Fernando Pozzi Semeghini Guastaldi

Caracterização físico-química, morfológica, análise mecânica e de elementos finitos 3D, de diferentes placas e parafusos metálicos e técnicas de fixação interna, empregadas em fraturas de ângulo mandibular

ARAÇATUBA - SP

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Orientador: Prof. Adj. Eduardo Hochuli Vieira

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Epígrafe

"É muito melhor lançar-se em busca de conquistas grandiosas, mesmo expondo-se ao fracasso, do que alinhar-se com os pobres de espírito, que nem gozam muito nem sofrem muito, porque vivem numa penumbra cinzenta, onde não conhecem vitória, nem derrota" .

Theodore Roosevelt

"Quase todos podemos suportar a adversidade; mas, se quiser colocar à prova o caráter de um homem, dê-lhe poder" .

Abraham Lincoln

Resumo Geral

Guastaldi, FPS. Caracterização físico-química, morfológica, análise mecânica e de elementos finitos 3D, de diferentes placas e parafusos metálicos e técnicas de fixação interna, empregadas em fraturas de ângulo mandibular [Tese]. Araçatuba: Faculdade de Odontologia da Universidade Estadual Paulista; 2013.

Resumo Geral

Proposição: Realizar uma caracterização físico-química, morfológica e comparar o comportamento mecânico de uma liga experimental de Ti-Mo, ao sistema de fixação análogo à base de Ti, em fraturas de ângulo mandibular, favoráveis ao deslocamento. Adicionalmente, análises de elementos finitos 3D foram realizadas para avaliar o padrão de distribuição de tensões nas placas e nos parafusos.

Material e Método: Vinte e oito réplicas de mandíbulas de poliuretano foram usadas e uniformemente seccionadas na região do ângulo mandibular esquerdo. Estas foram divididas em 4 grupos considerando o material das placas e as técnicas de fixação interna: grupo Eng 1P, uma placa (zona de tensão da mandíbula) e 4 parafusos de 6 mm de comprimento; grupo Eng 2P, duas placas (uma na zona de tensão da mandíbula e a outra na zona de compressão), a primeira fixada com 4 parafusos de 6 mm de comprimento e a segunda com 4 parafusos de 12 mm de comprimento, sendo todo o material de fixação do sistema 2.0-mm. Os mesmos grupos foram criados para a liga Ti-15Mo. Cada grupo foi submetido a uma carga vertical linear no primeiro molar.

As médias e os desvios-padrão foram comparados para avaliação estatística (ANOVA; $p < .05$). Adicionalmente, foi construído um modelo de elementos finitos 3D considerando as mesmas variáveis para avaliar as tensões equivalentes de von Mises (σvM) nas placas e nos parafusos.

Resultados: Diferença estatisticamente significativa ($p < .05$) foi encontrada quando foi realizada a comparação entre ambas as técnicas de fixação (1 e 2 placas), independentemente do material das placas (cpTi and Ti-15Mo). Quando considerado os valores das tensões equivalentes de von Mises (σvM) para a comparação entre ambos os grupos (Eng and Ti-15Mo) com 1 placa, verificou-se uma redução de 10.5% na placa e de 29.0% nos parafusos, para o grupo da liga titânio-molibdênio. Ainda, quando foi realizada a comparação dos mesmos grupos com 2 placas, o fator mais relevante foi uma redução, na concentração das tensões, de 28.5% nos parafusos para o grupo Ti-15Mo.

Conclusão: A técnica de fixação com 2P mostrou melhor comportamento mecânico em fraturas de ângulo mandibular, favoráveis ao deslocamento, considerando ambos os materiais utilizados, Ticp e Ti-15Mo, quando submetidos a uma carga vertical linear na região de molar. As placas de titânio-molibdênio reduziram, substancialmente, as concentrações de tensões nos parafusos em ambas as técnicas de fixação interna.

General Abstract

Guastaldi FPS. Physico-chemical and morphological characterization, mechanical and 3D finite element analysis, of different metal plates and screws and internal fixation techniques, employed in mandibular angle fractures [Thesis]. Araçatuba: School of Dentistry of Sao Paulo State University; 2013.

General Abstract

Purpose: Perform a physico-chemical and morphological characterization and compare the mechanical behavior of an experimental Ti-Mo alloy to the analogous metallic Ti-based fixation system, for mandibular angle fractures, favorable to displacement. Additionally, finite element analysis was performed to assess the stress distribution in the plates and screws.

Material and Method: Twenty eight polyurethane mandible replicas were used and uniformly sectioned on the left mandibular angle. These were divided into 4 groups considering the material of the plates and the internal fixation techniques: group Eng 1P, one 2.0-mm plate (tension zone of the mandible) and 4 screws 6 mm long; group Eng 2P, two 2.0-mm plates (one in the tension zone of the mandible and the other in the compression zone), the first fixed with 4 screws 6 mm long and the second with 4 screws 12 mm long. The same groups were created for the titanium alloy (Ti-15Mo). Each group was subjected to linear vertical loading at the first molar. Means and standard deviations were compared with respect to statistical significance (ANOVA; $p < .05$). Additionally, an three-dimensional finite element model reproducing the characteristics of the

specimens used in the mechanical tests were created to evaluate the von Mises equivalent stress (σvM) in the plates and screws.

Results: Statistically significant difference ($p < .05$) was found when the comparison between both internal fixation techniques (1 and 2 plates) was performed, regardless the materials of the plates (cpTi and Ti-15Mo). When considering the von Mises equivalent stress (σvM) values for the comparison between both groups (Eng and Ti-15Mo) with 1 plate, an decrease of 10.5% in the plate and an decrease of 29.0% in the screws for the titanium-molybdenum-based group was observed. Also, when comparing the same groups with 2 plates, the relevant fact was an decrease of 28.5% in the screws for the Ti-15Mo group.

Conclusion: The 2P technique showed better mechanical behavior for favorable to displacement angle fracture fixation than 1P, considering both materials, cpTi and Ti-15Mo, of the bone plates when the fixation methods were subjected to linear vertical loading in the molar region. The titanium-molybdenum alloy plates substantially decreased the stress concentration in the screws for both internal fixation techniques.

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Lista de Abreviaturas

AEF	Análise de Elementos Finitos
Ti	Titanium
Mo	Molybdenum
EDXRF	Energy Dispersive X-ray Fluorescence
EDX	Energy Dispersive X-ray
wt %	Weight Percent
SEM	Scanning Electron Microscopy
cpTi	Comercially Pure Titanium
Ti-Mo	Titanium Molybdenum
®	Trademark
Ti-15Mo	Titanium 15% Molybdenum
ASTM	American Society for Testing and Materials
Ti6Al4V	Titanium 6% Aluminium 4% Vanadium
IQAr	Instituto de Química de Araraquara
UNESP	Universidade Estadual Paulista "Júlio de Mesquita Filho"
Eng	Engimplan®
1P	One Plate
mm	Millimeter
2P	Two Plates
MTS	Material Test System
mm/min	Millimiter per Minute
N	Newtons

SD	Standard Deviation
%	Percent Sign
Co	Cobalt
Cr	Chromium
SS	Stainless Steel
FEA	Finite Element Analysis
3D	Three-Dimensional
CT	Computed Tomography
1^{st}	First
2^{nd}	Second
.igs	Initial Graphics Exchange Specification
σvM	Von Mises Equivalent Stress
n	Significance
MPa	Megapascal
GPa	Gigapascal
ELI	Extra-Low Interstitial
FE	Finite Element

Sumário

Introdução Geral

Introdução Geral

As fraturas mandibulares constituem o tipo de trauma mais comum do esqueleto facial. Os relatos demonstram uma proporção de 6:2:1 entre as fraturas de mandíbula, do zigoma e da maxilla (Haug et al., 1990). O principal objetivo no tratamento das fraturas é o reparo do osso fraturado resultando no restabelecimento da forma e função. O controle do risco de infecção, da má-união e de lesões dos tecidos moles, são alguns dos desafios técnicos que podem ser incluídos no manejo global dos traumatismos (Laughlin et al., 2007).

Dentre as fraturas mandibulares, as da região de ângulo apresentam alta incidência, sendo uma das mais frequentes na atualidade e sua gravidade está diretamente relacionada ao tipo de trauma que as ocasionou (Ellis 3rd, 2009). O ângulo mandibular foi definido, anatomicamente, por uma região triangular, delimitada pela borda anterior do músculo masseter e uma linha oblíqua, que se estende da região do terceiro molar inferior à inserção posterior do músculo masseter (Killey, 1974). De acordo com Ellis 3rd et al. (1985), elas representavam 10% das fraturas mandibulares em pacientes vítimas de acidentes automobilísticos, 17% em pacientes vítimas de quedas, podendo representar até 30% das fraturas mandibulares em pacientes vítimas de agressão física.

Esse tipo de diversidade não ocorre em relação ao perfil dos pacientes que apresentam fratura do ângulo mandibular. Em sua grande maioria, são indivíduos do gênero masculino, economicamente ativos e na faixa etária de 20 à 40 anos (Ellis 3rd et al., 1985; Lee & Dodson, 2000; Gabrielli et al., 2003; Paza et al., 2008; De Matos et al., 2010).

Quanto à modalidade de tratamento a ser empregada, as fraturas de ângulo mandibular apresentam diversas formas de condução, sendo grande foco de controvérsias, talvez sendo superadas somente para as da região de côndilo mandibular. Controvérsias essas muito mais relacionadas a fatores ligados à preferência e/ou experiência do profissional responsável pela condução do caso, do que com base científica (Ellis 3rd, 1999, 2009). A fixação interna tem sido empregada com sucesso no tratamento das fraturas mandibulares durante as últimas décadas (Siddiqui et al., 2007) de acordo com os princípios estabelecidos por Michelet et al. (1973) e Champy et al. (1978).

Diversas formas de tratamento são propostas para as fraturas de ângulo mandibular, como por acesso intrabucal e aplicação de uma placa na linha oblíqua externa (Michelet et al., 1973; Champy et al., 1978), ou por acesso transbucal e aplicação de duas placas, ou ainda, acesso extrabucal e aplicação de duas placas. A primeira forma de tratamento citada destaca-se por ser tecnicamente mais simples e rápida, por evitar o risco de lesão ao nervo facial e à possibilidade de cicatriz aparente (Edwards & David, 1996).

Assim, para melhor compreensão do comportamento biomecânico da fixação interna das fraturas mandibulares, e para possibilitar o desenvolvimento de novos materiais e técnicas, foram realizados estudos experimentais in vitro (Haug et al., 2002; Rudderman et al., 2008). Estes estudos necessitam da utilização de osso humano ou de um substituto ósseo. Vários materiais, como costela bovina, mandíbulas de ovelhas, réplicas de mandíbulas humanas em resina de poliuretano, têm sido utilizados como substitutos ósseos em pesquisa de fixação interna (Bredbenner & Haug, 2000).

As placas e parafusos de titânio constituem-se no padrão ouro para a fixação de fraturas bucomaxilofaciais e sua utilização em trauma têm sido amplamente estudada (Bell & Kindsfater, 2006). Laughlin et al. (2007), reportaram que a escolha do tipo de fixação interna para as fraturas de mandíbula deve apresentar as seguintes características: simplicidade de instalação, apropriada resistência mecânica para suportar os esforços mastigatórios e o adequado treinamento e conhecimento, por parte do profissional, do sistema utilizado.

Ainda, a realização de pesquisas in vitro, in vivo, para o estudo e o desenvolvimento de diferentes materiais empregados na fabricação das placas e parafusos, das diferentes técnicas utilizadas como fixação interna, empregados no tratamento das fraturas e osteotomias da face, são imprescindíveis para avaliar o comportamento mecânico, a resposta biológica, local e sistêmica, que este biomaterial poderá desencadear ao receptor para, posteriormente, tornar possível sua aplicação em humanos.

Desta forma, para melhor compreensão do comportamento dos diferentes materiais e técnicas empregados nos traumas bucomaxilofaciais, a utilização de modelos matemáticos virtuais associados à simulação numérica empregando-se análise de elementos finitos (AEF) tem demonstrado ser um meio de prever a distribuição e concentração de tensões e deslocamentos em áreas fraturadas que necessitam de fixações (Takada et al., 2006; Wang et al., 2010; Ji et al., 2010; Takahashi et al., 2010).

É possível afirmar que a AEF é um método preciso para se avaliar o comportamento mecânico de estruturas, desde que as propriedades mecânicas do material em questão estejam inseridas corretamente no software de análise

(Vollmer et al., 2000). Com o auxílio da AEF, pode-se aprimorar a técnica cirúrgica, estimulando o desenvolvimento de novos biomateriais, através de simulações que representem diferentes formas de fratura do ângulo mandibular, com diferentes materiais e quantidade de parafusos, com o objetivo de reduzir a concentração de tensões na área fraturada, auxiliando para a redução de complicações pós-operatórias.

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Capítulo 1

1. Capítulo 1

BIOMECHANICAL STUDY IN POLYURETHANE MANDIBLES OF DIFFERENT METAL PLATES AND INTERNAL FIXATION TECHNIQUES, EMPLOYED IN MANDIBULAR ANGLE FRACTURES

Periódico para publicação do Capítulo 1: Journal of Craniofacial Surgery, Anexo A

1.1 Abstract

Purpose: Perform a physico-chemical and morphological characterization and compare the mechanical behavior of an experimental Ti-Mo alloy to the analogous metallic Ti-based fixation system, for mandibular angle fractures, favorable to displacement.

Material and Method: Twenty eight polyurethane mandible replicas were used and uniformly sectioned on the left mandibular angle. These were divided into 4 groups considering the material of the plates and the internal fixation techniques: group Eng 1P, one 2.0-mm plate (tension zone of the mandible) and 4 screws 6 mm long; group Eng 2P, two 2.0-mm plates (one in the tension zone of the mandible and the other in the compression zone), the first fixed with 4 screws 6 mm long and the second with 4 screws 12 mm long. The same groups were created for the titanium alloy (Ti-15Mo). Each group was subjected to linear vertical loading at the first molar on the plated side in an MTS-810 servo-hydraulic mechanical testing unit. The maximum load resistance values were measured. Means and standard deviations were compared with respect to statistical significance using the two-factor factorial analysis of variance (ANOVA; $p < .05$).

Results: The chemical composition of the Ti-15Mo alloy was close to the nominal value in all cases. The mapping of Mo and Ti showed a homogeneous distribution of these elements. SEM of the screw, revealed the presence of machining debris. Also, for the plates, only the cpTi plate undergoes a surface treatment. The metallographic analysis reveals granular microstructure, from the thermomechanical trials. No statistically significant difference ($p > .05$) was found when the materials of the plates (cpTi and Ti-15Mo) where considered for both techniques of fixation (1 and 2 plates). However, when the comparison between both internal fixation techniques was performed, statistically significant difference was found ($p < .05$).

Conclusion: The 2P technique showed better mechanical behavior for favorable to displacement angle fracture fixation than 1P, considering both materials, cpTi and Ti-15Mo, of the bone plates when the fixation methods were subjected to linear vertical loading in the molar region.

Keywords: Mandible; fracture fixation, internal; bone plates; titanium; molybdenum.

1.2 Introduction

Mandible fractures are among the most common injuries that affect the facial skeleton (Ellis et al., 1985; Haug et al., 1990). Moreover, fractures of the mandibular angle are the most problematic in the facial region because of the high frequency of complications and difficult surgical access to the site (Gear et al., 2005; Fernandez et al., 2003; Haug et al., 2001).

Infection and non-union are commonly reported after rigid internal fixation of these fractures (Mathog et al., 2000). Despite significant research on the subject, there is still some controversy on the ideal fixation scheme for fractures of this region (Gear et al., 2005; Kimsal et al., 2011). Treatment of mandibular fractures is based on the restoration of form and function, seeking suitable bone repair. The basic requirement for optimal function is adequate anatomic shape and stiffness (resistance to deformation under load) (Prein & Rahn, 1998).

After a fracture, the transmission of compressive forces can still take place across a fracture plane. The bone remains able to take over the compressive tasks, and the implant must substitute for the lost tensile properties. For more than 2 decades, open reduction with stable internal fixation has been the treatment of choice for mandibular fractures. Correct implant placement is determined by the location and type of fracture and its relation to the tension zones (Prein & Rahn, 1998).

Rigid internal fixation is now routinely used for surgical management of mandible fractures (Feller et al., 2002; Moreno et al., 2000; Fernandez et al., 2003; Dolanmaz et al., 2004). Mandible stability during functional activities takes the premier place in this technique. The ideal plate-screw system must be strong and rigid enough to withstand the functional loads and enable undisturbed fracture healing. Therefore, optimized internal fixation should attain a balance between the stability of the fragments and the stress shield effect of the miniplates (Ji et al., 2010).

Fixation methods can be evaluated empirically by mechanical tests using universal testing machines. Samples made with material that has a modulus of elasticity similar to that of bone are duly prepared to simulate fracture fixation. Thus, it is possible to observe the trend of the fixation system behavior when exposed to load (Vieira e Oliveira & Passeri, 2011).

The aim of this study was to perform a physicochemical and morphological characterization and a comparative evaluation of the mechanical behavior of an experimental Ti-Mo alloy to the analogous metallic Ti-based fixation system, for mandibular angle fractures, favorable to displacement.

1.3 Material and Method

Prior to the mechanical test, Energy Dispersive X-ray Fluorescence (EDXRF) and Energy Dispersive X-ray (EDX) spectra were used to confirm that the ingots composition was close to nominal (15Mo wt%). The chemical analyses were performed in a total of six different areas on the bulk and on the surface of each ingot by both techniques (EDXRF and EDX).

After chemical characterization, metallographic observation with Scanning Electron Microscopy (SEM) and mapping of Mo were performed on the samples' surface in order to verify possible defects from casting process and the distribution of Mo. The experiments were conducted using a SEM microscope (LEO 440, LEO Electron Microscopy Ltd., Cambridge, UK) coupled with an energy dispersive analyzer, while for EDXRF measurements, a fluorescence X-ray spectrometer (EDX-800 RayNy, Shimadzu, Kyoto, Japan) was used.

Also, an Optical Microscope (Leica DMR, Leica Microsystems, Wetzlar, Germany) coupled with Leica Qwin Software was used to capture and analyze the images of the microstructure of the cpTi and Ti-Mo alloy, after the surface attack with Kroll solution (5% Nitric acid, 10% hydrofluoric acid and 85% volume of water; ASTM E 407), to reveal its microstructure.

For this study, 28 human dentate mandibular replicas made of rigid polyurethane resin (Nacional®, Jaú, SP, Brazil), were used as substrate. The 2.0-mm titanium-based system group consisted of 21 straight 4-hole plates with 112 self-tapping screws 6 mm long and 56 self-tapping screws 12 mm long

(Engimplan®, Rio Claro, SP, Brazil). The 2.0-mm titanium-molybdenum-based system group consisted of 21 straight 4-hole plates (Ti-15Mo).

Note: In accordance with the manufacturer's specifications, the plates are made of cpTi grade 2 (ASTM F67-06) and the screws are made of the titanium alloy Ti-6Al-4V (ASTM F136-12a).

The titanium alloy (Ti-15Mo; ASTM F2066-08) used in this study, and developed by the Biomaterials Group (IQAr - UNESP), to be applied as biomaterials (Oliveira et al., 2004, 2007, 2008, 2009), was cast in an arc-melting furnace under ultrapure argon atmosphere, following a well-known procedure described in the literature (Oliveira et al., 2004, 2007). The ingots obtained after the fusion of the elements (Ti and Mo), and after thermo-mechanical treatments, were sent to Engimplan®, to be laminated into plates for internal fixation.

Before the study, a mandible was sectioned simulating a simple mandibular angle fracture, favorable to displacement, following a procedure described in the literature (Bregagnolo et al., 2011). Subsequently, the sectioned mandible was sent to National® (Jaú, SP, Brazil) for reproducing the standardized cut.

The samples were divided into 4 groups, with 7 mandibles each, according to the plate material and internal fixation technique employed, as described:

- Group Eng 1P was fixed with 1 straight 4-hole plate and 4 monocortical screws 6 mm long, in the tension zone of the mandible (Figure 1);

- Group Eng 2P was fixed with 2 straight 4-hole plates, one in the tension zone of the mandible and the other in the compression zone, the first was fixed with 4 monocortical screws 6 mm long and the second with 4 bicortical screws 12 mm long (Figure 1);

The same groups were created for the titanium alloy (Ti-15Mo; Figure 2).

To standardize the position of the plates and the screw insertion, guides of acrylic resin were made.

The mechanical test was performed on a servo-hydraulic machine MTS-810 (Material Test System). Two steel devices were made and set up on the MTS machine, one as a supporter to stabilize the mandible replicas and another as a tip to apply the vertical loads (Figure 3). The force was applied through the tip perpendicular to the occlusal plane at a rate of 1 mm/min at the first molar on the plated side.

The data from the load, in Newtons (N), applied during the mechanical test, was determined at the time at which the fixation failed.

The statistical analysis of the data obtained in the mechanical tests, were compared using ANOVA, with two factors of variation (the plate material and techniques of internal fixation), at a level of significance of 5%.

1.4 Results

The chemical analysis (EDXRF and EDX) showed that the actual chemical composition of the Ti-15Mo alloy was close to the nominal value in all cases (Table 1). The chemical composition of the alloy was homogeneous, and no expressive differences were found between surface and bulk with both techniques used ($p > .10$). The mapping of Mo and Ti showed a homogeneous distribution of these elements, without preferential zone, in the whole analyzed region (Figure 4).

Figure 5 shows the SEM of the screw (Ti-6Al-4V). Machining debris can be seen, what is undesirable for in vivo application, while Figure 6 shows the SEM of both plates. The cpTi plate undergoes a surface treatment not disclosed by the company, while the Ti-15Mo plate does not present treatment.

The Optical Microscopy of the cpTi and the Ti-15Mo alloy is shown in Figure 7. The metallographic analysis reveals granular microstructure, from the thermomechanical trials, performed in its gross structure of fusion during the manufacturing process. These trials are needed to show that these materials have adequate mechanical resistance for application.

During the mechanical tests no fractures of the synthetic mandibles, of the plates and the screws were detected. Table 2 shows the mean and standard deviation (SD) values relative to the maximum forces (N) obtained during the mechanical tests for all groups of the study.

No statistically significant difference ($p > .05$) was found when the materials of the plates (cpTi and Ti-15Mo) where considered for both techniques of internal fixation, 1 and 2 plates (Figure 8a and 8b). However, when the comparison between both internal fixation techniques (1P and 2P) was performed, statistically significant difference was found ($p<.05$).

1.5 Discussion

There have been many scientific researches that have studied the behavior of fixation techniques in the mandible region when subjected to mechanical tests, to confirm or support the best position, orientation, and selection of plate type and materials employed in mandibular angle fracture treatment. It is essential to understand the biomechanical behaviour of mandible and optimize the fixation pattern to enable surgeons to improve the outcomes of internal fixation (Dichard and Klotch, 1994; Choi et al., 1995a, 1995b; Shetty et al., 1995; Haug et al., 1996; Fedok et al., 1998; Alkan et al., 2007; Ji et al., 2012).

In 2000, Bredbenner & Haug compared human cadaver mandibular bone, bovine rib, porcine rib, photoelastic epoxy, and two types of polyurethane synthetic mandibles, each of which had been used previously in maxillofacial biomechanical research. The mechanical standards for comparison were pullout strength and insertional torque. They concluded that the polyurethane mandible showed results similar to cadaveric bone and was considered by the authors to be the material of choice for in vitro studies. Eliminating many of the variables associated with natural or live tissue, permits a unique opportunity to assess only the reconstruction technique and its mechanical interaction with the substrate being reconstructed.

However, it is important to emphasize that the data obtained from biomechanical studies, such as those used in the present study, can not be directly transferred to clinical use in humans serving only as indicative parameters of the behavior of a certain technique and/or material.

The introduction of modern devices for internal fixation substantially shortens the duration of intermaxillary fixation or even obviates it completely. One of the therapeutic goals of this kind of operation is to achieve uncomplicated bone healing, so as to prevent any relapse. The plate/screw osteosynthesis is a standard method for the surgical treatment of mandible fractures nowadays (Levy et al., 1991; Mathog et al., 2000; Feller et al., 2002; Arbag et al., 2008).

Models used in previous studies usually employ incisal edge loading or molar loading to simulate the force involved in mastication (Kroon et al., 1991; Dichard and Klotch, 1994; Choi et al., 1995a, 1995b; Shetty et al., 1995; Haug et al., 1996; Fedok et al., 1998; Alkan et al., 2007; Ji et al., 2012). In this study, a compressive load was applied to the occlusal surface of the mandibular 1st molar on the plated side perpendibular to the occlusal plane, which has been shown to exhibits the largest muscle recruitment activity (Lovald et al., 2009).

We agree that these models may lead to results not according with physical conditions, however, they can predict the behavior of different scenarios of internal fixation, with several fracture patterns, and the behavior of the most common materials used in fabrication of the bone plates and screws.

The fixation of fractures of the mandibular angle is possibly more critical than fixation of fractures located in other regions of the mandible. Fractures of the angle are associated with the highest rate of postoperative complications of all mandibular fractures (Iizuka et al., 1991; Ellis 3rd, 1999; Esen et al., 2012), which might be related to the use of different techniques of fixation (Ellis 3rd, 1999). The preferred type of fixation is still controversial (Ellis 3rd, 1999; Levy et al., 1991; Esen et al., 2012). Thereby, in planning stages of fracture treatment, the determination of best positioning, orientation, and selection of plate type and material are important.

Although most of the studies indicate increase stiffness and strength in multiple plate systems repair versus single-plate applications, much debate exists about the use of either one or two plates for treating angle fractures. The most common surgical treatment for angle fractures is the use of a single miniplate with or without maxillo-mandibular fixation (Gear et al., 2005), with the next most common being the two-miniplate technique. However, all biomechanical models developed to date have shown that two plates provide much more stability than one (Kroon et al., 1991; Dichard and Klotch, 1994; Choi et al., 1995a, 1995b; Shetty et al., 1995; Haug et al., 1996; Fedok et al., 1998; Alkan et al., 2007; Ji et al., 2012). Our results corroborates with the literature and support the contention that the use of 2 plates when treating simple fractures of the mandibular angle, unfavorable for treatment, with internal fixation is superior to the use of 1 plate.

More, even if no statistically significant difference was found when the comparison between the materials of the plates was performed, for both 1P and 2P, considering only the technique with 1 plate, there is a higher mechanical resistance of the titanium-molybdenum alloy. This can be explained by the fact that both, cpTi and Ti-15Mo, present different metallurgical structures what implies in distinct deformation processes. Probably, when the cpTi plate enters the permanent deformation process (plastic deformation), the Ti-15Mo plate still is in the elastic deformation process.

Also, it is important to point out that the combined use of cpTi (bone plate material) and Ti-6Al-4V (screw material), may lead to galvanic corrosion because they are different metals with different electrochemical potentials (Silva et al., 1990). Thereby, the ideal scenario is to use the same material for the manufacture of the plates and screws.

More, the literature showed that the vanadium (V) and aluminum (Al) release in the Ti-6Al-4V alloy could induce Alzheimer’s disease, allergic reaction, and neurological disorders (Mark & Waqar, 2007). Therefore, the development of titanium alloys targeted for biomedical applications are highly required, fact that corroborate with this study, once the titanium-molybdenum-based alloy used, as published elsewhere (Oliveira et al., 2007, 2011), is composed of biocompatible and non-toxic elements.

1.6 Conclusion

According to the methodology used and based in the results obtained, it can be concluded that the fixation of a linear fracture of the mandibular angle, favorable to displacement, is more resistant to mechanical testing when fixed with the 2 plates technique. Moreover, we suggest that the plates and screws be made of the same material.

Acknowledgements

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Conflict of Interest: None declared.

1.7 References

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Figures

1.8 Figures

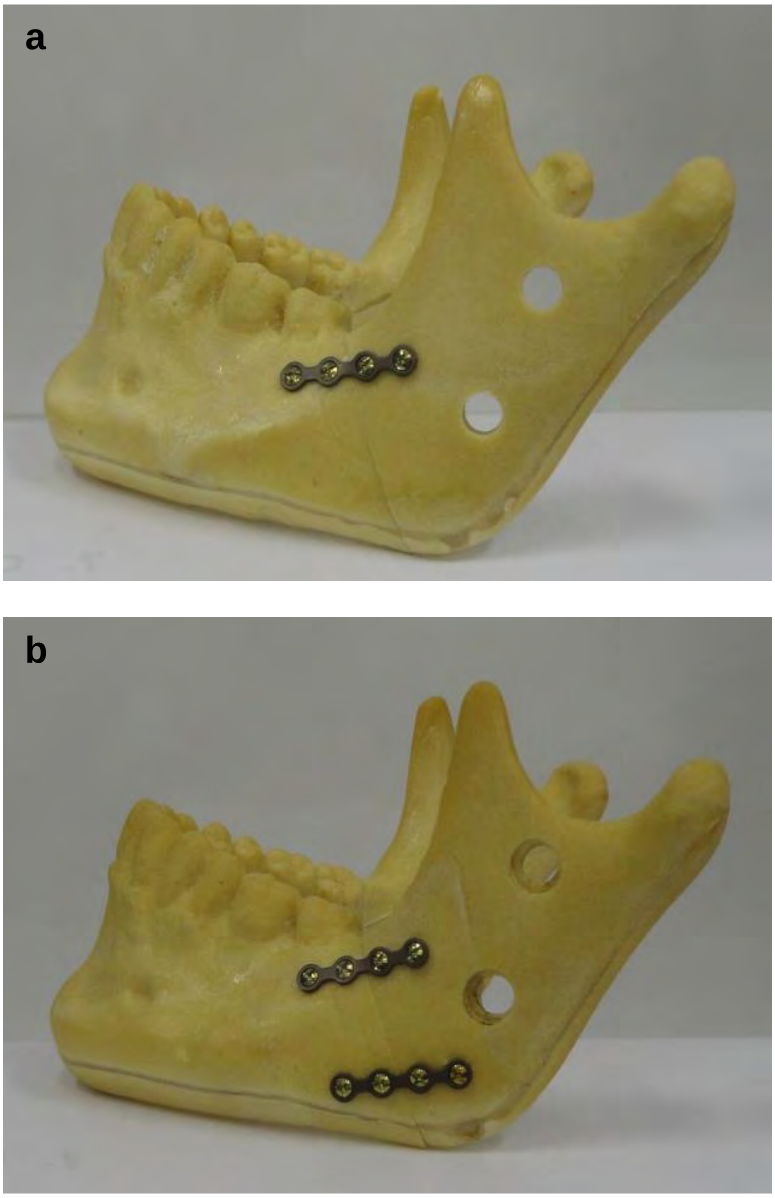

Figure 1. The location of the titanium-based system for both internal fixation techniques, (a) 1 plate and (b) 2 plates.

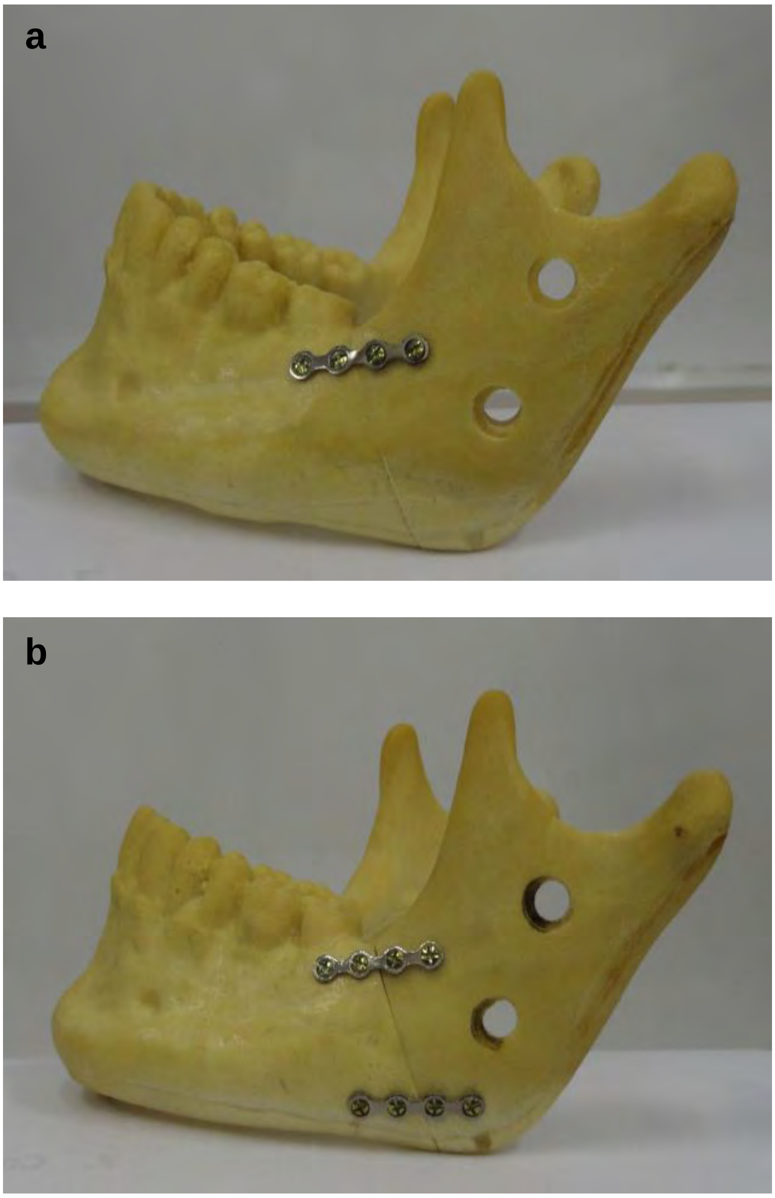

Figure 2. The location of the titanium-molybdenum-based system for both internal fixation techniques, (a) 1 plate and (b) 2 plates.

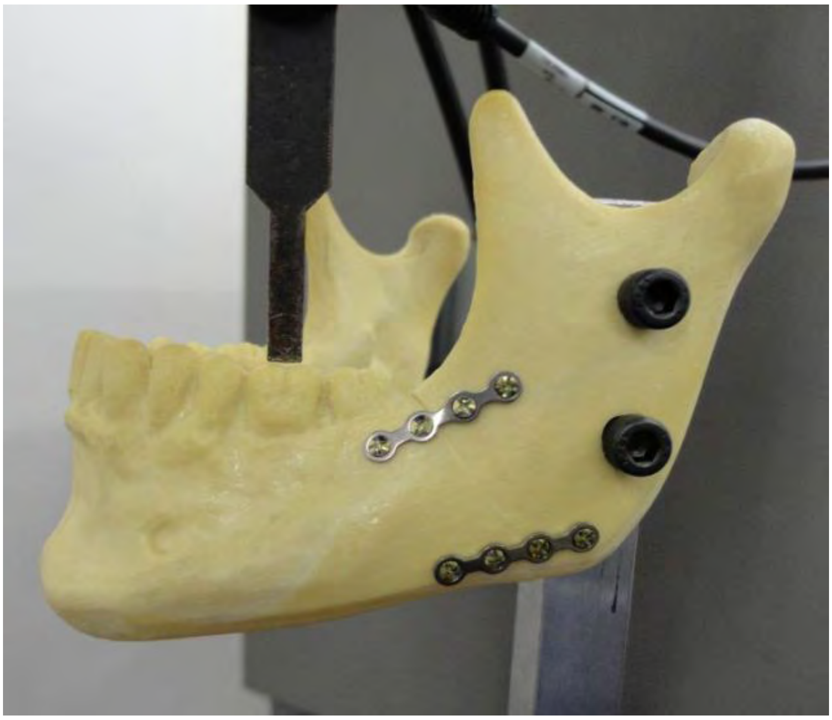

Figure 3. Vertical linear load applied at the first inferior molar, during the mechanical test on a servo-hydraulic machine.

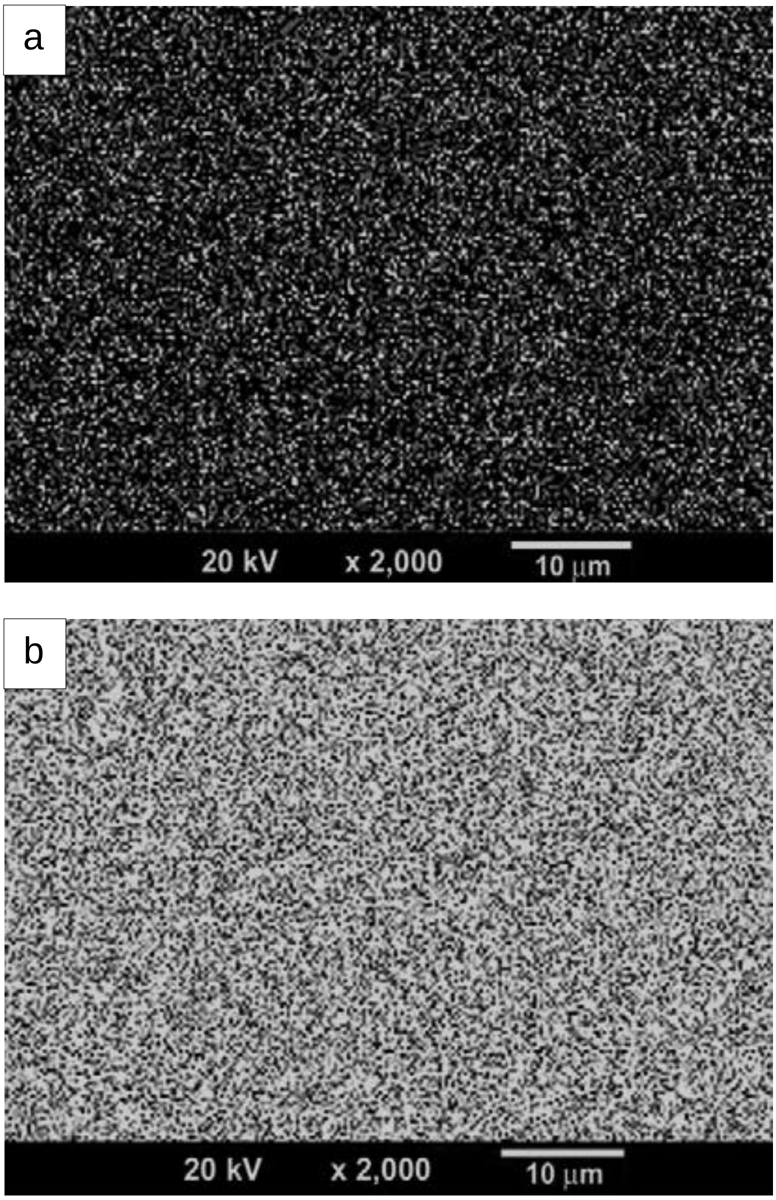

Figure 4. SEM micrograph of Ti-15Mo alloy sample; (a) Mo mapping (white points) and (b) Ti mapping (white points) of the Ti-15Mo alloy sample. Magnification 2.000X.

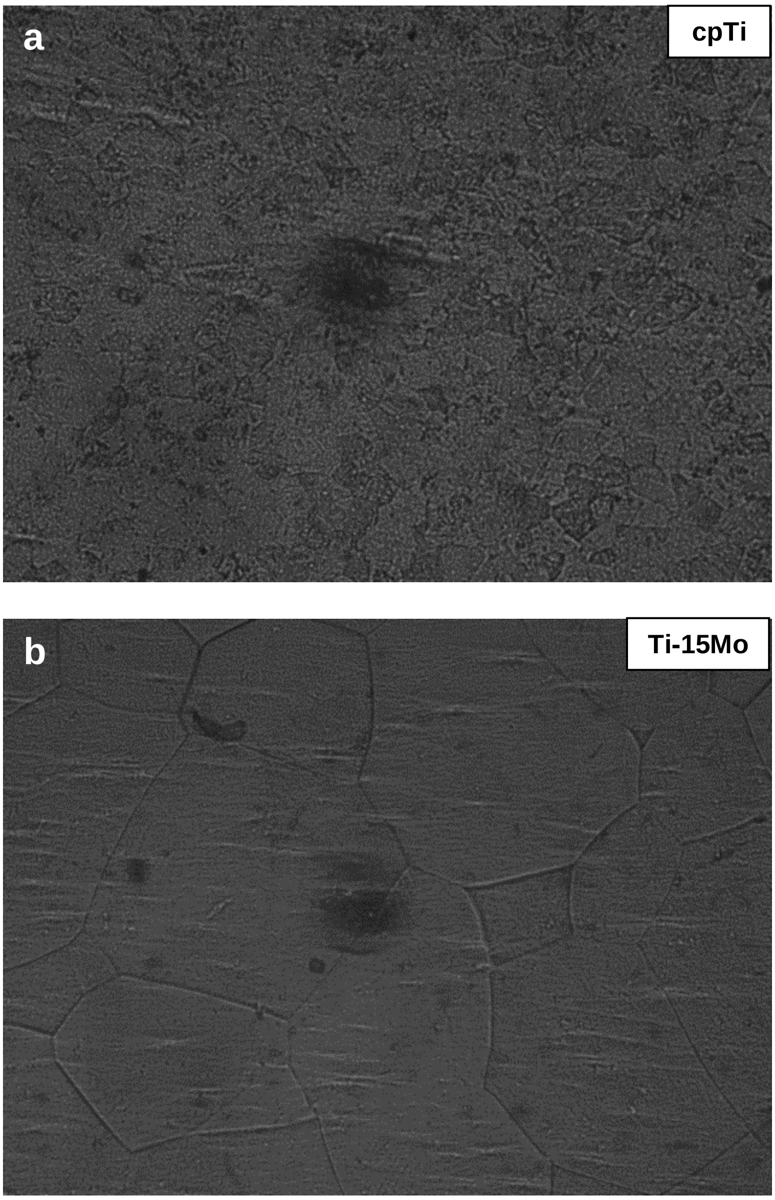

Figure 5. Optical microscopy of the plates, after the surface attack with Kroll solution, revealing the microstructures of the (a) cpTi and the (b) Ti-15Mo alloy. Magnification 500X.

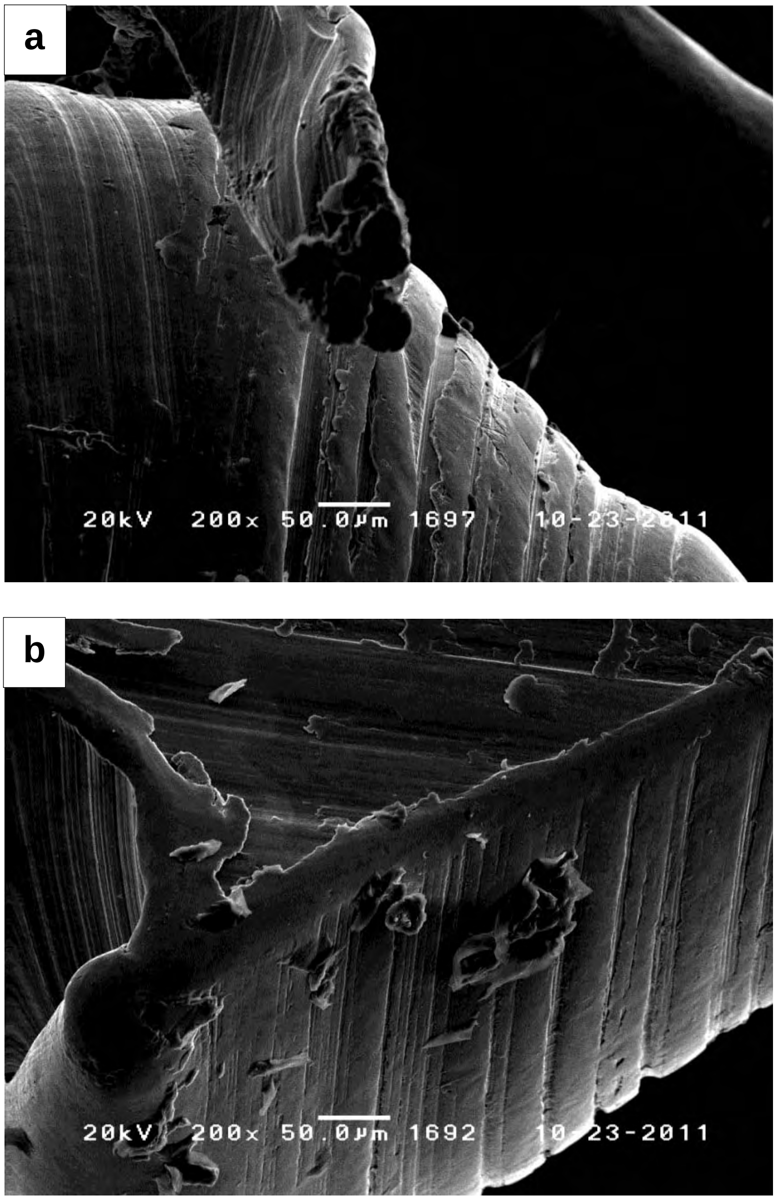

Figure 6. SEM micrograph showing the screw (Ti-6Al-4V) morphology; (a) screw tip and (b) screw thread. Magnification 200X.

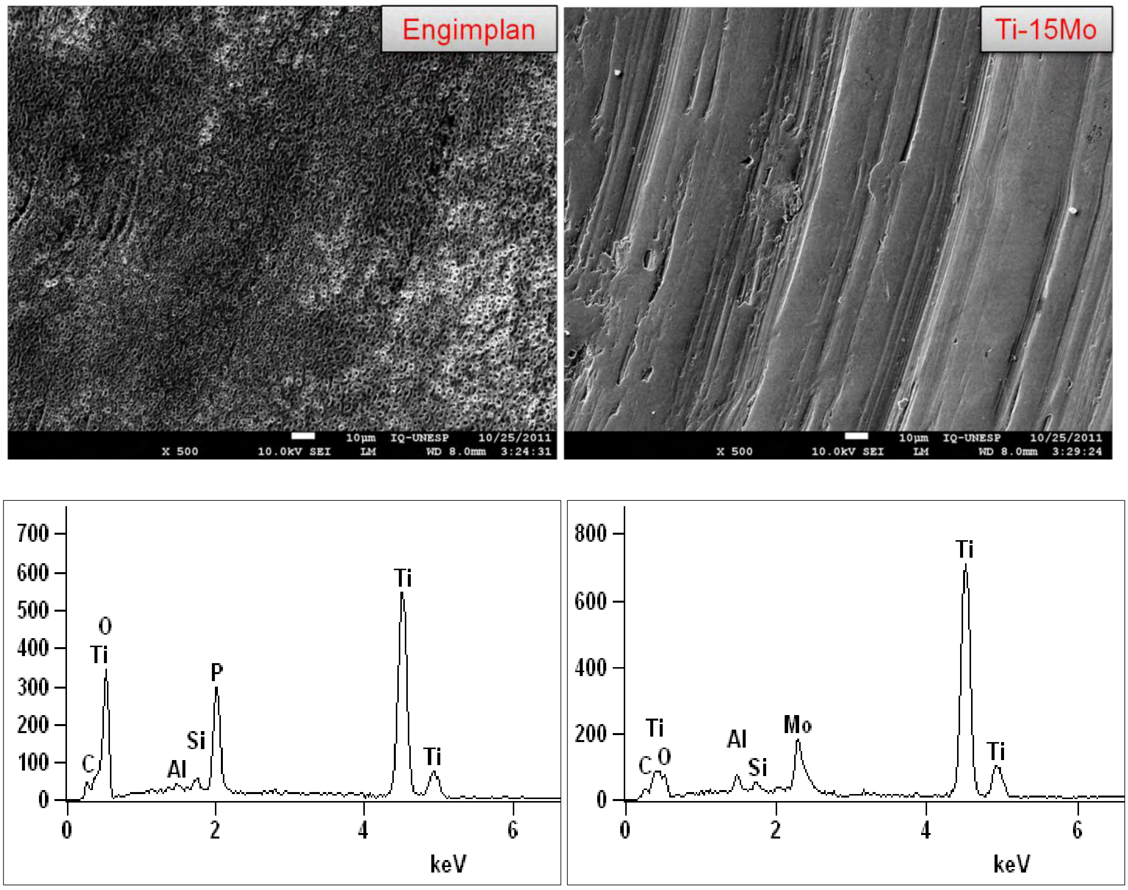

Figure 7. (top) SEM micrograph showing the plates (Engimplan e Ti-15Mo) morphology (plate thread); (bottom) EDX of the same surfaces. Magnification 500X.

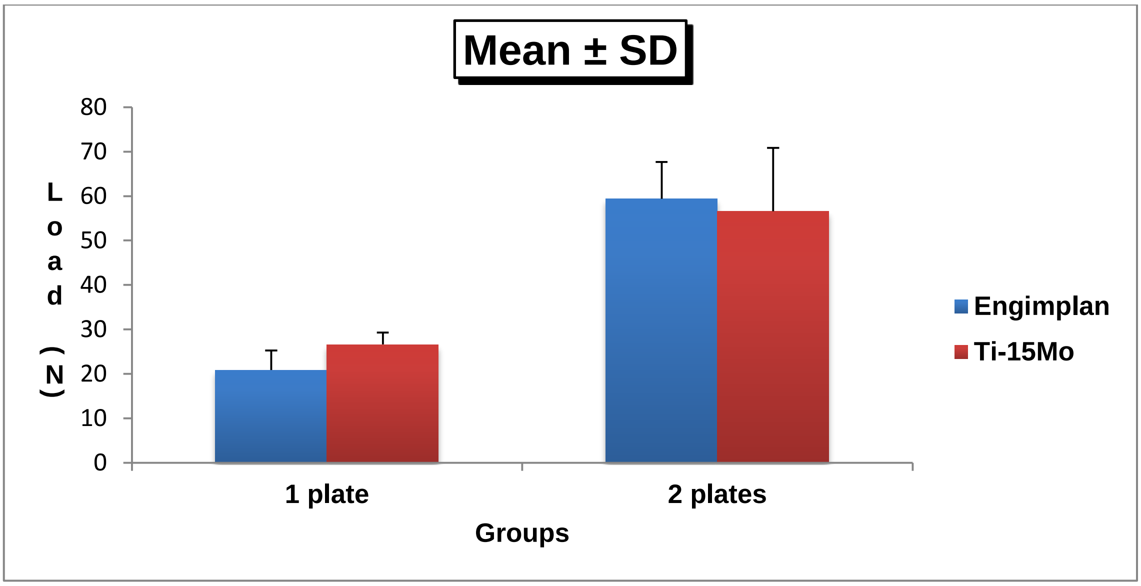

Figure 8. Mean and standard deviation (SD) of the results obtained in the biomechanical analysis, considering the material of the bone plates and the internal fixation technique employed (two-factor factorial ANOVA).

Tables

1.9 Tables

Table 1 - Chemical analysis for Ti-15Mo alloy ingots (wt %).

	Surface Mean ± SD	Bulk Mean ± SD	p value*
EDX	15.13 ± 0.25	15.11 ± 0.26	> .9999
EDXRF	14.86 ± 0.19	15.14 ± 0.32	.2499

* The p values are considered not significant.

Table 2 - Mean and Standard Deviation (SD) of the loads obtained during the mechanical test, for all groups.

GROUPS				
	Engimplan		Ti-15Mo	
	1 plate	**2 plates**	**1 plate**	**2 plates**
Mean	20.80 N	59.40 N	26.60 N	56.50 N
SD	±4.06	±7.70	±2.50	±13.20

Capítulo 2

2. Capítulo 2

3D FEA OF THE STRESS DISTRIBUTION WITHIN DIFFERENT METAL PLATES AND SCREWS AND INTERNAL FIXATION TECHNIQUES, IN MANDIBULAR ANGLE FRACTURES

Periódico para publicação do Capítulo 2: International Journal of Oral and Maxillofacial Surgery, Anexo B

2.1 Abstract

Purpose: Conduct a computational, laboratory-based comparison of the mechanical stability of 2.0 non-compression plates made of commercially pure titanium and a titanium-molybdenum alloy and two methods of internal fixation, employed in favorable to displacement mandibular angle fractures, using 3D finite element analysis.

Material and Method: A CT scan of a synthetic mandible was performed. After the CT scan, the geometric model was reconstructed in Mimics 13.1. Then, the file was reconstructed in a graphic design program (SolidWorks) and a simple mandibular angle fracture, unfavorable for treatment, was simulated. The samples were divided into 4 groups, according to the plate material and internal fixation technique: group Eng 1P, one 4-hole plate and 4 screws 6 mm long, in the tension zone of the mandible; group Eng 2P, two 4-hole plates, one in the tension zone of the mandible and the other in the compression zone, the first was fixed with 4 screws 6 mm long and the second with 4 screws 12 mm long. The same groups were created for the titanium alloy (Ti-15Mo). The plates and screws were modeled in the graphic design program SolidWorks and adapted to the mandible. The finite element mesh and the numerical analysis were performed using the finite element software, ANSYS Workbench 10.0.For the computational simulation, a 100 N compressive load was applied to the occlusal surface of the mandibular 1st molar on the plated side. The results were analyzed considering the von Mises equivalent stress (σvM) for the plates and screws.

Results: When considering the von Mises equivalent stress (σvM) values for the comparison between both groups (Eng and Ti-15Mo) with 1 plate, an decrease of 10.5% in the plate and an decrease of 29.0% in the screws for the titanium-molybdenum-based group was observed. Also, when comparing the same groups with 2 plates the relevant fact was an decrease of 28.5% in the screws for the Ti-15Mo group.

Conclusion: The titanium-molybdenum alloy plates substantially decreased the stress concentration in the screws for both internal fixation techniques.

Keywords: Finite element analysis; mandible; fracture fixation, internal; titanium; molybdenum.

2.2 Introduction

The treatment of mandibular fractures has been the focus of some controversy due to the frequency of this trauma as well as the treatment difficulty in healing a sensitive load-bearing region that is susceptible to infection. These fractures most commonly occur in 20- to 40-year-old males as the result of personal assault, falls, or motorized vehicle accidents (Gabrielli et al., 2003).

In recent years, there have been many studies concerned with the development of new bone-plates with appropriate mechanical properties to improve fractured bone healing. Precise evaluation of the mechanical stresses that develop in a fractured mandible is essential.

The literature includes two main ways to reduce stress shielding and damage to the bone's blood supply in the fractured bone. The first way is modification of the bone-plate material. The second is reduction of the contact between the bone and the plate. Little work has been done to investigate the combined effects of these two parameters on stress shielding in the fractured bone.

Various types of internal fixation devices like bone-plates are used to promote bone structure stabilisation (Kim et al., 2010; Kharazia et al., 2010). The bone-plates should be biocompatible and have the appropriate mechanical properties for supporting the fractured bone (Kharazia et al., 2010; Uhthoff et al., 2006; Lovald et al., 2009; Ramakrishna et al., 2004; Veerabagu et al., 2003). Conventional bone-plates that are made of metals such as cobalt-chromium (Co, Cr, Mo), stainless steel (SS) and titanium alloys (Ti) are commonly used to treat bone fractures. These plates have acceptable bio-compatibility, provide excellent reduction in the number of bone fragments and have the necessary strength to stabilise and support the fracture.

Titanium alloy is the most commonly used material in the manufacture of miniplates and screws because of its stiffness, strength and biocompatibility. It is these properties that help to maintain the relative position of the bone segments. Rigid internal fixation procedures have improved the prospects of healthy bone union and lowered the rate of mal-union and non-union (Uckan et al., 2001).

The primary goal of a bone plate should be to provide the maximum stability in the bone fracture region with a minimum amount of implanted material. Achieving this goal will reduce patient complications, time in surgery, and overall patient discomfort. Greater biomechanical understanding allows the designer to take a more structural perspective on the design and the composition of bone plates.

Finite element analysis (FEA), a computational technique, originally developed by engineers to model the mechanical behavior of structures such as buildings, aircraft, and engine parts, can determine the displacements, stresses, and strains over an irregular solid body given the complex material behavior and the loading conditions imposed on that body. FEA has been used previously to evaluate the treatment of facial fractures (Fernandez et al., 2003; Wagner et al., 2002; Lovald et al., 2006, 2009) and its use in evaluating plating techniques has been confirmed (Lovald et al., 2006).

Thus, the objective of the present study was to conduct a computational, laboratory-based comparison of the biomechanical stability of 2.0 noncompression plates made of cpTi grade 2 (control group) and a titanium alloy (Ti-15Mo; experimental group) and two methods of internal fixation, employed in favorable to displacement mandibular angle fractures, using 3D finite element analysis.

2.3 Material and Method

To create the 3D finite element model, it was necessary to build geometric structures of the mandible, the plates and the screws. A computed tomography (CT) scan of a synthetic dentate mandible model (Nacional®, Jaú, SP, Brazil) made of polyurethane (Figure 1), with barium marker in its composition, was performed to obtain *dicom* format images.

After the CT scan, the data set format was imported into Mimics 13.1 (Interactive Medical Image Control System, Materialise Inc., Leuven, Belgium), for the reconstruction of the geometric model. To simplify the modeling, operations to obtain the segment of the mandible involving only part of the body (with the 1st and 2nd molars), the lower half of the ramus and the mandibular angle (Figure 2) were performed. After obtaining this segment, the file was reconstructed in a graphic design program (SolidWorks 2010, Dassault Systèmes SolidWorks Corporation, Concord, MA, USA) and a simple mandibular angle fracture, favorable to displacement, was simulated, following a procedure described in the literature (Bregagnolo et al., 2011) (Figure 3).

The samples were divided into 4 groups, according to the plate material and internal fixation technique employed. Group Eng 1P was fixed with 1 straight 4-hole plate and 4 monocortical screws 6 mm long, in the tension zone of the mandible. Group Eng 2P was fixed with 2 straight 4-hole plates, one in the tension zone of the mandible and the other in the compression zone. The first was fixed with 4 monocortical screws 6 mm long and the second with 4 bicortical screws 12 mm long. The same groups were created for the titanium alloy (Ti-15Mo). There was a small amount of clearance between the modeled plate and bone, as seen in clinical situations (Caraveo et al., 2008).

The 2.0-mm titanium-based system group used in this study was provided by Engimplan® (Rio Claro, SP, Brazil): 1 straight 4-hole plate, 1 self-tapping screw 6 mm long and 1 self-tapping screw 12 mm long. The experimental metallic alloy used (Ti-15Mo; ASTM F2066-08), was developed by the Biomaterials Group (IQAr - UNESP), to be applied as biomaterial (Oliveira et al., 2007, 2008, 2009, 2011).

Note: In accordance with the manufacturer's specifications, the plates are made of cpTi grade 2 (ASTM F67-06) and the screws are made of the titanium alloy Ti-6Al-4V (ASTM F136-12a).

The modeling of the plates and screws was performed in SolidWorks 2010 (Figure 4) (Dassault Systèmes SolidWorks Corporation, Concord, MA, USA SolidWorks Corp., Concord, MA, USA). To assist the modeling and the production of these models, a plate and a screw were analyzed in an optical microscope (Axiophot, Zeiss DSM-940 A, Oberkochen, Germany) using a software (Zeiss DSM-940 A, Oberkochen, Germany) through which images and measurements of the characteristics of each object were made to support the modeling in SolidWorks 2010.

After the models' generation with the plates and screws in Solidworks, they were imported in .igs (Initial Graphics Exchange Specification) format into ANSYS Workbench 10.0 (Swanson Analysis Inc., Houston, PA, USA) to generate the finite element mesh and to perform the numerical analysis (Figure

5). The mesh refinement was established based on the convergence of analysis (6%). The number of nodes and elements obtained after the modeling for 1 plate was 37,261 and 22,916, respectively, and for 2 plates was 71,518 and 44,239, respectively. The materials were considered isotropic, homogeneous and linearly elastic, with all interfaces considered perfectly bonded. Their mechanical properties, used for the numerical analysis, are shown in Table 1.

For the computational simulation, a 100 N compressive load was applied to the occlusal surface of the mandibular 1st molar on the plated side perpendibular to the occlusal plane. As boundary condition, the cross section of the mandibular ramus was fixed in the Cartesian axes (x = y = z = 0). The FEA was conducted at the Department of Dental Materials and Prosthodontics, Araçatuba School of Dentistry (UNESP).

The results were analyzed considering the following criteria: von Mises equivalent stress (σvM) for the plates and screws (Almeida et al., 2011). Comparison of the results of each tested model was made by descriptive statistical analysis, since n=1.

2.4 Results

The Von Mises stress's scalar running from minimum stress value (blue) to the maximum value (red) represented the general effective stress of the plates and screws. The contour map of the mandible model showed that von Mises stress (MPa) decreased gradually with distance from the loading region; little stress was found at the angle region (Figure 6).

The von Mises stress (σvM) distributions predicted in the plates and screws for all groups are presented in Table 2. The results of the von Mises equivalent stress levels for each group are shown in Figures 7 through 10.

When considering the von Mises (MPa) equivalent stress (σvM) values (Table 2) for the comparison between both groups (Eng and Ti-15Mo) with 1 plate, an decrease of 10.5% in the plate and an decrease of 29.0% in the screws for the titanium-molybdenum-based group was observed. Also, when comparing the same groups with 2 plates the relevant fact was an decrease of 28.5% in the screws for the Ti-15Mo group.

2.5 Discussion

The finite element method is a suitable tool to conduct comparative stress investigations in the field of maxillofacial surgery and to make inferences that will enable more efficient designs of osteosynthesis systems (Knoll et al., 2006).

Several authors have reported on the accuracy of finite element analysis in describing the biomechanical behavior of bone specimens (Hart et al., 1992; Korioth et al., 1997; Voo et al., 1996). There are several studies on biomechanics of the mandible that used FEA to investigate the stress-strain distribution and rigidity comparison for both fixation of fractured mandibles and fixation of saggital split osteotomies.

Vollmer et al (2000) found a high correlation between this method and in vitro measurements on mandibular specimens. Clinical extrapolations from mathematical models may not give absolutes, but they can provide a detailed description of the stresses within natural variability (Wagner et al., 2002).

The purpose of surgical fixation for mandibular fractures is to secure the reduced fragments during osteogenesis to permit sound healing. Inevitable frequent masticatory loads can cause motion at the fracture site, and interfere with the healing process. As a result, nonunion can occur. Also, inadequate stabilization or reduction of the fractured bone, are important causes of nonunions (Mathog et al., 2000).

During the fracture healing period, premature failure of the plates must be prevented. The loads transmitted through the plates should not exceed the limit of strength of the material (Tams et al., 1999). The literature supports that stability in the fracture region is the best protection against complications (Gabrielli et al., 2003). Further, the aim of general orthopaedics should be to reduce the volume and quantity of any implanted material (Kim et al., 2001).

An ideal internal fixation method should obtain maximum rigidity between the segments while exerting minimum stress on the surrounding tissue for proper healing. Excessive stress around fixative appliances may cause gradual resorption of the surrounding bone and loosening of the screws (Ellis 3rd & Esmail, 2009) The data obtained in the present study showed an decrease of approximately 29% in the screws when the Ti-15Mo alloy was used for both plating techniques.

Titanium and its alloys are widely used as biomaterials in load bearing sites as dental and orthopedic implants, because of their high mechanical properties, corrosion resistance, and biocompatibility (Geetha et al., 2009). The disadvantage for the use of pure Ti as implant materials is its low strength and insufficient hardness (Aparicio et al., 2003). Thus, the Ti-6Al-4V alloy is preferentially in clinical use because of its favorable mechanical properties. However, some studies showed that the vanadium (V) and aluminum (Al) release in the Ti-6Al-4V alloy could induce Alzheimer’s disease, allergic reaction, and neurological disorders (Mark & Waqar, 2007).

Therefore, the development of titanium alloys targeted for biomedical applications are highly required, because they have excellent specific strength and corrosion resistance and the best biocompatibility among metallic biomaterials. Then the research and development on titanium alloys composed of non-toxic elements were started, and are under development with the increasing continuing in common (Kuroda et al., 1998; Niinomi, 1998; Okazaki et al., 1998; Oliveira et al., 2007, 2011), facts that support and are in full agreement with our study.

It is well known that the stress transfer between an implant device and a bone is not homogeneous when Young's moduli of the implant device and the bone are different; this is defined as stress shielding. In such conditions, bone atrophy occurs and leads to the loosening of the implant and refracturing of the bone (Sumitomo et al., 2008). Therefore, it is desirable if the stiffness (Young's modulus) is not too high compared to that of bone. Young's moduli of the most widely used stainless steel for implant devices, SUS316L stainless steel and Co-Cr alloys, are around 180 GPa and 210 GPa, respectively (Niinomi, 2002). Titanium and its alloy, Ti-6Al-4V ELI, which are widely used for constructing implant devices, have a Young's modulus around 110 GPa. However, this value is still higher than that of the bone, that is, 10-30 GPa (Niinomi, 1998).

Ti alloys are grouped into α-, (α + β)-, and β-type alloys. Young's moduli of α- and (α + β)-type titanium alloys such as Ti and Ti-6Al-4V ELI are higher than those of β-type titanium alloys. Therefore, β-type titanium alloys are advantageous for the development of titanium alloys with low Young's modulus for biomedical applications (Niinomi & Nakai, 2011). The titanium-molybdenum-based alloy used in this study, as published elsewhere (Oliveira et al., 2007), is an β-type alloy, with low Young's modulus (75GPa - ASTM F2066-08), composed of biocompatible and non-toxic elements.

When designing bone plates design, material selection, and biocompatibility are the three important considerations. The bone plate must be strong enough to support the load normally placed on the bone while the bone heals. The plate must also have stiffness similar to that of the bone to which it is attached. The stiffness of the bone plate is important because the stress shielding will increase with the difference in stiffness. Stress shielding is the phenomenon in which the implant bears most of the load normally placed on the bone.

Although bone is an anisotropic material, Korioth et al. (1992), showed that isotropic models of the mandible were capable of discerning meaningful stress differences when replicating functional loading. The properties of bone used in our study were compatible with those used by Sato et al. (2012). As in most reported studies, we assumed that the materials (synthetic bone, plates and screws) were homogenous, isotropic and presented linear elastic behavior, characterized by their 2 material constants (Young's modulus and Poisson's ratio).

The boundary conditions in the FE models represent the loads imposed on the structures under study and their fixed counterparts, and restraints. Loads placed on craniofacial FE models are often oversimplified, because of their inability to reproduce the multiplicity of lines of action of the masticatory muscles. In this study, a compressive load was applied to the occlusal surface of the mandibular 1st molar on the plated side perpendibular to the occlusal plane, which has been shown to generate the highest fracture-site callus strain and exhibits the largest muscle recruitment activity (Lovald et al., 2009).

This model still far from being realistic, however, our simulations, like most finite element simulations, were based on an idealized model to which idealized properties (Young's modulus and Poisson's ratios) were assigned.

2.6 Conclusion

According to the methodology used and based in the results obtained, we can conclude that the titanium-molybdenum alloy plates substantially decreased the stress concentration in the screws for both internal fixation techniques. Also, the volume of the bone plates can be reduced, maintaining the same mechanical resistance.

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Patient permission: Not required.

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Figures

2.8 Figures

Figure 1. Synthetic mandible before the CT scan.

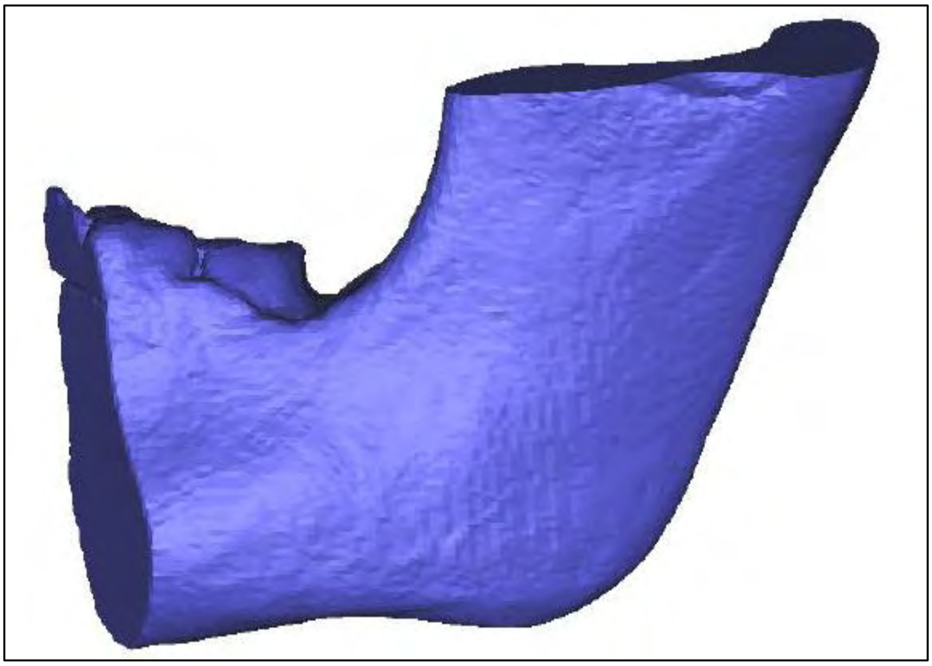

Figure 2. Geometric model of the mandibular segment (Mimics 13.1) involving only part of the body (with the 1st and 2nd molars), the lower half of the ramus and the mandibular angle.

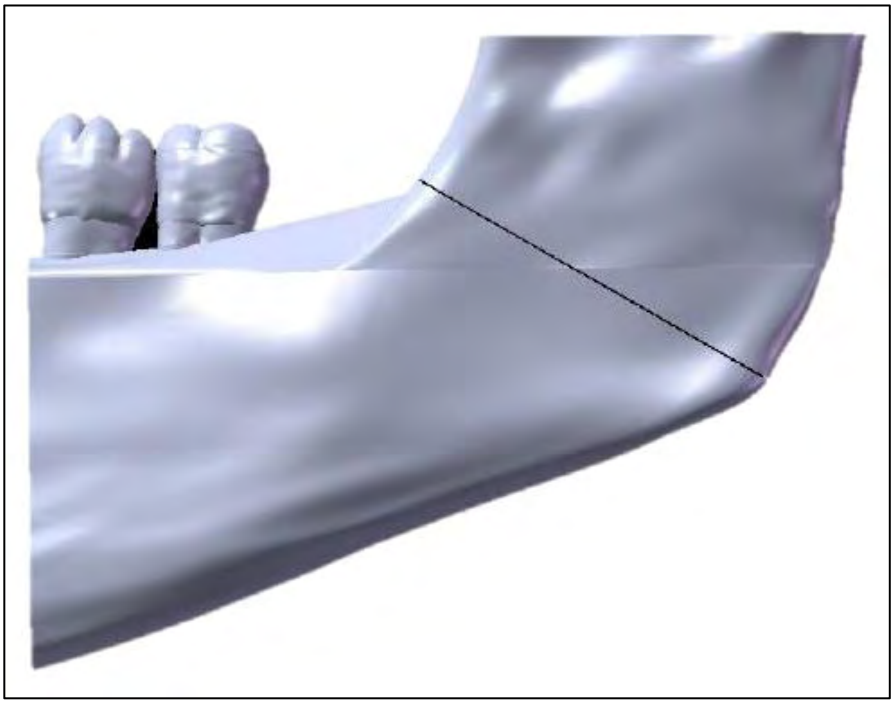

Figure 3. Reconstruction of the mandible segment (SolidWorks 2010) simulating the fracture in the mandibular angle.

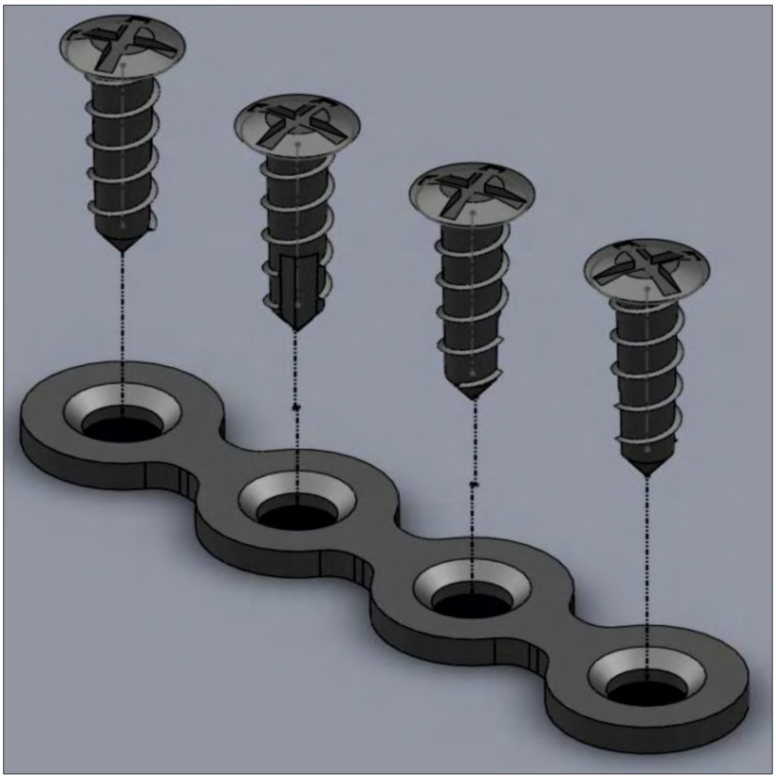

Figure 4. Geometric models of the plate and the screws (SolidWorks 2010).

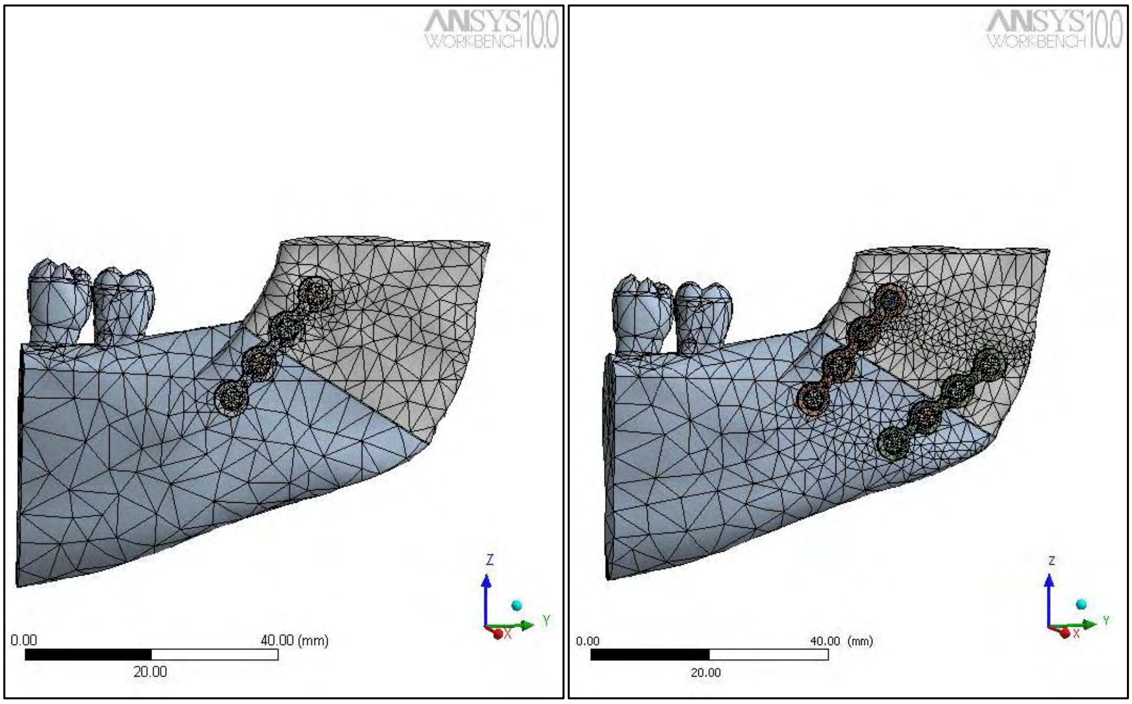

Figure 5. Meshed models showing the 2 plate configurations analyzed in the study: (left) 4-hole monocortical tension band plate at the superior border, and (right) 4-hole monocortical tension band plate and 4-hole bicortical compression band plate at the inferior border.

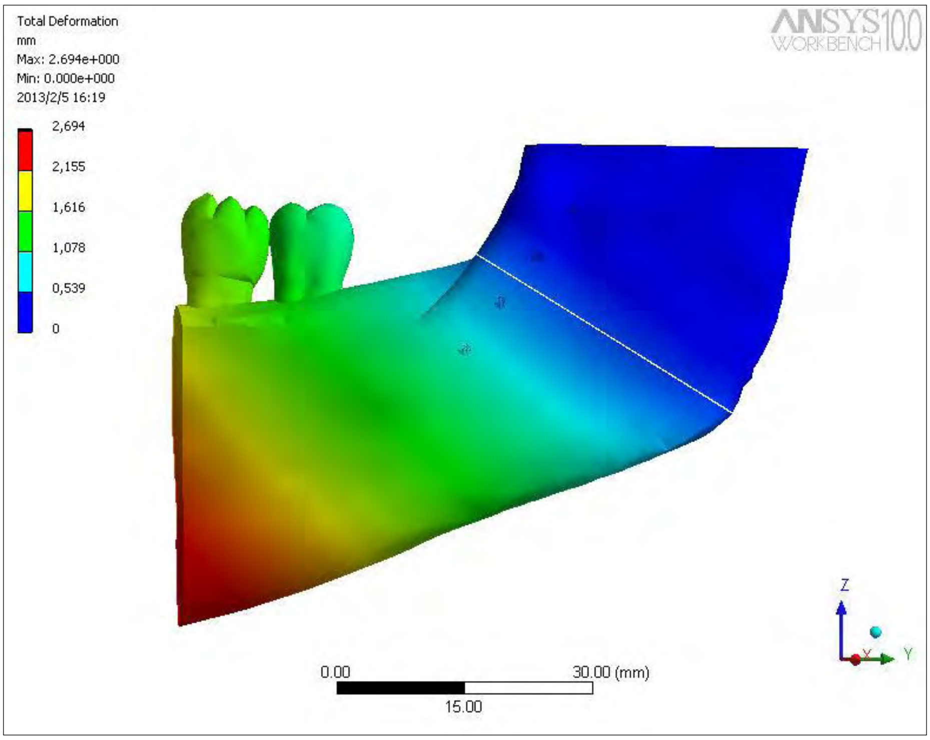

Figure 6. Stress distributions in the mandibular model by a 100 N vertical load.

Stress was mainly located around the loading region (1st molar).

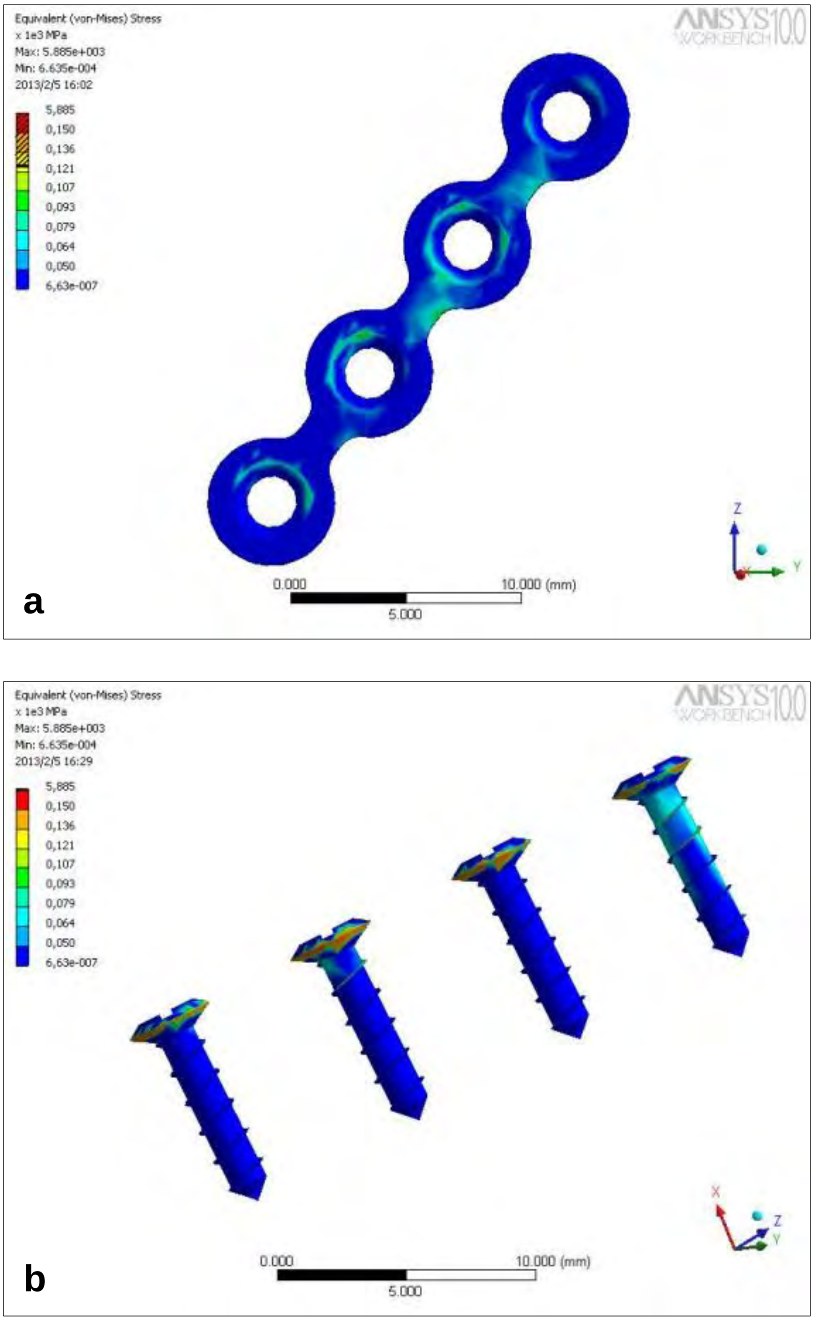

Figure 7. Group Eng 1P: von Mises equivalent stress (σvM) for the (a) plate and (b) the screws.

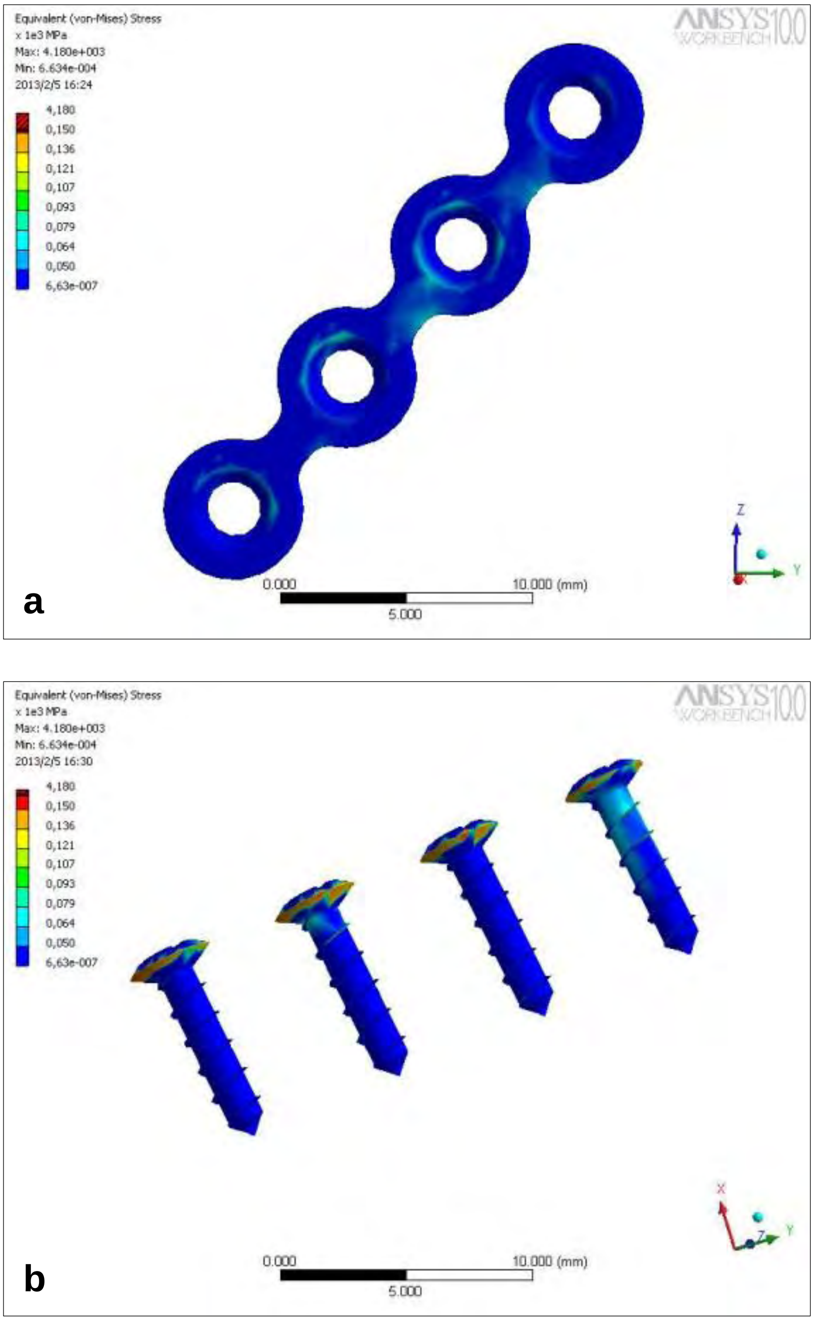

Figure 8. Group Ti-15Mo 1P: von Mises equivalent stress (σvM) for the (a) plate and (b) the screws.

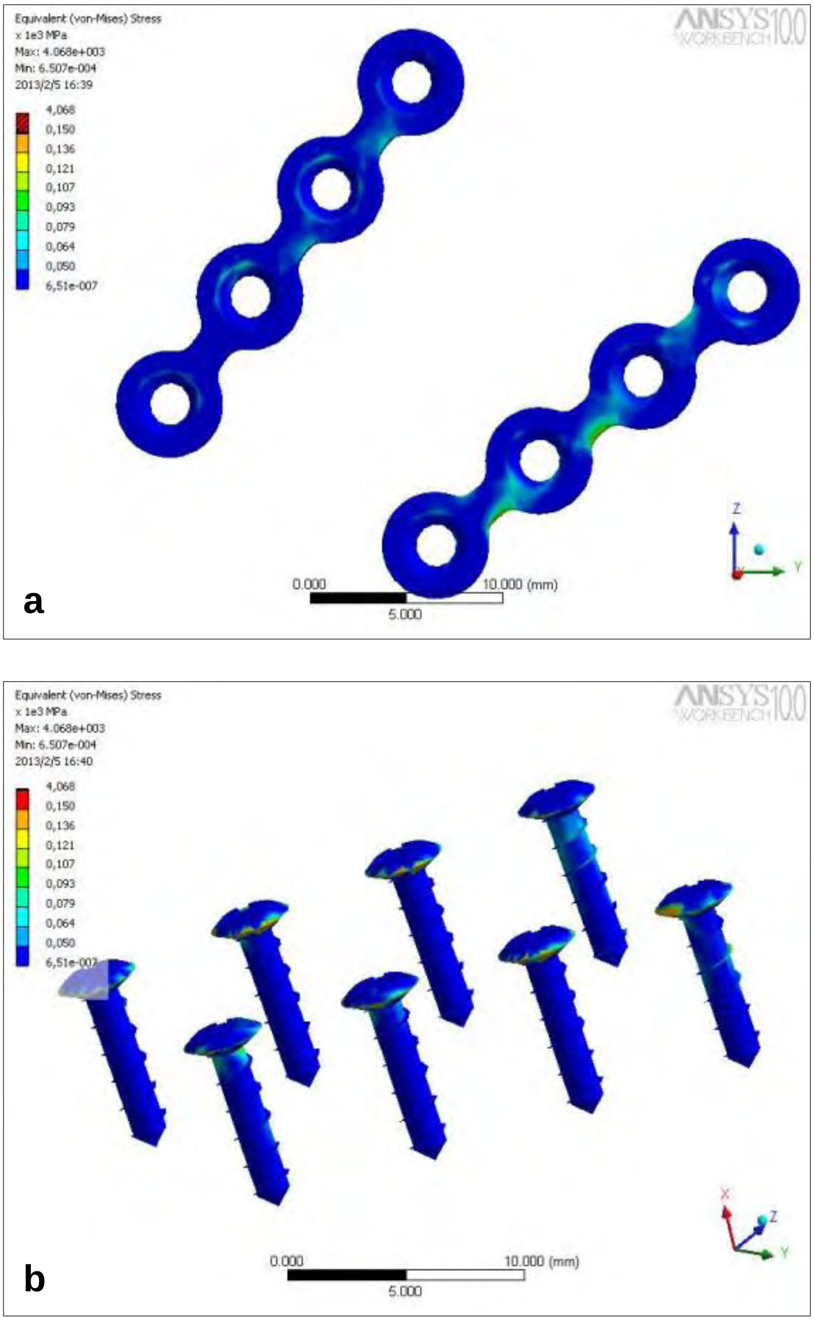

Figure 9. Group Eng 2P: von Mises equivalent stress (σvM) for the (a) plates and (b) the screws.

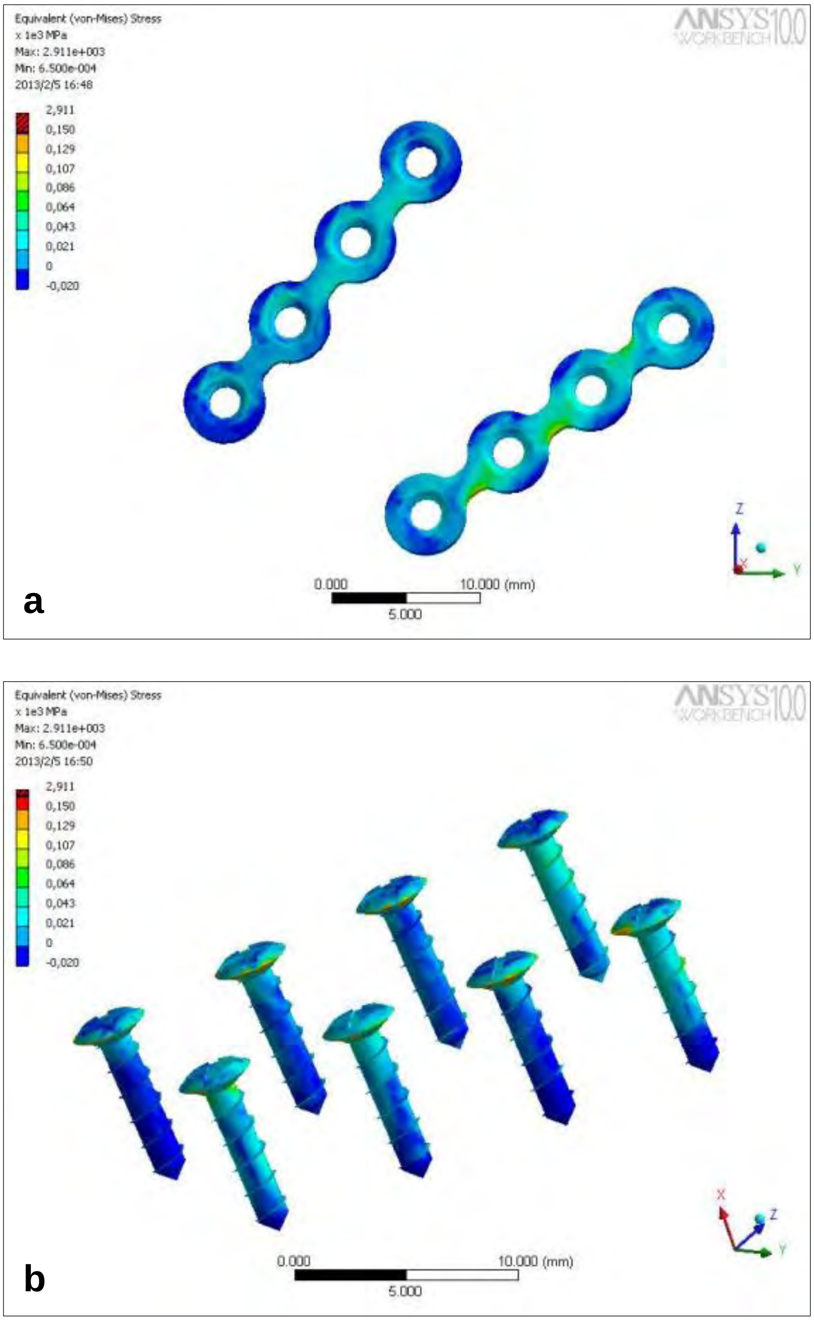

Figure 10. Group Ti-15Mo 2P: von Mises equivalent stress (σvM) for the (a) plates and (b) the screws.

Tables

2.9 Tables

Table 1 - Mechanical properties (Elasticity modulus and Poisson's ratio) of the materials.

Materials	Elasticity modulus (GPa)	Poisson’s ratio
Synthetic mandible*	0,624	0,34
cpTi grade 2 (control)**	100-110	0,34
Ti-15Mo (experimental)***	75-80	0,30
Ti-6Al-4V (screw)****	110-120	0,34

*Sato et al., 2012

**ASTM F67-06

***ASTM F2066-08

**** ASTM F136-12a

Table 2 - Von Mises (MPa) equivalent stress (σvM) values.

	Plates	Screws
Eng 1 plate	**126**	**5885**
Ti-15Mo 1 plate	**113**	**4179**
Eng 2 plates	**167**	**4068**
Ti-15Mo 2 plates	**166**	**2911**

Anexos

ANEXO A - NORMAS DO PERIÓDICO **JOURNAL OF CRANIOFACIAL SURGERY (JCS)**, SELECIONADO PARA A PUBLICAÇÃO DO CAPÍTULO 1.

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Conflicts of Interest and Source of Funding: A has received honoraria from Company Z. B is currently receiving a grant (#12345) from Organization Y, and is on the speaker's bureau for Organization X – the CME organizers for Company A. For the remaining authors none were declared.

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Manuscripts that do not adhere to the following instructions will be returned to the corresponding author for technical revision before undergoing peer review.

Title page: Include on the title page (a) complete manuscript title; (b) authors' full names, highest academic degrees, and affiliations; (c) name and address for correspondence, including fax number, telephone number, and e-mail address; (d) address for reprints if different from that of corresponding author; and (e) sources of support that require acknowledgment.

The title page must also include disclosure of funding received for this work from any of the following organizations: National Institutes of Health (NIH); Wellcome Trust; Howard Hughes Medical Institute (HHMI); and other(s).

Unstructured abstract and key words: Limit the abstract to 250 words. It must be factual and comprehensive. Limit the use of abbreviations and acronyms, and avoid general statements (eg, "the significance of the results is discussed"). List three to five key words or phrases.

Text: Organize the manuscript into four main headings: Introduction, Materials and Methods, Results, and Discussion. Define abbreviations at first mention in text and in each table and figure. If a brand name is cited, supply the manufacturer's name and address (city and state/country). Acknowledge all forms of support, including pharmaceutical and industry support, in an Acknowledgments paragraph.

Abbreviations: For a list of standard abbreviations, consult the **Council of Biology Editors Style Guide** (available from the Council of Science Editors, 9650 Rockville Pike, Bethesda, MD 20814) or other standard sources. Write out the full term for each abbreviation at its first use unless it is a standard unit of measure.

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Journal article

1. Farkas LG, Tompson B, Phillips JH, et al. Comparison of anthropometric and cephalometric measurements of the adult face. *J Craniofacial Surg* 1999;10:18-25

Book chapter

2. Todd VR. Visual information analysis: frame of reference for visual perception. In: Kramer P, Hinojosa J. eds. *Frames of Reference for Pediatric Occupational Therapy*. Philadelphia: Lippincott Williams & Wilkins, 1999:205-256

Entire book

3. Kellman RM, Marentette LJ. *Atlas of Craniomaxillofacial Fixation*. Philadelphia: Lippincott Williams & Wilkins 1999

Software

4. **Epi Info** [computer program]. Version 6. Atlanta: Centers for Disease Control and Prevention; 1994

Online journals

5. Friedman SA. Preeclampsia: a review of the role of prostaglandins. Obstet Gynecol [serial online]. January 1988;71:22-37. Available from: BRS Information Technologies, McLean, VA. Accessed December 15, 1990

Database

6. CANCERNET-PDQ [database online]. Bethesda, MD: National Cancer Institute; 1996. Updated March 29, 1996

World Wide Web

7. Gostin LO. Drug use and HIV/AIDS [**JAMA** HIV/AIDS web site]. June 1, 1996. Available at: http://www.ama-assn.org/special/hiv/ethics. Accessed June 26, 1997

Figures:

A) Creating Digital Artwork

1. Learn about the publication requirements for Digital Artwork: http://links.lww.com/ES/A42
2. Create, Scan and Save your artwork and compare your final figure to the Digital Artwork Guideline Checklist (below).
3. Upload each figure to Editorial Manager in conjunction with your manuscript text and tables.

B) Digital Artwork Guideline Checklist

Here are the basics to have in place before submitting your digital artwork:

- Artwork should be saved as TIFF, EPS, or MS Office (DOC, PPT, XLS) files. High resolution PDF files are also acceptable.
- Crop out any white or black space surrounding the image.
- Diagrams, drawings, graphs, and other line art must be vector or saved at a resolution of at least 1200 dpi. If created in an MS Office program, send the native (DOC, PPT, XLS) file.
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- Each figure must be saved and submitted as a separate file. Figures should not be embedded in the manuscript text file.

Remember:

- Cite figures consecutively in your manuscript.
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Would authors please note that the reference style for the journal has now changed. Please pay special attention to the guidelines under the heading "References" below

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(2) drafting the article or revising it critically for important intellectual content
(3) final approval of the version to be submitted.

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