Dental Implant Macro-Design Features Can Impact the Dynamics of Osseointegration

Marcio Vivan Cardoso, DDS, PhD;* Katleen Vandamme, DDS, PhD;† Amol Chaudhari, PhD;*
Judith De Rycker, MD, DDS;‡ Bart Van Meerbeek, DDS, PhD;§ Ignace Naert, DDS, PhD;¶
Joke Duyck, DDS, PhD**

ABSTRACT

Purpose: The purpose of this study was to compare the clinical performance of two dental implant types possessing a different macro-design in the in vivo pig model.

Materials and Methods: Titanium Aadva™ implants (GC, Tokyo, Japan) were compared with OsseoSpeed™ implants (Astra, Mölndal, Sweden), with the Aadva implant displaying significant larger inter-thread dimensions than the OsseoSpeed implant. Implants were installed in the parietal bone of 12 domestic pigs and left for healing for either 1 or 3 months. Implant osseointegration was evaluated by quantitative histology (bone volume relative to the tissue volume [BV/TV]; bone-to-implant contact [BIC]) for distinct implant regions (collar, body, total implant length) with specific implant thread features. The Wilcoxon–Mann–Whitney nonparametric test with $\alpha = 0.05$ was performed.

Results: An inferior amount of bone enveloping the Aadva implant compared with the OsseoSpeed implant was observed, in particular at the implant body part with its considerable inter-thread gaps ($p < .05$). Concomitantly, the Aadva macro-design negatively affected the amount of bone in direct contact with the implant for this specific implant part ($p < .05$), and resulted in an overall impaired implant osseointegration at the initial healing stage (total implant length; 1-month healing; $p < .05$).

Conclusion: Although the Aadva implant displayed a clinically acceptable level of osseointegration, the findings demonstrate that implant macro-design features can impact the dynamics of implant osseointegration. Consideration of specific implant macro-design features should be made relative to the biological and mechanical microenvironment.

KEY WORDS: implant design, osseointegration, titanium

INTRODUCTION

Titanium implants are widely used in dentistry, whether they are required to replace a single tooth or serve as anchoring point for a larger prosthetic superstructure. In general, unfunctionalized, moderately rough titanium implants have reached excellent success rates in oral implant dentistry.[1–3] The attainment of a faster, stronger, and more predictable osseointegration, particularly in situations where immediate or early loading protocols are anticipated, is highly desired but still remains a challenge.[4] Enhanced bone-implant integration could also be advantageous in bone conditions that are less favorable, be it systemic or implantation site related.

In order to improve the osseointegration of titanium implants, several designs were generated throughout the past 20 years.[5,6] Besides modifications in implant

*Post-doctoral researcher, Department of Oral Health Sciences & BIOMAT Research Cluster, KU Leuven & University Hospitals Leuven, Prosthetic Dentistry, Leuven, Belgium; †assistant professor, Department of Oral Health Sciences & BIOMAT Research Cluster, KU Leuven & University Hospitals Leuven, Prosthetic Dentistry, Leuven, Belgium; ‡dental trainee, Department of Oral Health Sciences & BIOMAT Research Cluster, KU Leuven & University Hospitals Leuven, Prosthetic Dentistry, Leuven, Belgium; §full professor, Department of Oral Health Sciences & BIOMAT Research Cluster, KU Leuven & University Hospitals Leuven, Conservative Dentistry, Leuven, Belgium; ¶full professor, Department of Oral Health Sciences & BIOMAT Research Cluster, KU Leuven & University Hospitals Leuven, Prosthetic Dentistry, Leuven, Belgium; **professor, Department of Oral Health Sciences & BIOMAT Research Cluster, KU Leuven & University Hospitals Leuven, Prosthetic Dentistry, Leuven, Belgium

Reprint requests: Prof. Dr. Joke Duyck, Department of Oral Health Sciences & BIOMAT Research Cluster, KU Leuven & University Hospitals Leuven, Dentistry, Prosthetic Dentistry, Kapucijnenvoer 7 – Box 7001, Leuven 3000, Belgium; e-mail: joke.duyck@uzleuven.be

DOI 10.1111/cid.12178

surface structure, the implant design itself has been the target of variations in both its macro- and micro-properties. The former was the primary variable of the present study, and two implant types displaying a different macro-design were considered. The OsseoSpeed™ implant (Astra Tech, Mölndal, Sweden), possessing a fluoride-modified surface with excellent long-term scientific documentation and high levels of clinical success,[7–9] was selected as "golden standard" implant type. The implant under consideration, with a different macro-design, was a clinical, undocumented though CE (European Conformity)-certified titanium implant (Aadva™, GC, Tokyo, Japan). The aim of the present study was to compare the clinical performance of the OsseoSpeed and the Aadva implant types in the in vivo pig model, with the objective to evaluate whether differences in the peri-implant bone response between the implant types (OsseoSpeed vs Aadva implants) could be attributed to the dissimilarity of the macro-design.

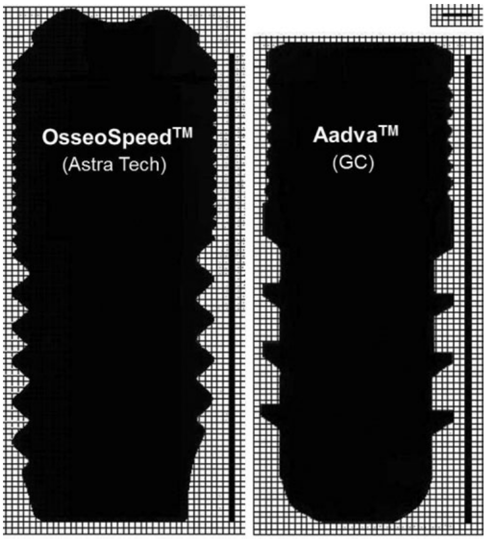

Figure 1 Schematic drawing of the OsseoSpeed (*left*) and the Aadva implant (*right*). The vertical bar indicates the total region considered for histomorphometrical analyses, that is, over a length of 8 mm. Scale bar: 0.5 mm.

MATERIALS AND METHODS

Animal Model, Implant and Surgical Protocol

Following approval of the research protocol by the ethical committee for laboratory animal research of the Catholic University of Leuven (P141-2009), 12 domestic pigs (*Sus scrofa domestica*) of 6 months old having a weight range of 103 to 124 kg were purchased for the study (Collaert, Hoegaarden, Belgium). All procedures were performed according to the Belgian animal welfare regulations and guidelines. The animals were preanesthetized with an intramuscular (im) injection of 1 mL of butyrophenone (Stresnils®, Ausrichter, Annandale, Australia). Anesthesia was induced by intravenous injection of a cocktail of the following drugs: a premixed combination of tiletamine and zolazepam (Zoletil 100®, Virbac, Barneveld, the Netherlands), added at 1/6 dilution to xylazine (Vexylans, CEVA, Brussels, Belgium), and injected at 1 mL/10 kg. A concentration of 1.5% isoflurane (IsoFlos, Abott, Quebec, Canada) was used to maintain anesthesia.

The implants were placed in the trabecular bone of the parietal part of the skull. The skull bone was exposed by incision of skin and periosteum and four implants per animal were installed, at least 15 mm apart to avoid tissue regeneration interactions and at a level equally to the outer cortical bone surface. OsseoSpeed and Aadva implants were installed. The OsseoSpeed implant was used as control because of its evidenced successful clinical performance. The dimensions of the OsseoSpeed implant were 8 mm in length, 3.5 mm in diameter, and a uniform screw thread angle of ~83° (Figure 1). The Aadva implant selected had a length of 8 mm, a diameter of 3.3 mm, and a thread angle of ~100° for the upper implant part and ~120° for the lower implant part. Unlike the OsseoSpeed implants, Aadva implants possessed less screw threads at the implant "body part" (cf. infra), resulting in an inter-thread gap of 0.8 mm in height. Also, the collar part of the Aadva implant was different from the one of the OsseoSpeed implant: 7 tissue spikes residing in the V-thread areas between the screw threads were observed at the Aadva implant collar part, compared with 14 for the OsseoSpeed implant, over a distance of 2.5 and 3.3 cm, respectively, and corresponding to inter-thread gaps of 0.36 and 0.26 mm in height, respectively. Each animal received two OsseoSpeed and two Aadva implants that were randomly installed in the parietal bone (Figure 2). The drilling sequence for implantation of the OsseoSpeed implants was as follows: (i) guide drill (round bur), (ii) twist drill with a diameter of 2.0 mm, and (iii) twist drill with a diameter of 3.2 mm. This procedure resulted in a diameter difference of 0.3 mm between the last drill and the implant. The Aadva drilling sequence also started off with a round bur as guide drill and a twist drill of 2.0 mm diameter, but was then continued with a twist drill of 2.9 mm and finally of 3.1 mm, resulting in a

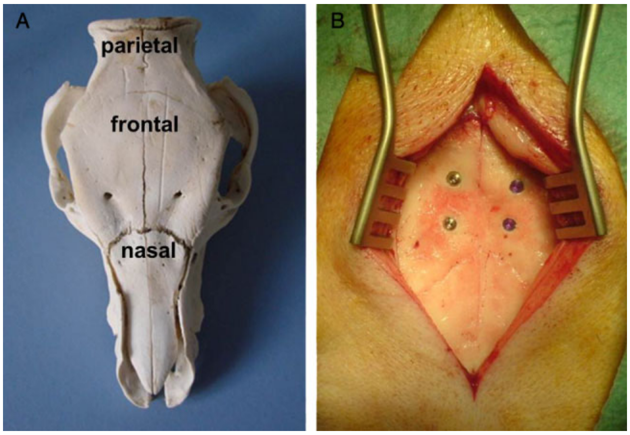

Figure 2 (A) Anatomy of the pig skull. (B) Implants in situ in the parietal skull region. OsseoSpeed and Aadva implants have a yellow- and purple-colored cover screw, respectively.

difference of 0.2 mm between the diameter of the final drill and of the implant. All drilling steps occurred at a speed of 1500 rpm. For OsseoSpeed implant installation, constant saline cooling was used, whereas Aadva implantation was performed without (following the manufacturer's instructions). For both systems, the implant installation was performed with a torque of 35 Ncm for the implant itself and 10 Ncm for the cover screw, both at a speed of 25 rpm. At the end of the surgical procedure, soft tissue flaps were carefully repositioned and sutured. Postoperatively, ibuprenorfine (0.005 mg/kg; im; Temgesic, Schering-Plough, Brussels, Belgium) was administered as analgesic and enrofloxacin (0.5 ml/10 kg; im; Baytril 5%, Bayer, Puteaux, France) as antibiotics for 3 days.

Half of the animals ($n = 6$) were euthanized 1 month (further referred to as "1-month group") and the other half 3 months ("3-months group") postimplantation. Euthanasia was performed through sedation induction by im injection of 1 mL of butyrophenone, followed by an intravascular injection of an embutramide–mebenzoniumjodide–tetracaıne-HCl solution (1 mL/5 kg; T61, Intervet, Mechelen, Belgium) into the ear vein until cardiac arrest occurred.

Specimen Preparation and Analysis

Implants were harvested en bloc with the surrounding skull bone tissue, fixed in a $CaCO_3$-buffered formalin solution for 4 days and then dehydrated in an ascending series of ethanol concentrations over a period of 15 days. Embedding was performed by infiltration of a benzoylperoxide (0.018%)–methylmetacrylate solution over a period of 7 days. The samples were then sectioned through their long axes using a precision diamond saw (Leica SP 1600, Leica Microsystems, Nussloch, Germany). Five sections per implant were obtained of which the central one was selected, micro-grinded, and polished to a final thickness of 20 to 30 μm (Exakt 400 CS, Exakt Technologies Inc., Norderstedt, Germany). The sections were stained with a combination of Stevenel's blue and Von Gieson's picrofuchsin red. Histological examination was performed using a light microscope (Leica Laborlux, Wetzlar, Germany) at a magnification of ×40, ×100, and × 400, and the images were captured using a high-sensitivity color video camera (JVC TK-1280E, Ibaraki-ken, Japan). The assessment of the histomorphometrical data was performed using a commercially available semiautomatic image analysis software program (Axiovision 4.0, Zeiss, Gottingen, Germany), with an additional customized script (Ogawa et al., 2011).

Histomorphometrical analyses were performed for three different implant regions, that is, over the total implant length ("T"), at the collar part of the implant ("C"), and at the implant body part ("B") (Figure 3A). The small, unthreaded zone of the Aadva implant, representing the transition zone between the collar and the body implant parts, was excluded for quantifications. Two measurements were performed at both implant sides on each histological section:

- Peri-implant bone volume relative to the tissue volume (BV/TV, %): the amount of bone in the peri-implant region up to 100 μm away from the implant surface (Figure 3A).
- Bone-to-implant contact (BIC, %): summation of the lengths of contact between bone and implant/implant length under consideration (Figure 3B).

Statistical Analyses

Statistical analyses were performed using the software package *STATISTICA* (Stat Soft 7.1, Tulsa, OK, USA). Diagnostic tests comprising normal probability plots and Shapiro–Wilk tests were employed to evaluate the homogeneity of the variance and to determine whether the residual errors were distributed according to the Gaussian curve. Because the data did not meet the rigor required by a parametric test, and considering the dependence among samples implanted in the same animal, a Wilcoxon signed-rank test was used to determine differences between groups of paired data.

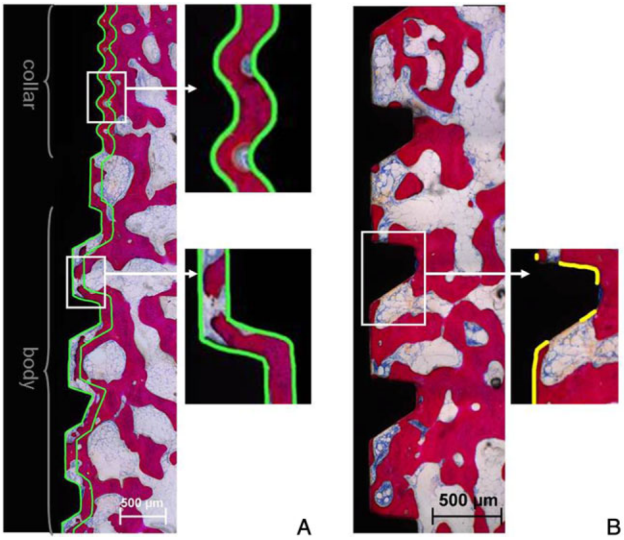

Figure 3 Illustration of histomorphometrical analyses: peri-implant bone volume relative to tissue volume in a 100-µm-wide zone (BV/TV) (A) and bone-to-implant contact (BIC) (B). Illustrations are given for the Aadva implant.

Differences were considered significant at *p* values lower than .05. The results obtained for the 1-month and the 3-month groups were also compared using the Mann–Whitney *U* test with a significance level of 5%.

RESULTS

Histological Findings

The healing of the surgical sites was uneventful. However, in one animal allocated to the 1-month group, signs of inflammation and fibrous tissue invasion were observed around all four implants. These implants were excluded from analysis. The bone formation occurred exclusively via a primary repair sequence, without a cartilaginous intermediary. Immature bone observed after 1 month of healing became reorganized by 3 months of healing, resulting in dense bone tissue surrounding and adhering onto the implant. The distance between the implant shoulder and the first BIC after 1 month of healing was consistently larger around the OsseoSpeed implants (529.9 ± 197.1 µm) compared with the Aadva implants (224.8 ± 91.9 µm) (Figure 4). This difference, however, attenuated after 3 months of healing. The vertical level of the establishment of BIC compared with the level of the implant shoulder was then −102.9 ± 59 µm for the OsseoSpeed implants and −81.1 ± 53.5 µm for the Aadva implants.

Histomorphometrical Findings

For both BV/TV and BIC, data are presented for three different implant regions, namely the entire implant length [T], the implant collar part [C], and the implant body part [B] (Figure 3A). The difference in macro-design of the implants, in particular the inter-thread distance variation at both the collar and the body part of the implant, constituted the rationale for quantitative histology at different vertical levels.

No significant differences were noted for the peri-implant BV/TV at the implant collar part and over the entire implant length, neither between the implant types nor between the healing times (Figure 5A). However, significant differences for BV/TV between the two implant types were observed for the implant body part for both observation points (OsseoSpeed vs Aadva [BV/TV_B] at 1 month and at 3 months; $p < .05$).

The BIC at the collar part [BIC_C] was equal for both implant types at both observation points. BIC at the implant body part [BIC_B], however, was significantly higher for the OsseoSpeed implant compared with the Aadva implant after 1 month of healing ($p < .05$) (Figure 5B), which resulted in a significant difference of the BIC values for the total implant length [1-month BIC_T] ($p < .05$). The observed superior degree of osseointegration of the body part [BIC_B] of the OsseoSpeed implant compared with the Aadva implant was sustained over the 3 months healing period ($p < .03$). Furthermore, a similar trend, although not

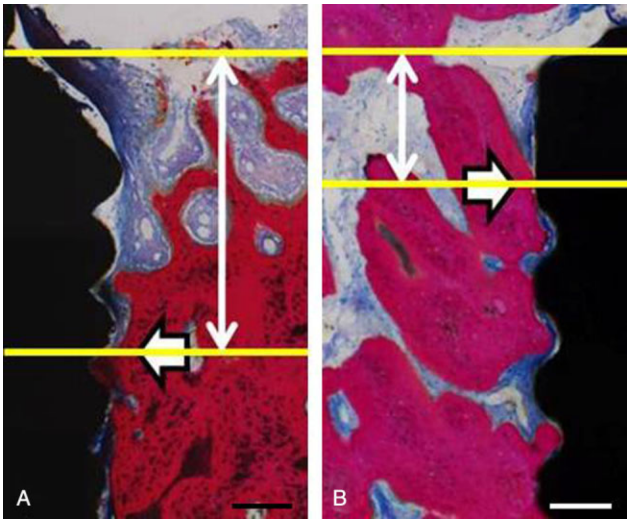

Figure 4 Illustration of the vertical level of the first bone-to-implant contact compared with the implant shoulder level for a 1-month healed OsseoSpeed (A) and Aadva (B) implants. Scale bar: 200 µm.

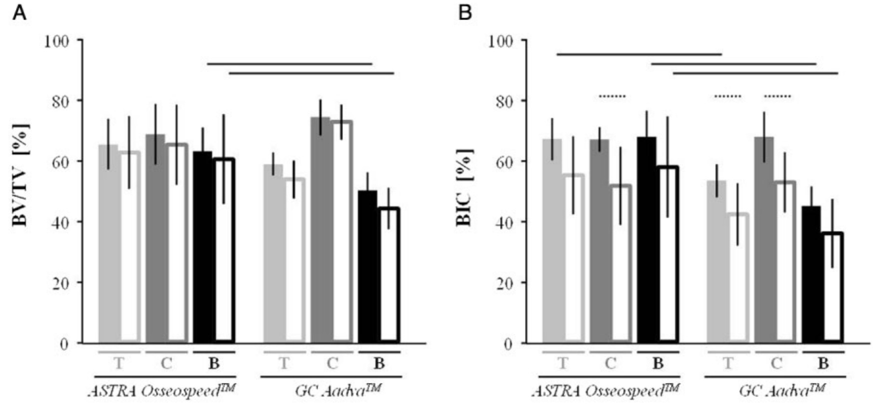

Figure 5 (A) Results of bone volume relative to the tissue volume (BV/TV) for the two implant designs (OsseoSpeed and Aadva) and two healing times (1 month and 3 months). (B) Results of bone-to-implant contact (BIC) for the two implant designs (OsseoSpeed and Aadva) and two healing times (1 month and 3 months). Plain horizontal bars indicate significant differences between the implant groups for the considered healing time. Dotted horizontal bars indicate differences over time within each implant group (Mann–Whitney *U* test, $p < .05$). Filled bars, 1-month data; Open bars, 3-months data. T = total; C = collar; B = body.

significantly different, was observed for [BIC_T]. Finally, the evolution of BIC over time was overall negative, with significant decreases from 1 to 3 months of integration for both the OsseoSpeed [BIC_C] and for the Aadva implants [BIC_T and BIC_C] ($p < .05$, $p < .05$, and $p < .03$, respectively).

DISCUSSION

Introducing a new implant system onto the dental market should be accompanied by providing scientific documentation that supports its clinical safety and performance. The present study therefore aimed to provide proof of concept for the osseointegration potential of a recently developed implant with a specific macrodesign, namely the Aadva implant. In this context, the use of a positive control is of paramount interest to establish the level of excellence of this new implant system. The OsseoSpeed implant was selected to serve as control, an implant having a long-term scientific documentation, a significant level of clinical success, and an implant surface with osteogenic properties.[7,10–12] The OsseoSpeed implant is the next generation implant of its predecessor, TiOblast, because it presents the same titanium surface properties but the innovative concept of surface fluoride modification that is claimed to induce bioactive properties.[12–14] The aim of the study was to compare the clinical performance of the OsseoSpeed and the Aadva implant types in the in vivo pig model. It was hypothesized that both implant systems, despite their considerable difference in macro-design, performed equally well with respect to the peri-implant bone response and to the establishment of osseointegration.

For revealing the clinical performance of the Aadva implant, it is important to simulate as close as possible the human clinical condition. The domestic pig was the animal of choice for this experiment because its rate of bone regeneration (1.2–1.5 mm/day) is comparable with that of humans (1–1.5 mm/day).[15] The surgical protocol for installing the OsseoSpeed implants, in particular the monitoring of the implant insertion torque values, served as input for establishing the Aadva installation procedure. The actual study was preceded by a pilot experiment in which the Aadva drills were used for implant installation. Following this protocol, implant insertion torque values exceeded the generally adopted 35 Ncm implant installation "threshold value." Therefore, an extra surgical drill with thicker diameter was added to the Aadva surgical sequence in order to avoid a high strain environment with potential negative impact on the osseointegration biological processes.[16,17] At the same time, the attainment of primary implant stability was primordial and respected.

Quantitative histology revealed that Aadva implants displayed initially, that is, after 1 month of healing, significantly less BIC at the implant body part (and consequently over its whole length [BIC_T]) compared with the OsseoSpeed implant. It is suggested that the larger void areas surrounding the Aadva body implant, created by the macro-design with less screw threads and resulting in enlarged inter-thread gaps, required more bone formation and growth into these "regeneration areas" and thus more time to reach the implant surface. Indeed, the recorded significantly smaller bone volume amount surrounding the Aadva body part may have led to a compromised initial BIC. A catch-up of BIC in the following healing phase, that is, after 3 months of healing, was not observed and BIC remained inferior for Aadva compared with OsseoSpeed implants. Of note is that the difference between the osteotomy diameter and the outer implant diameter, which was smaller for the Aadva implant (3.3 mm–3.1 mm = 0.2 mm) compared with the OsseoSpeed implant (3.5 mm–3.2 mm = 0.3 mm) and resulted in the host bone located more nearby to the Aadva implant (potentially favoring implant osseointegration), was not able to compensate for the large void inter-thread spaces associated with the Aadva implant requiring extensive bone formation. At the implant [C] part, in contrast to the implant [B] part, no differences between Aadva and OsseoSpeed implants could be observed for BIC (cf. Figure 5B), despite the larger V-thread tissue spikes also associated with the collar part of the Aadva implant. Furthermore, identical kinetics of the [BIC_C] values was observed for both implant types. These results suggest that the Aadva implant collar part, notwithstanding its larger inter-thread gaps and its nonfunctionalized surface compared with the fluoride-modified osteogenic surface of the OsseoSpeed implant, performs equally well as the OsseoSpeed implant in terms of early bone apposition onto the implant surface. It is noteworthy mentioning that the macro-design of the collar part of an implant is of upmost importance, not only for the distribution of the forces acting onto the implant to the surrounding bone but also for offering the primary stability at installation.

Assuming that strain and strain peaks in bone trigger bone remodeling, the macro-design of a screw-threaded implant is important for an optimal load transfer, in particular at the implant collar area for preservation of the marginal bone level. In this context, Abuhussein and colleagues[18] reviewed the effect of implant thread pattern upon implant osseointegration via a systematic literature approach of simulated laboratory models and animal and human studies. The results confirmed the importance of the thread geometry on the distribution of forces around the implant. Particularly interesting for the present study are the results reported in the aforementioned paper on the implant thread pitch. The thread pitch is the distance from the center of the thread to the center of the next thread and is thus inversely related to the number of threads in the unit area. It was found that a decreased thread pitch can provide a positive contribution to BIC and to the implant stability, via an increased surface area and a better force distribution. In the present study, the latter variable was not investigated as only the unloaded situation was covered in the experimental setup. Despite the inferior surface area of the collar part of the Aadva implant compared with the OsseoSpeed implant, no significant differences in BIC at the implants' collar part could be observed, and the addition of more screw threads (as the collar design of the OsseoSpeed implant) thus seems to be redundant.

The macro-design of the body part of the two implant types differed, not only in thread pitch but also in thread pattern (V-thread vs buttress thread for the OsseoSpeed and Aadva implant, respectively), and significant differences in BIC were observed for this implant part in favor of the OsseoSpeed implant. The inferior BIC for the Aadva implant may be attributable on the one hand to the larger gap areas between the host bed and the implant surface created by a smaller thread number, demanding a considerable bone ingrowth up to the implant surface, and on the other hand (combined or not) to higher stress concentrations generated via a buttress implant thread pattern as compared with standard V-threads.[19,20] Translated to the clinical setting, consideration of specific implant macro-design features in the decision-making process can contribute to the success of implant therapy. However, other factors than the implant design features, such as the bone quality and the attainable primary stability, may be more critical for the ultimate success. Nevertheless, increasing the implant surface area exposed to the surrounding bone is advised when the primary stability is a concern,[18] and is suggestive for the selection of the implant body design of the OsseoSpeed implant instead of the one of the Aadva implant in compromised bone conditions. However, evidence needs to be provided to corroborate this statement.

A limitation of the study is that the contribution of the specific surface properties of the Aadva (standard sandblasted, acid-etched moderately rough implant surface) versus OsseoSpeed (additionally fluoride modified) implants on the bone response could not be differentiated. The same holds true for the individual evaluation of the implant thread pattern and implant thread pitch parameters. Furthermore, it is noteworthy that the present study evaluated the clinical performance of a new implant design in an unloaded setting. Future studies submitting the implants to loading protocols and simulating occlusal forces are needed.

In conclusion, the Aadva implant displayed clinically acceptable osseointegration in the present preclinical study. Furthermore, the findings confirmed that dental implant macro-design features, in particular the thread pattern and thread pitch, can be responsible for differences in the amount of bone surrounding the implant and in the degree of bone apposition onto the Aadva versus OsseoSpeed implant, and ultimately may impact the success of the establishment and/or maintenance of implant osseointegration. Consideration of specific implant macro-design features should be made relative to other factors such as the biological and mechanical microenvironment.

ACKNOWLEDGMENTS

GC Inc. (Tokyo, Japan) is gratefully acknowledged for financially supporting this study.

REFERENCES

1. Albrektsson T, Donos N. Working Group 1. Implant survival and complications. The Third EAO consensus conference 2012. Clin Oral Implants Res 2012; 23(Suppl 6):63–65.
2. Palmquist A, Omar OM, Esposito M, Lausmaa J, Thomsen P. Titanium oral implants: surface characteristics, interface biology and clinical outcome. J R Soc Interface 2010; 7(Suppl 5):S515–S527.
3. Goodacre CJ, Bernal G, Rungcharassaeng K, Kan JY. Clinical complications with implants and implant prostheses. J Prosthet Dent 2003; 90:121–132.
4. Esposito M, Grusovin MG, Achille H, Coulthard P, Worthington HV. Interventions for replacing missing teeth: different times for loading dental implants. Cochrane Database Syst Rev 2009; (21)CD003878.
5. Steigenga JT, Al-Shammari KF, Nociti FH, Misch CE, Wang HL. Dental implant design and its relationship to long-term implant success. Implant Dent 2003; 12:306–317.
6. Lan TH, Du JK, Pan CY, Lee HE, Chung WH. Biomechanical analysis of alveolar bone stress around implants with different thread designs and pitches in the mandibular molar area. Clin Oral Investig 2012; 16:363–369.
7. Palmer RM, Howe LC, Palmer PJ, Wilson R. A prospective clinical trial of single Astra Tech 4.0 or 5.0 diameter implants used to support two-unit cantilever bridges: results after 3 years. Clin Oral Implants Res 2012; 23:35–40.
8. Mertens C, Steveling HG. Implant-supported fixed prostheses in the edentulous maxilla: 8-year prospective results. Clin Oral Implants Res 2011a; 22:464–472.
9. Mertens C, Steveling HG. Early and immediate loading of titanium implants with fluoride-modified surfaces: results of 5-year prospective study. Clin Oral Implants Res 2011b; 22:1354–1360.
10. Barbier L, Abeloos J, De Clercq C, Jacobs R. Peri-implant bone changes following tooth extraction, immediate placement and loading of implants in the edentulous maxilla. Clin Oral Investig 2012; 16:1061–1070.
11. Freitas-Júnior AC, Almeida EO, Bonfante EA, Silva NR, Coelho PG. Reliability and failure modes of internal conical dental implant connections. Clin Oral Implants Res 2013; 24:197–202.
12. Monjo M, Petzold C, Ramis JM, Lyngstadaas SP, Ellingsen JE. In vitro osteogenic properties of two dental implant surfaces. Int J Biomater 2012; 2012:181024. DOI: 10.1155/2012/181024
13. Choi JY, Lee HJ, Jang JU, Yeo IS. Comparison between bioactive fluoride modified and bioinert anodically oxidized implant surfaces in early bone response using rabbit tibia model. Implant Dent 2012; 21:124–128.
14. Liu R, Lei T, Dusevich V, et al. Surface characteristics and cell adhesion: a comparative study of four commercial dental implants. J Prosthodont 2013. DOI: 10.1111/jopr.12063
15. Hönig JF, Merten HA. Subperiosteal versus epiperiosteal forehead augmentation with hydroxylapatite for aesthetic facial contouring: experimental animal investigation and clinical application. Aesthetic Plast Surg 1993; 17:93–98.
16. Coelho PG, Granato R, Marin C, et al. Biomechanical evaluation of endosseous implants at early implantation times: a study in dogs. J Oral Maxillofac Surg 2010; 68:1667–1675.
17. Freitas-Júnior AC, Rocha EP, Bonfante EA, et al. Biomechanical evaluation of internal and external hexagon platform switched implant-abutment connections: an in vitro laboratory and three-dimensional finite element analysis. Dent Mater 2012; 28:e218–e228.
18. Abuhussein H, Pagni G, Rebaudi A, Wang HL. The effect of thread pattern upon implant osseointegration. Clin Oral Implants Res 2010; 21:129–136.
19. Geng JP, Ma QS, Xu W, Tan KB, Liu GR. Finite element analysis of four thread-form configurations in a stepped screw implant. J Oral Rehabil 2004; 31:233–239.
20. Geng JP, Xu DW, Tan KB, Liu GR. Finite element analysis of an osseointegrated stepped screw dental implant. J Oral Implantol 2004; 30:223–233.