performed the evaluation of the implant stability to standardize the outcomes of the study.

The IT was measured using an Implantmed (Implantmed, W&H) implant surgical unit. The maximum torque required to insert the implants (Test A and Test B) with their platforms leveled with the bone block surface was recorded as provided by the surgical unit. For Test C, the maximum IT was recorded when the implant's treated surface was fully inserted, leaving the polished neck outside the block. The values were recorded as Ncm.

The RFA measurements were completed with the Osstell Mentor (Integration Diagnostics) and expressed as implant stability quotient (ISQ) values. After the implant insertion, a smart-peg insert specific for each test group connected to each implant. Two ISQ values (from different directions representing buccolingual and mesiodistal orientations in clinical settings) and mean values were recorded for each implant and grouped by an

**Table 1** Insertion Torque and ISQ Mean (SD) Values for the Three Implant Designs Placed in Type I and Type IV Artificial Bone Block

	Group A BioHorizons 4.6 mm	Group B Astra Tech 4.8 mm	Group C Straumann 4.8 mm	<i>P</i> values <sup>a</sup>	<i>P</i> values <sup>b</sup>	<i>P</i> values <sup>c</sup>	<i>P</i> values <sup>d</sup>
<b>Implants placed in dense bone</b>							
IT	52.500 (5.257)	49.000 (5.982)	46.250 (3.932)	.0013*	.1054	.0009*	.2861
ISQ	67.250 (2.760)	69.250 (1.674)	61.800 (5.688)	< .0001*	< .0001*	< .0001*	.2983
<b>Implants placed in soft bone</b>							
IT	14.000 (2.052)	15.500 (2.763)	9.750 (1.118)	< .0001*	.0809	< .0001*	< .0001*
ISQ	53.275 (1.990)	60.650 (2.116)	51.975 (4.509)	< .0001*	< .0001*	.5688	< .0001*

IT = insertion torque; ISQ = implant stability quotient.

<sup>a</sup>Tested by one-way analysis of variance (ANOVA); <sup>b</sup>tested by Bonferroni tests of differences between means of BioHorizons vs Astra Tech; <sup>c</sup>between means of BioHorizons vs Straumann; <sup>d</sup>between means of Astra Tech vs Straumann.

\*Statistically significant differences.

unbiased examiner who was calibrated and blinded to the implant system (J.L.).

### Statistical Analysis

The sample size was calculated using the analysis of variance (ANOVA) F test. Assuming the alpha level of .05, the study had 20 per group (80% power) to detect a medium effect size of 0.42 standard deviation.

Statistical analysis was performed using one-way ANOVA and Bonferroni correction (multiple comparisons) test between implant systems. The significance level was .05.

## RESULTS

The overall Spearman rank-order correlation between IT and ISQ was 0.73. Short implants placed in bone type IV presented lower values ( $P < .001$ ) of IT and ISQ than in the type I bone. The values were statistically different. Based on overall ANOVA F tests, the statistical power for comparisons of IT and ISQ are both higher than 0.99.

In dense (type I) bone, the IT and ISQ values presented statistical differences ( $P < .05$ ). The IT values of the group A implants and group B implants were comparable. The group A implants compared with the group C implants achieved statistically significantly higher ISQ values. The ISQ values were significantly higher for group B implants, followed by group A implants and group C implants (Table 1).

In type IV bone, group B implants achieved higher IT followed by group A implants and group C implants. The ISQ values were lower for group C implants compared with group A and group B implants ( $P < .0001$ ). Table 1 shows IT and ISQ mean values and standard deviations and *P* values and statistical differences. According to

the statistical data, there is a statistical difference between the different macrogeometries in type I and type IV artificial bone quality in vitro, and therefore, the null hypothesis was rejected.

## DISCUSSION

The present study tested short dental implant stability in type I and type IV artificial bone blocks. The results showed that implant stability is higher in dense bone compared with type IV bone and that in both bone densities, the Test C group achieved the lowest IT.

Without a doubt, a limitation of the study is the use of an artificial bone block and not a human bone. The reason for this evaluation is the consistent bone density in the synthetic bone stimulant, which presents similarities to human bone in terms of the elastic module and can show similar conditions for all implants for this comparison.

In previous studies, including from the present authors' scientific group, the same bone models were used in vitro to test the mechanical primary stability of different macrogeometries and implant lengths.<sup>14-16</sup> During the calibration stage and development of the protocol, various clinicians used different drill designs to drill polyurethane resin blocks and assess bone quality.

Implant macrogeometry seems to have a fundamental role in the level of IT. Also, because of the manufacturer-designed drills, the preparation technique presents a compression in the type IV bone (Test A and B groups) and allows an improvement of the initial stability compared with group C implants.

Since the bone quality, the surgeon, and the drilling speed were the same for all implant designs used in the present study, there was better stability for the group B implants, especially in the type IV bone.

The primary reason for this level of good stability of a narrow and a short implant seems to be the tapered macrodesign. Previous studies showed that tapered implants seem to have higher stability than cylindrical implants.<sup>12,17-19</sup> Tapered macrogeometries are associated with good and successful clinical outcomes in advanced clinical protocols.<sup>20,21</sup>

Insertion torques > 35 are excellent since implants can also be loaded immediately after insertion, and ISQ values > 60 are associated with good primary stability and osseointegration. There is a positive relationship between IT and ISQ values.<sup>22</sup> The present study confirms the good values of the implant designs based on the stability measurements in type IV and type I bone stimulant.

The mechanical anchorage of the threads and the tapered microgeometry seem to improve the initial stability of such short implants and therefore increase the osseointegration.<sup>23</sup>

Since this *in vitro* study does not have any clinical evidence, it provides some basic information for clinical scenarios and compares different implant macrodesigns under similar biomechanical conditions. Specific implant geometries with short lengths can be beneficial in advanced clinical applications such as immediate loading protocols. Previous studies showed that immediate loading of short implants in posterior parts of the jaws can be considered a treatment option in patients with bone atrophy, especially if the implants are splinted to longer implants.<sup>24</sup> However, the ISQ and IT values for the tested implant systems do not represent clinical differences, even if these values are statistically different.

Immediately loaded short implants seem to have comparable clinical success to implants with conventional length and immediate function in terms of stability and crestal bone changes.<sup>25</sup> However, more studies are required to test the long-term stability and clinical outcomes of short implants when graftless clinical conditions are requested. Last but not least, implant thread geometry is essential in short dental implants to improve the initial mechanical anchorage with the surrounding bone in compromised bone qualities.

However, systematic reviews have shown that short implants presented higher failure rates over 3 years compared with short implants that were in function for shorter periods.<sup>26</sup>

Splinting implant-supported single fixed dental prostheses supported by short implants should be considered in clinical practice to avoid advanced surgical procedures.<sup>27</sup> Also, short implants may be used in severe bone atrophy because of the low predictability of vertical bone augmentation procedures and the high complication rates.<sup>28,29</sup>

Recent studies showed high success rates of short (7-mm) implants over the last 4 years in medically

compromised patients. The survival rate of 7-mm-long implants was 95.74% from stage I surgery to the last follow-up. Survival rates did not differ according to implant diameter. Based on this clinical study, the crestal marginal bone loss (MBL) at 3 months, 1 and 2 years was significantly higher than at implant placement, and the MBL at 1 year was also significantly higher than at 3 months. MBL at 1 and 2 years did not differ significantly.<sup>30</sup> The authors concluded that according to these results, short dental implants provide a reliable treatment, especially for compromised clinical conditions, to avoid grafting procedures.

Using short-length implants (< 8 mm) in the posterior anatomical areas can reduce the need for grafting, which is associated with many complications and the need for advanced training of the surgeon. Patients often prefer this kind of treatment approach since complex procedures may lead to complications and increased morbidity and are associated with higher costs and longer treatment times. When an inadequate bone volume is present, bone augmentations may be recommended to achieve the required bone for use of short implants, providing predictability and long-term outcomes.<sup>5</sup>

Guida et al<sup>31</sup> compared two groups of patients (a total of 30) with five intraforaminally placed implants with 6-mm vs 11-mm implant length. After 3 months, screw-retained full-arch prostheses with distal cantilevers were delivered (baseline). Crestal bone changes, implant and prosthesis survival rate, and biologic/technical complications were evaluated after 1 and 3 years. They evaluated 150 implants after 1 year and 140 implants after 3 years. No implant or prosthesis loss occurred. No statistically significant intergroup difference for biologic/technical complications and crestal bone loss was observed (bone changes < 1 mm). According to the authors, 6-mm implants may be a reliable approach for the rehabilitation of totally edentulous mandibles.

Gürlek et al<sup>32</sup> also showed good prognosis for extra-short (4 to 6 mm) length compared with regular-length (8- to 10-mm-long) implants in the posterior maxilla within 12 months. Chen et al<sup>33</sup> compared short implants (5 to 8 mm) vs long implants ( $\geq$  10 mm) with augmentation in atrophic posterior jaws and showed similar survival rates in both implant groups, with more crestal bone loss in the sites with augmentations and longer implants.

The clinical implication of the present report is that clinicians must know the influence of the short implant macrogeometry and the peri-implant bone density on the primary stability. It seems beneficial to use short implants with multiple threads and a diameter of at least 4.6 mm to achieve increased primary stability in type IV and I bone.

## CONCLUSIONS

Short implant macrogeometries define primary (mechanical) stability in type I and IV bone. Six-millimeter implants with multiple threads can achieve good primary stability in vitro (ISQ values > 60) in type I and sufficient stability in type IV artificial bone (ISQ values > 50).

## ACKNOWLEDGMENTS

The authors thank the companies Osstell and BioHorizons for supporting the materials and devices for this in vitro study as well as BioHorizons for the grant funding. The authors reported no conflicts of interest related to this study.

## REFERENCES

- Thoma DS, Cha JK, Jung UW. Treatment concepts for the posterior maxilla and mandible: Short implants versus long implants in augmented bone. *J Periodontol* 2017;47:2–12.
- Glossary of Implant Dentistry III. Fairfield, New Jersey: International Congress of Oral Implantologists, 2017:119.
- Thoma DS, Zeltner M, Hüsler J, Hämmerle CH, Jung RE. EAO Supplement Working Group 4—EAO CC 2015 short implants versus sinus lifting with longer implants to restore the posterior maxilla: A systematic review. *Clin Oral Implants Res* 2015;26(suppl 11):154–169.
- Thoma DS, Haas R, Tutak M, Garcia A, Schincaglia G, Hämmerle CHF. Randomized controlled multicentre study comparing short dental implants (6 mm) versus longer dental implants (11–15 mm) in combination with sinus floor elevation procedures. Part 1: Demographics and patient-oriented outcomes at 1 year of loading. *J Clin Periodontol* 2015;42:72–80.
- Misch CM, Polido WD. A “graft less” approach for dental implant placement in posterior edentulous sites. *Int J Periodontics Restorative Dent* 2019;39:771–779.
- Maló P, Nobre Md, Lopes A. Short dental implants in posterior jaws. A prospective 1-year study. *Eur J Oral Implantol* 2011;4:47–53.
- Schwartz SR. Short implants: An answer to a challenging dilemma? *Dent Clin North Am* 2020;64:279–290.
- Renouard F, Nisand D. Short dental implants in the severely resorbed maxilla: A 2-year retrospective clinical study. *Clin Implant Dent Relat Res* 2005;7(suppl 1):s104–s110.
- Hoefler VJ, Al-Sabbagh M. Are there alternatives to invasive site development for dental implants? Part I. *Dent Clin North Am* 2019;63:475–487.
- Romanos GE, Javed F, Delgado-Ruiz R, Calvo-Guirado JL. Peri-implant diseases: A review of treatment interventions. *Dent Clin North Am* 2015;59:157–178.
- Do TA, Le HS, Shen YW, Huang HL, Fuh LJ. Risk factors related to late failure of dental implant—A systematic review of recent studies. *Int J Environ Res Public Health* 2020;17:3931.
- González-Serrano J, Molinero-Mourelle P, Pardo-Peláez B, Sáez-Alcaide L, Ortega R, López-Quiles J. Influence of short implants geometry on primary stability. *Med Oral Patol Oral Cir Bucal* 2018;23:e602–e607.
- Sawbones website. <https://www.sawbones.com>. Accessed February 25, 2021.
- Soldatos N, Gozal D, Font K, Moreno D, Powell C. Temperature changes during implant osteotomies utilizing three different implant systems: A pilot study. *J Implant Adv ClinDen* 2016;7:34–43.
- Romanos GE, Kuyunov O, Sacks D, Calvo-Guirado JL, Delgado-Ruiz R. Apical stability of implants with progressive thread design in vitro, based on clinicians with different levels of experience. *J Periodontol* 2019;90:1320–1324.
- Romanos GE, Lau J, Delgado-Ruiz R, Javed F. Primary stability of narrow-diameter dental implants with a multiple condensing thread design placed in bone with and without osteotomes. An in vitro study. *Clin Implant Dent Related Res* 2020;22:409–414.
- 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 Related Res* 2000;2:85–92.
- Barikani H, Rashtak S, Akbari S, Badri S, Daneshparvar N, Rokn A. The effect of implant length and diameter on the primary stability in different bone types. *J Dent (Tehran)* 2013;10:449–455.
- Romanos GE, Ciornei G, Jucan A, Malmstrom H, Gupta B. In vitro assessment of primary stability of Straumann implant designs. *Clin Implant Dent Related Res* 2014;16:89–95.
- Javed F, Romanos GE. The role of primary stability for successful immediate loading of dental implants. A literature review. *J Dent* 2010;38:612–620.
- Östman PO, Wennerberg A, Ekestubbe A, Albrektsson T. Immediate occlusal loading of NanoTite tapered implants: A prospective 1-year clinical and radiographic study. *Clin Implant Dent Relat Res* 2013;15:809–818.
- Turkylmaz I, Sennerby L, McGlumphy EA, Tözüm T. Biomechanical aspects of primary implant stability: A human cadaver study. *Clin Implant Dent Relat Res* 2009;11:113–119.
- Javed F, Ahmed HB, Crespi R, Romanos GE. Role of primary stability for successful osseointegration of dental implants: Factors of influence and evaluation. *Interv Med Appl Sci* 2013;5:162–167.
- Alvira-González J, Díaz-Campos E, Sánchez-Garcés MA, Gay-Escoda C. Survival of immediately versus delayed loaded short implants: A prospective case series study. *Med Oral Patol Oral Cir Bucal* 2015;20:e480–e488.
- Weerapong K, Sirimongkolwattana S, Sastraruji T, Khongkhunthian P. Comparative study of immediate loading on short dental implants and conventional dental implants in the posterior mandible: A randomized clinical trial. *Int J Oral Maxillofac Implants* 2019;34:141–149.
- Vazouras K, de Souza AB, Gholami H, Paspaspyridakos P, Pagni S, Weber HP. Effect of time in function on the predictability of short dental implants (≤ 6 mm): A meta-analysis. *J Oral Rehabil* 2020;47:403–415.
- Xu X, Hu B, Xu Y, Liu Q, Ding H, Xu L. Short versus standard implants for single-crown restorations in the posterior region: A systematic review and meta-analysis. *J Prosthet Dent* 2020;124:530–538.
- Esposito M, Buti J, Barausse C, Gasparro R, Sammartino G, Felice P. Short implants versus longer implants in vertically augmented atrophic mandibles: A systematic review of randomized controlled trials with a 5-year post-loading follow-up. *Int J Oral Implantol* 2019;12:267–280.
- Felice P, Pistilli R, Barausse C, Piattelli M, Buti J, Esposito M. Posterior atrophic jaws rehabilitated with prostheses supported by 6-mm-long 4-mm-wide implants or by longer implants in augmented bone. Five-year post-loading results from a within-person randomized controlled trial. *Int J Oral Implantol* 2019;12:57–72.
- Nguyen TTH, Eo MY, Cho YJ, Myoung H, Kim SM. 7-mm-long dental implants: Retrospective clinical outcomes in medically compromised patients. *J Korean Assoc Oral Maxillofac Surg* 2019;45:260–266.
- Guida L, Annunziata M, Esposito U, Sirignano M, Torrisi P, Cecchinato D. 6-mm-short and 11-mm-long implants compared in the full-arch rehabilitation of the edentulous mandible: A 3-year multicenter randomized controlled trial. *Clin Oral Implants Res* 2020;31:64–73.
- Gürlek Ö, Kaval ME, Buduneli N, Nizam N. Extra-short implants in the prosthetic rehabilitation of the posterior maxilla. *Aust Dent J* 2019;64:353–358.
- Chen S, Ou Q, Wang Y, Lin X. Short implants (5–8 mm) vs long implants (≥ 10 mm) with augmentation in atrophic posterior jaws: A meta-analysis of randomised controlled trials. *J Oral Rehabil* 2019;46:1192–1203.