

RESEARCH AND EDUCATION

Biomechanical behavior of extra-narrow implants after fatigue and pull-out tests



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Planning for patients with missing teeth has become predictable through the use of osseointegrated implants.^{1,2} Modifications in the design and surface properties of implants facilitate their adaptation to different locations and to varied bone patterns.³

The quantity and quality of the remaining bone are critical when determining whether it is possible to place regular-diameter implants, which are defined as those with a 3.75-mm diameter. However, in patients in whom the alveolar ridge has a reduced buccolingual width (less than 4 mm), the use of regular-diameter implants becomes impractical due to the increased risk of implant exposure.⁴ Similarly, when a regular-diameter implant is placed in a reduced space between adjacent teeth, the risk of periodontal ligament damage is increased.

Bone volume can be increased with grafts or osteogenic distraction.⁵ However, these procedures are costly and add risks to the patients, such as unpredictable bone resorption or membrane exposure risk

ABSTRACT

Statement of problem. Narrow implants have limited indications, and implant fracture may occur when these indications are not followed.

Purpose. The purpose of this in vitro study was to investigate the mechanical behavior of a 2.9-mm-diameter implant using a fatigue limit test and to investigate the Morse effect of 2 different Morse taper systems, 2.9-mm-diameter (FAC group) and 3.75-mm-diameter (CM group) implants, using a pull-out test. The null hypothesis was that the tensile strengths of the components for both systems would be similar.

Material and methods. The fatigue properties of 13 specimens under 6 loads were determined. The test was performed at 15 Hz and for 5×10^6 cycles. In the pull-out test, the specimens were divided into 2 groups (n=8), the FAC group (2.9-mm-diameter) and the CM group (3.75-mm-diameter). Statistical analysis for the pull-out test was performed with the Student *t* test ($\alpha=.05$).

Results. Thirteen specimens underwent the fatigue test. Only 5 did not fail when subjected to the frequency and number of cycles examined. Three of the specimens did not fail under a load of 130 N. The pull-out test showed a significant difference between the FAC and CM groups ($P<.001$).

Conclusions. According to the fatigue test, the extra-narrow implant (Facility; Neodent) was compatible with the low masticatory effort regions, as indicated by the manufacturer. The better performance of the FAC group in the pull-out test may be due to its design, which promotes the pure Morse effect in the implant-abutment interface, and the angulation of its internal conical portion. (*J Prosthet Dent* 2019;122:54.e1-e6)

and prolonged treatment time. These procedures may cause some patients to decline treatment.⁶ Narrow-diameter implants are a treatment option for regions with limited space, such as the small mesiodistal space between adjacent teeth (mandibular incisors and lateral maxillary incisors) and severely reabsorbed ridges.⁷ Implants with diameters less than 3.5 mm are considered narrow implants.

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Clinical Implications

Narrow-diameter implants present inferior mechanical characteristics when compared with regular-diameter implants and should be recommended carefully. Moreover, narrow implants with a Morse interface and no internal screws have better retention than the regular-diameter implants. The Morse interface without internal screws prevents the narrowing of the walls of the implant, which may be one of the factors that contributes to the clinically acceptable mechanical resistance of narrow implants, according to their clinical indications.

The use of narrow implants has been reported in borderline clinical situations through a variety of surgical techniques (immediate loading, with or without allografts, or guided surgery).^{3,4,8-10} Both medium- and long-term survival rates have been satisfactory (from 96.9% to 100%), with a follow-up period varying from 1 to 7 years.^{11,12} However, this implant indication is restricted to regions of low masticatory effort (mandibular incisors and lateral maxillary incisors), and fracture may occur when the implants are not placed in accordance with the manufacturer's recommendation.¹³⁻¹⁵ The development of stronger alloys that would allow for further indications is warranted.¹⁶

Some narrow implants have been developed without internal threads to achieve a smaller diameter with acceptable mechanical behavior. Facility (Neodent) is a narrow implant with a 2.9-mm diameter and 5 degrees of angulation of the internal conical portion, with the advantage of preserving strength and narrowing of the walls due to the presence of a pure Morse taper friction lock connection with no internal screw.

The purpose of the present study was to investigate the mechanical behavior and fatigue limit of a 2.9-mm-diameter implant (Facility; Neodent) under fatigue loading (dynamic test) in compliance with ISO 14801:2007.¹⁷ The pull-out test was also used to investigate the Morse effect of 2 different Morse taper systems: 2.9-mm-diameter implants (Facility; Neodent) with 5 degrees of angulation of the internal conical portion (FAC group) and 3.75-mm-diameter Morse taper implants (Titamax CM; Neodent) with 11.5 degrees of angulation of the internal conical portion (CM group).¹⁷ The null hypothesis was that the tensile strengths of the components of the 2 groups of implants would be similar.

MATERIAL AND METHODS

The fatigue loading test was performed in compliance with ISO 14801:2007.¹⁷ The free end of the component

was covered with a semispherical rigid body, the center of which coincided with the center of the free longitudinal axis and was anchored at 11.0 ± 0.5 mm (measured on a line parallel to the longitudinal axis of the implant). For the fatigue loading test, a mechanical test cone component was developed for the extra-narrow implant (Facility \varnothing 2.9 mm \times 12 mm; Neodent) to transfer the load through the semispherical free edge (Fig. 1).

The loading force was applied to the semispherical surface by means of a device whose flat surface was perpendicular to the load direction. The device was not restricted in the transverse direction of loading to avoid reducing the magnitude of the generated bending moment. The loading test was performed using a junction transducer placed at least 50 mm from the semispherical surface. For the fatigue test, the implant was placed 3.0 mm above the bone (simulating high bone resorption) in a rigid base used for anchorage angled at 30 degrees.

The implant components for the fatigue mechanical test (Facility; Neodent) were assembled and submitted to axial pressure as recommended by the manufacturer. First, a static loading test was performed in a wear simulator (Instron 3382 with 100 kN capacity; Instron) using the same configuration as that used for the dynamic loading test (Instron E3000 wear simulator with 3 kN capacity; Instron). The static loading test was performed to obtain the maximum load, and 3 specimens were used (speed of 1.0 mm/min).

Dynamic loading was conducted to determine the fatigue properties of 13 specimens through multiple tests under 6 loads (194 N, 178 N, 162 N, 155 N, 150 N, and 130 N), which were selected from the maximum load and obtained from the static loading test. The test was performed with a loading frequency of 15 Hz and for 5×10^6 cycles, which corresponded to an estimated 5-year clinical function. The fatigue limit was defined as the load limit value below which the test object could withstand more than 5×10^6 regular cycles without failure. These loading values did not correlate with the clinically presented values and were obtained by testing in compliance with ISO 14801:2007, item 5.6.2.¹⁷

The pull-out test was performed to evaluate the tensile strength of the Morse taper implants and abutments (anatomic abutment of 1.5 mm) of different groups of internal Morse taper designs. The components were divided into 2 groups (n=8) according to their internal Morse taper design: the FAC group (2.9-mm-diameter), with pure Morse taper friction lock connection with 5 degrees of angulation of the internal conical portion, and the CM group (3.75-mm-diameter), with Morse taper implants with 11.5 degrees of angulation of the internal conical portion. To perform the tests, the implants were placed in a polymeric support.

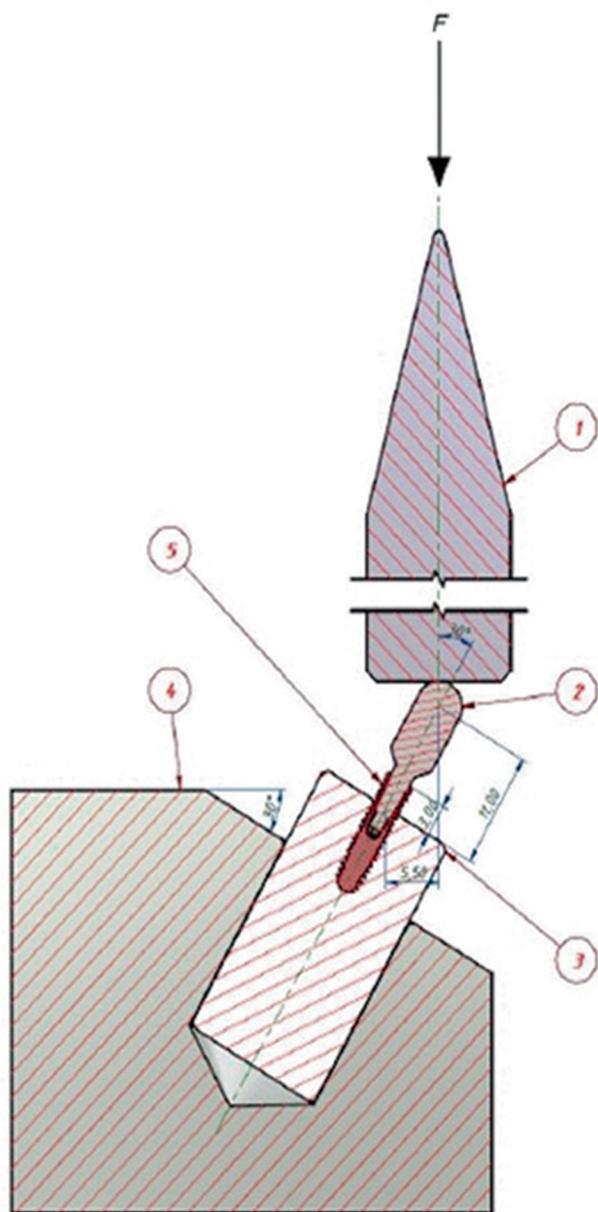


Figure 1. Schematic of fatigue test.

Anatomic 1.5-mm abutments were placed in their respective implants. A pneumatic hammer developed by Neodent (Facility; Neodent) was used to position the extra-narrow abutment. According to the manufacturer's recommendation, these abutments should be struck 3 times with a hammer for optimal installation. For both component groups, the abutments were placed in this fashion and not screwed so that the screws of the CM abutments were removed.

The set implants/abutments were placed in a mechanical testing machine (MultiTest 2.5 XT; Mecmesin). The tensile (N) required to remove the abutments was measured with a velocity of 5 mm/min, and the obtained



Figure 2. Implant/abutment assembly placed for pull-out test.

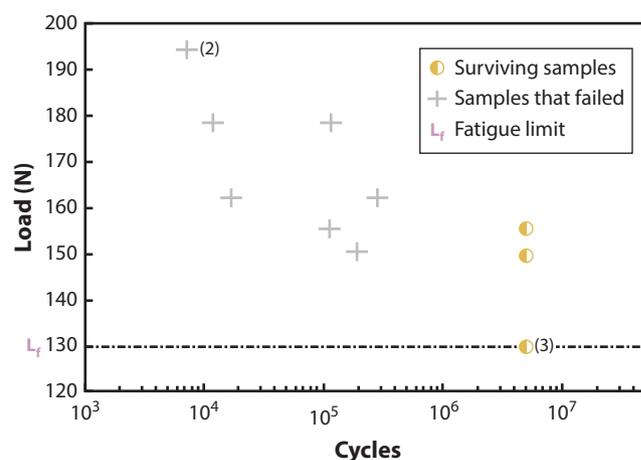


Figure 3. Wöhler diagram (load×cycles) for fatigue test with up to 5×10^6 cycles for 13 specimens.

data were analyzed with computer software (Mecmesin) (Fig. 2).

Statistical analysis of the pull-out test was performed with the Student *t* test ($\alpha=.05$). All analyses were performed with statistical software (Sigma Plot v12.0; Systat Software, Inc).

RESULTS

In the compression test, 3 specimens were used, and the mean value obtained for the maximum load supported by the 2.9-mm-diameter implant (Facility; Neodent) was 324.3 ± 7.4 N. The results of the fatigue loading test are presented in a diagram (load×cycles) summarizing the number of cycles that each specimen was subjected to for each load (Fig. 3).

The calculated bending moments are displayed in Table 1. Thirteen specimens underwent the dynamic fatigue test, but only 5 did not fail when subjected to the frequency and number of cycles determined for this test.

Table 1. Bending moment calculated for each specimen

Specimen	Maximum Load (N)	Minimum Load (N)	Amplitude	Cycles	Point of Failure
1	194.6	19.46	87.57	7247	Implant thread near anchorage base
2	194.6	19.46	87.57	7395	Implant thread near anchorage base
3	178.39	17.84	80.27	12 076	Implant thread near anchorage base
4	178.39	17.84	80.27	11 4835	Implant thread near anchorage base
5	162.17	16.22	72.98	300 000	Implant thread near anchorage base
6	162.17	16.22	72.98	16 631	Implant thread near anchorage base
7	155.68	15.57	70.06	104 715	Implant thread near anchorage base
8	155.68	15.57	70.06	5 000 000	Without fail
9	150	15	67.50	185 314	Implant thread near anchorage base
10	150	15	67.50	5 000 000	Without fail
11	130	13	58.50	5 000 000	Without fail
12	130	13	58.50	5 000 000	Without fail
13	130	13	58.50	5 000 000	Without fail

According to the obtained results, the fatigue limit of the extra-narrow implant (Facility, Ø 2.9 mm×12 mm; Neodent) with the prosthetic interface of the Morse taper was 130 N. Eight specimens exhibited fracture of the implant body.

The data obtained for each group in the pull-out test are described in Table 2. The mean and standard deviation of the pull-out test are shown in Table 3. A significant difference between the implants in the FAC and CM groups ($P<.001$) was observed. Narrow implants in the FAC group presented a Morse effect 7.5 times harder to separate than for the regular-diameter implants.

DISCUSSION

In the present study, the maximum load supported by the 2.9-mm-diameter implant was 324.3 ± 7.4 N. In a previous study that compared different 3.5-mm Morse taper implants, a similar value was found for the implants with no index and those with no index abutment (353.7 ± 51.9 N).¹⁸ A static test is a prerequisite for obtaining the reference load for the fatigue test of extra-narrow implants.

The fatigue properties of 13 specimens were determined under 6 different loads selected from the maximum load obtained from the static test with the same configuration as that of the dynamic test. The fatigue limit was defined as the load limit value below

Table 2. Results of pull-out test

CM Group	FAC Group
39.6	193.4
29.3	277.1
25.6	368.9
33	267.1
27	231.5
27.4	227.8
42.6	253.4
49.6	231.9

Table 3. Mean ±standard deviation values for FAC and CM groups in pull-out test

Group	Mean ±Standard Deviation
FAC	256.3 ±52.4
CM	34.2 ±8.7

which the test object could withstand more than 5×10^6 regular cycles without failure. For the extra-narrow implant (Facility; Neodent), the diameter did not vary and remained at 2.9 mm for all implant heights. The fatigue limit determined by the dynamic loading test was 130 N. This value is consistent with the manufacturer's recommendation for regions of low masticatory effort, such as mandibular incisors and lateral maxillary incisors. Notably, this implant was designed for specific clinical situations—low masticatory effort regions—to avoid bone regeneration. In the fatigue test, 36 specimens were divided into 2 groups according to their diameters: narrow (Ø 3.3 mm×10 mm) and extra-narrow (Ø 2.9 mm×10 mm).¹⁵ The test was carried out under water with 4 different loads (50 N, 100 N, 150 N, and 180 N) at 9 Hz for 50 000 and 100 000 cycles until failure or survival. When the load was 50 N or 100 N, the probability of survival was higher than 97% for both groups. When the load was increased to 150 N, the probability of survival after 100 000 cycles was 61.5% for the Ø 2.9-mm implants and 26% for the Ø 3.3-mm implants. After 50 000 and 100 000 cycles at 180 N, both implant diameters showed 0% reliability. These results are in agreement with the present findings. All the failures observed in this study occurred with a load higher than 150 N, varying from 7395 to 300 000 cycles. Although manufacturers recommend narrow implants for regions of low masticatory effort, the use of these implants in posterior regions has been reported.^{4,13,14} As such, these implants may fail after extended use, and fracture of the implant body may occur.^{13,14} When narrow implants are placed according to the manufacturer's recommendation, the survival rates are satisfactory, highlighting the importance of compliance.^{8,9,11,12}

The loading frequency chosen was 15 Hz based on ISO 14801:2007¹⁷; however, the frequency of human mastication is 1 to 4 Hz; therefore, the implants were

submitted to an unfavorable situation.¹⁹ The number of cycles at each load was set at 10^6 , thereby mimicking mastication and swallowing conditions over a 5-year period.²⁰

Thirteen specimens underwent the dynamic fatigue test, but only 5 did not fail when subjected to the frequency and number of cycles determined for this test. One of the specimens failed under a maximum load of 155.68 N, another under 150 N and another 3 under 130 N. These values are the load limits below which the test object could withstand more than 5×10^6 regular cycles without failing. Eight specimens exhibited fracture of the implant body, indicating overloading of the assembly when forces greater than those endured by the implant were used (for example, narrow implants placed in the posterior region).

The null hypothesis for the pull-out test was rejected. The tensile strength of the FAC group components was higher than that for the CM group components. The pull-out test is one of the methods used to evaluate implant stability and the mechanical interface between the implant and the bone.¹⁸ In addition, because pull-out tests are more efficient than insertion torque analysis, they are more commonly used to evaluate different designs in mini-implants.¹⁸

A mechanical test was conducted to evaluate the stability provided by the Morse effect in the Morse taper implants with different internal Morse taper designs (unpublished data). The finding is relevant because the locations at which the forces applied on these implants are concentrated when their abutments are screwed on their respective platforms are known, mainly through finite element analysis.²¹ The authors are unaware of a prior study that evaluated the stability provided by the abutments lacking internal screws when only the Morse effect was considered.

Implants with a diameter of 3.5 mm are considered narrow implants, but in some patients, even these implants may be too wide for the prosthetic space available. This limitation was the main reason for the manufacturing of extra-narrow implants. Regarding the differences between the groups tested in this study, the extra-narrow implant (Facility; Neodent) was developed with a unique Morse interface (with 5 degrees of angulation of the internal conical portion, which enhances the Morse effect) and without internal screws may have performed better in the pull-out test than the CM group. Furthermore, this interface prevents the narrowing of the walls with the placement of internal threads, which may be one of the factors contributing to the clinically acceptable mechanical resistance of narrow implants. The limitation of this study is the only in vitro evaluation of the 2.9-mm-diameter implants. So, clinical

studies are suggested to evaluate the clinical longevity of these implants.

CONCLUSIONS

From the results of this in vitro study, the following conclusions were drawn:

1. From the fatigue test, extra-narrow implants (Facility; Neodent) with prosthetic frictional lock connections were compatible with low masticatory effort regions, in agreement with the manufacturer's recommendation.
2. The better performance of the extra-narrow implants in the pull-out test may be due to the absence of internal threads in the design, and only the Morse effect anchored the intermediates and internal conical portion angulation.

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