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# INFLUENCE OF THE SCREW RAW MATERIAL AND SURFACE TOPOGRAPHY ON MECHANICAL BEHAVIOR OF MORSE TAPER DENTAL IMPLANT SYSTEMS

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**Abstract.** Contextualization: Dental implant manufacturers are seeking constant technological advances in the development of implantable medical devices. From a design perspective, the proper raw material selection and surface topography for each of the constituent parts of the dental implant system are as relevant as their geometry. So, it is relevant to evaluate the performance of new combinations of raw materials and surface topographies as candidates for those products. Purpose: This study aimed to evaluate the influence of screw raw materials and surface topographies on the mechanical behavior of a commercial Morse Taper implant system. Materials and methods: Four non-commercial combinations of raw materials and surface topographies (G1 - annealed, milled, and pink anodized Ti6Al4V-ELI titanium, G2 - annealed, milled and blue anodized Ti6Al4V-ELI titanium; G3 - annealed and milled Ti6Al7Nb titanium and G4 - extra hard and milled 316LVM stainless steel) were chosen as candidates to be used in the fabrication of prosthetic screws of a commercial Morse Taper implant system (Removal Prosthetic Screw Helix GM Implant manufactured by Neodent®). Mechanical compression and fatigue tests were performed following ISO 14801 recommendations. Statistics analyses were made using Minitab. Results: Compressive Tests: The 316LVM stainless steel screws from the G4 group reached the highest average compressive load at  $420.8 \text{ N} \pm 6.2 \text{ N}$ , statistically significant by Anova one way ( $\alpha=0.01$ ) in relation to the other groups tested. It was only possible to differentiate the means of the maximum compressive load between the other groups (G1, G2, and G3), resorting to the aid of Student's t-statistical analysis. Fatigue Tests: The maximum load value in high cycle fatigue, 200 N at 5M cycles, was also reached for G4, being 17.64% higher than the other groups tested in fatigue tests, which only reached 170 N at 5 M cycles. Conclusions: 316LVM stainless steel screw allowed the dental implant system to withstand higher loads in static and dynamic tests when compared to the other groups. It is suggested to carry out further studies using 316LVM stainless steel prosthetic screws in different implant systems to confirm the trend observed in this study, and once confirmed, evaluate the risk of galvanic corrosion between screws, prosthetic abutment, and implant.

**Keywords:** Mechanical Tests, Dental Implant, Morse Taper, 316LVM Stainless Steel, Titanium alloys

## 1. INTRODUCTION

Dental implants manufacturers are seeking constant technological advances in the development of implantable medical devices (new geometries, manufacturing processes, surface treatments or raw materials) (Hayashi *et al.*, 2023; Hoque *et al.*, 2022; Pjetursson, Fehmer and Sailer, 2022; Wang and Gao, 2021; Yang and Huang, 2021; Koie *et al.*, 2021; Blendinger *et al.*, 2021; Ban, 2021; Benakatti, Sajjanar and Acharya, 2021; Qu and Liu, 2021; Revilla-León, Sadeghpour and Özcan, 2020; Mishra and Chowdhary, 2019; Nishihara, Adanez and Att, 2019; Yao *et al.*, 2019; Felippi, Silva and Almeida, 2019; Kim *et al.*, 2018; Huang *et al.*, 2018; El-Anwar, 2017; Cheng *et al.*, 2017; Hafezeqoran, Koodaryan, 2017; Fischer, Schott and Martin, 2016; Eliaz, 2016; Jemat *et al.*, 2015; Kirsten *et al.*, 2015; Osman and Swain, 2015; Brunette *et al.*, 2013; Chang *et al.*, 2012; Karpagavalli *et al.*, 2007; Pierrisnard *et al.*, 2003).

Despite that, titanium and its alloys are the most common choice for dental implant system manufacturing. This is usually attributed to their properties, like long fatigue life, osseointegration potential, excellent biocompatibility, corrosion resistance, high strength and relatively low modulus of elasticity and good machinability (Hayashi *et al.*, 2023; Hoque *et al.*, 2022; Hafezeqoran, Koodaryan, 2017; Eliaz, 2016; Jemat *et al.*, 2015; Brunette *et al.*, 2013). According to Eliaz (2016), some titanium and titanium alloys include the standards: ASTM F67 (2017) and ISO 5832-2 (2018) for unalloyed titanium; ASTM F136 (2013) for wrought Ti-6Al-4V ELI; ASTM F1472 (2014) and ISO 5832-3 (2016) for wrought Ti-6Al-4V; ASTM F1713 (2013) for wrought Ti-13Nb-13Zr; ASTM F1295 (2016) and ISO 5832-11 (2014) for wrought Ti-6Al-7Nb; ASTM F1813 (2013) for wrought Ti-12Mo-6Zr-2Fe and ISO 5832-10 (2016) for wrought Ti-5Al-2.5Fe alloy.

The wide possibility of surface modifications to enhance the osseointegration potential of titanium dental implants has also played an important role in this aspect (Hoque *et al.*, 2022; Wang and Gao, 2021; Yang and Huang, 2021; Koie *et al.*, 2021; Blendinger *et al.*, 2021; Yao *et al.*, 2019; Kim *et al.*, 2018; Huang *et al.*, 2018; Hafezeqoran, Koodaryan, 2017; Fischer, Schott and Martin, 2016; Jemat *et al.*, 2015; Kirsten *et al.*, 2015; Chang *et al.*, 2012; Karpagavalli *et al.*, 2007).

Despite all the aforementioned innovative studies, the main technological advances presented by manufacturers are related to geometric improvements (e.g. launch of the Neodent® line of GM implants) or the use of alternative raw materials (e.g., zirconia implants). One example of alternative raw material that has been successfully employed for over a decade in human implant applications, in contact with soft tissue and bone, is 316LVM stainless steel (ASTM F138, 2020). However, there is no research on the interaction between titanium parts and 316LVM stainless steel parts in an implant dental system.

From a design perspective, the proper raw material selection and surface topography for each of the constituent parts of the dental implant system are as relevant as their geometry. So, it is relevant to evaluate the performance of those new combinations of raw materials and surface topographies as candidates for those products, not only the implant itself. This study aimed to evaluate the influence of screw raw materials and surface topographies on the mechanical behavior of a commercial Morse Taper implant system (‘Removal Prosthetic Screw Helix GM Implant’ provided by Neodent®).

## 2. MATERIALS AND METHODS

### 2.1 Materials

Four non-commercial combinations of raw materials and surface topographies described in Table 1 were chosen as candidates to be used in the manufacturing of prosthetic dental screws of the commercial Morse Taper implant system: Removal Prosthetic Screw Helix GM Implant manufactured by Neodent®.

Table 1. Experimental groups of dental implant screws.

Group	Raw Material	Acronym	Standard	Bar condition	Topography
G1	Ti6Al4V-ELI Titanium	TAV	ASTM F316	Annealed	Milled and pink anodized
G2	Ti6Al4V-ELI Titanium	TAV	ASTM F316	Annealed	Milled and blue anodized
G3	Ti6Al7Nb Titanium	TAN	ASTM F1295	Annealed	Milled
G4	316LVM Stainless Steel	LVM	ASTM F318	Extra-Hard	Milled

Neodent®’s commercial dental implants and prosthetic abutments from the ‘Removal Prosthetic Screw Helix GM’ line were provided by Neodent® to be used in this work. No modifications were made in the design, raw material, or manufacturing processes of those commercial products. The implants are milled in cold-worked grade 4 titanium (ASTM F67) with Neoporos® surface treatment, and the prosthetic abutments are milled in annealed Ti6Al4V-ELI titanium (ASTM F136). Neodent®’s commercial prosthetic tools (screwdriver, torque wrench) and supplies for the mechanical tests. An overview of the macrogeometry of the materials used in this work is provided in Figure 1.

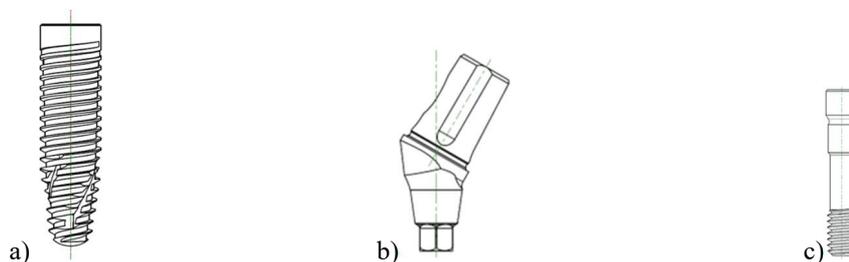


Figure 1. Overview of the macrogeometry<sup>1</sup> of the materials used in this work. a) Neodent® 3.5 x 8 mm Helix GM dental implant; b) Neodent® 4.5 x 6 x 3.5 mm and 30° angled Universal Helix GM prosthetic abutment with removable screw and c) Removable Helix GM prosthetic dental screw.

Typical chemical compositions of titanium alloys (G1, G2 and G3) and 316LVM (G4) used as biomaterials in this work are provided in and Table 3.

<sup>1</sup> These drawings are Neodent® intellectual property, so are presented without quotes and are out of scale.

Table 2. Typical Chemical Composition of titanium and titanium alloys (implant, G1, G2 and G3) (ASTM F67, 2017; ASTM F136, 2013; ASTM F1295, 2016).

Material	Mass Fraction (%) <sup>2</sup>									
	N	C	H	Fe	O	Al	V	Nb	Ta	Ti
Ti gr4 (implant)	0.05	0.08	0.015	0.5	0.4	-	-	-	-	Balance
TAV – G1 and G2	0.05	0.08	0.012	0.25	0.13	5.50-6.50	3.50-4.50	-	-	Balance
TAN – G3	0.05	0.08	0.009	0.25	0.2	5.50-6.50	-	6.50-7.50	0.5	Balance

Table 3. Typical Chemical Composition of 316LVM (G4) (ASTM F138, 2020).

Mass Fraction (%) <sup>1</sup>											Composition Index (%)
C	Si	Mn	P	S	N	Cr	Mo	Ni	Cu	Fe	% Cr + 3.3 x % Mo
0.030	0.75	2.0	0.025	0.010	0.10	17.0-19.0	2.25-3.00	13.0-15.0	0.5	Balance	26,00 min

Typical mechanical properties of selected titanium alloys and 316LVM stainless steel are summarized in Table 1.

Table 4. Typical Mechanical Properties of titanium alloys and 316LVM. (implant, G1, G2, G3 and G4) (ASTM F67, 2017; ASTM F136, 2013; ASTM F1295, 2016; ASTM F138, 2020; Eliaz, 2016).

Material	Supply Condition	Tensile Strength – UTS (MPa) (min)	Yield Strength – YS (MPa) (min)	Elongation – EL (%) (min)	Young Modulus – E (GPa)
Ti gr4 (implant)	Cold worked	...	...	10	110
TAV (G1   G2)	Annealed	860	795	10	116
TAN (G3)	Annealed	900	800	10	114
LVM (G4)	Extra hard <sup>4</sup>	1350	...	...	190

## 2.2 Methods

The mechanical (static compression and compressive fatigue) tests were carried out according to ISO 14801 (2016) at the Integrated Materials Laboratory (LIM) of the Neodent<sup>®</sup> company, aiming to characterize, respectively, the mechanical resistance under compression and under cyclic loading of each of the 04 test groups previously defined in Table 1.

These tests simulate the behavior of the dental implant system under different types of loads: the compressive strength indicates the maximum load supported in a single bite in one single ‘tooth’, and the maximum load supported in high-cycle fatigue indicates the maximum masticatory load supported at 5 million cycles, and represents the life of the implant system.

ISO 14801 (2016) specifies a method of dynamic testing of single post-endosseous dental implants of the transmucosal type in combination with their premanufactured prosthetic abutments. Also, it recommends defining the fatigue load to start the fatigue test from a previous static compression test with the same configuration that will be used in fatigue tests.

As the requirements for test setup and the steps for system preparation (specimen assembly) and specimen fixation to the multifunctional machine are the same for both tests, these are briefly presented:

- Mechanical Test configuration, according to ISO 14801
  - Loading device without lateral restriction (with freedom of movement in the transverse direction);
  - Implant installation level 3.0 mm above the bone level (simulating bone resorption);
  - Hemispherical loading member with center  $11.0 \pm 0.5$  mm away from the anchoring face, designed respecting the modeling of the prosthetic abutment;
  - Rigid device for anchoring the implant with a modulus of elasticity  $> 3$  GPa.
- System preparation (specimen assembly)
  - The specimen assembly device was aligned, and the implant connection was fixed in the mandrel;

<sup>2</sup> The mass percent value shown is the maximum value unless a range of values or a minimum value is indicated.

<sup>3</sup> Only for reference, the minimum values of the UTS, YS and EL of the annealed Ti gr4 according to ASTM F67 (2017) are: UTS – 550 MPa, YS – 483 MPa and EL – 15 %.

<sup>4</sup> Only for reference, the minimum values of the UTS, YS and EL of cold worked 316LVM according to ASTM F138 (2020) are: UTS – 860 MPa, YS – 690 MPa and EL – 12 %.

- A release agent was applied inside the support (so that it would be easy to remove the resin, in case of leakage after its application) and the titanium cylinder was positioned into the support;
  - The implant was fixed in the implant connection (instrument that had previously been fixed in the mandrel), the liquid bicomponent resin (powder + catalyst) was prepared and then, the newly prepared resin was applied in the titanium cylinder;
  - Finally, with the aid of a template (known as measurement base), the implant was inserted into the titanium cylinder with resin in a vertical position with  $3.0 \pm 0.5$  mm exposed, and the prosthetic abutment was installed inside the implant, applying a torque of 20 N.cm in the TQ-8800 portable digital torqueometer.
  - After assembling, the specimens were identified.
- Fixing the specimen on the multifunctional machine
    - To carry out static compression and high cycle fatigue tests in a dry environment, the titanium cylinder (bottom part of the specimen) was fixed to the  $40^\circ$  specimen holder and positioned at the multifunctional machine;
    - The titanium hemispherical loading member was adapted over the prosthetic abutment, pointing to the loading element, simulating the dental crown;
    - Subsequently, the face of the pin on the hemispherical loading member was brought closer and the contact point on the cap of the hemispherical loading member was centered with the flat face of the free pin. The specimen holder was then fixed to the multifunctional machine.

### 2.2.1 Methodology of Compressive Tests

After being assembled and identified, the specimens were randomly chosen to be fixed on the multifunctional machine. Before proceeding with the static compression test, an unscrewing torque was applied, and the re-tightening torque was applied to the system. Next, one of the compression specimens was randomly chosen and fixed in the multifunctional machine (steps described in topic 2). Once the pin was centrally supported on the hemispherical loading member, a maximum compression preload of 10 N was applied. Finally, an increasing compressive load was applied until the specimen was broken.

This process was repeated for the 05 samples from each of the 04 test groups, totaling 20 static compression tests.

### 2.2.2 Methodology of Fatigue Tests

First, the test parameters were selected in ISO 14801 (2016), according to the raw material of the implant system:

- Medium: dry
- Number of Cycles:  $5 \times 10^6$  cycles
- Frequency: 15 Hz
- Test temperature:  $20 \pm 5$  °C
- Loading Angle:  $40^\circ$

Then, once the specimens were assembled and identified, they were randomly chosen to be fixed on the multifunctional machine (steps described in topic 2). Once the pin was centrally supported on the hemispherical loading member and set to a maximum compression preload of 10 N, the cycles of compressive fatigue started. The load range was set to 30 to 80% of the maximum compressive loads obtained from the static tests.

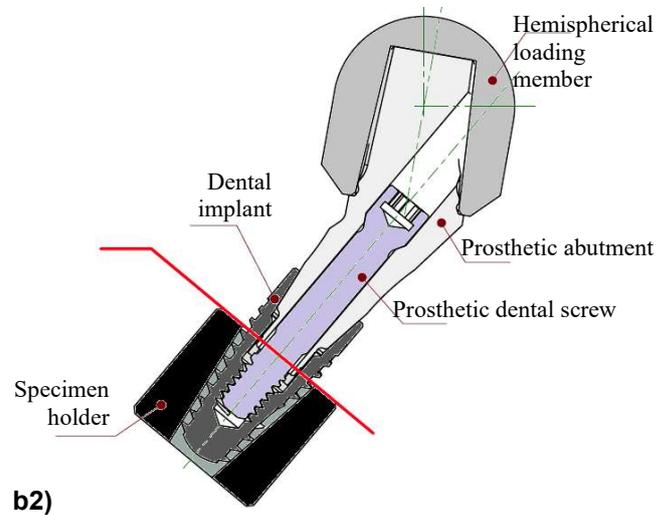
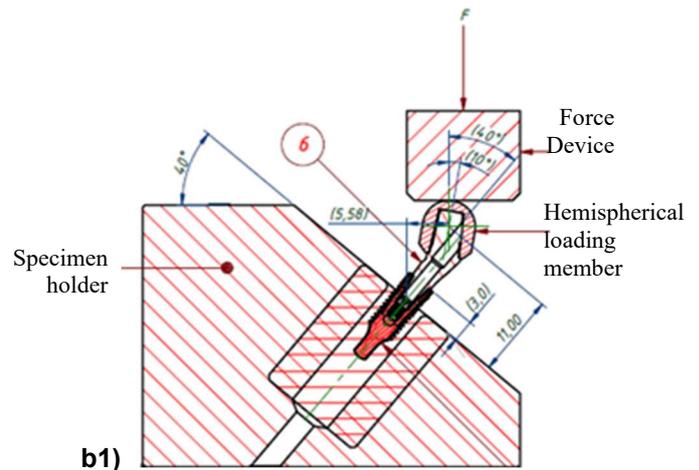
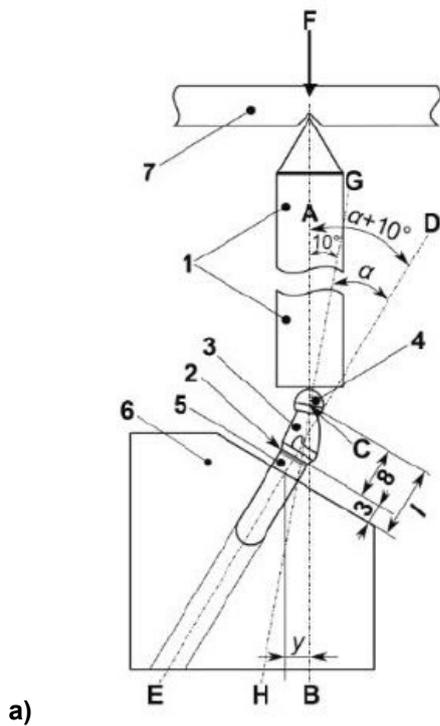
To comply with ISO 14801, this process was repeated for 09 specimens (minimum) from each of the 04 test groups. In addition to the minimum sampling, the ISO 14801 standard also establishes that at the end of the test:

- There are at least 03 surviving specimens, that is, 03 specimens withstood 5 million cycles without failing;
- At least 04 different loads have been tested, with at least 03 loads subsequent to the maximum load supported by the system, and a minimum of 02 specimens for each of these loads;
- The fault region of the fractured specimens must be identified;
- The bending moment of the surviving and fractured specimens must be calculated.

At the end of the test, the highest testing load at which a minimum of 03 surviving specimens are obtained is considered the maximum load supported by the system.

A schematic representation of the assembly of the dental implant system with prosthetic abutment, according to ISO 14801 (2016), is shown in Figure 2, where it is possible to observe the identification of the force device, hemispherical loading member, prosthetic abutment, exposed portion of the dental implant and specimen holder.

Additionally, the intersection of the loading axis (Line AB) with the axis of the endosteal dental implant (Line DE), the direction of load application in relation to the angulation of the prosthetic abutment and the angulation compensation made by the specimen holder are also identified, as well as the lever arm ( $y$ ).



Where:

- 1) Force device (must allow free movement transverse to the loading direction)
- 2) Prosthetic interface level
- 3) Prosthetic abutment;
- 4) Hemispherical loading member
- 5) Dental implant
- 6) Specimen holder
- 7) Load cell.

Figure 2. a) Schematic representation of the assembly of the implant system, according to ISO 14801 (2016).  
b) Implant system assembly<sup>5</sup> with materials used in this work.

The bending moment (MF) is calculated from the lever arm ( $y$ ) and the load ( $F$ ) used in the compressive fatigue test, both identified in Figure 14, as defined in Equation 1 (ISO 14801, 2016):

$$MF = y \cdot F$$

Equation 1 – Bending Moment

It is noteworthy that, according to ISO 14801 (2016), the position of the intersection of the loading axis (Line AB) with the axis of the endosteal dental implant (Line DE) (Figure 2) must be well defined, so that the lever arm can be measured or calculated. The lever arm is defined by (Equation 2):

$$y = l \cdot \sin 30^\circ$$

Equation 2 – Lever arm

Where  $l$  is the distance in mm between the center of the hemispherical loading member, where the load is being applied, and the upper part of the specimen holder (which represents the bone level), measured in a direction parallel to the axis of the endosteal dental implant (Line DE) (Figure 14). For the standard configuration, the lever arm for dental implant systems with angled prosthetic abutments is  $0.5 \times l$  or  $5.5$  mm.

### 2.2.3 Statistical Analysis

To ensure a statistically significant difference between the compressive loads average of the tested groups, the following hypothesis test was considered:

<sup>5</sup> These drawings are Neodent® intellectual property, so are presented without quotes and out of scale.

- Ho: The compressive loads average for all studied screw groups is statistically equal
- H1: There is at least one of the compressive loads average different between all studied screw groups

For a complementary analysis, a Student's t-statistical analysis was performed. Both statistical analyses were made using Minitab.

### 3. RESULTS

#### 3.1 Compressive Tests

The 316LVM stainless steel prosthetic dental screws from the G4 group reached the highest average compressive load at  $420.8 \text{ N} \pm 6.2 \text{ N}$ , statistically significant by Anova One Way ( $\alpha=0.01$ ) in relation to the other groups tested.

At first glance, the average of maximum compressive load withstood by the implant system with blue anodized TAV prosthetic screw presents the lowest average of maximum compressive load, and also the highest result dispersion (i.e., coefficient of variation), however, it was only possible to differentiate the average of the maximum compressive load between the groups G1 and G3 resorting to the aid of Student's t-statistical analysis.

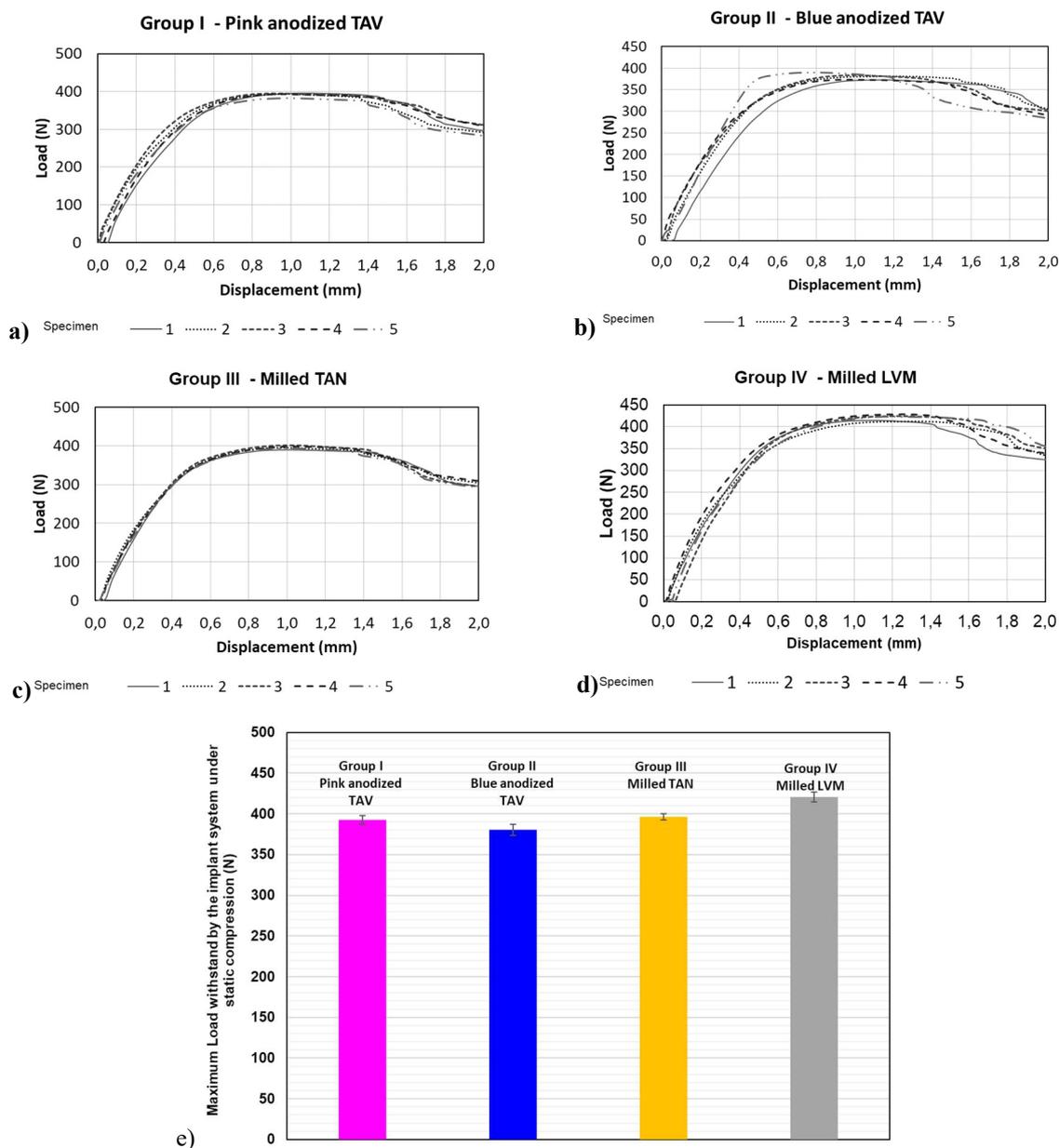


Figure 3. Load vs Displacement Curve of the Compression Test: a) Group I - Pink anodized TAV; b) Group II - Blue anodized TAV; c) Group III - Milled TAN; d) Group IV - Milled LVM and e) Maximum Load withstood by the implant system under static compression (N).

### 3.2 Fatigue Tests

The maximum load value in high cycle fatigue was 200 N at 5 M cycles was also reached for G4, being 17.64% higher than the other groups tested in fatigue tests, which only reached 170 N at 5 M cycles.

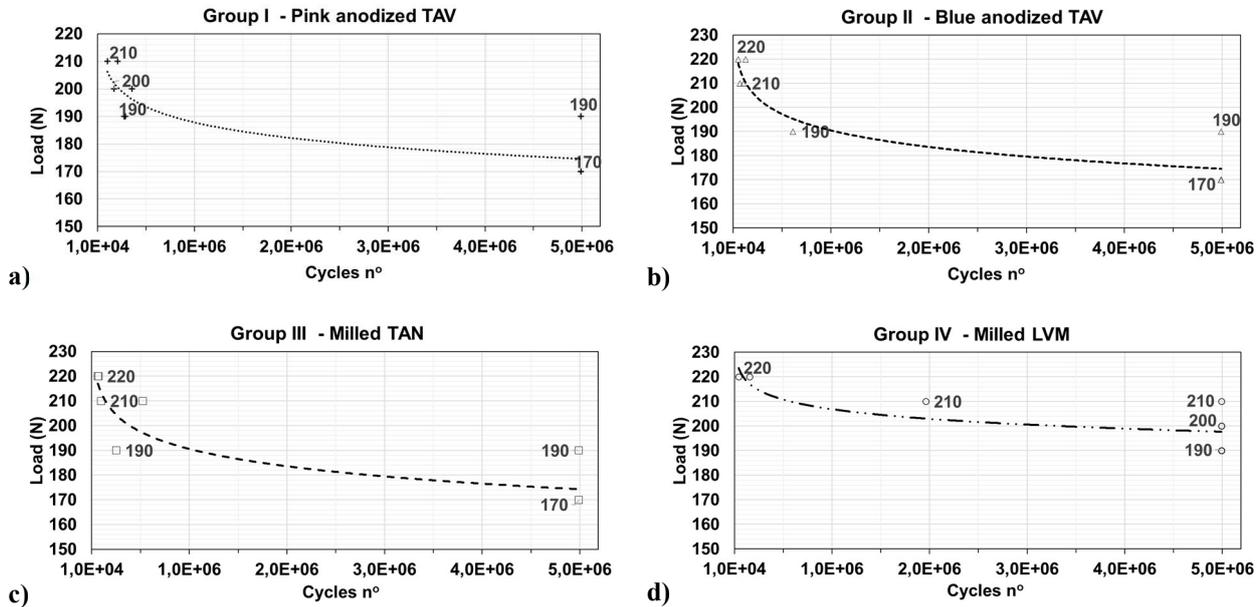


Figure 4. SN Curve of the Fatigue Compressive Test: a) Group I - Pink anodized TAV; b) Group II - Blue anodized TAV; c) Group III - Milled TAN and d) Group IV - Milled LVM.

### 4. CONCLUSIONS

In this work, the ISO 14801 (2016) methodology was used to compare the behavior of the endosseous dental implants with parts manufactured in different raw materials and topographies. It is important to highlight that, although this test is not designed to find the fundamental fatigue properties of the materials from which the endosseous implants and prosthetic abutments are made, the mechanical properties of the raw material (including its tensile strength, yield strength, elongation, Young Modulus, and tensile fatigue endurance) and topographies (e.g., roughness, residual stress, etc.) of the screw do have influence on the fatigue behavior of the entire system.

The results obtained in this work corroborate, as expected, that any change in any part of the dental implant system, can affect at a certain level the performance of the entire dental implant system.

Special attention shall be given to dental implant screw raw material selection, because, as demonstrated in this work, it can statistically increase/decrease the mechanical resistance (static compression and high cycle fatigue) of a Morse Taper dental system without changing its geometry, i.e., stress distributions. This is very relevant, especially for some specific applications, such as very thin implants, where more mechanically resistant materials, such as the tested 316LVM stainless steel screws, are required because they allow the dental implant system to withstand higher loads under static and dynamic conditions.

Additionally, screw raw material selection is a very cost-effective strategy to make the implant system more affordable to the overall population.

It is suggested to carry out further studies using 316LVM stainless steel prosthetic screws in different implant systems to confirm the trend observed in this study, and once confirmed, evaluate the risk of galvanic corrosion between screws, prosthetic abutment, and implant.

### 5. ACKNOWLEDGEMENTS

We thank Neodent® for providing the commercial products (dental implants and prosthetic abutments) and non-commercial products (dental implant screw prototypes) necessary to carry out this research. Also, for all the other meaningful resources provided that made this work feasible (prosthetic instruments, lab supplies, lab equipment, and, most importantly, human resources).

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