Brazilian Dental Science
Ciência Odontológica Brasileira

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UNIVERSIDADE ESTADUAL PAULISTA
"JÚLIO DE MESQUITA FILHO"
Instituto de Ciência e Tecnologia
Campus de São José dos Campos

ORIGINAL ARTICLE

doi: 10.14295/bds.2013.v16i2.863

# Mechanical behavior of NiCr and NiCrTi alloys for implant prosthetic components

Comportamento Mecânico de ligas NiCr e NiCrTi utilizados para componentes protéticos de implantes

**Ivete Aparecida de Mattias SARTORI[1], Carla Müller RAMOS[2], Fernanda FAOT[1], Luciano Monteiro da SILVA[3], Laiz VALGAS[4], Ana Flávia Sanches BORGES[2]**

1 - Latin American Institute of Dental Research – ILAPEO – Curitiba – PR – Brazil.

2 - University of São Paulo – Bauru School of Dentistry – Department of Dentistry – Endodontics and Dental Materials Bauru – SP – Brazil.

3 - School of Science – São Paulo State University – Bauru – SP – Brazil.

4 - Neodent® – Curitiba – PR – Brazil.

## ABSTRACT

**Objective:** The aim of this study was to evaluate the tensile and hardness mechanical properties, as well as the composition and microstructure of three different alloys used for implant prosthetic components casting. **Methods:** The alloys were divided into three groups: Tilite (Tilite), Vera (Verabond) and Malloy (DanCeramalloy). For the tensile test, the specimens (n = 10) of each group were evaluated in "alter" form and the maximum load fracture, the deformation at maximum load and Young´s modulus were determined. The data was subjected to one-way ANOVA and Turkey's test. For the hardness test, five discs from each group were evaluated for Vickers hardness. The data was analyzed using multiple regression ANOVA followed by the Turkey's test. The significance level was set at 5% ($\alpha = 0.05$). The composition and microstructure was determined through analysis of two specimens from each group by metallographic analysis (MEV/EED). **Results:** With regards to maximum load tensile, the deformation and the Young´s Modulus the three alloys evaluated were statistically similar. Regarding hardness, Tilite showed significant higher values than the others alloys. **Conclusion:** All the examined alloys can be used in implant prosthetic components and the presence of the element Ti did not influence the mechanical behavior of the alloy.

## KEYWORDS

Prostheses and implants; Hardness tests; Alloys; Tensile strength.

## RESUMO

**Objetivo:** O objetivo deste estudo foi avaliar as propriedades mecânicas de tensão e dureza, assim com a composição e microestrutura de três diferentes ligas utilizadas em componentes protéticos de implantes. **Métodos:** As ligas foram divididas em três grupos: Tilite (Tilite), Vera (Verabond) e Malloy (DanCeramalloy). Para o teste de tensão, os espécimes (n = 10) de cada grupo foram avaliados em forma modificada e a força máxima de fratura, a deformação em carga máxima e o módulo de Young foram determinados. Os dados foram submetidos ao teste ANOVA a um fator e teste de Tukey. Cinco discos de cada grupo foram avaliados para o teste de dureza Vickers. Os dados foram analisados utilizando o teste ANOVA de regressão múltipla, seguido do teste de Tukey. O nível de significância adotado foi de 5% ($\alpha = 0{,}05$). A composição e microestrutura foram determinados em dois espécimes de cada grupo por meio de análise metalográfica (MEV/EED). **Resultados:** Não houve diferenças estatísticas entre as três ligas estudadas em relação à força de tensão máxima, à deformação e ao modulo Young. Em relação à dureza, Tilite mostrou valores estatisticamente superiores em comparação às outras ligas. **Conclusão:** Todas as ligas examinadas podem ser utilizados em componentes protéticos de implantes e a presença do elemento Titânio não influenciou o comportamento das ligas.

## PALAVRAS-CHAVE

Próteses e implantes; Ligas; Testes de dureza; Resistência à tração.

## INTRODUCTION

In The NiCrMo alloys are the most utilized for the casting of prosthetic abutments as well as for metalloceramic crowns in Brazil, due to their low cost and satisfactory properties, when compared to other alloy compositions [1]. However, these alloys are not totally accepted for casting because they contain low percentages of beryllium and other chemical elements such as nickel, which could cause damage [2]. In addition, due to their high hardness, the NiCrMo alloys present difficulties in their laboratory manipulation. Some specifics procedures are required before ceramic firing [3,4]. NiCrMoTi alloys are commercially available and may be used in replacement of the NiCrMo alloy. Titanium (Ti) is a chemical element that presents satisfactory mechanical properties [5-7] and corrosion an absence of corrosion in the oral environment due to its titanium oxide passive layer [8,9].

An important property is the mechanical strength, such as hardness and tensile strength. Hardness is the first strength, like a “surface protection”, against the first contact with external loads that can cause plastic deformation [10]. An alloy with high hardness protects the abutment against surface plastic deformations, which is very important, considering that abutments need to resist loads from other materials with a different Young´s modulus and pass on the implants. Many prosthetic ceramic crowns, based on lithium disilicate and leucite reinforced, present different fracture resistance values under fatigue [11]. Furthermore, the tensile strength can identify future behavior patterns of alloys, such as like their rigidity (Young´s modulus), plastic deformation under load and their strength in the maximum tensile load, which predicts how resistant the alloy is before a fracture. NiCrMo and NiCrMoTi comparisons are needed in order to predict their clinical behavior for basic mechanical requirements.

## METHODS AND MATERIAL

The metallic alloys evaluated are three that are commercially available in Brazil. Trademarks, composition and manufacturers are described in Table 1. The tensile and hardness specimens were casting from resin material (Neodent, Curitiba, PR, Brasil).

**Table 1** – Sintering cycles of studied porcelains

| Groups | Trademark | Composition | Manufacturer's |
|---|---|---|---|
| Tilite | Tilite® | Ni – 60 to 76%<br>Cr – 12 to 21%<br>Mo – 4 to 14%<br>Ti – 4 to 6% | Talladium Inc., Valencia, CA, USA |
| Vera | Verabond® | Ni – balanced<br>Cr – 14%<br>Mo – 8.5%<br>Al – 1.7%<br>Be – 1.8% | VeraBond ; Aalba Dent Inc, Cordelia, Ca, USA |
| Malloy | Dan ceramalloy® | Ni – 65.7%<br>Cr – 20%<br>Mo – 8%<br>Others – 6.3% | Osaka, Japan |

*Chemical composition from manufacturer´s, however, according to Bezzon et al. (1998) the Ni quantity varies from 68 to 80% for NiCr alloys.

### Tensile test

The tensile specimens (n = 10) of each group were constructed in “alter” form, with 3 mm (± 0.1) of diameter in the tensile area, according to #1562 ISO specifications (Figure 1a, 1c and 1d).

The tensile test was carried out on a universal test machine INSTRON 3382 (Instron Corporation, Norwood, MA, USA). The maximum load fracture, the deformation at maximum load and the Young´s modulus were determined. The data was subjected to one-way ANOVA and Turkey’s test.

### Hardness test

Five discs measuring 5 mm in diameter and 2 mm in thickness (Figure 1b) from each group were evaluated for Vickers hardness (kg/mm$^2$), recommended by the manufacturer without prior surface treatment, in a micro hardness tester (HMV-2, Shimadzu, Tokyo, Japan). The mean values were calculated by means of three indentations with a distance of 150 $\mu$m between each of them, with a load of 100 g for 10 s. Data was analyzed using a multiple regression ANOVA test followed by the Turkey’s test. The significance level was set at 5% ($\alpha = 0.05$).

## Metallographic analysis

For the metallographic analysis two randomly chosen hardness specimens from each group were mounted on a semi-automatic mounting press for hot compression (LaboPress 1, Struers, Ballerup, Denmark) with phenolic resin (MultiFast, Struers, Ballerup, Denmark). The basic steps for the metallographic specimen preparation included: mounting, planar grinding, rough polishing, final polishing and etching, followed by an optical microscopic analysis. The plane grinding was performed with 220- to 1000-grit silicone carbide paper (Struers, Ballerup, Denmark) under water cooling in a LaboPol-21 grinding/polishing machine (Struers, Ballerup, Denmark). The rough polishing was performed with a LaboPol-5 polishing machine (Struers, Ballerup, Denmark) and a 6 $\mu$m diamond suspension (Struers, Ballerup, Denmark), and the final polishing with 3 and 1 $\mu$m diamond pastes (Arotec, São Paulo, Brazil) at 200 rpm without refrigeration. To prevent any contamination between abrasives, the surfaces were washed with propyl alcohol. In order to maintain a shiny surface, the alloys were chemically and mechanically polished using a mixture of colloidal silica (OP-S, Struers, Ballerup, Denmark) and hydrogen peroxide. The polishing pattern was produced by dipping the samples for 20 seconds into an acid mixture of Kroll’s reagent (100 mL water, 6 mL nitric acid, 3 mL hydrofuoric acid), and the reaction was interrupted with 70% alcohol. After drying, the surface microstructure was examined by a light microscope (Olympus BX60, Hamburg, Germany) 200x magnifcations and photographed by a digital camera (Olympus SC35 Type 12, Hamburg, Germany).

After that, the two specimens from each group were chemically analyzed by Energy Dispersive Spectroscopy (EDS) ( Scanning Electron Microscopic JEOL JSM-5600LV, Tokyo, Japan).

The results of the morphological and microstructural analysis were submitted to further descriptive analysis and the chemical components identified had their spectra arranged as well as their regions analyzed.

## RESULTS

The metallic alloys evaluated are three that are commercially available in Brazil. Trademarks, composition and manufacturers are described in Table 1. The tensile and hardness specimens were casting from resin material (Neodent, Curitiba, PR, Brasil).

For the maximum load tensile, the three alloys were similar. The values were 756.25, 776.03 and 722.05 kgf for Tilite, Vera and Malloy, respectively (Figure 1). Deformation at maximum load among the three alloys were similar. The values were 9.91 (2.98), 12.37 (3.63) and 9.99 (2.04) for Tilite, Vera and Malloy, respectively (Figure 2). The results of Young´s modulus showed higher values for Vera, 57.50 (48.87) GPa,in comparison to Tilite values, 52.08 (40.15) Gpa. Malloy values, 55.57 (38.18) GPa did not differ from the other teo groups (Figure 3). Regarding hardness, Tilite showed statistically significant higher values (433.32 ± 11.77) than the others alloys; which were 357.24 ± 14.93 for Vera and 377.72 ± 32.99 for Malloy) (Figure 4). The metallographic images and EDS data were described (Figures 5 and 6).

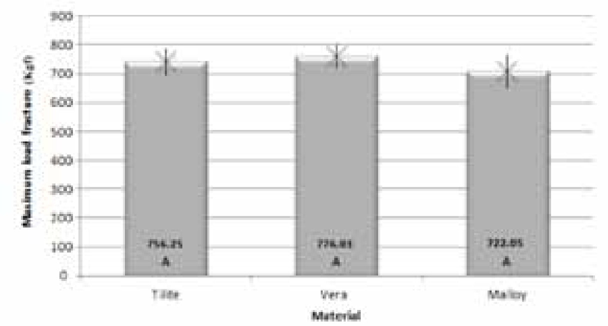


**Figure 1** – Ultimate load fracture under tensile (Mean ± SD) of the evaluated alloys.

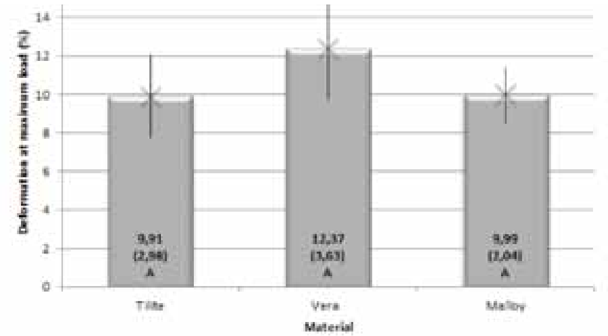


**Figure 2** – Deformation at maximum load (Mean ± SD) of the evaluated alloys.

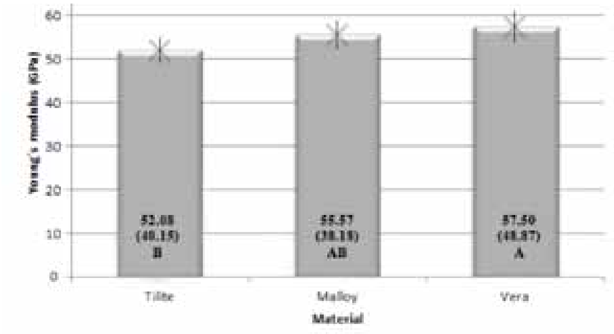


Figure 3 – Young's modulus (Mean ± SD) of the evaluated alloys.

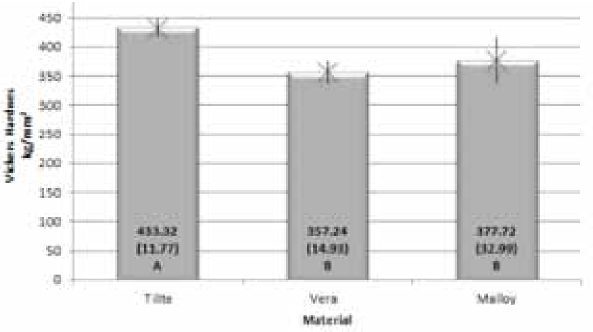
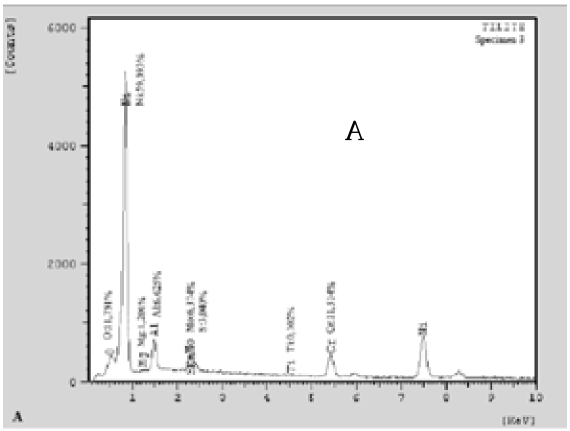
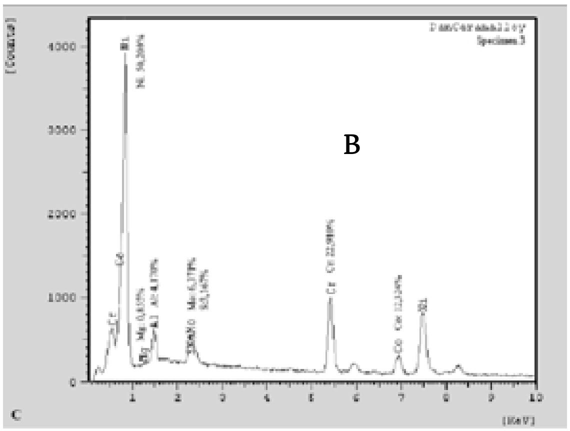


Figure 4 – Vickers Hardness (Mean ± SD) of the evaluated alloys.





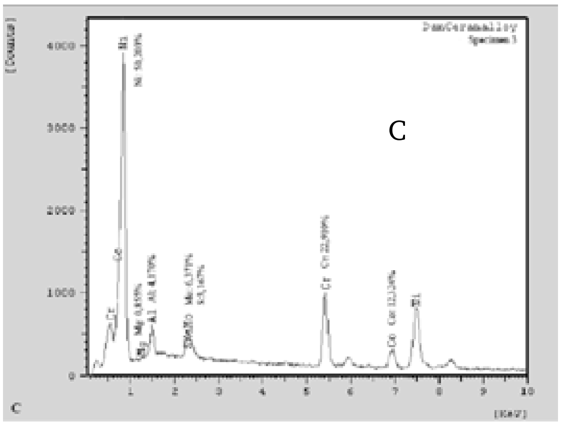


Figure 5 – The most representative Chemical Analysis of A) Tilite, B) Vera and C) Malloy. Percentage by weight of each chemical.

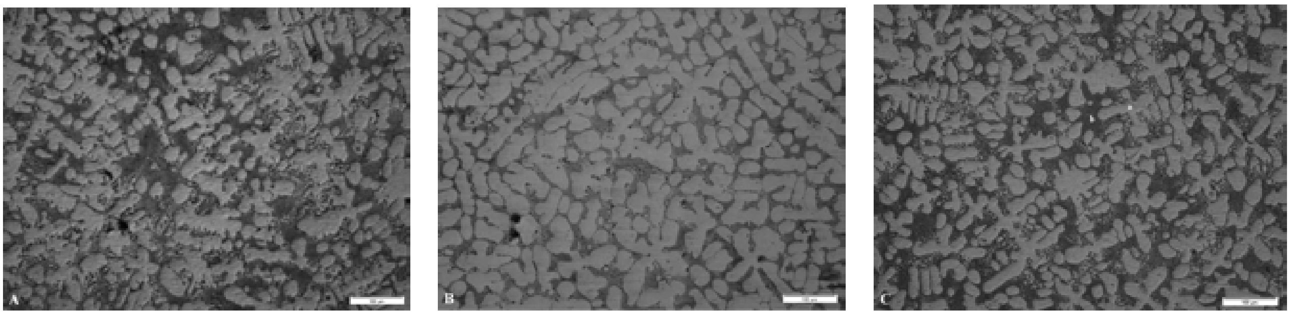


Figure 6 – Metallographic Analysis A) Tilite, B) Vera and C) Malloy. a) phase gamma (γ) and b) an intermetallic phase (8").

## DISCUSSION

It is relevant to emphasize the clinical mechanical properties for selection between the different types of alloys available in the market for use in prosthetic components. The value of the modulus of elasticity must be high for bridges of the various elements, whereas the deflection of the alloy should be minimized and the fracture strength is essential for restoration to be subjected to substantial functional loads [12]. Additionally, the laboratory manipulation of these alloys for a more precise adjustment of the castings, will be dependent on the relationship between the elastic modulus, elongation and strain.

The quality of an elastic material, which is presented by the interatomic or intermolecular force is related to the forces of attraction of a material which is similar when it is subjected to tensile or compression is the case with prosthetic components [13]. Young´s modulus is the tension divided by deformation up to the elastic limit of each material under load [10]. This property is generally independent of any thermal or mechanical treatment, but depends largely on the composition of the material [13]. In the present study, the three alloys presented similar results of elastic modulus to each other and with values indicated by the manufacturers, confirming the findings of chemical elements, that are also similar.

The maximum load fracture, the deformation at maximum load and the Young´s modulus of the three alloys are not affected by the concentrations of their elements. Deformation at maximum load (%) is calculated by the formula = [(Lf-Li)/ Li] x 100; Lf = Final length of the specimen body after the test start until its fracture; Li = Initial length of the specimen body. The presence of high amounts of plastic deformation characterizes the material as a ductile fracture. This fracture is often preferred because the deformation gives a warning and preventive measures are taken, in addition, a higher strain energy is required to induce this type of fracture [23]. When a metal is stretched beyond its yield point, hardness and resistance to deformation increases as the discrepancies are concentrated along the intergranular boundaries and thus, a plastic deformation area becomes more difficult [10].

Concerning hardness, Tilite alloy was the hardest of the three alloys. These values were similar to those related in previous studies that evaluated under the same conditions [17,24]. Analyzing the surface hardness of the different materials sit is important, not only to explain the risk of surface roughness of the prosthetic component during the cleaning work or even during normal oral hygiene procedures [14], but also may show the need for heat treatments in order to optimize properties such as tensile and fatigue [15]. In addition, alloys with higher hardness properties can hinder the finishing and polishing, requiring more time to run and altering the routine prosthesis laboratory [16,17].

Tilite is the only one that has titanium in its composition, suggesting that the presence of this chemical element could be related to the higher hardness. Ti shows a satisfactory mechanical performance and excellent corrosion resistance [5,21]. However, according to the results of chemical analysis, the Ti while present in small amounts (0.524% by weigth), did not justifying the higher hardness of Tilite.

The metallographic has an important role in ensuring that products have the correct microstructure, determine whether a material was processed correctly and may explain why the alloy faile [18]. In the metallographic analysis of the three alloys, no differences were observed between the structures. Figure 6 shows that there is a similarity in size and direction of the dendrites formed during the solidification of the alloys. All the alloys had a microstructure of two equilibrium phases, as shown in Figure 7, consisting of gamma (γ) and gamma-prime (γ') and the phases resulting in a transition zone between the matrix and the training inter dendritic euthetic [19]. The γ'', an intermetallic phase, is responsible for the high temperature resistance of the material and its resistance to deformation. However, it was observed that the alloy Vera presented a more homogeneous matrix can be sufficiently low because on the quantity of chemical elements present in the alloy and all of these elements have been incorporated into a solution nickel.

The amount of γ'' depends on the chemical composition and temperature, as shown in the quaternary phase diagram [20]. The addition of Cr in the alloy forms Ni-Cr dendrites and is essential for oxidation resistance, due to the formation of a Cr-rich film, that is highly resistant to acid attack, while adding the molybdenum-based alloy NiCr increases resistance to localized corrosion [2,22]. These elements (Cr and Mo) are also enhancers, both in a solid solution γ and γ' phase [20]. With regards to the different chemical composition based alloys of the Ni-Cr studied, some scientific findings are important in regard to critical interpretation. For general applications in dentistry, the Ni-Cr base alloys added with 12% Cr, 2-5% Mo are recommended for improving corrosion resistance [2]. For the Ti oxide layer and its reactive and protective properties, usually based onTiO2 oxide, an excellent range of Ti in the passive film of the NiCr-based alloy is still unknown [2,15].

Within the limitations of this study, it was concluded that all three alloys can be used to fabricate prosthetic components with appropriate physical and microstructural properties. Higher hardness and lower Young´s modulus of Tilite predict a higher initial resistance to better absorption of strain and stress to prosthetic abutments. The presence of the element Ti did not influence the mechanical behavior of the alloy.

## ACKNOWLEDGEMENTS

The authors would like to thank Professor Roberto Grandini, from UNESP for collaborating with us.

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**Carla Müller Ramos**
**(Corresponding author)**

Rua Jacarezinho, 656
Bairro Mercês - Curitiba
80710-150 – Paraná - PR
Email: carla_muller@yahoo.com.br

Received: 2013 Feb 15

Accepted: 2013 Mar 06