UNICAMP

CRISTINA JARDELINO DE LIMA

MECHANICAL AND PHOTOELASTIC ANALYSIS OF CONVENTIONAL SCREWS AND CANNULATED SCREWS FOR SAGITTAL SPLIT OSTEOTOMY FIXATION: A COMPARATIVE STUDY

ANÁLISE MECÂNICA E FOTOELÁSTICA DE PARAFUSOS CANULADOS E PARAFUSOS CONVENCIONAIS PARA FIXAÇÃO DE OSTEOTOMIAS SAGITAIS: ESTUDO COMPARATIVO

Piracicaba
2014

UNICAMP

Universidade Estadual de Campinas

Faculdade de Odontologia de Piracicaba

CRISTINA JARDELINO DE LIMA

ANÁLISE MECÂNICA E FOTOELÁSTICA DE PARAFUSOS CANULADOS E PARAFUSOS CONVENCIONAIS PARA FIXAÇÃO DE OSTEOTOMIAS SAGITAIS: ESTUDO COMPARATIVO

MECHANICAL AND PHOTOELASTIC ANALYSIS OF CONVENTIONAL SCREWS AND CANNULATED SCREWS FOR SAGITTAL SPLIT OSTEOTOMY FIXATION: A COMPARATIVE STUDY

Tese apresentada à Faculdade de Odontologia de Piracicaba da Universidade Estadual de Campinas, como parte dos requisitos exigidos para obtenção do Título de Doutora em Clínica Odontológica, na Área de Concentração em Cirurgia e Traumatologia Buco-maxilo-faciais.

Thesis presentes to the Piracicaba Dental School of the University od Campinas in partial fulfillment of the requirements for the degree of Doctor in Odontologic Clinic, in maxillofacial area

Orientador: Prof. Dr. Roger William Fernandes Moreira

Este exemplar corresponde à versão final da tese defendida por Cristina Jardelino de Lima e orientada pelo Prof. Dr. Roger Willian Fernandes Moreira.

Roger Moreira

____

Assinatura do Orientador

Piracicaba
2014

Ficha catalográfica
Universidade Estadual de Campinas
Biblioteca da Faculdade de Odontologia de Piracicaba
Marilene Girello - CRB 8/6159

	Lima, Cristina Jardelino de, 1985-
L628a	Análise mecânica e fotoelástica de parafusos canulados e parafusos convencionais para fixação de osteotomias sagitais : estudo comparativo / Cristina Jardelino Lima. – Piracicaba, SP : [s.n.], 2014.
	Orientador: Roger William Fernandes Moreira. Tese (doutorado) – Universidade Estadual de Campinas, Faculdade de Odontologia de Piracicaba.
	1. Osteotomia sagital do ramo mandibular. 2. Cirurgia ortognática. I. Moreira, Roger William Fernandes,1971-. II. Universidade Estadual de Campinas. Faculdade de Odontologia de Piracicaba. III. Título.

Informações para Biblioteca Digital

Título em outro idioma: Mechanical and photoelastic analysis of conventional screws and cannulated screws for sagittal split osteotomy fixation : a comparative study
Palavras-chave em inglês:
Osteotomy, sagittal split ramus
Orthognathic surgery
Área de concentração: Cirurgia e Traumatologia Buco-Maxilo-Faciais
Titulação: Doutor em Clínica Odontológica
Banca examinadora:
Roger William Fernandes Moreira [Orientador]
Marcelo Marotta Araújo
Alessandro Costa da Silva
Raul Seabra Guimarães Neto
Erica Cristina Marchiori
Data de defesa: 28-07-2014
Programa de Pós-Graduação: Clínica Odontológica

UNIVERSIDADE ESTADUAL DE CAMPINAS
Faculdade de Odontologia de Piracicaba

A Comissão Julgadora dos trabalhos de Defesa de Tese de Doutorado, em sessão pública realizada em 28 de Julho de 2014, considerou a candidata CRISTINA JARDELINO DE LIMA aprovada.

Prof. Dr. ROGER WILLIAM FERNANDES MOREIRA

Prof. Dr. MARCELO MAROTTA ARAÚJO

Prof. Dr. ALESSANDRO COSTA DA SILVA

Prof. Dr. RAUL SEABRA GUIMARÃES NETO

Profa. Dra. ÉRICA CRISTINA MARCHIORI

ABSTRACT

The aim of the present study was to use mechanical and photoelastic tests to compare the performance of cannulated-screws with that of solid-core screws in sagittal split osteotomy fixation. Ten polyurethane mandibles, with a prefabricated sagittal split ramus osteotomy, were fixed with the inverted L technique and allocated to the following groups: CSG Group, fixed with three 2.3-canullated-screws and SCSG Group, fixed with three 2.3-solid-core-screws. Vertical linear loading tests were performed. The differences between mean values were analysed using the T test for independent samples. The photoelastic test was carried out using a polariscope. The results revealed that there were only differences between the two groups at 1 mm of displacement, at which point the cannulated-screw exhibited more resistance. The photoelastic test confirmed higher stress concentration close to the mandibular branch in the solid-core group. Cannulated-screws performed better than solid-core screws in photoelastic tests and in a mechanical test at 1 mm displacement.

Keywords: sagittal osteotomy; orthognathic surgery

RESUMO

O objetivo do presente estudo foi comparar, por meio de testes mecânicos e fotoelásticos, o desempenho de parafusos canulados em relação a parafusos convencionais, ambos do sistema 2,3 mm, utilizados na fixação de osteotomia sagital do ramo mandibular. Dez réplicas de mandíbulas humanas fabricadas em poliuretano e uma em resina fotoelástica (Nacional, Jaú, SP, Brazil) foram utilizadas em cada grupo e fixadas em L invertido. Foram realizados testes de carregamento linear vertical em uma máquina de ensaio universal (Instron Corporation, Norwood, MA). O teste Shapiro-Wilk foi realizado para verificar a presença de normalidade entre os resultados ($p<0,05$), em seguida o teste T foi utilizado para verificar a diferença entre as médias. O teste fotoelástico foi realizado, com o auxílio de um polariscópio plano. A avaliação dos dados do teste fotoelástico foi qualitativa e descritiva. Os resultados mecânicos obtidos demonstraram diferença entre os grupos apenas no deslocamento de 1mm, no qual o parafuso canulado provou ser mais estável. Os resultados da análise fotoelástica revelaram maior tensão entre os parafusos superior anterior e inferior, sendo o parafuso posterior superior o que sofreu menor carga de estresse, o teste revelou ainda franjas de tensão na região de ramo mandibular no grupo convencional. De acordo com os resultados do presente estudo foi possível concluir que os parafusos canulados cônicos apresentaram melhor desempenho nos testes mecânicos em 1 mm de deslocamento e nos testes fotoelásticos, sendo uma opção viável para a fixação da osteotomia sagital do ramo mandibular.

Palavras-chave: Osteotomia sagital. Cirurgia ortognática.

SUMÁRIO

Dedico essa dissertação à mulher mais importante da minha vida – ***Maria Luiz Jardelino de Lima***. Minha mãe, meu exemplo de vida. Pessoa honesta, humilde e humana. Mãe presente, em todos os momentos da minha vida.

AGRADECIMENTOS

Finalizada essa etapa singular e de extrema importância em minha vida, não poderia deixar de agradecer a todos aqueles que fazem parte da minha história e que me fizeram uma pessoa mais humana e muito mais feliz.

À ***Deus***, por me permitir viver. Por ser capaz de abrir tantas portas, as quais consideradas por muitos impossíveis.

À minha mãe ***Maria Luiz Jardelino De Lima,*** pelo exemplo de vida, força, perseverança e fé, sempre presente em minha vida, me apoiando incondicionalmente nas minhas decisões com todo amor e carinho, mesmo sem entender exatamente o que eu faço.

Ao meu pai ***José Jardelino de Lima*** *in memoriam* pelos exemplos de integridade e disciplina que foram fundamentais para minha formação pessoal.

Ao meu pai por opção ***José kenneng Alves***, por todo apoio e carinho dedicado desde o primeiro momento em que entrou na minha vida.

Aos meus irmãos ***Mônica Luiz Jardelino de Lima, Jardel Jardelino de Lima e Luciana Jardelino de Lima*** pelo apoio, companheirismo, incentivo e admiração que sempre tiveram comigo.

À ***Faculdade de Odontologia de Piracicaba*** – Universidade Estadual de Campinas, pela possibilidade oferecida para minha formação e por toda infraestrutura disponível aos alunos.

Ao Reitor da Universidade Estadual de Campinas, ***José Tadeu Jorge***, e ao diretor da Faculdade de Odontologia de Piracicaba, ***Jacks Jorge Júnior***, pelo excelente trabalho realizado em nossa instituição.

Ao ***Prof. Dr. Roger Willian Fernandes Moreira*** por ter me escolhido como orientada, pela compreensão das minhas necessidades, pela amizade e paciência. Por hoje ser, na minha vida, exemplo de competência a ser seguido e, mais que isso, exemplo de pessoa de bom coração. Roger eu quero ser assim quando crescer! Nunca vou esquecer o que você fez por mim e pelos colegas ao meu redor.

Aos ***membros do Departamento de Cirurgia e Traumatologia Buco-Maxilo-Facial*** da faculdade de odontologia de Piracicaba, que, com seu trabalho diário, permitem um ótimo funcionamento do setor.

Aos professores ***João Sarmento Pereira Neto, Fábio Ricardo Loureiro Sato*** e ***Rafael Ortega Lopes*** pela preciosa contribuição durante o exame de qualificação.

Ao ***Departamento de Materiais Dentários*** da Faculdade de Odontologia de Piracicaba - Unicamp em nome do Prof. Dr. ***Lourenço Correr Sobrinho*** pela possibilidade de realização dos experimentos no laboratório do departamento.

Ao engenheiro ***Tóride Sebastião Calegatti Filho*** pela doação do material de osteossíntese utilizado na presente pesquisa.

Ao engenheiro ***Marcos Bianco Cangini,*** do Departamento de Materiais Dentários da Fop-Unicamp pelo auxílio e prestatividade durante a realização dos testes mecânicos.

À ***Universidade Federal Fluminense***, onde dei meus primeiros passos na odontologia e continuei até o mestrado, meu eterno agradecimento.

Aos ***preceptores, e hoje colegas de trabalho,*** que tive em todos os hospitais onde passei durante minha formação, os quais me prepararam para que meu conhecimento fosse capaz de perpetuar o bem a cada paciente que Deus confiar nas minhas mãos.

A todos os colegas do curso de mestrado e doutorado em Cirurgia e Traumatologia Buco-maxilo-facial da FOP-UNICAMP, em especial, ***Danillo Costa Rodrigues e Saulo Gabriel Moreira Falci***, homens totalmente do bem, pelo companheirismo e apoio para que esse trabalho fosse concluído.

Ao ***Dr. Fábio Ricardo Loureiro Sato*** pelos ensinamentos em cirurgia e por ser um exemplo de profissional jovem e dedicado.

À professora e amiga desde o primeiro instante, ***Érica Cristina Marchiori***, por ter sido minha companheira desde o primeiro instante em que tivemos contato. Professora estarei sempre torcendo por você e estarei sempre pronta para ajudá-la sempre que precisar. Amiga que conquistei e levo para vida! Obrigada por tudo!!!

Aos professores ***Marcelo Marotta Araújo, Alessandro Costa Da Silva, Raul Seabra Guimarães Neto,*** por terem aceitado fazer parte da banca de defesa e sem dúvida contribuírem para o aperfeiçoamento do presente trabalho.

Há muito mais a quem agradecer... À todos aqueles que, embora não nomeados, brindaram-me pelo simples fato de fazerem parte da minha vida, por fazerem parte da minha história. Muito obrigada!

INTRODUÇÃO

Sugawara e Mitami (1997) definiram as maloclusões e as deformidades dentofaciais como uma resultante de distorções moderadas ou severas do processo de desenvolvimento normal. Tais deformidades foram descritas como ”desvios nas proporções normais da face e das relações dentais, que são severas demais ao ponto de serem incapacitantes”, as quais, em determinados casos, necessitam de tratamentos corretivos integrados através de ortodontia associado à cirurgia ortognática.

Desde o início das cirurgias para as correções das deformidades faciais, em especial as mandibulares, diversas técnicas foram desenvolvidas e aperfeiçoadas. Schuchardt (1942) foi o primeiro a descrever a osteotomia escalonada através do ramo mandibular por abordagem intra-oral, sendo dessa forma o precursor da técnica da osteotomia sagital do ramo mandibular para correção das deformidades dentofaciais, em especial as que afetam a mandíbula.

Abeloos *et al* (1993) reconheceram que osteotomia sagital do ramo mandibular (OSRM) é o procedimento cirúrgico mais utilizado para a correção das deformidades da mandíbula, servindo tanto para os avanços, como para os recuos mandibulares e ainda para correção de laterognatismo. A técnica atualmente utilizada foi proposta inicialmente por Trauner e Obwegeser em 1957 e ao longo do tempo foi recebendo diversas contribuições, sendo a mesma já bem estabelecida nos dias atuais.

Apesar de a OSRM ter ganho grande credibilidade e aceitação entre os cirurgiões bucomaxilofaciais, algumas questões ainda se fazem presentes. Uma dessas questões diz respeito à técnica de fixação a ser utilizada. Atualmente, diversas técnicas são empregadas para essa fixação, ao contrário da osteotomia propriamente dita que possui pouca variação técnica. Segundo Anucul *et al* (1992), na avaliação das técnicas de fixação, os principais fatores que devem ser testados são: resistência dos materiais e os métodos de fixação frente às forças mastigatórias exercidas sobre as estruturas mineralizadas. Frente a essa grande diversidade de técnicas de fixação, são necessários estudos demonstrando a eficácia e a efetividade de cada uma delas na prática clínica.

Ardary *et al* (1989) reconheceram que no decorrer da evolução da OSRM variadas técnicas de fixação foram propostas, desde a não fixação, fixação não rígida com a utilização de fios de aço até a fixação interna rígida (FIR), com uso de parafusos e/ou placas e parafusos.

Ardary *et al* (1989), Van Sickels *et al* (1991) e Abeloos *et al* (1993), concordaram ser o uso da FIR capaz de proporcionar vantagens como: permitir função mandibular imediata ou precoce, promovendo excelente estabilização e controle do segmento proximal; rápido reparo ósseo e eliminação do uso de bloqueio maxilo-mandibular (BMM) pós-operatório. Paulus e Steinhauser (1982) e Reitzik e Schoorl (1983) reconheceram a melhora das condições para cuidados em higiene bucal quando na utilização da mesma. Assim, a fixação rígida mandibular pode ser realizada de quatro métodos diferentes, são eles: parafusos bicorticais posicionais; parafusos bicorticais compressivos; placas e parafusos monocorticais, e ainda uma combinação de placas e parafusos monocorticais associados a parafusos bicorticais.

Anucul *et al* (1992), quando em estudo sobre as técnicas de fixação de OSRM em movimentos de avanço mandibular e uso de parafusos bicorticais, descreveram que podem ser realizados pelos métodos compressivo, posicional ou a associação destes. Gabrielli (2007) afirmou que de acordo com a via de acesso, podem ser realizados por via intrabucal ou por via transcutânea.

Assim, buscando uma maior estabilização dos segmentos proximal e distal na OSRM, Spiessl, em 1974, relatou a técnica de fixação com parafusos bicorticais compressivos, propondo a técnica conhecida como *lag screw*. Foram utilizados três parafusos do sistema 2,7 mm posicionados por via percutânea e caracterizava-se por promover o efeito de compressão entre os segmentos distal e proximal. A técnica consistia em perfurar a cortical vestibular com broca do mesmo diâmetro que o parafuso a ser utilizado. Após esta primeira perfuração, a cortical lingual é perfurada com broca de menor diâmetro. Assim, o parafuso passa livre pela primeira cortical engajando o segmento proximal e promovendo compressão entre os segmentos. Ellis e Carlson (1983) afirmaram que isto resultava em aumento da área de contato ósseo, permitindo reparo ósseo mais rápido, com restauração da função de forma imediata ou precoce.

O conceito de máximo contato ósseo foi objeto de pesquisa de diversos autores como Paulus e Steinhauser (1982), Ardary *et al* (1989), Lindorf (1986) e Obeid e Lindquist (1991), os quais observaram que fraturas estabilizadas com técnica compressiva reparavam por primeira intenção, sem formação de calo ósseo externo e com diminuição do período de tempo de reparação. No entanto, descreveram como desvantagens a compressão do feixe vásculo-nervoso alveolar inferior e a possibilidade de ocorrência de maior torque condilar.

Ardary *et al* (1989) realizaram estudo comparativo entre dois métodos distintos de disposição de parafusos do sistema 2,0 mm para fixação da OSRM em mandíbulas de cadáveres humanos, por meio de teste de carregamento. Um grupo foi fixado com três parafusos dispostos linearmente próximo à borda superior do ramo e o outro grupo recebeu dois parafusos na borda superior e um parafuso na borda inferior. Submetidos às cargas, o grupo com parafusos na disposição em L invertido foi ligeiramente superior. Com isso, concluiram que a disposição dos parafusos influenciaram no grau de resistência após a OSRM.

Ozden *et al* (2006) usaram mandíbulas frescas de ovelhas submetidas a OSRM e compararam a estabilidade de 10 tipos de fixação. Os autores concluíram que os grupos de parafusos bicorticais no padrão de "L" invertido eram capazes de promover uma maior estabilidade mecânica.

Loukota (2007) e Pilling *et al* (2006) definiram os parafusos canulados como parafusos que possuem um orifício no sentido longitudinal, da base para o ápice, onde podem ser inseridos fios para guiar a inserção do mesmo, durante o ato cirúrgico. Messer *et al* (2002) e Schimidt *et al* (2004) reconheceram que eles foram originalmente desenvolvidos para a realização de artrodese das articulações dos dedos até que Chou *et al* (2012) e Geissler (2006) descreveram sua utilização para fixação percutânea das fraturas dos dedos e dos ossos da mão.

Na região bucomaxilofacial os parafusos canulados foram utilizados para a fixação de fraturas intracapsulares de côndilo mandibular. Loukota (2007) e Pilling *et al* (2006) relataram a utilização desse parafuso guiado por um fio de Kirchner e sua fixação através de um pequeno acesso pré-auricular. Ellis (2012) descreveu que a utilização desse parafuso poderia ser mais simples do que a aplicação dos parafusos do tipo *Lag*-screw. Entretanto, de acordo com a literatura mundial, não existem evidências de que esse tipo de parafuso foi utilizado nas osteotomias sagitais.

Sendo a osteotomia sagital dos ramos mandibulares associada à fixação interna rígida um procedimento amplamente utilizado, este trabalho buscou avaliar a resistência mecânica do conjunto da fixação utilizando a técnica de fixação L invertido com três parafusos bicorticais inseridos perpendicularmente ao corpo mandibular.

Dessa forma, objetivou-se comparar a utilização de um novo parafuso canulado do sistema 2,3 mm em relação aos parafusos convencionais do mesmo sistema, bem como verificar a distribuição das tensões exercidas por estes nos componentes desses sistemas de fixação, procurando assim contribuir com a indústria nacional inserindo no mercado uma nova opção de fixação que poderá ser utilizada em larga escala diminuindo os custos do procedimento.

Essa tese foi desenvolvida em formato alternativo, de acordo com deliberação CCPG 002/06, a qual descreve uma análise comparativa baseada em testes *in vitro,* avaliando a resistência mecânica e fotoelástica dos parafusos canulados e sua similaridade com parafusos convencionais.

OBJETIVO

Avaliar a resistência mecânica dos parafusos canulados em osteotomias sagitais do ramo mandibular.

CAPÍTULO

Mechanical and Photoelastic analysis of conventional screws and cannulated screws for sagittal split osteotomy: A comparative study

Purpose: The aim of the present study was to use mechanical and photoelastic tests to compare the performance of cannulated-screws with that of solid-core screws in sagittal split osteotomy fixation.

Materials and Methods: Ten polyurethane mandibles, with a prefabricated sagittal split ramus osteotomy, were fixed with the inverted L technique and allocated to the following groups: CSG Group, fixed with three 2.3-canullated-screws and SCSG Group, fixed with three 2.3-solid-core-screws. Vertical linear loading tests were performed. The differences between mean values were analysed using the T test for independent samples. The photoelastic test was carried out using a polariscope.

Results: The results revealed that there were only differences between the two groups at 1 mm of displacement, at which point the cannulated-screw exhibited more resistance. The photoelastic test confirmed higher stress concentration close to the mandibular branch in the solid-core group.

Conclusions: cannulated-screws performed better than solid-core screws in photoelastic tests and in a mechanical test at 1 mm displacement.

Keywords: sagittal osteotomy, cannulated screw, orthognathic surgery

1 INTRODUCTION

Malocclusion and dentofacial deformity have been defined as the result of moderate or severe distortions of the normal development process. These deformities have been described as “deviations from the normal proportions of facial and dental relations, which are severe enough to be incapacitating”. In certain cases, they require corrective treatment involving integrated orthodontia associated with orthognathic surgery (*Sugawara and Mitami*, 1997). One of the surgical techiniques used to correct dentofacial deformities is sagittal split ramus osteotomy (SSRO). This technique brings together different qualities in the same surgical procedure. The possibility of separating fragments based on their sagittal character allows several mandibular movements and improves the interfragmentary bone contact (*Trauner and Obwegeser*, 1957; *Dal Pont*, 1961; *Husunck*, 1968; *Epker*, 1977).

Lag screws are recognized as one of the most efficient fixation devices in orthopedic surgery because they provide the maximal amount of interfragmentary compression with the minimal amount of implanted material (*Brasileiro and Passeri*, 2006). Interfragmentary compression can decrease the loads supported by the screw due to the transmission of some of the shearing and rotational forces through the underlying bone, thereby decreasing stress on the screw interface. Compressive stress can be maximized by pretapping the screw hole, which increases the holding power of the screw. The use of “so-called” position screws (non-lagged) increases the load on the screw as maximal interfragmentary compression is not achieved (*Schwimmer* et al, 1994).

Lag screw fixation to stabilize the SSRO of the mandible was introduced in 1976, (*Spiessl*, 1976). However, due to the increase in neurosensory disturbances resulting from compressive forces caused by the lagging technique, as well as the potential for condylar displacement, a number of authors have proposed alternative fixation methods. The use of three bicortical screws, either in lag screw or positional screw techniques, is currently accepted as a very rigid and predictable way to fixate SSRO. Numerous screw patterns can be used, taking advantage of location, angulation, the regions of maximal bone contact and thickness. The perpendicular insertion of positional screws in the inverted L configuration is one of the most critically assessed techniques of rigid internal fixation and is considered the gold standard to which other forms of fixation have been compared in most biomechanical experiments (*Foley*, et al, 1989).

Fixation methods can be assessed empirically by mechanical tests using universal testing machines. Samples made with material that has a modulus of elasticity, similar to that of bone, are capable of simulating fracture fixation. Thus, it is possible to observe the trend of the fixation system behavior when exposed to load (*Foley*, et al, 1989). Ozden et al (2006) used fresh mandibles of sheep subjected to SSRO and compared the stability of 10 fixation types. The authors concluded that groups of bicortical screws in the inverted “L” pattern promoted greater mechanical stability.

The cannulated bone screw has been introduced in recent years and it is becoming increasingly more popular (*Burns*, 2000) due to several advantages: a) guide pins can be used for provisional fixation, enabling a more accurate placement of the screws; b) cannulated screw placement consists of fewer steps than the lag screw technique; c) the cannulated screw reduces the chance of angulational errors since there is no need to view the instrumentation in three dimensions (*Shaw*, 1991; *Leggon* et al, 1993; *Thompson*, et al, 1997). In the worldwide literature, there are two studies about the use of cannulated screws in the maxillofacial region: one study on condylar fractures (*Pilling*, et al, 2006) and another on simphysys fracture (*Falci*, et al, 2014). As yet, there have been no studies on cannulated screws in SSRO.

The aim of the present study was to compare the resistance of solid-core screws and cannulated screws in sagittal split osteotomy fixation using mechanical and photoelastic tests.

2 MATERIAL AND METHODS

2.1 Study Design

The present study did not require ethics committee approval since it was an *in vitro* study and no humans or animals were involved.

Twenty Nacional Ossos® hemimandibles of rigid polyurethane, with a prefabricated SSRO, were used in the mechanical test, with a standardized density of 200 /L (Franceschi & Costa e Silva Ltda. – Jaú, São Paulo - Brazil). Each hemimandible from the same lot was prepared and rigidly attached, with the distal segment repositioned in a 5 mm advancement position. The setting was stabilized by means of bicortical screws in an inverted L pattern. The screws (TORIDE, Mogi Mirim, SP, Brazil) used were 2.3 mm cannulated and solid-core titanium screws. The specimens were divided into two groups. In the first group, 10 synthetic polyurethane hemimandibles were fixed with three bicortical titanium cannulated screws (Cannulated Screw Group- CSG), with a diameter of 2.3 mm. The second group contained 10 synthetic polyurethane hemimandibles fixed with 3 bicortical titanium solid-core screws (Solid-Core Screw Group- SCSG), with a diameter of 2.3 mm, totaling 60 screws (Figure 1a, 1b). The fixation technique used was compressive, providing a single bit for drilling the distal and proximal segments.

2.2 Sample Preparation

All of the screws were applied in an inverted L pattern with two screws placed on the tension, or alveolar, side of the osteotomy and one screw placed on the inferior, or compression, side of the osteotomy, perpendicular to the cortical bone. The length of the screw was calculated to cross both corticals and overlap at least 1 mm of the internal cortical (10 mm length) in both groups. The distance between the screws on the top border was approximately 10 mm, as they were placed in areas that had better contact with the cortical. The most posterior bicortical screw was inserted 5 mm under the retromolar alveolar crest. The inferior screw was installed along the bottom border, in a place where cortical thickness was greater and there was a greater contact area. The distance between the anterior superior screw and the inferior screw was approximately 10 mm, maintaining a distance of 5 mm from the osteotomy line. Guides made of acrylic resin were used to standardize the perforations (Figure 2 a, b).

2.3 Mechanical and Photoelastic Tests

The biomechanical and photoelastic tests were performed using a universal testing machine (Instron Universal 4411; Instron Corporation, Norwood, MA). The adaptation of the polyurethane and photoelastic mandibles in the loading machine was carried out using a metallic support. Once the mandible was fixed in the support, it was positioned perpendicularly to the point of the loading device, where force was initiated. The fixed point of the compression load selected was the central fossa of the first lower molar. The machine was programmed to apply a progressive load at a displacement speed of 1 mm/min. The resistance values were obtained in Newtons (N) when the displacement reached 1, 2, 3, 4, 5, 7, and 10 mm for each sample only once. The photoelastic analysis was conducted using a plane polariscope interposed between the light source and the mandibles. In order to visualize the fringes of tension in the SSRO fixation, the mandible was embedded with transparent mineral oil. The loading machine was programmed to apply a progressive force up to a displacement of 5 mm, at which point a photograph was taken to assess the fringes of tension.

.

2.4 Statistical Analysis

Data from the mechanical tests were collected, organized, and entered into a database using SPSS for Windows, version 17.0 (SPSS Inc., Chicago, IL, USA). Descriptive analysis of the data was then carried out. The Shapiro-Wilk test was performed and revealed a normal distribution of values between the groups. Next, the T test was used to compare the mean values between the groups. The level of significance was set at $p < 0.05$. Descriptive and qualitative data analysis were conducted for the photoelastic test.

3 Results

The resistance to the compression force, as well as the dispersion of the force values, was directly proportional to the displacement in the groups tested (Figure 3). The T test showed statistical differences between the groups at only 1 mm of displacement (Table 1).

Table 1 – Comparison of the resistance loading values between fixation groups

Groups	Displacement	Mean	SD	*p**
Cannulated	1 mm	34,89	10,59	0,024
Solid-core		24,58	7,91	
Cannulated	2 mm	52,42	20,41	0,068
Solid-core		38,24	10,84	
Cannulated	3 mm	64,87	26,57	0,113
Solid-core		49,19	13,47	
Cannulated	4 mm	76,73	29,54	0,091
Solid-core		57,68	16,28	
Cannulated	5 mm	88,42	32,50	0,115
Solid-core		68,37	20,10	
Cannulated	7 mm	112,60	35,78	0,200
Solid-core		92,60	31,37	
Cannulated	10mm	125,33	58,78	0,953
Solid-core		126,84	55,09	

* Teste t for independent samples

The photoelastic test revealed, in both groups, that the highest maximal principal stress of the proximal segment was measured around the superior and inferior anterior screws, with minimal stress distribution in the posterior superior screw. In both groups, the screws that exhibited the greatest concentration of isochromatic fringes were near the anterior area of the fracture (Figure 4). The group of solid-core screws was still able to show the presence of isochromatic fringes in the mandibular branch, confirming that voltage presence dissipated toward the mandibular condyle, which can clinically be considered as an increased risk of fracture in this region.

4 DISCUSSION

The present study assessed the effects of two different types of fixation of SSRO in synthetic models of human mandibles. The results obtained showed that all methods provided satisfactory stabilization of mandibles after the application of mechanical and photoelastic tests to determine the maximal force and displacement of the segments. The authors of the present study proposed the use of cannulated screws due to their excellent clinical and mechanical performance in mandibular SSRO fixation. This study confirmed the hypothesis that the cannulated screw would exhibit a stronger resistance than the other fixation method, as well as adequate distribution.

The choice of setting for the study of SSRO of the mandible was due to its wide acceptance in clinical practice. The SSRO has been performed to correct dentofacial deformities and malocclusion for the last 50 years. During this time, several modifications have been proposed to reduce morbidity and to improve stability. Fixation with miniplates and/or screws improves stability in most instances and enables an early return to preoperative function (*Anacul* et al, 1992; *Hammer*, et al, 1995; *Murphy*, et al, 1997; *Ochs*, 2003). Moreover, the use of stable fixation favors the maintenance of the airway in the immediate postoperative period, as well as improving nutritional support and reducing discomfort for the patient (*Trauner and Obwegeser*, 1957; *Wolford*, et al, 1987).

Synthetic models of human mandibles were used in this study, although there are differences in the modulus of elasticity of fresh and synthetic bones. These models were used because they are easy to obtain, are less costly, and allow for standardization. The literature demonstrates variability in the geometry and mechanical properties between different regions of the mandible and between different cadaveric mandibles (*Bredbenner and Haug*, 2000). Additionally, the material properties of human and animal bone are influenced by age as well as by genetic, environmental, and nutritional factors (*Rho*, et al, 1995). Resistance, as an isolated factor, is not characteristic enough to determine the quality of a material (*Bredbenner and Haug*, 2000). Bone consists of cortical and medullary portions that vary in thickness and height, depending on the region. In the same way, it possesses a changeable modulus of elasticity in its extension (*Rubo and Souza*, 2008).

An ideal internal fixation method should obtain maximal rigidity between segments while exerting minimal stress on the surrounding tissue. Excessive stress around fixative appliances may cause a gradual resorption of the surrounding bone and loosen screws (*Murphy* et al, 1997; *Van Sickels*, et al, 2005). The photoelastic analysis performed in the present study demonstrated the superiority of the CSG, in relation to the SCSG, since the latter exhibited a greater area of fringe voltage afflicting the ramus. At 5 mm of displacement, the group of cannulated screws exhibited fringes close to the previous tension screws.

The results obtained from the photoelastic analysis in the present study corroborated the findings of *Sato* et al, (2012). Both tests exhibited great mechanical resistance when the screws were arranged in an inverted L. Both tests indicated that the greater the proximity of the osteotomized area screws, the greater number of voltage fringes are found close to the previous ones, especially the upper front.

The present study assessed bicortical screws inserted in an inverted L at 90°, which, according to the literature, is the most stable option studied to date. The influence of various screw configurations on fixation strength after SSRO has been previously studied. *Wolford* et al (1987) found that three screws in an inverted L at 90° (bicortical) exhibited the greatest mechanical resistance, followed by the linear 60° bicortical screw pattern and the miniplate with four monocortical screws. The results obtained in the photoelastic analysis showed that the amount and distribution of stress was lower when the inverted L screw arrangement was used, when compared with linear configurations of both 90° and 60°. The same results were found in the fixative appliance when comparing the maximal principal stress between techniques of bicortical screw fixation. This improved stress distribution in the FEA model probably explains the better results obtained by the inverted L distribution mechanical test, when compared with other techniques. This hypothesis had already been proposed based on the results of previous photoelastic analysis (*Wolford*, et al, 1987).

The present study used a 2.3 screw system to increase the stability of fixation, as described by *Shetty*, et al, (1996), who examined the effects of the size of the screw insertion pattern and the functional stability of synthetic replicas of human jaws (7 mm advancement). Screws were positioned in systems of 2.0 mm and 2.4 mm in a linear pattern and an inverted L. After mechanical testing of the compression force applied to the first molars, it was notable that the inverted L position exhibited less displacement of the distal segment than the linear pattern. The 2.4 mm screws exhibited more resistance to displacement than the 2.0 mm screw system (*Sato* et al, 2012).

The present study corroborates the findings from *in vitro* studies using cannulated screws in mandibular symphysis (*Falci*, et al, 2014). Both sets of results confirm the superiority of cannulated screws when it comes to strength and a better distribution of fringes when applying tension load.

Leggon et al (1993) compared cannulated screws and solid-core screws using both cortical and cancellous bone. Using adult canine femora, the midshaft was used as cortical bone and the condyle was used as cancellous bone. The authors concluded that the holding power is similar for cannulated and solid-core screws of similar size and in similar types of bone. Thompson et al (1997) compared large-fragment cannulated and solid-core screws of various lengths and various thread patterns. The investigators used a synthetic polyurethane foam that was designed to have the same mechanical properties as human cancellous bone. They concluded that cannulated and solid-core screws of similar dimension and thread length have similar holding strengths. They also concluded that there was no demonstrable effect on holding power when the screws were inserted, with or without tapping (*Thompson*, et al, 1997).

The present study is an *in vitro* study with limitations that must be recognized. The results of the present study should be carefully extrapolated for clinical situations, given that the substrate can affect results owing to different elasticity moduli in the mandibular bone and polyurethane mandibles (*Cordey*, et al, 2000). These differences in the elasticity moduli were easily recognized during the fixation of polyurethane mandibles. Another limitation is the fact that mechanical load was only applied vertically and perpendicularly in the molar area, which does not occur in the mandible. Mastication and facial musculature enable movements in all directions. Mechanical studies are necessary before applying a new material in a determinated clinical situation. Therefore, further studies are required with other methods, such as biomechanical comparison, photoelasticity, and finite element analysis of cannulated and solid-core groups.

According to the results of the present study, cannulated screws performed better than solid-core screws in photoelastic tests and a mechanical test at 1 mm displacement. Considering the methodological limitations of the present study, it is possible to conclude that cannulated screws could be considered a viable method for sagittal osteotomy in orthognathic surgery.

Figure Legends

FIGURE 1- Method of fixation in the study groups, using inverted L screw disposition for all. **(a)** Cannulated group; **(b)** solid-core group; **(c, d)** screw head zoom.

FIGURE 2- Sample preparation. **(a)** Acrylic resin guide positioned in the mandible for perforation; **(b)** Resin guide removed from the jaw showing the perforation that served as a guide for screw fixation.

FIGURE 3- Box Plot graph showing the dispersion of the compression strength values in newtons (vertical axis) and in milimeters of displacement (horizontal axis). **(a)** Cannulated screw group; **(b)** solid-core screw group.

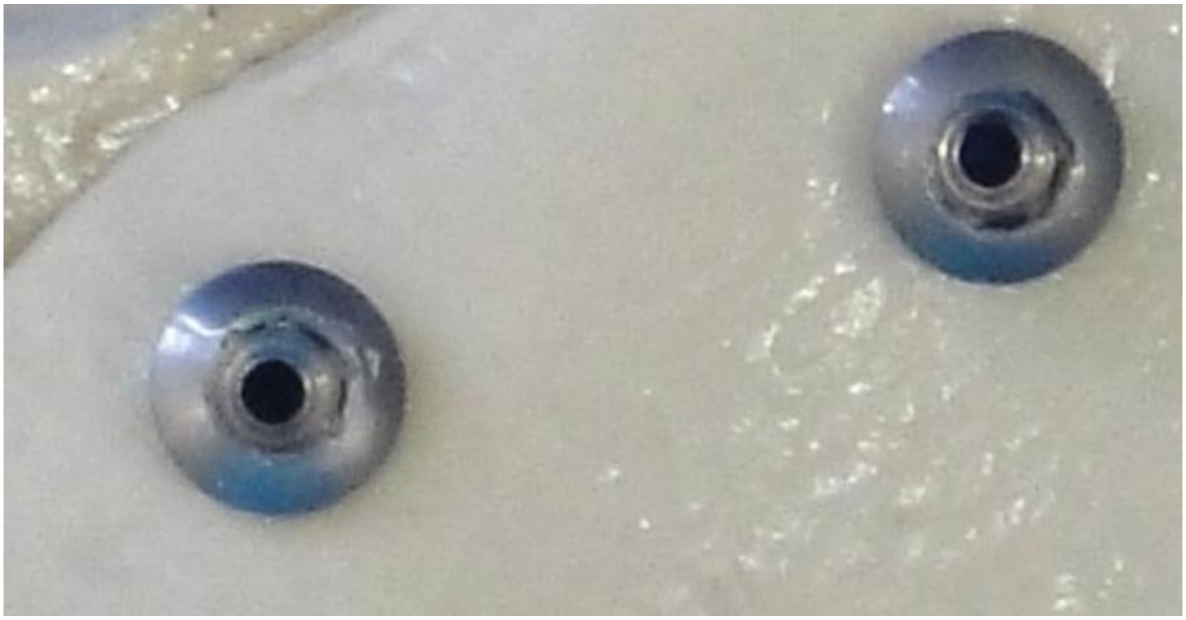
FIGURE 4- **(a)** Photoelastic analysis with 5mm of displacement in the cannullated group; **(b)** Photoelastic analysis with 5mm of displacement in the solid-core group. Note the concentration of tension around the superior and inferior anteriors screws, with minimal stress distribution in the posterior superior screw.

FIGURE 1

a

b

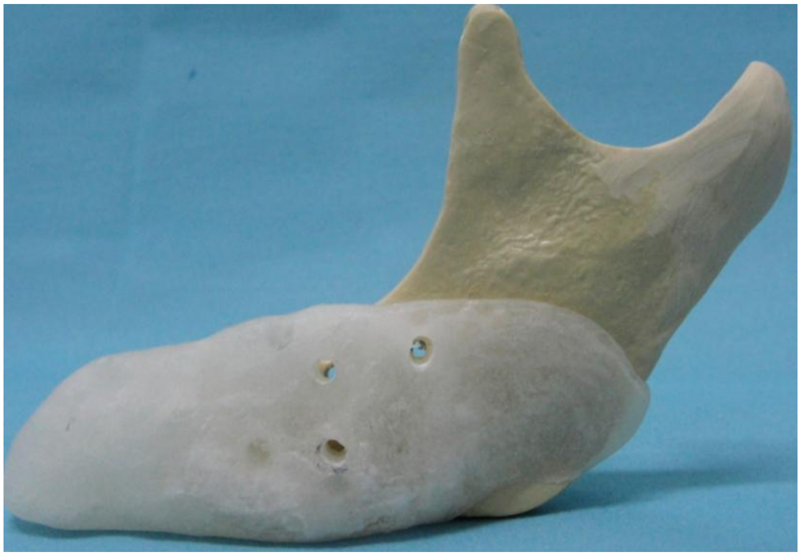
c



d

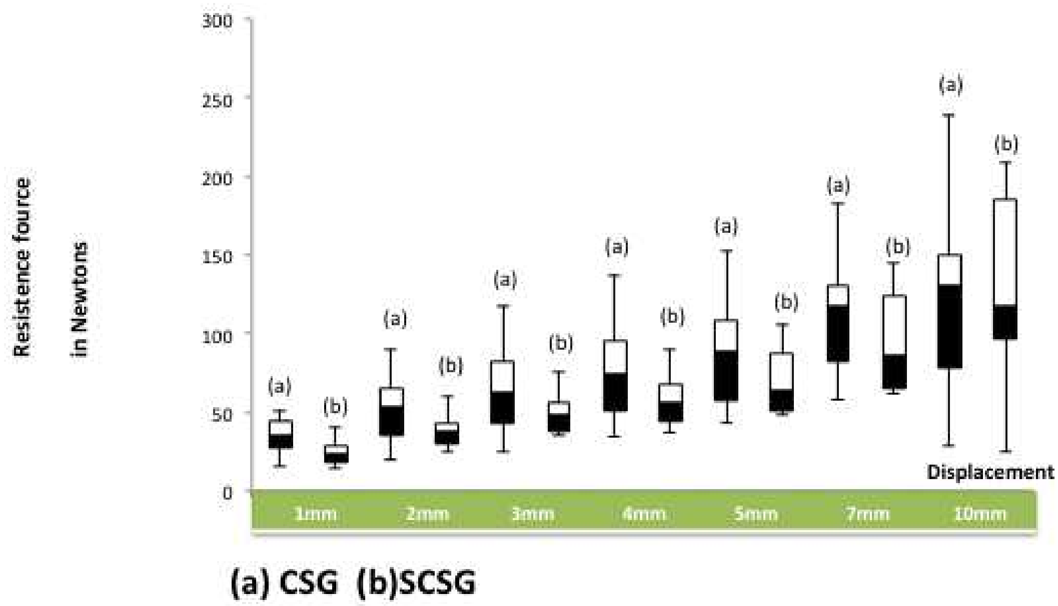
FIGURE 2

a



b

FIGURE 3



Resistence fource
in Newtons
300
250
200
150
100
50
0
(a)
(b)
Displacement
1mm
2mm
3mm
4mm
5mm
7mm
10mm
(a) CSG (b)SCSG

FIGURE 4

a

b

5 REFERENCES*

Anacul B, Waite PD, Lemons JE. In vitro strength analysis of sagittal split osteotomy fixation: noncompression monocortical plates versus bicortical position screws. J Oral Maxillofac Surg. 1992;50:1295.

Brasileiro BF, Grempel RG, Ambrosano GMB, Passeri LA. An in vitro evaluation of rigid internal fixation techniques for sagittal split ramus osteotomies: advancement surgery. J Oral Maxillofac Surg. 2009;67:809-17.

Bredbenner TL, Haug RH. Substitutes for human cadaveric bone in maxillofacial rigid fixation research. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2000;90:574-80.

Burns A. Use of small cannulated screws for fixation in foot surgery. J Am Podiatr Med Assoc. 2000;90:240–6.

Cordey J. Introduction: Basic concepts and definitions in mechanics injury. 2000;31(Suppl 2):B1-13.

Dal Pont G. Retromolar osteotomy for the correction of prognathism. J. oral Surg. Anesth. Hosp. dent serv. 1961;19(1):42-47.

Epker BN. Modifications in the sagittal osteotomy of the mandible. J. oral Surg. 1977;35(2):157-159.

Falci SG, Rodrigues DC, Marchiori EC, Brancher G, Makyama A, Moreira RWF. Assessment of the fixation of mandibular symphysis fractures using conical cannulated screws: mechanical and photoelastic tests. Oral Surg Oral Med Oral Pathol Oral Radiol. 2014. [In press]

* De acordo com a norma da Unicamp/FOP baseada na norma do International Committee of Medical Journal Editors – Grupo de Vancouver. Abreviatura dos periódicos em conformidade com o Medline.

Foley WL, Frost DE, Paulin WB, Tucker MR. Uniaxial pullout evaluation of internal screw fixation. J Oral Maxillofac Surg. 1989;47:277.

Hammer B, Ettlin D, Rahn B, Prein J. Stabilization of the short sagittal split osteotomy: in vitro testing of different plate and screw configurations. J CranioMaxillofac Surg. 1995;23:321.

Husunck EE. A modified intraoral sagittal splitting technic for correction of mandibular prognathism. J oral Surg. 1968;26(4):250-3.

Leggon R, Lindsey RW, Doherty BJ, Alexander J, Noble P. The holding strength of cannulated screws compared with solid core screws in cortical and cancellous bone. J Orthop Trauma. 1993;7:450–7.

Leggon R, Lindsey RW, Doherty BJ, Alexander J, Noble P. The holding strength of cannulated screws compared with solid core screws in cortical and cancellous bone. J Orthop Trauma. 1993;7:450–7.

Murphy MT, Haug RH, Barber JE. An in vitro comparison of the mechanical characteristics of three sagittal ramus osteotomy fixation techniques. J Oral Maxillofac Surg. 1997;55:489-94.

Ochs MW. Bicortical screw stabilization of sagittal split osteotomies. J Oral Maxillofac Surg. 2003;61:1477-84.

Ozden B, Alkan A, Arici S, Erdem E. In vitro comparison of biomechanical characteristics of sagittal split osteotomy fixation techniques. Int J Oral Maxillofac Surg. 2006;35:837-41.

Pilling E, Schneider M, Mai R, Loukota RA, Eckelt U. Minimally invasive fracture treatment with cannulated lag screws in intracapsular fractures of the condyle. J Oral Maxillofac Surg. 2006; 64(5): 868-72.

Rho JY. Mechanical properties of human cortical and cancellous bone [dissertation]. Dallas (TX): University of Texas Southwestern Medical Center; 1991.

Rubo JH. Análise das tensões em prótese sobre implantes pelo método de element finito: estudo paramétrico de sete variáveis clínicas [Livre-Docência]. Bauru: Universidade de São Paulo. Faculdade de Odontologia de Bauru; 2004.

Sato FSL, Aspirino L, Consani S, Noritomi PY, Moraes M. A comparative evaluation of hybrid technique for fixation of the sagittal split ramus osteotomy in mandibular advancement by mechanical, photoelastic, and finite element analysis. Oral Surg Oral Med Oral Pathol Oral Radiol. 2012;114:S60-8.

Schwimmer A, Greenberg AM, Kummer F, Kaynar A. The effect of screw size and insertion technique on the stability of the mandibular sagittal split osteotomy. J Oral Maxillofac Surg. 1994;52:45-8.

Shaw JA. Biomechanical comparison of cannulated small bone screws: a brief follow-up study. J Hand Surg. 1991;16A:998–1001.

Shetty V, Freymiller E, McBrearty D, Caputo AA. Experimental analysis of functional stability of sagittal split ramus osteotomies secured by miniplates and position screws. J Oral Maxillofac Surg. 1996;54(11):1317-24.

Spiessl B. Rigid internal fixation after sagittal split osteotomy of the ascending ramus. In: Spiessl B, ed. New Concepts in Maxillofacial Bone Surgery. New York: Springer Verlag; 1976. p.115-22.

Sugawara J, Mitami H. Facial growth of skeletal class III malocclusion and the effects, limitations and long term dentofacial adaptation to clinical therapy. Semim Orthod I. 1997; 3(4): 244-54.

Thompson JD, Benjamin JB, Szivek JA. Pullout strengths of cannulated and noncannulated bone screws. Clin Othop Rel Res. 1997;341:241–9.

Thompson JD, Benjamin JB, Szivek JA. Pullout strengths of cannulated and noncannulated bone screws. Clin Othop Rel Res. 1997;341:241–9.

Trauner R, Obwegeser H. The surgical correction of mandibular prognathism and retrognathia with consideration of genioplasty. II. Operating methods for microgenia and distoclusion. Oral Surg Oral Med Oral Patho. 1957;10(8):787-92.

Trauner R, Obwegeser H. The surgical correction of mandibular prognathism and retrognathia with consideration of genioplasty II. Oral Surg Oral Med Oral Pathol. 1957;10:787.

Van Sickels JE, Peterson GP, Holms S, Haug RH. An in vitro comparison of an adjustable bone fixation: a comparative study. J Oral Maxillofac Surg. 2005;63:1620-5.

Wolford LM, Bennett MA, Rafferty CG. Modification of the mandibular ramus sagittal split osteotomy. Oral Surg Oral Med Oral Pathol. 1987;64:146.

CONCLUSÃO

De acordo com a metodologia apliacada e com os resultados obtidos, podemos concluir que os parafusos canulados podem ser considerados uma opção de fixação das osteotomias sagitais, podendo, dessa forma, serem utilizados em cirurgia ortognática.

REFERÊNCIAS*

Abeloos J, De Clerq C, Neyt L. Skeletal stability following miniplate fixation after bilateral sagittal split osteotomy for mandibular advancement. J Oral Maxillofac Surg. 1993; 51(4): 366-9.

Anucul B, Waite PD, Lemons JE. In vitro strength analysis of sagittal split osteotomy fixation: noncompression monocortical plates versus bicortical position screws. J Oral Maxillofac Surg. 1992; 50(12): 1295-9.

Ardary WC, Tracy DJ, Brownridge GW, Urata MM. Comparative evaluation of screw configuration on the stability of the sagittal split osteotomy. Oral Surg Oral Med Oral Pathol. 1989; 68(2): 125-9.

Chou YC, Hsu YH, Cheng CY, Wu CC. Percutaneous screw and axial Kirschner wire fixation of acute transscaphoid perilunate fracture dislocation. J Hand Surg Am. 2012; 37(4): 715-20.

Ellis III E, Carlson DS. Stability two years after mandibular advancement with and without suprahyoid myotomi: an experimental study. J Oral Maxillofac Surg. 1983; 41(7): 426-37.

Ellis E 3rd. Is lag screw fixation superior or plate fixation to treat fractures of the mandibular symphysis? J Oral Maxillofac Surg. 2012; 70(4): 875-82.

* De acordo com a norma da Unicamp/FOP baseada na norma do International Committee of Medical Journal Editors – Grupo de Vancouver. Abreviatura dos periódicos em conformidade com o Medline.

Gabrielli MRF. Stable fixation of the sagittal split ramus osteotomy. Select Read Oral Maxillofac Surg. 2007; 15(1): 1-46.

Geissler WB. Cannulated percutaneous fixation of intra-articular hand fractures. Hand Clin. 2006; 22(3); 297-305.

Lindorf HH. Sagittal ramus osteotomy with tandem screw fixation. Technique and results. J Maxillofac Surg. 1986; 14(6): 311-6.

Loukota RA. Fixation of diacapitular fractures of the mandibular condyle with a headless bone screw. Br J Oral Maxillofac Surg. 2007; 45(5): 399-401.

Messer TM, Nagle DJ, Martinez AG. Thumb metacarpophalangeal joint arthrodesis using the AO 3.0-mm cannulated screw: surgical technique. J Hand Surg Am. 2002; 27(5): 910-2.

Obeid G, Lindquist CC. Optimal placement of bicortical screws in sagittal split-ramus osteotomy of mandible. Oral Surg Oral Med Oral Pathol. 1991; 71(6): 665-9.

Özden B, Alkan A, arici S, Erdem E. In vitro comparison of biomechanical characteristics of sagittal split osteotomy fixation techniques. Int J Oral Maxillofac Surg. 2006; 35(9): 837-41.

Paulus GW, Steinhauser EW. A comparative study of wire osteosynthesis versus bone screws in the treatment of mandibular prognathism. Oral Surg Oral Med Oral Pathol. 1982; 54(1): 2-6.

Pilling E, Schneider M, Mai R, Loukota RA, Eckelt U. Minimally invasive fracture treatment with cannulated lag screws in intracapsular fractures of the condyle. J Oral Maxillofac Surg. 2006; 64(5): 868-72.

Reitzik M, Schoorl W. Bone repair in the mandible: a histologic and biometric comparison between rigid and semi-rigid fixation. J Oral Maxillofac Surg .1983; 41(4): 215-8.

Schmidt CC, Zimmer SM, Boles SD. Arthrodesis of the thumb metacarpophalangeal joint using cannulated screw and threaded washer. J Hand Surg Am. 2004; 29(6): 1044-50.

Schuchardt, K. Ein Betrag zur chirurgishen Kieferorthopädie unter Berücksichtigung ihrer Bedeutung für die Behandlung angeborener und erworbener Kieferdeformitäten bei Soldaten. Dtsch Zahn Mund Kieferheil. 1942; 9: 73-89.

Spiessl B. New concepts in maxillofacial bone surgery. Int J Oral Surg. 1974; 3(5):349–52.

Sugawara J, Mitami H. Facial growth of skeletal class III malocclusion and the effects, limitations and long term dentofacial adaptation to clinical therapy. Semim Orthod I. 1997; 3(4): 244-54.

Trauner R, Obwegeser H. The surgical correction of mandibular prognathism and retrognathia with consideration of genioplasty. Oral Surg. 1957; 10: 677-89.

Van Sickels JE. A comparative study of bicortical screws and suspension wires versus bicortical screws in large mandibular advancements. J Oral Maxillofac Surg. 1991; 49(12): 1293-6.