BJOS
Brazilian Journal of Oral Sciences

Original Article

Volume 21
2022
e226036

Influence of diameter on mechanical behavior of morse taper narrow implants

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Editor: Altair A. Del Bel Cury

Received: June 14, 2021
Accepted: June 17, 2022

Dental implants could give back function, esthetics and quality of life to patients. The correct choice of the implant, especially in borderline cases, is essential for a satisfactory result. **Aim:** Thus, the objective of this study was to evaluate the mechanical behavior of Morse taper implants with two different prosthetic interfaces. **Methods:** Twenty self-locking Morse taper implants, 2.9 mm in diameter (FAC), and 20 Morse taper implants, 3.5 mm in diameter (CM) were divided into two groups (n=10), and submitted to strength to failure test, optical microscopic evaluation of fracture, metallographic analysis of the alloy, finite element analysis (FEA) and strain gauge test. A Student's t test ($\alpha = 0.05$) was made for a statistical analysis. **Results:** For the strength to failure test, a statistically difference was observed ($p < 0.001$) between FAC (225.0 ± 19.8 N) and CM (397.3 ± 12.5 N). The optical microscopic evaluation demonstrated a fracture pattern that corroborated with FEA´s results. The metallographic analysis determined that the implants of the FAC group have titanium-aluminum-vanadium alloy in their composition. In the strain gauge test, there was no statistical difference ($p = 0.833$) between CM (1064.8 ± 575.04 μS) and FAC (1002.2 ± 657.6 μS) groups. **Conclusion:** Based on the results obtained in this study, ultra-narrow implants (FAC) should ideally be restricted to areas with low masticatory effort.

Keywords: Dental implantation. Flexural strength. Tensile strength.

Introduction

In recent decades, the use of dental implants has progressively improved the planning and management of patients who have partially or completely lost their teeth[1]. For successful rehabilitation, the appropriate selection of the implant type is crucial. The diameter is one factor that should be considered: some specific conditions restrict the placement of a regular implant, such as a severely resorbed and narrow ridge, a narrow mesiodistal space and replacement of teeth with small cervical diameters, such as inferior incisors[2,3]. Chronic pathological conditions, including endodontic and periodontal problems could also result in severe bone defects, resulting in narrow alveolar ridges in areas of anterior teeth[4-6].

Due to these limitations, small diameter implants (less than 3.75 mm) were introduced in Implantology and designed for narrow interdental spaces (spaces not compatible with implants with a diameter of 3.75 mm or more)[7,8]. However, these narrow implants were still not able to solve some cases with narrower spaces. Therefore, several companies presented ultra-narrow implants with diameters of 3.0 mm or less, to solve border situations. Moreover, the prosthetic connection also developed alongside the rise of internal connections, such as the inner hexagon and Morse taper, since it is considered an important factor that promotes interference in stress distribution[9].

Beyond this, the development of alloys with higher strength was important for the manufacturing of ultra-narrow implants, as it can be observed in the titanium Ti6Al4V alloy. This alloy consists in a more compact and resistant alloy and because of this could present higher strength and a better maintenance on the osseous apposition, especially on treated surfaces (sandblasted or acid-etched titanium surface, for example)[10]. This alloy combined with theses treated surfaces can enhanced osteoblast differentiation, production of local factors in vitro and improved the osseointegration process in vivo[11]. The metallographic analysis identifies the microstructure of alloys. Prior acid treatment increases the visualization of the metallic characteristics. This methodology could explain differences in mechanical behavior of different implants' alloy; more concise microestructure results in more resistant alloy.

Neodent launched in the market in 2013, a narrow implant with 2.9 mm diameter (Facility, Neodent, Brazil), which was developed for borderline cases (regions of maxillary lateral incisor and mandibular incisors). Its main attraction is that it has a pure self-locking Morse taper interface (6-degree prosthetic interface), using the titanium Ti6Al4V alloy, with no internal screw[12], in order to preserve its strength to avoid the narrowing of the walls. This prosthetic interface is different when comparing to others, with internal screws and 11.5-degree prosthetic interface. In this case, a prosthetic screw is used to connect the prosthetic part to the implant; in Facility, a specific pneumatic prosthetic hammer needs to be used to connect all parts. Still, there is a lack in literature about the biomechanical behavior comparing both prosthetic interfaces and how different prosthetic interfaces could affect the mechanical behavior of implants.

Therefore, the aim of this study was to evaluate the mechanical behavior of two different Morse taper systems of narrow dental implants (pure self-looking Morse taper implants, 2.9 mm in diameter, with 5° angulation of the internal conical portion – FAC; and Morse

taper implants, 3.5 mm in diameter, with internal threads 11.5° angulation of the internal conical portion – CM). The null hypothesis is that there is no difference in resistance to fracture and deformation of the external walls of both Morse taper implants.

Material and Methods

Two different Morse taper implant systems were evaluated in the current study: CM implants with 3.5mm diameter versus implants with 2.9mm diameter. CM implants are Morse taper implants with 11.5° angulation of the internal conical portion, and in the present study, are 3.5 mm in diameter. The narrow implants (FAC) are Morse taper self-locking implants with 5° angulation of the internal conical portion and are 2.9 mm in diameter (Figure 1).

Figure 1. A) CM implants - Morse taper implants with 11.5° angulation of the internal conical portion and 3.5mm in diameter. B) FAC group implants (FAC) - Morse taper self-locking implants with 5° angulation of the internal conical portion and 2.9 mm in diameter.

Twenty CM and 20 FAC implants were evaluated regarding their mechanical strength and deformation, by two methodologies: the strength to failure test (n=10) and the strain gauge test (n=10) (Table 1). For Optical microscopic evaluation of the fractures, all samples were examined (n=20). For Metallographic analysis, 3 implants of each group are used for a qualitative analysis.

Table 1. Type of implants and abutments in each test.

Type of test	Implant	Abutment
Resistance to fracture test	Morse taper self-locking implants with 5° angulation of internal conical portion (2.9 mm in diameter) – FAC	Facility anatomic abutment (1.5 mm)
	Morse taper implants with 11.5° angulation of internal conical portion (3.5 mm in diameter) – CM	Universal abutment
Strain gauge test	Morse taper self-locking implants with 5° angulation of internal conical portion (2.9 mm in diameter) – FAC	Facility anatomic abutment (1.5 mm)
	Morse taper implants with 11.5° angulation of internal conical portion (3.5 mm in diameter) – CM	CM exact lateral anatomic abutment (1.5 mm)

Strength to failure test

Each implant was positioned in a metallic holder[9]. The implant shoulder was also positioned 4 mm above the metallic holder, to simulate critical marginal bone crest resorption and to isolate the prosthetic index of each implant[9,13]. A metallic index was used to confirm this distance. The implant was then fixed to the metallic base with a screw, and the abutment was installed over the implants, according to the manufacturer's recommendation.

The samples were subjected to a 90° compressive load at a crosshead speed of 0.5 mm/min in a mechanical testing machine using a stainless-steel spherical point (4 mm diameter) connected to a load cell of 500 KN capacity[9,13].

A computer mounted in association with the machine was programmed to interrupt the test cycle process when one of the following occurred: a fracture, an abrupt break in resistance, or a displacement greater than 5.0 mm. A load was applied at 2 mm of the abutment platform (Figure 2).

Figure 2. The implant and the metallic holder were fixed on the mechanical testing machine (EMIC; 2000DL) and submitted to a load cell of 500 KN capacity (KN500; EMIC).

After each mechanical testing, the alignment of the stainless-steel spherical point was conferred. The computer coupled to the load cell was programmed to record the force (N) during flexion of the implant/abutment versus displacement (mm) and convert it into graphics.

The samples were numbered from 1 to 10 in each group and a table was produced according to the force applied (N) versus the displacement of the implant (mm).

After the test, the implant and the abutment were removed from the metallic holder, each sample was identified, and a macroscopic evaluation was performed to verify the compression mark of the screw in the implant's body to confirm that there was no sample displacement during the test. This macroscopic analysis demonstrated that the screw of the metallic holder avoided the displacement of the samples during the strength to failure test.

Optical microscopic evaluation

All samples were examined. The microscopic evaluation was performed to identify the different forms of fractures that occurred for both implant systems during the strength to failure test. For the analysis, the surface of the fracture was examined for each sample using an optical microscope with magnifications of 50x and 200x.

Metallographic analysis

The metallographic analysis was performed in 3 samples of each group to determine the microstructure of the implant's alloy and to illustrate the differences presented by each alloy. For this analysis, the alloy was examined using an optical microscope (AxioVision Imager.A1m, Zeiss), with a magnification of 200x[9]. Prior to the analysis, the samples were submitted to acid treatment in order to increase the visualization of the metallic characteristics[9,13].

Finite element analysis (FEA)

Two three-dimensional finite element models were created, representing each experimental group. The drawings of all parts of models (implant, abutment, and abutment screw) were supplied by the manufacturer (Neodent) in *.IGES format. The stress analysis was performed using FEMAP with NX Nastran (v11.1.1 64-bits).

All models were considered homogeneous, isotropic, and linearly elastic. The material properties are described in Table 2. To create the mesh, a semiautomatic meshing tool was used, with tetrahedral solid elements with quadratic trial function (element type SOLID187).

Table 2. Property of the materials.

Structure	Young's Modulus (Mpa)	Poisson's Ratio (V)	Yeld Stress Ratio (Mpa)	Tensile Strength (MPa)
Titanium grade IV	103000	0.361	703	970.1
Ti6Al-4V-ELI titanium alloy	105000	0.361	881	1059.4

The boundary conditions were determined with sliding contact with friction (0.2) between the abutment and implant. The bottom nodes of the implant were held fixed to avoid movement of the model. The load was applied with an angle of 90 degrees relative to the long axis. The implant shoulder was also positioned 4 mm above the FEA model to isolate the prosthetic index and simulate marginal bone crest resorption. Data were recorded using Von Mises criteria. Only a qualitative analysis of data was performed.

Strain gauge test

Ten Morse taper implants, 2.9 mm in diameter, with 5° angulation of the internal conical portion (FAC) and 10 Morse taper implants, 3.5 mm in diameter, with 11.5° angulation of the internal conical portion (CM) were manufactured specifically for this test

without external threads, in order to allow strain gauge fixation. All implants were mounted in resin, in order to expose 3 mm of the cervical portion. Then, the abutment was fixed to the implant as recommended by the manufacturer (Figure 3)[14].

Figure 3. Strain gauge fixed in the cervical portion of the implant. Note that the implant was fabricated without external threads to permit this fixation.

One strain gauge was fixed with cyanoacrylate glue to the cervical portion of the implant to measure the cervical deformation during the loading application. The strain gauge was connected to a data acquisition device. After switching the acquisition device on, the value of the gauge factor was recorded. The samples were subjected to a 45° oblique compressive load, from 0 to 200 N, at a crosshead speed of 0.5 mm/min in a mechanical testing machine, according to ISO 14801[15].

At the end of the tests, the strain gauge was completely disconnected from the acquisition device, which was switched off. The same operator performed all the tests in the same experimental session in order to prevent the yields from being altered by environmental conditions.

Statistical analysis

Tests for normality (Shapiro-Wilk test) and equality of variance test were applied. The statistical analysis of the strength to failure test and strain gauge tests were performed using Student's t-test (α=0.05). A statistical software (Sigma Plot version 12.0; Systat Software Inc.) was used to perform all analyses.

Results

The mean and standard deviation of the strength to failure test (N) were 397.3±12.5 (CM group) and 225.0±19.8 (FAC group). There was a significant difference ($P<0.001$) between the FAC and CM groups. Therefore, the mechanical performance of the FAC group implant compared to the CM group was different according to strength to failure test.

The optical microscopic evaluation demonstrated that all implants fractured, and the fractures tended to occur in the discontinuity region of the abutment/implant interface (Figures 4 and 5).

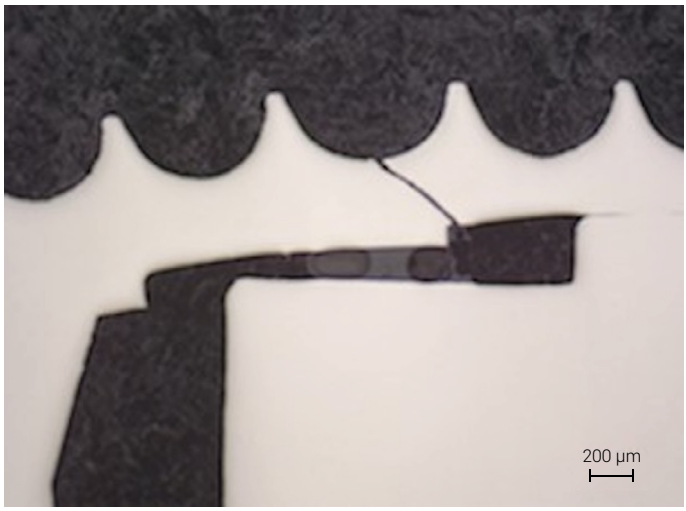

Figure 4. Optical microscopic evaluation: implant fracture at the discontinuity region of the abutment/implant interface (approximated view). - FAC group.

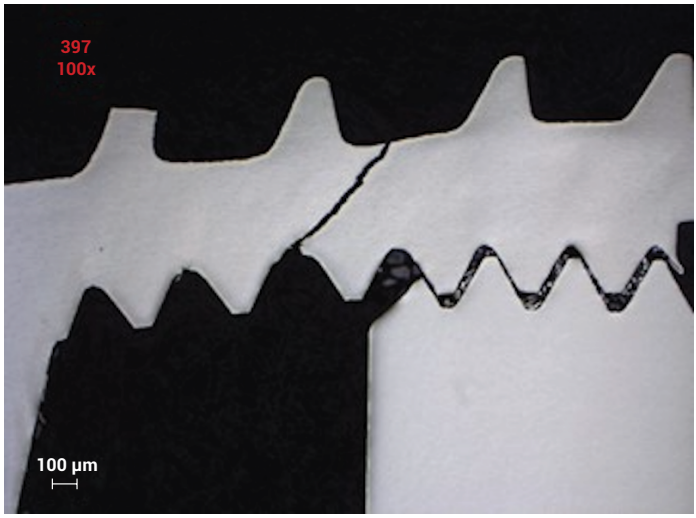

Figure 5. Optical microscopic evaluation: implant fracture at the discontinuity region of the abutment/implant interface (approximated view). – CM group.

The metallographic analyses verified the microstructure of the titanium alloy and demonstrated that the CM implants contained titanium grade IV (commercially pure). In contrast, the FAC group implants contained a Ti6Al4V alloy (Figure 6).

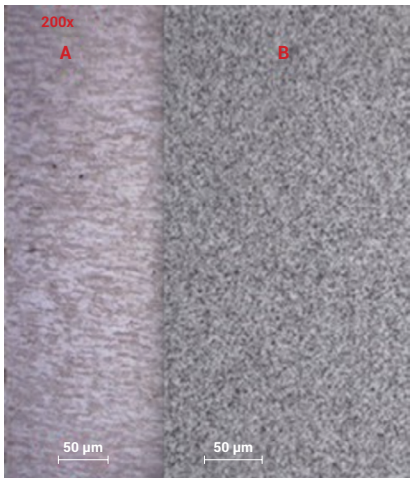

Figure 6. Metallographic analysis of the CM group (A) and FAC group (B).

The finite element analysis revealed, in both groups, that the region with the highest stress concentration (red color) was the area with no contact between the abutment and implant (Figures 7 and 8). This trend was confirmed by microscopic analysis demonstrating that fractures started at this region.

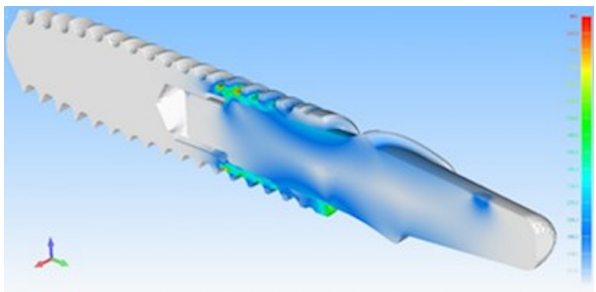

Figure 7. Finite element analysis of the FAC group implants: stress accumulation is represented in the red color located in the region with no contact of abutment/implant.

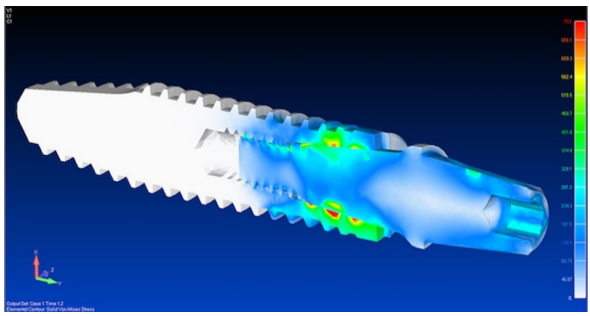

Figure 8. Finite element analysis of the CM group: stress accumulation is represented in the red color located in the region with no contact of abutment/implant.

The implant diameter has no significantly influenced the strain around the cervical region of the Morse taper implants tested. For the strain gauge analysis, there was no statistical difference (P=0.833) between CM group (1064.8 ±575.04 μS) and FAC group (1002.2±657.6 μS).

Discussion

The null hypothesis of this study was rejected. Although the strength to failure test demonstrated that the mechanical performance of the FAC group was inferior to the CM group (P<0.001); for the strain gauge analysis, there was no statistical difference between the analyzed groups (P=0.833).

In clinical practice, some borderline cases cannot be treated with standard-diameter implants, especially in areas with considerable vestibule lingual bone loss and small mesio-distal spaces[16]. Implants with a reduced diameter offer some benefits in these cases, attesting to the main advantages of narrow implants being the replacement of small-cervical-diameter teeth, reduction or avoidance of bone grafts or preliminary orthodontic treatment[17-19]. Therefore, several manufacturers have introduced narrow implants to the market (<3,5 mm) with the main objective of addressing the clinical difficulties cited above. The majority of these borderline cases could be solved with implants 3.25 mm to 3.5 mm in diameter; but there remains an issue for rehabilitating more narrow spaces. The implant-abutment interface of self-locking Morse taper system is mostly connected with cold-welding[20,21], thus eliminating the prosthetic complications associated with screws[22]. The abutment is fixed only by means of friction. Moreover, cold-welding provides a well-closed abutment-implant interface, which is conducive to plaque control and may reduce the incidence of biological complications[23]. Compared to screw-based systems, self-locking Morse taper interface connections could be more stable and better resist lateral and axial forces[20,24]. Bicon Dental Zimmer was the first implant company to launch on the market an implant with self-locking Morse taper interface. Bicon implants were evaluated in a retrospective study with a follow-up of 5 years and the results demonstrated that the mean marginal bone loss values at 1- year, 5-years and 10- years were 0.25 mm (95% CI±0.12), 0.40 mm (95% CI±0.03) and 0.51 mm (95% CI±0.05), respectively[25].

Implants whose diameters varied from 2,9 mm up to 3,2 mm were classified as "ultra-narrow implants"[26] and to obtain an acceptable degree of mechanical performance for 2.9 mm narrow implants, two solutions were found by manufacturers[12]: a self-locking connection, avoiding the necessity of internal threads, and stronger raw material. As presented in Table 2, the tensile strength for Ti6Al4V is 9% higher than titanium grade IV. Even so, the mechanical behavior in the strength to failure test of the 2.9 mm implant was inferior to the 3.5 mm implant, emphasizing that it is necessary to follow manufacture's recommendations. These implants have restricted indications and must be used only in areas with low masticatory effort. It's inappropriate use could favor fractures, as well as not accomplishing frequent occlusal adjustments. Material development should be pursued to achieve an implant as resistant as FAC group implants, but without the limitations observed in this study.

The FEA and microscopic examination revealed that the fractures occurred more frequently in the region where there was no contact between the abutment and the implant (Figures 7 and 8). The region with the highest stress concentration is the most fragile and susceptible to fracture, and could be observed in the discontinuity of the interface abutment/implant[9]. Probably, the internal thread (minimum diameter of the implant) causes areas of fragility where fractures appear when overloaded. The absence of threads changes the pattern of fracture. Nevertheless, a critical situation was simulated[27,13]. In normal clinical conditions, it is expected that bone preserves this region, and the implant receives stress at approximately 45° along the long axis. This situation is similar to the strain gauge analysis, in which there was no statistical difference between the groups, demonstrating that the differences between the evaluated systems did not affect the deformation around the external walls of the cervical region. This experimental finding confirms that FAC implants could be used in areas without great masticatory effort. Due to data available for implants smaller than 3 mm, caution is recommended to professionals when they consider their use. The results of this study confirm this statement.

The benefit of using narrow implants is that specific cases can be treated, for example, the replacement of teeth with small cervical diameters (e.g. incisors)[2,3], reduction or avoidance of bone grafts[3,27-29] or preliminary orthodontic treatment[3]. This could help some patients, especially elderly patients or patients with risk factors (such as chronic diseases) that can benefit from the use of narrow implants with reduced surgical invasion[27]. Epidemiological studies show that edentulous patients, especially elderly ones, are not able or disposed to be submitted to invasive surgical procedures[29-31]. Furthermore, there are some concerns and restrictions against longer treatments, associated with pain and complications[31-33].

FAC group implants have clinical indications restricted to upper lateral incisors, lower incisors and to support overdentures. With respect to performance and clinical longevity of implants smaller than 3 mm, a systematic review[34] related a survival rate upwards of 90%, with a follow-up between 1 and 3 years (BTI implants, 2.5mm; Tiny, 2.5 and 3.0mm; Hitec, 2.4mm; Sendax, 1.8mm; MicroPlant, 2.5mm; 3i, 2.9mm). However, a narrow implant (with a diameter inferior to 3.0 mm) that can be used in any clinical situation still does not exist.

Within the limitations of this study, it could be concluded that the FAC group implants, with 2.9 mm in diameter, has inferior mechanical strength when compared to CM implants, that are 3.5 mm in diameter. Though, the deformation around the external walls showed no statistical difference. Nonetheless, their use should ideally be restricted to areas with low masticatory effort.

Acknowledgements

The authors thank FAPEMIG, CNPq, CAPES, Neodent (Curitiba, Brazil), Neodent Mechanical Department and NEPRO Research Group for the support. The authors also acknowledge CPBio – Biomechanics, Biomaterials and Cell Biology Dental Research Center.

Conflicts of interest

The authors have no proprietary, financial, or other conflict of interest of any nature or kind in any product, service, and/or company that is presented in this article.

Data availability

Datasets related to this article will be available upon request to the corresponding author.

Author contribution

Conceptualization: FDN, KZ. Methodology: KZ, TAR, Formal analysis: KZ, TAR. Investigation: TAR. Resources: FDN, KZ. Data curation: TAR, GCSB. Writing—original draft preparation: TAR, GCSB. Writing—review and editing: FDN, KZ. Project administration: FDN, KZ. Funding acquisition: FDN, KZ. All authors have read and agreed to the published version of the manuscript.

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