



Primary Stability of Conventionally Tapered Versus Reverse Tapered Body Shift Implants Under Varying Bone Support Conditions—An In-Vitro Study

Jeremy Pitman¹ · Véronique Christiaens¹ · Jan Cosyn¹ · Maarten Glibert¹

Received: 29 March 2022 / Accepted: 23 June 2022 / Published online: 8 July 2022
© Taiwanese Society of Biomedical Engineering 2022

Abstract

Purpose Achieving adequate primary stability is of crucial importance for successful osseointegration. However, many implant systems struggle to achieve adequate stability in cases where support around the upper coronal aspect of the implant is limited. The aim of this in-vitro study was to compare the stability of conventionally tapered (CT) versus reverse tapered body shift (RTBS) implants at varying bone support levels.

Methods Peak insertion torque measurements of CT and RTBS implants were assessed in synthetic bone blocks at relative bone support levels representing scenarios in which a 13 mm long implant was 100%, 80%, 60%, 40% and 20% surrounded by bone according to its length (n = 20 for each group).

Results The mean [95% CI] insertion torque (Ncm) for the CT implants at the 100%, 80%, 60%, 40% and 20% relative bone support scenarios was 39.9 [38.38, 41.38], 31.8 [30.91, 32.73], 17.0 [16.40, 17.62], 10.3 [9.80, 10.70] and 4.3 [3.96, 4.55], respectively. Similarly, the mean insertion torque (Ncm) for the RTBS implants at each bone support level was 49.7 [47.54, 51.87], 50.1 [47.42, 52.79], 45.5 [42.99, 48.09], 23.6 [22.11, 25.13] and 7.3 [6.72, 7.89], respectively. The difference in performance (CT vs RTBS) was statistically significant (p < 0.001).

Conclusion Reverse tapered body shift implants appear to provide superior primary stability to CT implants when bone support around the coronal section is limited.

Keywords Implant design · Implant stability · Implantology · Tapered implants

1 Introduction

The level of stability achieved by a dental implant during placement, more commonly referred to as primary stability, is crucial for successful osseointegration [1]. A high level of primary stability creates a buffer-like situation against micromovement, which could compromise the osseointegration process. In addition to the quality and quantity of bone, the surgical technique, the morphology of the osteotomy and the implant design all play an important role in achieving good primary stability [2–5].

For many years, implants were mostly cylindrical and intended to be placed with profuse irrigation and minimal torque, followed by a mandatory 3–6 month integration period before loading [6, 7]. More recently, implants with more prominent external threads and modifications to the apex have been introduced to increase primary stability and bone to implant contact [8–11]. As a result, dental implant design can be broadly classified into two macro-geometric types: cylindrical (following the original Brånemark design) and tapered (following the natural shape of the tooth).

Both cylindrical and tapered design implants are intended to achieve maximum stability once fully surrounded by bone. However, it is not always possible for a surgeon to ensure that the implant will be fully surrounded by bone. More specifically, in immediate placement cases this might be challenging or impossible to achieve. Often, the upper coronal section will not be fully surrounded by bone. The majority of the stability must therefore be generated by the lower apical section of the implant.

✉ Jeremy Pitman
jeremy.pitman@ugent.be

¹ Department of Periodontology and Oral Implantology, Faculty of Medicine and Health Sciences, Oral Health Sciences, Ghent University, C. Heymanslaan 10, 9000 Ghent, Belgium

Reverse Tapered Body Shift design implants have recently been developed for cases where good stability must be achieved by the apical half of the implant. The narrower upper coronal part ensures a gap between the implant and the thin buccal bone plate is maintained [12–17]. The purpose behind maintaining this gap is to mitigate, and compensate for, buccal bone plate resorption following extraction [18, 19]. The aim of this in-vitro study was therefore to evaluate the impact of dental implant macrogeometry (conventionally tapered (CT) vs reverse tapered body shift (RTBS)) on insertion torque performance under various bone support scenarios.

2 Materials and Methods

2.1 Insertion Torque Analysis

Comparative insertion torque measurements of $\varnothing 4.0$ CT implants (IBT13, Southern Implants, Irene, South Africa) and $\varnothing 4.0/5.0$ RTBS implants (Inverta™; IV-EX40-5013, Southern Implants, Irene, South Africa) were assessed in different scenarios representing various levels of bone support in synthetic bone blocks (density = 0.32 g/cm^3 , SAWBONES, Vashon Island, WA, USA). Both the CT

and RTBS implants had an overall length of 13 mm and a coronal diameter of $\varnothing 4.0$ mm, while the RTBS implant had a diameter of $\varnothing 5.0$ mm roughly midway along the length of the body.

Customized synthetic bone blocks were prepared by the manufacturer to simulate scenarios in which a 13 mm long implant would be 100%, 80%, 60%, 40% and 20% surrounded by bone, according to its length (referred to henceforth as scenarios A, B, C, D and E, see Fig. 1).

Osteotomies in the various bone support scenario were prepared by two experienced implant surgeons (VC and MG) for each implant type according to the manufacturer's guidelines (see Fig. 2).

The implants were then placed by the same implant surgeons (VC and MG) using a dental handpiece set (W&H, Salzburg, Austria). Peak insertion torque measurements required for the final seating positions were recorded using a digital Tohnichi BTGE100CN-G torque gauge (Tohnichi, Tokyo, Japan). The insertion torque measurements from the CT implants in scenario A (100% bone support) were considered the control group, as it represents a classic design implant placed in a healed ridge. From the four remaining bone level support scenarios, 9 test groups were created according to implant type (CT vs RTBS) and bone support level.

Fig. 1 Control and test groups for 13 mm long conventionally tapered and RTBS implants at 100%, 80%, 60%, 40% and 20% bone support scenarios

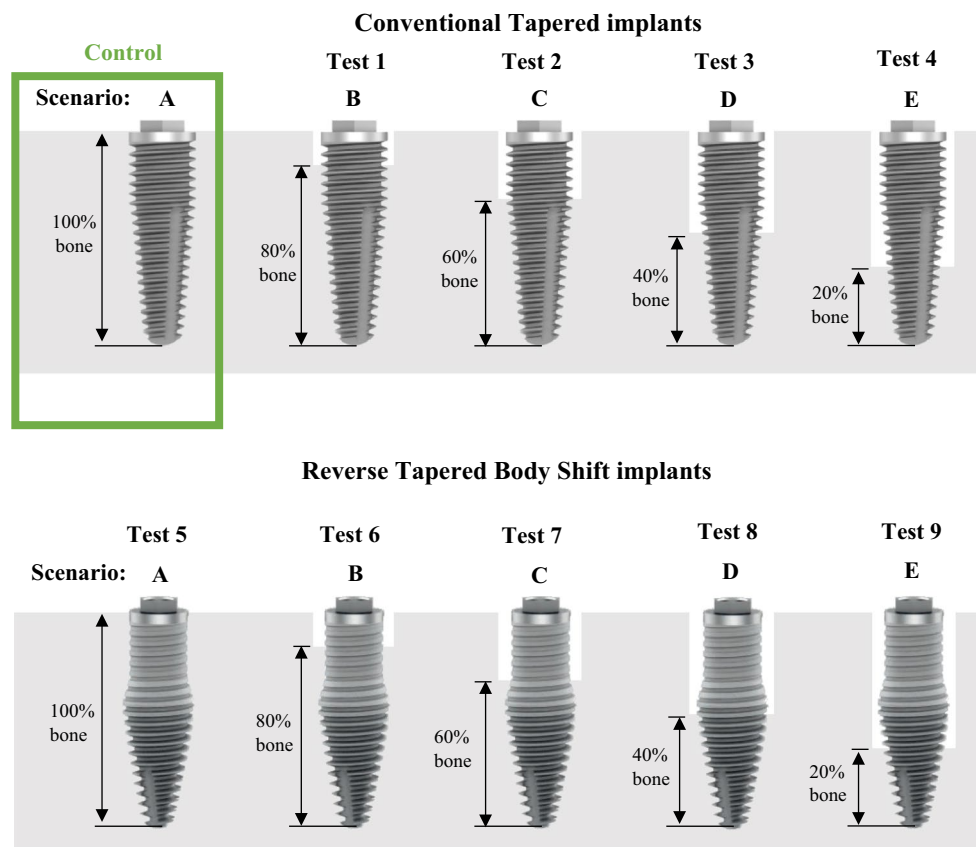
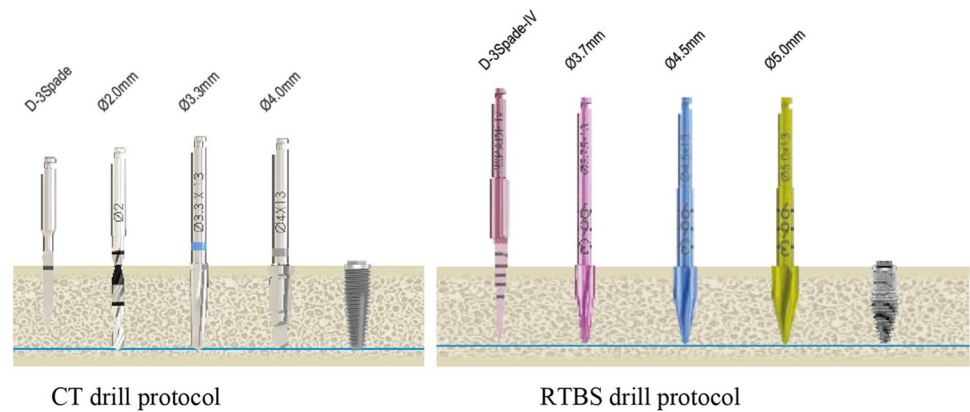


Fig. 2 Site preparation protocol for CT (left) and RTBS implants (right) (Southern Implants, Irene, South Africa)



2.2 Maximum Bone to Implant Contact

Based on external measurements of each implant type, the approximate surface area in contact with the synthetic bone blocks at each bone support level was calculated, to obtain a maximum theoretical bone to implant contact value. For the sake of comparison, all bone to implant contact values were normalized to that of the CT implants in the 100% bone support condition. However, the extractive nature of the site preparation prevents the RTBS implants from being fully surrounded in bone, due to its narrower coronal section.

2.3 Statistical Analysis

Data analysis was performed in IBM SPSS® Statistics 27.0 (IBM Corp. Armonk, NY, USA). Statistically significant differences in insertion torque performance between the two implant types in each relative bone support scenario were assessed using paired samples t-tests (i.e., control group vs group 5, group 1 vs group 6, etc.). Finally, the influence of implant type and relative bone support on insertion torque performance was assessed using 2-way analysis of variance (ANOVA) with Welch's test for unequal variance and Dunnett's T3 multiple comparison test. The level of significance was set to 0.05.

3 Results

3.1 Insertion Torque Analysis

A total of 200 insertion torque measurements were recorded, consisting of 10 groups (1 control group and 9 test groups) of 20 measurements each. The mean insertion torque (Ncm) for the CT implants in scenario A was 39.9, 95% CI [38.38, 41.38], which was considered as the gold standard as this scenario represents a classic design implant placed in a healed ridge. The mean insertion torque measurements for the CT implants in the remaining support scenarios (B, C,

D and E) were 31.8 [30.91, 32.73], 17.0 [16.40, 17.62], 10.3 [9.80, 10.70] and 4.3 [3.96, 4.55], respectively. Similarly, the mean insertion torque measurements for the RTBS implants in scenario A, B, C, D and E were 49.7 [47.54, 51.87], 50.1 [47.42, 52.79], 45.5 [42.99, 48.09], 23.6 [22.11, 25.13] and 7.3 [6.72, 7.89], respectively (see Fig. 3). Statistically significant ($p < 0.001$) differences in the insertion torque results were found when comparing pairwise between the CT and RTBS implants at each relative bone support level.

The implant type and relative bone support level had a significant effect on the insertion torque performance ($p < 0.001$); however, homogeneity of variances was violated ($p < 0.001$). Post-hoc testing found statistically significant differences when comparing between the CT implant insertion torque values at all relative bone support scenarios ($p < 0.001$). Similarly, significant differences were found when comparing between the CT and RTBS insertion torque results at all relative bone support levels ($p < 0.05$). Significant differences were also found when comparing between the RTBS implant insertion torque results at the 40% and 60% bone support levels ($p < 0.001$). Non-significant differences were found when comparing between the RTBS insertion torque values at the 100% and 80% bone support levels ($p = 1.00$); the 100% and 60% bone support levels ($p = 0.391$); and the 80% and 60% bone support levels ($p = 0.410$).

3.2 Maximum Bone to Implant Contact

Maximum bone to implant contact values, normalized to that of the CT implants at the 100% bone support condition, at each bone support level were calculated and are shown in Table 1.

4 Discussion

Due to the novelty of the RTBS implant, only a proof-of-concept animal study [13], a cadaver study [12] and a few case series studies have been conducted [16, 17]. In all of the

Fig. 3 Estimated marginal means of implant type and relative bone support conditions on insertion torque performance

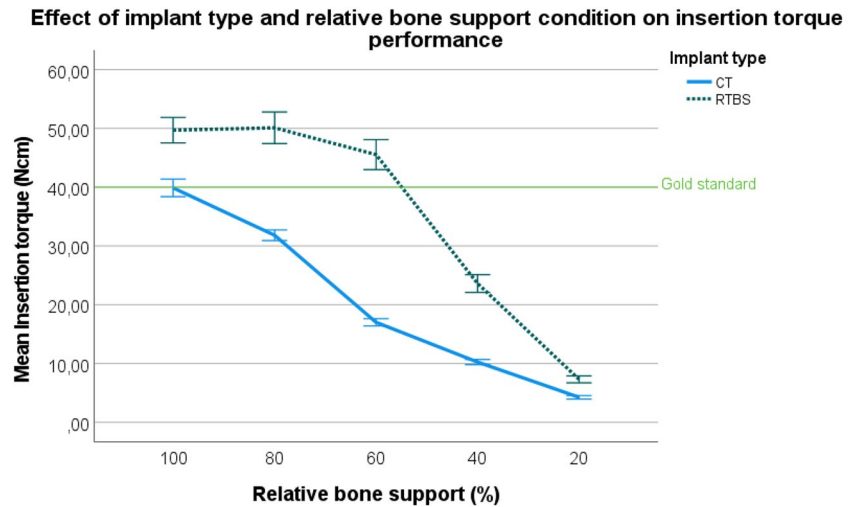


Table 1 Maximum Bone to implant contact (BIC) and mean insertion torque for CT and RTBS implants at each relative bone support level

Bone volume (%)	Conventional tapered implant		Reverse tapered body shift implant	
	BIC (%)	Mean insertion torque (Ncm) [95% CI]	BIC (%)*	Mean insertion torque (Ncm) [95% CI]
100	100	39.9, 95 [38.38, 41.38]	67	49.7 [47.54, 51.87]
80	77	31.8 [30.91, 32.73]	67	50.1 [47.42, 52.79]
60	55	17.0 [16.40, 17.62]	67	45.5 [42.99, 48.09]
40	33	10.3 [9.80, 10.70]	39	23.6 [22.11, 25.13]
20	15	4.3 [3.96, 4.55]	16	7.3 [6.72, 7.89]

*Due to the drilling protocol and wider mid-section for the RTBS implant, the narrower coronal section does not come into contact with the bone as this material is removed during site preparation

clinical studies, the focus was more on the aesthetic outcome and survivability rather than the mechanical performance. To the best of our knowledge, this is the first study to examine the technical performance of this novel implant design.

The aim of this in-vitro study was to evaluate the insertion torque performance of CT implants versus RTBS implants in different relative bone support conditions. Both implant types had the same coronal diameter, the same grit-blasted surface, and the same overall length, while RTBS implants have a wider mid-section to achieve good stability when there is limited bone support at the coronal diameter (such as in an immediate placement case). The results of the present study support this intention, as the RTBS implants achieved significantly higher ($p < 0.001$) insertion torque than the CT implants at all bone support levels tested.

As one would expect, the surface area of a CT implant in contact with the bone decreases in proportion to the bone support scenario. This is in contradiction to an RTBS implant, where the bone support scenario has minimal influence on the surface area in contact with the surrounding bone. This relationship is also reflected in the torque values for the two implant types. Bone to implant contact has an

effect on the stability of dental implants [2, 20, 21]. Due to the specific shape of RTBS implants, this influence is only important when 40% (or less) of the length of the implant is in bone compared to CT implants, in which the bone to implant contact has an effect in every bone support scenario. It may seem paradoxical that the RTBS implants achieve only 67% bone to implant contact in the 100% bone support condition, however this is due to the wider middle section preventing the upper coronal section contacting the bone. The wider middle section creates a steeper taper angle in the apical bottom half and greater surface area to engage the bone when support for the coronal section is not available. There is a clear drop in insertion torque performance and bone to implant contact by the CT implants as the bone support level decreases, however the RTBS implants maintains a higher insertion torque performance despite having lower bone to implant contact at all bone support levels.

While implant stability is important in immediate placement cases, it must be counterbalanced with the need to maintain a gap between the thin buccal bone plate and the implant (the buccal gap) of at least 2 mm [22–24]. It may be possible to use a wide diameter CT implant to achieve

similar insertion torque results to those of the RTBS implants reported herein, however this may result in a smaller buccal gap being created and a greater risk of mucosal recession [19, 22–25]. An investigation into the potential buccal gap distance available in extraction sockets with RTBS implants was conducted by Christiaens et al. [12], who reported an average buccal gap distance of 2.8 mm.

While synthetic bone blocks may not fully represent human bone found in clinical practice, their use in the current study provide the opportunity to record repeated stability measurements in a consistent medium which is not ethically possible in human patients. Furthermore, the bone blocks allowed the insertion torque performance to be evaluated at different bone support levels in a controlled manner, which is also physically impossible in a clinical situation since human bone differs in every patient. The blocks used in the current study conform to ASTM F1839 (“Standard specification for Rigid Polyurethane Foam for Use as a Standard Material for Testing Orthopaedic Devices and Instruments”) and have been used in previous in-vitro assessments of insertion torque for dental implants [1, 26, 27]. The insertion torque results from the control group (CT implant in 100% bone support) is in a similar range to those reported by Brown and colleagues [28] for 12° co-axis Ø4.0 mm and Ø4.7 mm implants from the same manufacturer in a prospective clinical trial (mean = 36.7 Ncm, range: 20–45 Ncm). Similarly, in a prospective case series of RTBS implants, Levin and colleagues reported a mean clinical insertion torque value of 51.42 Ncm [14], which is also very close to the insertion torque results reported herein for the RTBS implants.

Insertion torque is not the only way to assess implant stability. Alternative methods include Percussion Testing, Pulsed Oscillation Waveform, the Impact Hammer Method and Resonance Frequency Analysis (RFA) [29]. Of these, RFA is one of the most widely used clinical methods to monitor stability over time, by measuring the Insertion Stability Quotient (ISQ) [30]. However, its use in the present study design would have been limited to a single measurement. Aparicio et al. [31] found that a single ISQ measurement does not define bone or interface characteristics nor provide a quantitative evaluation of the bone tissue integration. For this reason, it was not considered for use in the present study.

The focus of the present study was on primary stability (i.e. directly after placement), which is an important clinical parameter to determine whether or not an immediate placement or immediate loading procedure can be performed. Of course, stability during the bone remodelling phase (i.e. secondary stability) is also an important consideration for a successful outcome in the longer term. Secondary stability enhancing strategies such as fluorapatite coated implants and the addition of periodontal tissue stem cells into the osteotomy have been proposed [32, 33], however the in-vitro

nature of the present study prevented further investigation of these options.

An interesting finding from the present study is that the only point at which the RTBS implants achieved less insertion torque than the gold standard (CT implant in 100% bone support condition), was when the RTBS implants were tested in the 40% and 20% bone support conditions (scenarios D and E). The results would suggest that RTBS implants can consistently achieve good stability, even when the bone surrounding the lower apical section of the implant is less than half the length of the implant.

The favourable insertion torque results achieved by the RTBS implants herein should be examined more closely in an appropriately powered clinical study.

5 Conclusion

RTBS implants appear to provide superior primary stability to CT implants in scenarios in which the bone support around the upper coronal section of the implant is limited. However, a randomized controlled trial is required to validate these results in a clinical setting.

6 Summary Box

What is known

- Numerous dental implant designs are available on the market, each with their advantages and disadvantages
- Many implant systems struggle to achieve adequate primary stability when support around the upper coronal section of the implant is limited.

What this study adds

- A comparative stability evaluation of a different implant design that might be helpful in specific clinical scenarios

Author Contributions Drs JP contributed to the concept/design of the study, data collection and analysis/interpretation, statistics, drafting and final approval of the manuscript. Prof. VC contributed to the concept/design of the study, data collection and analysis/interpretation as well as critical revision and final approval of the manuscript. Prof. JC contributed to the concept/design of the study, analysis/interpretation of the data as well as critical revision and final approval of the manuscript. Dr. MG contributed to the concept/design of the study, analysis/interpretation of the data as well as critical revision and final approval of the manuscript.

Funding The authors declare that no funds were received for the preparation of this manuscript, however some study materials (implants,

drills and tools) were provided by Southern Implants (Irene, South Africa).

Data Availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest Prof. Véronique Christiaens has a collaboration agreement with Southern Implants (Irene, South Africa). Prof. Jan Cosyn has a collaboration agreement with Nobel Biocare (Göteborg, Sweden) and Straumann (Basel, Switzerland) as well as grants from the Osteology Foundation and the ITI. Dr. Maarten Glibert and Drs Jeremy Pitman have no relevant financial or non-financial interests to disclose.

Ethical Approval Due to the in-vitro design of this study, ethical approval for human or animal research was not mandatory.

References

- Kim, D. S., Lee, W. J., Choi, S. C., Lee, S. C., Heo, M. S., Huh, K. H., Kim, T. I., & Yi, W. J. (2014). Comparison of dental implant stabilities by impact response and resonance frequencies using artificial bone. *Medical Engineering Physics*, 36(6), 715–720. <https://doi.org/10.1016/j.medengphy.2013.12.004>
- O'Sullivan, D., Sennerby, L., & Meredith, N. (2004). Influence of implant taper on the primary and secondary stability of osseointegrated titanium implants. *Clinical Oral Implants Research*, 15(4), 474–480. <https://doi.org/10.1111/j.1600-0501.2004.01041.x>
- Elias, C. N., Rocha, F. A., Nascimento, A. L., & Coelho, P. G. (2012). Influence of implant shape, surface morphology, surgical technique and bone quality on the primary stability of dental implants. *Journal of Mechanical Behaviour of Biomedical Materials*, 16, 169–180. <https://doi.org/10.1016/j.jmbbm.2012.10.010>
- Bilhan, H., Geckili, O., Mumcu, E., Bozdogan, E., Sunbuloglu, E., & Kutay, O. (2010). Influence of surgical technique, implant shape and diameter on the primary stability in cancellous bone. *Journal of Oral Rehabilitation*, 37(12), 900–907. <https://doi.org/10.1111/j.1365-2842.2010.02117.x>
- Martinez, H., Davarpanah, M., Missika, P., Celletti, R., & Lazara, R. (2001). Optimal implant stabilization in low density bone. *Clinical Oral Implants Research*, 12, 423–432.
- Adell, R., Lekholm, U., Rockler, B., & Branemark, P. I. (1981). A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. *International Journal of Oral Surgery*, 10, 387–416.
- O'Sullivan, D., Sennerby, L., & Meredith, N. (2000). Measurement comparing the initial stability of five designs of dental implants. *Clinical Implant Dentistry and Related Research*, 2(2), 85–92.
- Sciasci, P., Casalle, N., & Vaz, L. G. (2018). Evaluation of primary stability in modified implants: Analysis by resonance frequency and insertion torque. *Clinical Implant Dentistry and Related Research*, 20(3), 274–279. <https://doi.org/10.1111/cid.12574>
- Sivan-Gildor, A., Machtei, E. E., Gabay, E., Frankenthal, S., Levin, L., Suzuki, M., Coelho, P. G., & Zigdon-Giladi, H. (2014). Novel implant design improves implant survival in multirooted extraction sites: A preclinical pilot study. *Journal of Periodontology*, 85(10), 1458–1463. <https://doi.org/10.1902/jop.2014.140042>
- Lundgren, D., Slotte, C., & Grondahl, K. (2013). A novel type of dental tube implant for areas with limited bone height. Clinical and radiographic data from three patients with 5-year follow-up. *Clinical Implant Dentistry and Related Research*, 15(4), 509–16. <https://doi.org/10.1111/j.1708-8208.2011.00414.x>
- Meirelles, L., Branemark, P. I., Albrektsson, T., Feng, C., & Johansson, C. (2015). Histological evaluation of bone formation adjacent to dental implants with a novel apical chamber design: Preliminary data in the rabbit model. *Clinical Implant Dentistry and Related Research*, 17(3), 453–460. <https://doi.org/10.1111/cid.12139>
- Christiaens, V., Pitman, J., Glibert, M., Homme, G., Atashkadeh, M., & De Bruyn, H. (2020). Rationale for a reverse tapered body shift implant for immediate placement. *International Journal of Oral & Maxillofacial Surgery*, 49(12), 1630–1636. <https://doi.org/10.1016/j.ijom.2020.04.007>
- Nevins, M., Chu, S. J., Jang, W., & Kim, D. M. (2019). Evaluation of an innovative hybrid macrogeometry dental implant in immediate extraction sockets: A histomorphometric pilot study in foxhound dogs. *International Journal of Periodontics & Restorative Dentistry*, 39(1), 29–3. <https://doi.org/10.11607/prd.3848>
- Levin, B. P., Chu, S. J., Saito, H., Nevins, M., & Levin, J. P. (2021). A novel implant design for immediate extraction sites: Determining primary stability. *International Journal of Periodontics & Restorative Dentistry*, 41(3), 357–364. <https://doi.org/10.11607/prd.5527>
- Chu, S. J., Saito, H., Levin, B. P., Baumgarten, H., Egbert, N., Wills, M. J., Del Castillo, R. A., Tarnow, D. P., & Nevins, M. (2021). Outcomes of a 1-year prospective single-arm cohort study using a novel macro-hybrid implant design in extraction sockets. Part 1. *International Journal of Periodontics & Restorative Dentistry*, 41(4), 499–508. <https://doi.org/10.11607/prd.5709>
- Chu, S. J., Levin, B. P., Egbert, N., Saito, H., & Nevins, M. (2021). Use of a novel implant with an inverted body-shift and prosthetic angle correction design for immediate tooth replacement in the esthetic zone: A clinical case series. *International Journal of Periodontics & Restorative Dentistry*, 41(2), 195–204. <https://doi.org/10.11607/prd.5401>
- Chu, S. J., Saito, H., Levin, B. P., Baumgarten, H., Egbert, N., Wills, M. J., Del Castillo, R. A., Tarnow, D. P., & Nevins, M. (2018). Prospective multicenter clinical cohort study of a novel macro hybrid implant in maxillary anterior postextraction sockets: 1-year results. *International Journal of Periodontics & Restorative Dentistry*, 38(Suppl), s17–s27. <https://doi.org/10.11607/prd.3987>
- Wagenburg, B., & Froum, S. J. (2006). A retrospective study of 1235 consecutively placed immediate implants from 1988 to 2004. *International Journal of Oral and Maxillofacial Implants*, 21, 71–80.
- Araujo, M. G., Sukekava, F., Wennstrom, J. L., & Lindhe, J. (2005). Ridge alterations following implant placement in fresh extraction sockets: An experimental study in the dog. *Journal of Clinical Periodontology*, 32(6), 645–652. <https://doi.org/10.1111/j.1600-051X.2005.00726.x>
- Hsu, J. T., Shen, Y. W., Kuo, C. W., Wang, R. T., Fuh, L. J., & Huang, H. L. (2017). Impacts of 3D bone-to-implant contact and implant diameter on primary stability of dental implant. *Journal of the Formosan Medical Association*, 116(8), 582–590. <https://doi.org/10.1016/j.jfma.2017.05.005>
- Akkocaoglu, M., Uysal, S., Tekdemir, I., Akca, K., & Cehreli, M. C. (2005). Implant design and intraosseous stability of immediately placed implants: A human cadaver study. *Clinical Oral Implants Research*, 16(2), 202–209. <https://doi.org/10.1111/j.1600-0501.2004.01099.x>
- Buser, D., & Chen, S. (2017). Implant placement post extraction in esthetic single tooth sites: When immediate, when early, when

- late? *Periodontology*, 2000(73), 84–102. <https://doi.org/10.1111/prd.12170>
23. Evans, C. D., & Chen, S. T. (2008). Esthetic outcomes of immediate implant placements. *Clinical Oral Implants Research*, 19(1), 73–80. <https://doi.org/10.1111/j.1600-0501.2007.01413.x>
 24. Pluemsakunthai, W., Le, B., & Kasugai, S. (2015). Effect of buccal gap distance on alveolar ridge alteration after immediate implant placement: A microcomputed tomographic and morphometric analysis in dogs. *Implant Dentistry*, 24(1), 70–76. <https://doi.org/10.1097/ID.0000000000000194>
 25. Ferrus, J., Cecchinato, D., Pjetursson, E. B., Lang, N. P., Sanz, M., & Lindhe, J. (2010). Factors influencing ridge alterations following immediate implant placement into extraction sockets. *Clinical Oral Implants Research*, 21(1), 22–29. <https://doi.org/10.1111/j.1600-0501.2009.01825.x>
 26. Valente, M. L., de Castro, D. T., Shimano, A. C., Lepri, C. P., & dos Reis, A. C. (2015). Analysis of the influence of implant shape on primary stability using the correlation of multiple methods. *Clinical Oral Investigations*, 19(8), 1861–1866. <https://doi.org/10.1007/s00784-015-1417-4>
 27. Han, H. C., Lim, H. C., Hong, J. Y., Ahn, S. J., Shin, S. I., Chung, J. H., Herr, Y., & Shin, S. Y. (2016). Primary implant stability in a bone model simulating clinical situations for the posterior maxilla: An in vitro study. *Journal of Periodontal and Implant Science*, 46(4), 254–265. <https://doi.org/10.5051/jpis.2016.46.4.254>
 28. Brown, S. D., & Payne, A. G. (2011). Immediately restored single implants in the aesthetic zone of the maxilla using a novel design: 1-year report. *Clinical Oral Implants Research*, 22(4), 445–454. <https://doi.org/10.1111/j.1600-0501.2010.02125.x>
 29. Karnik, N., Bhadri, K., Bora, U., Joshi, S., & Dhattrak, P. (2021). A Mathematical Model for Biomechanical Evaluation of Micromotion in Dental Prosthetics using Vibroacoustic RFA. *Journal of Medical and Biological Engineering*, 41(4), 571–580. <https://doi.org/10.1007/s40846-021-00636-w>
 30. Meredith, N. (1996). Quantitative determination of the stability of the implant-tissue interface using resonance frequency analysis. *Clinical Oral Implants Research*, 7, 261–267.
 31. Aparicio, C., Lang, N. P., & Rangert, B. (2006). Validity and clinical significance of biomechanical testing of implant/bone interface. *Clinical Oral Implants Research*, 17(2), 2–7.
 32. Ghorbel, H., Guidara, A., Guidara, R., Trigui, M., Bouaziz, J., Keskes, H., & Coddet, C. (2019). Assessment of the addition of fluorapatite-alumina coating for a durable adhesion of the interface prosthesis/bone cells: Implementation in vivo. *Journal of Medical and Biological Engineering*, 40(2), 158–168. <https://doi.org/10.1007/s40846-019-00498-3>
 33. Jokar, H., Rouhi, G., & Abolfathi, N. (2020). The effects of splinting on the initial stability and displacement pattern of periodontio-integrated dental implants: A finite element investigation. *Journal of Medical and Biological Engineering*, 40(5), 719–726. <https://doi.org/10.1007/s40846-020-00544-5>