



UNESP - Universidade Estadual Paulista
Faculdade de Odontologia de Araraquara



SERGEI GODEIRO FERNANDES RABELO CALDAS

**COMPORTAMENTO MECÂNICO DA MOLA "T" DE BETA-TITÂNIO:
INFLUÊNCIA DA MARCA COMERCIAL E DO ALÍVIO DE TENSÃO ESTRUTURAL**

Araraquara

2013



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Tese apresentada ao Programa de Pós-Graduação em Ciências Odontológicas Área de Ortodontia da Faculdade de Odontologia de Araraquara, da Universidade Estadual Paulista para obtenção do título de Doutor em Ciências Odontológicas.

Orientador: Profa. Dra. Lídia Parsekian Martins

Araraquara

2013

Caldas, Sergei Godeiro Fernandes Rabelo

Comportamento mecânico da mola "T" de beta-titânio: influência da marca comercial e do alívio de tensão estrutural / Sergei Godeiro Fernandes Rabelo Caldas.— Araraquara: [s.n.], 2013.

127 f. ; 30 cm.

Tese (Doutorado) – Universidade Estadual Paulista,
Faculdade de Odontologia

Orientadora : Profa. Dra. Lídia Parsekian Martins

1. Ortodontia 2. Biomecânica 3. Movimentação dentária I. Título

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Araraquara, 18 de Janeiro 2013.

DADOS CURRICULARES

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Associações:	ABO/RN, ABOR/RN, AOA e SBPqO



DEDICATÓRIA

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À **Deus**, por ser a força maior que guia nossas vidas!! Obrigado por sempre estar comigo em todas as horas.

Aos meus pais, **João Batista Rabelo Caldas e Maria Terezinha Godeiro Fernandes Rabelo Caldas**, pelo amor e apoio incondicional. Vocês são meu porto seguro, meu exemplo de vida!!

Painho e Mainha, agora vocês terão um filho Doutor. O sonho se realizou...tantos choros no adeus do portão se concretizaram neste título. Devo tudo da minha vida à vocês! Podem contar comigo para tudo...

Obrigado Deus, por fazer parte dessa família!!

AMO MUITO vocês!!

À minha esposa, **Marília Regalado Galvão Rabelo Caldas**, por sempre acreditar e incentivar meus sonhos. Vivemos anos maravilhosos em Araraquara, com muita cumplicidade, amor e dedicação. Já estamos colhendo os frutos desta jornada. Você é demais, exemplo de determinação e garra. É muito bom viver ao seu lado!

Docência, Tese e Concurso não é fácil de conciliar! Você mostrou uma garra sem limites. Tenho muito orgulho de você...

TE AMO DE MAIS!!!

Aos meus irmãos, **Vladimir e Boris**, por serem exemplos de determinação e caráter.

Aos meus avós maternos, **Liberalino e Maria Godeiro (Biia)** e avós paternos, **Odemar e Laura**, por terem iniciado este sonho a muito tempo atrás. O sacrifício de vocês para educarem os filhos, fizeram com que um neto de vocês realizassem o sonho de se tornar Doutor em tão respeitada Universidade. Em especial, a minha **Vó Biia**, minha companheira de orações e preces. Esta vitória é de vocês!

"Com paciência e sabedoria, o difícil é fácil."

(João Rabelo - 05/10/2007)



AGRADECIMENTOS

ESPECIAIS

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À minha orientadora, **Profa. Dra. Lídia Parsekian Martins**, muito obrigado por fazer parte da minha vida. Neste período em Araraquara, tive na senhora a figura da minha mãe, onde eu poderia contar para qualquer eventualidade.

Aproveito o momento para agradecer a toda Família Parsekian Martins, o carinho e respeito que sempre tiveram comigo. Ter a oportunidade de ter convivido com vocês, é poder ter a chance de aprender indiretamente com o **Prof. Dr. Joel Cláudio da Rosa Martins**.

Forte abraço e muito obrigado por tudo!

À meu co-orientador, **Prof. Dr. Renato Parsekian Martins**, por ter acreditado na minha capacidade de trabalho e ter aguçado mais ainda a minha vontade de estudar biomecânica. Assim como falei nos agradecimentos do mestrado, acompanhar teu raciocínio foi a tarefa mais árdua do curso de pós-graduação, contudo me fez estudar cada vez mais, ser mais crítico e lutar por uma Ortodontia baseada em evidências.

Tenho certeza que você será um dos grandes nomes da Ortodontia em um futuro próximo, em virtude do seu *ENORME* conhecimento e capacidade de trabalho.

Deixo registrado abertamente aqui minha opinião... A Faculdade de Odontologia de Araraquara precisa de seus conhecimentos para continuar a ser grande no futuro.

Serei eternamente grato pelos inúmeros e-mails trocados, encontros na faculdade, consultório, idas e vindas à Catanduva, etc... Após estes 5 anos, encontrei além de um orientador espetacular, um amigo para a vida toda!

E não esqueça que eu fui o seu primeiro Orientado... risos!

Forte abraço e muito sucesso!

Ao amigo e irmão, **Alexandre Ribeiro**, grande parceiro de trabalho e sonhos. Meu amigo, chegamos lá! Nossos sonhos se tornaram realidade. Obrigado por tudo!



AGRADECIMENTOS

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À Universidade Estadual Paulista Júlio de Mesquita Filho - UNESP, na presença de seu Magnífico Reitor Prof. Dr. Júlio Cezar Durigan.

À Faculdade de Odontologia de Araraquara - FOAr, da Universidade Estadual Paulista Júlio de Mesquita Filho - UNESP, na pessoa de sua Diretora Profa. Dra. Andreia Affonso Barreto Montandon e de sua vice diretora Profa. Dra. Elaine Maria Sgavioli Massucato.

Ao Departamento de Clínica Infantil da Faculdade de Odontologia de Araraquara - UNESP, representados pelo Chefe de Departamento Profa. Dra. Lídia Parsekian Martins e pelo vice-chefe Prof. Dr. Fábio Cesar Braga de Abreu e Lima.

Ao Programa de Pós-Graduação em Ciências Odontológicas da Faculdade de Odontologia de Araraquara - UNESP, coordenado pela Profa. Dra. Josimeri Hebling Costa e Prof. Dr. Osmir Batista de Oliveira Júnior, pela oportunidade de ser aluno deste tão conceituado programa.

Aos docentes da Disciplina de Ortodontia da Faculdade de Odontologia de Araraquara - UNESP, Prof. Dr. Ary dos Santos Pinto, Prof. Dr. Dirceu Barnabé Raveli, Prof. Dr. João Roberto Gonçalves, Profa.

Dra. Lídia Parsekian Martins, Prof. Dr. Luiz Gonzaga Gandini Júnior e Prof. Dr. Maurício Tatsuei Sakima, pela convivência e contribuição à minha formação profissional.

Aos docentes da **Disciplina de Odontopediatria** da Faculdade de Odontologia de Araraquara - UNESP, Profa. Dra. Ângela Cristina Cilense Zuanon, Prof. Dr. Cyneu Aguiar Pansani, Profa. Dra. Elisa Maria Aparecida Giro, Prof. Dr. Fábio César Braga de Abreu e Lima, Profa. Dra. Josimeri Hebling Costa, Profa. Dra. Lourdes Aparecida Martins dos Santos Pinto (Tuka) e Profa. Dra. Rita de Cássia Loiola Cordeiro, muito obrigado pela forma carinhosa que sempre me trataram e os ensinamentos transmitidos. A Disciplina é um modelo de ensino que vou buscar implantar onde eu me inserir.

Aos funcionários do **Departamento de Clínica Infantil** da Faculdade de Odontologia de Araraquara - UNESP, Antonio Parciaseppe Cabrini, Célia Aparecida Brogna Braga da Silva, Cristina Ferreira Affonso, Diego Cardoso Pendenza, Dulce Helena de Oliveira, Odete Amaral, Pedro César Alves, Regina Aparecida Favarin Bausells, Sílvia Maria Sandaniello, Sônia Maria Tircailo e Tânia Aparecida Moreira dos Santos, pelo convívio agradável e por sempre nos auxiliarem.

Aos funcionários da **Seção de Pós-Graduação** da Faculdade de Odontologia de Araraquara - UNESP, Mara, Alexandre e Sérgio, pelo auxílio prestado durante todo o curso e pela atenção com que sempre atenderam às minhas solicitações.

Ao Prof. Dr. Ary dos Santos Pinto, Prof. Dr. Dirceu Barnabé Raveli, Profa. Dra. Lídia Parsekian Martins e Prof. Dr. Luiz Gonzaga Gandini Júnior, pelo imenso orgulho de ser aluno de vocês. Expresso meus sinceros agradecimentos, admiração e profundo respeito. Eu sempre sonhei em estudar nesta casa, obrigado por confiarem em mim!!

Ao Prof. Dr. Ary dos Santos Pinto, lembro como se fosse hoje do nosso primeiro contato. A paciência, atenção e gentileza que nos transmitiu durante nosso Typodont, no ano de 2005, da Especialização em Ortodontia da ABO/RN foram fundamentais para que eu buscasse estudar em Araraquara. O senhor possui um coração gigante, sempre semeando sorrisos e tranquilizando as pessoas. Conviver com o senhor foi uma experiência fantástica e enriquecedora, tanto pessoal com intelectualmente. Meus sinceros, muito obrigado!!

Ao Prof. Dr. Luiz Gonzaga Gandini Júnior, que orgulho ser seu aluno. Hábil e sensato nas decisões, exímio Ortodontista e Professor! O senhor não tem idéia como fico feliz e lisonjeado quando escuto um elogio seu, para mim é algo do outro mundo. Uma pessoa que eu tanto admiro fazendo uma referência a mim, inacreditável!

O senhor sabe compreender todas as situações que envolvem os alunos e a pós-graduação. Quando em uma reunião, mencionou que tudo era direcionado para cima de mim, e eu gostava de receber essa incumbência, o senhor se via nesta situação por eu ter perfil semelhante ao seu. Eu nunca tive oportunidade de conversar isso com ninguém, mas este peso que eu sempre carreguei, algumas vezes era demais! Sua percepção foi importante

para que, a partir daquele dia, eu soubesse dizer *NÃO* em algumas situações, ou ainda, controlasse essa responsabilidade de forma mais tranquila.

Esses momentos estão guardados na minha consciência por toda minha vida. Aproveito o momento para agradecer também ao carinho que a **Prof. Dra. Márcia Gandini** sempre demonstrou por mim. Vocês são especiais!

Ao **Prof. Dr. Dirceu Barnabé Ravelli**, pela forma carinhosa e tranquila que sempre me tratou. Nossos bate-papos sempre foram muito agradáveis e engraçados. Muito obrigado por nos convidar para seu convívio familiar, estes momentos serão inesquecíveis. Meus sinceros, muito obrigado!!

Ao **Prof. Dr. João Roberto Gonçalves**, pelos ensinamentos transmitidos e contribuição na minha formação profissional. Seus seminários foram fantásticos!

Ao **Prof. Dr. Roberto Hideo Shimizu**, pela orientação na utilização do sistema de ensaio mecânico. Sua disponibilidade e atenção foram fundamentais para a conclusão do trabalho. Meus sinceros, muito obrigado!!

Aos amigos de turma do curso de **Pós-Graduação em Ciências Odontológicas, Área de Concentração em Ortodontia, Nível Doutorado** da Faculdade de Odontologia de Araraquara - UNESP,

Alexandre, Patrícia, Sandra e Betina pela amizade e convivência não somente nas atividades científicas, mas em todos os momentos.

Aos amigos do curso de Pós-Graduação em Ciências Odontológicas, Área de Concentração em Ortodontia, Nível Mestrado da Faculdade de Odontologia de Araraquara - UNESP, Camilla Jvini, Jsabela, Tiago, Taísa, Ana Patrícia, Cibele, Kélei, Liliane, Patrícia Amato, Vanessa, Roberto, Fernando, Raquel, Daniela e Guilherme. Em especial à amiga **Camilla**, pela apoio incondicional durante a realização dos ensaios mecânicos. Mais uma vez, muito obrigado por tudo!!

Aos amigos do curso de Pós-Graduação em Ciências Odontológicas, Área de Concentração em Ortodontia, Nível Doutorado da Faculdade de Odontologia de Araraquara - UNESP, Adriano, Aldrieli, Alexandre Vianna, Amanda, André Monini, André Wilson, Fernanda Meloti, Denise, Luis Guilherme, Renata, Roberta e Savana, pela amizade, carinho e convívio. Em especial ao amigo **André Machado**, pela parceria de trabalho e transmissão de conhecimentos e experiências. Vibe irmão, você é uma pessoa especial que apareceu na minha vida, muito obrigado por tudo!

À todos os meus **familiares**, por sempre acreditarem em mim, pelo valioso incentivo, harmonia e amor permutado. Em especial à **Tio Júnior**, meu padrinho querido, sempre me educando e aconselhando para o caminho do bem.

Às minhas **cunhadas** Kalyna e Juliana, pelo carinho e atenção que têm por mim.

Aos meus **sobrinhos** Diego, Beatriz e Gabriel, pelo sorriso no rosto quando nos reencontramos.

Aos meus **sogros** João Carlos e Lenira, minhas **cunhadas** Camila e Beatriz, e meus **concunhados** Ruthnaldo e Alexandre, pelo amor, carinho e convivência sempre tão agradável.

À querida **Julieta Galvão (Fujú)**, pelo amor incondicional e por sentir tanto com nossa partida para Araraquara. Você é muito especial para mim e Marília. Os choros agora são de alegria, já estamos de volta!

Aos **docentes da Especialização em Ortodontia da ABO/RN**, Prof. Cícero, Prof. Heitel, Prof. Marcus Vinícius, Prof. Otávio e Prof. Rildo, por terem sido os responsáveis pela construção do meu alicerce científico na Ortodontia e convivência tão agradável durante os três anos do curso. Em especial, ao **Prof. Heitel**, por ter sempre acreditado e incentivado meu sonho acadêmico e pelo grande incentivo no início da minha vida profissional. Trabalhar com o senhor é a realização de um sonho. Obrigado por me escolher!

Aos docentes da *Especialização em Ortodontia da Universidade Potiguar (UnP)*, Prof. Cícero, Prof. Marcus Vinícius e Prof. Alexandre, muito obrigado pela confiança. Em especial ao **Prof. Marcus**, por lutar tanto para nos inserir na Universidade. A confiança do senhor vai ser retribuída com muito trabalho e dedicação. Faremos este curso o melhor possível!

À **Profa. Dra. Hallissa Simplício**, por ter sempre me apoiado e acreditado no meu potencial. Trabalhei muito estes 5 anos para honrar sua indicação. Muito obrigado pelas orientações, indicações e convites. Você foi fundamental para eu realizar este sonho! Serei eternamente grato...

Aos amigos do *Curso de Especialização em Ortodontia da ABO/RN*, Adriana, Alexandre, Ana Paula, Ângela, Edrisi, Enzo, Flávia, João Humberto (Joca), Lislye, Luciana, Nara, pelo incentivo e amizade.

Aos alunos do *Curso de Especialização em Ortodontia da UnP*, Allison, Ariane, Eduardo, Estevam, Eugênio, Danielle, Giovanna, Marcela, Patrícia e Thiago, pela convivência tão agradável e conhecimentos compartilhados. Trabalharei duro para vocês se formarem adequadamente, principalmente, com muita responsabilidade!

Aos amigos, **Norberto e Gustavo**, pelo acolhimento e apoio incondicional nos meus primeiros passos em Araraquara no ano de 2006. Sou profundamente grato à ajuda de vocês. Meus sinceros, muito obrigado!!

Aos amigos, **Bruno e Ana Luísa**, pela agradável convivência e os excelentes momentos que passamos em Araraquara. Nossos almoços nordestinos foram inesquecíveis!!

Ao amigo, **Fábio (Fabinho) e Sarah**, que apesar de conhecê-los a tão pouco tempo, parece que somos amigos de infância. Fabinho, sua alegria fez muita falta para todos nós em Araraquara. Agora poderemos manter esta amizade mais de perto em Natal!

Ao amigo, **Artur Wagner**, pela amizade verdadeira, por sempre torcerem por mim e pelo apoio apesar da distância.

Aos amigos Pernambucanos da Turma 2004.2 do Curso de Odontologia da Universidade Federal de Pernambuco – Turma dos Iluminados, em especial ao grande amigo João, pela amizade verdadeira e por terem sido os primeiros a me incentivarem na carreira acadêmica.

Aos **amigos**, Andrés, Gustavo, Mila, Antônio, Carol, Erica, Fabiana, Fabiano, Felipe, Fernanda, Leila, Mariana, Marcell, Ruy, Sérgio, Aloisio, Raphael, Rafael, Cibele, Mariana, Raniel e Daniele pela amizade sincera e por todo apoio, carinho e alegria. Aos amigos que participaram da minha despedida, aquele momento foi inesquecível. Robertino, Raphinha, Cibele, Mariana, Raniel, Alexandre, Bia e Marília, aquelas palavras foram marcantes! Muito obrigado amigos pela convivência e carinho. Aos que ainda

estão em Araraquara, apenas um conselho: *APROVEJTEM!* Araraquara é bom demais!

Em especial ao amigos, *Aloisio e Raphael*, vocês são fora de série! Apesar de pouco tempo de convivência, agradeço por tê-los com amigos e tenho a certeza que posso contar com vocês. Pense em dois parceiros gente fina!

Ao amigo e Prof. Dr. José Maurício dos Santos Nunes Reis, pelo apoio nos ensaios mecânicos e amizade construída.

Ao Prof. Dr. Luis Geraldo Vaz, pela confiança, atenção e contribuição no desenvolvimento da minha dissertação, tese e pesquisas na UNESP.

À Prof. Dra. Ana Maria Elias, pela execução da análise estatística do trabalho. Muito obrigado pela paciência e atenção!!

À Maria do Carmo, pela ajuda com os formulários, compras e prestação de contas referentes ao auxílio pesquisa concedido pela FAPESP.

Aos funcionários do Gestos - Grupo de Estudos Ortodônticos e Serviços, pela prontidão e gentileza com que me atenderam sempre que precisei.

Aos funcionários da Biblioteca da Faculdade de Odontologia de Araraquara - UNESP, pela ajuda na busca de dissertações, teses, livros, artigos e revistas.

À Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), pela bolsa de estudo concedida durante todo o curso.

À Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), pela concessão do auxílio à pesquisa para a realização deste trabalho.

À todos aqueles que de alguma forma colaboraram com a realização deste trabalho.

MUITO OBRIGADO!!



RESUMO

Caldas SGFR. Comportamento mecânico da mola "T" de beta-titânio: influência da marca comercial e do alívio de tensão estrutural [Tese de Doutorado]. Araraquara: Faculdade de Odontologia da UNESP; 2013.

RESUMO

Objetivo: Os objetivos do estudo foram (1) avaliar o comportamento biomecânico das molas "T" confeccionadas com diferentes marcas comerciais de beta-titânio (β -Ti), (2) avaliar a estabilidade do sistema de força das molas "T" pré-ativadas por curvatura quando submetidas ao alívio de tensão estrutural a longo prazo, assim como, (3) comparar seus resultados com as molas pré-ativadas por dobras. **Materiais e Métodos:** No artigo 1, a amostra foi constituída de 40 molas "T" (6 x 10mm) confeccionadas com fio 0,017" x 0.025" de β -Ti e divididas em 4 grupos de 10 molas de acordo com a marca comercial: Grupo 1 - TMA[®] (Ormco), Grupo 2 - BETA FLEXY[®] (Orthometric), Grupo 3 - BETA III TiMo[®] (Morelli) e Grupo 4 - CNA[®] (Ortho Organizers). O ensaio mecânico foi realizado utilizando-se um transdutor de momentos acoplado a um indicador para extensometria, adaptado a uma máquina de ensaios mecânicos Emic (DL2000) com célula de carga de 0,1kN e velocidade 5mm/min. Para o ensaio de tração, a amostra foi constituída de 05 segmentos com 30cm de comprimento para cada marca comercial. O ensaio foi realizado na máquina de ensaios mecânicos com célula de carga de 5kN e velocidade de 2mm/min. A análise

metalográfica foi realizada por fluorescência de raios X no equipamento Energy Dispersive X-ray Fluorescence Spectrometer. A dimensão dos fios calculada com auxílio de um paquímetro digital com precisão de $\pm 1\mu\text{m}$. A análise estatística foi realizada por meio da análise de variância a um critério (ANOVA) e pós teste de Tukey ($\alpha=5\%$). No artigo 2, a amostra foi constituída de 90 molas de dimensões 6 X 10mm, confeccionadas com fios 0,017" x 0,025" de TMA®, pré-ativadas por curvatura e divididas aleatoriamente em 9 grupos de 10 molas. As molas do grupo 1 (imediato) foram avaliadas logo após a pré-ativação e simulação de ativação, enquanto as molas dos demais 8 grupos (24, 48 e 72 horas, 1, 2, 4, 8 e 12 semanas) foram avaliadas após serem mantidas ativadas por 5mm. O ensaio mecânico foi semelhante ao artigo 1. A análise estatística foi realizada por meio da análise de perfis multivariados, ANOVA e pós teste de Tukey ($\alpha=5\%$). No artigo 3, a amostra foi constituída de 120 molas idênticas ao artigo 2, pré-ativadas por dobra (60) e curvatura (60), e divididas aleatoriamente em 6 grupos de 10 molas para cada tipo de pré-ativação. As molas do grupo 1 (imediato) foram avaliadas logo após a pré-ativação e simulação de ativação, enquanto as molas dos demais 5 grupos (24, 48 e 72 horas, 1 e 2 semanas) foram avaliadas após serem mantidas ativadas por 5mm. O ensaio mecânico foi semelhante ao artigo 1 e 2. A análise estatística foi realizada por meio da análise de perfis multivariados e pós teste de Tukey (intragrupo) e Teste T para amostra independentes (intergrupo) ($\alpha=5\%$). **Resultados:** Todos os grupos de artigo 1, exceto o G2 (Orthometric), produziram níveis de força similares inicialmente. O G3 (Morelli) produziu as maiores relações carga-deflexão (CD) e, o G1 (Ormco)

e G4 (Ortho Organizers) tiveram quantidades similares de posição neutra. O G1 e G3 produziram os níveis mais altos de momentos e, G2 e G3 produziram as maiores proporções momento-força (MF). Os fios de β -Ti do G3 apresentaram o maior módulo de Young (MY) e todos os grupos apresentaram composição semelhante, exceto do G2. As forças horizontais diminuíram gradualmente entre os grupos do artigo 2 ($P<0,001$) e os momentos mostraram uma redução significativa e gradual em relação ao tempo quando os perfis totais da molas "T" foram comparados ($P<0,001$). Todos os grupos produziram proporções MF semelhantes ($P=0,532$), sem influência do tempo. Ambos os grupos do artigo 3 mostraram uma diminuição nos níveis de força ao longo do tempo ($P<0,001$ e $0,005$ para pré-ativação por dobra e curvatura, respectivamente), mas com comportamentos diferentes. O grupo pré-ativado por dobras mostrou uma redução dos momentos ao longo do tempo ($P<0,001$), enquanto que o grupo pré-ativado por curvatura não ($P=0,410$). A proporção MF não mudou ao longo do tempo nos dois grupos. **Conclusões:** As quatro marcas de fios de β -Ti analisados produziram sistemas de forças diferentes quando usado em um desenho mais elaborado, devido ao fato de que cada um dos fios responder diferentemente à dobras. As molas "T" pré-ativadas por curvatura sofreram uma deformação gradual ao longo do tempo e o efeito do alívio de tensão estrutural foi mais evidente no grupo pré-ativado por dobras.

Palavras-chave: Ortodontia; biomecânica; movimentação dentária.



ABSTRACT

Caldas SGFR. Mechanical behavior of the beta-titanium T-loop springs: trademark influence and stress relaxation [Tese de Doutorado]. Araraquara: Faculdade de Odontologia da UNESP; 2013.

ABSTRACT

Objective: The aim of this study were (1) evaluation of the force system produced by four brands of beta-titanium (β -Ti) wires bent into a T-Loop spring (TLS), (2) evaluate changes in the force system of TLSs preactivated by curvature due to stress relaxation and (3) assess the changes in the force system of TLSs preactivated by bends and curvature. **Materials and Methods:** The paper 1, the sample consisted of forty springs (6 x 10mm) from 0.017" x 0.025" β -Ti and divided into 4 groups of 10 springs according to wire brand: Group 1 - TMA[®] (Ormco), Group 2 - BETA FLEXY[®] (Orthometric), Group 3 - BETA III TiMo[®] (Morelli) and CNA[®] (Ortho Organizers). The mechanical testing was performed using a moment transducer coupled to a digital extensometer indicator adapted to an Emic testing machine (DL2000) with a load cell of 0.1kN and speed 5mm/min. For the tensile test, the sample consisted of five 30cm segments of each of the wires. The test was performed on a mechanical testing machine equipped with a load cell of 5kN and speed of 2mm/min. An energy dispersive X-ray fluorescence spectrometer machine was used to determine the surface chemical composition of the wires in each group. The height and width of

each wire were measured to the nearest 0.001 mm with a digital micrometer accurate to $\pm 1\mu\text{m}$. Statistical analysis was performed using one-way analysis of variance (ANOVA) and Tukey post hoc test ($\alpha=5\%$). The paper 2, the sample consisted of ninety TLSs with dimensions 6 x 10mm, produced out of .017" x .025" TMA[®] and preactivated by gradual curvature, were randomly distributed into nine groups according to time point of evaluation. Group 1 was tested immediately and the remaining subgroups were tested after they were secured at 5 mm activation for different periods. Groups 2, 3, 4, 5, 6, 7, 8 e 9 were kept activated for 24, 48 and 72 hours, 1, 2, 4, 8 and 12 weeks, respectively. The mechanical test was similar to paper 1. Statistical analysis was performed using the multivariate profile analysis, ANOVA and Tukey post hoc test ($\alpha=5\%$). The paper 3, the sample consisted of one hundred and twenty identical TLSs to paper 2 and were randomly divided into two groups of sixty TLSs each according to what preactivation was going to be used, concentrated bends or gradual curvature. Subgroup 1 was tested immediately and the remaining subgroups were tested after they were secured at 5 mm activation for different periods. Subgroups 2, 3, 4, 5 and 6 were kept activated for 24, 48 and 72 hours, 1 and 2 weeks, respectively. The mechanical test was similar to paper 1 and 2. Statistical analysis was performed using the multivariate profile analysis and Tukey post hoc test (intragroup) and T test for independent samples (intergroup) ($\alpha=5\%$).

Results: All groups from paper 1, except by G2 (Orthometric), produced similar force levels initially. The G3 (Morelli) produced the highest LD rates and G1 (Ormco) and G4 (Ortho Organizers) had similar amounts of overlap of the vertical

extensions of the TLSs in “neutral position”. The G1 and G3 delivered the highest levels of moments and G2 and G3 produced the highest MF ratios. The β -Ti wires from G3 produced the highest YM and all groups showed similar composition, except from G2. The horizontal forces decreased gradually among the groups from paper 2 ($P<.001$) and the moments showed a significant and slow decrease due to time among the groups when the total profiles of the TLSs were compared ($P<.001$). All groups produced similar MF ratios ($P=.532$), with no influence of time. Both groups from paper 3 showed a decrease in force levels over time ($P<.001$ and $.005$ for bend and curvature preactivation, respectively), but with different behaviors. The group preactivated by bends showed a reduction in moments over time ($P<.001$), whereas the group preactivated by curvature didn't ($P=.410$). The MF ratio has not changed over time in either group. **Conclusions:** The four beta-titanium wires analyzed produced different force systems when used in a more elaborate design due to the fact that each wire responds differently to bends. The TLSs preactivated by curvature suffered a gradual deformation over time and the stress relaxation effect was more evident on group preactivated by bends.

Key words: Orthodontics; biomechanics; tooth movement.



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1 INTRODUÇÃO E REVISÃO DE LITERATURA

1 INTRODUÇÃO E REVISÃO DE LITERATURA

A Técnica do Arco Segmentado (TAS) idealizada pelo Dr. Charles Burstone em 1962, preconiza a utilização de molas pré-calibradas para o emprego da filosofia de estresse diferencial para o fechamento de espaços. Esta técnica apresenta duas vantagens principais sobre a mecânica de deslizamento: ausência de atrito e capacidade de produzir movimentos diferenciais dos dentes⁴.

As forças aplicadas aos dentes causam pressões ao ligamento periodontal que se equilibram ao redor de dois minutos⁹, causando um processo biológico em resposta à deformação imposta ao ligamento periodontal. De acordo com a teoria aceita nos dias de hoje para explicar a velocidade da movimentação dentária, existe uma correlação positiva entre a velocidade de movimentação dentária e a quantidade de estresse aplicada ao ligamento periodontal dos dentes. Portanto, biologicamente, a TAS controla a ancoragem reduzindo a pressão, ou a deformação do periodonto dos dentes onde se deseja uma menor movimentação, enquanto aumenta a pressão, ou a deformação do periodonto dos dentes onde se deseja maior movimentação^{5,23,27,41}.

Enfatizando o controle do sistema de força, Burstone³ (1966), citava alguns fatores que poderiam determinar o sucesso ou não do tratamento ortodôntico, dentre eles, é citada a proporção momento-força (MF). Esta proporção entre a força aplicada pela mola e o momento produzido pela mola possibilita a produção de diferentes tipos de movimentos.

A correta manipulação da proporção MF pode produzir os diferentes tipos de movimentos dentários. Estes, por sua vez, geram diferentes pressões ao ligamento periodontal^{14,44,45} e podem ser modificados a fim de diminuir ou aumentar a velocidade da movimentação dentária durante o fechamento de espaços^{23,41}, controlando a perda de ancoragem. Quanto maior for a pressão aplicada ao periodonto, ou a sua deformação (até um determinado ponto), mais rápido um dente se movimentará, e vice-versa. Sabe-se que a translação, por distribuir melhor a pressão ao periodonto^{15,44}, causa uma menor deformação do que a inclinação. Sendo assim, dada uma mesma força horizontal, um dente movimentado por translação tem uma velocidade menor de movimentação do que se o mesmo fosse inclinado^{2,14,23,41}. A inclinação descontrolada, apesar de gerar pressões mais altas no periodonto do que a inclinação controlada, é pouco utilizada na TAS, pois altera muito as angulações dentárias e envolve movimentações desnecessárias dos ápices radiculares, concentrando muita pressão na região apical^{14,44}.

A mola de escolha para o fechamento de espaços na TAS é a mola "T" da liga de titânio-molibdênio, também chamada de beta-titânio (β -Ti) (TMA[®])³⁸. Esta mola, por ter uma configuração específica, apresenta uma relação carga-deflexão (CD) baixa e um limite elástico alto e, em segunda análise, por ser feita de β -Ti tem as duas qualidades acima melhoradas^{6,7}. Outra vantagem da mola "T" é a possibilidade de poder ativá-la de maneiras diferentes^{5,25,32,36,47}, fazendo com que a mesma produza momentos simétricos ou assimétricos em suas extremidades³².

Diversos parâmetros sobre o comportamento biomecânico das molas "T" de β -Ti simétricas foram amplamente estudados, incluindo o efeito da altura da

mola^{8,11,18,39,47}, o deslocamento da mola dentro da distância interbráquete (DIB)^{8,18,25,39,47}, a quantidade e tipo de pré-ativação^{12,18,19,35,39,40,47}, a ativação horizontal^{18,47} e o tipo de liga metálica^{7,33,42}. Apesar do grande número de relatos científicos, o efeito da marca comercial de β -Ti utilizado para confecção das molas ainda não é bem conhecido, assim como, à influência do alívio de tensão estrutural sobre o sistema de força liberado pelas molas "T" a longo prazo¹³.

Os fios de β -Ti foram introduzidos na Odontologia do final dos anos 70²¹ e desde então têm sido amplamente utilizados na Ortodontia, devido às suas excelentes propriedades mecânicas, tais como boa memória de forma, baixa rigidez, alta formabilidade e boa soldabilidade^{7,16,18,20,46}. Após a expiração da patente⁴⁶ sobre a primeira marca comercial de β -Ti (TMA[®],Ormco Co., Glendora, EUA), a utilização desta liga expandiu drasticamente com uma grande variedade de preços e qualidade. Apesar de várias marcas comerciais disponíveis, apenas alguns poucos estudos^{28,29,46} foram realizados, a fim de comparar diferentes marcas comerciais de β -Ti.

Esses estudos, no entanto, comparam as propriedades mecânicas das ligas de β -Ti através de teste de tração^{28,29,46}, ou por meio de teste de flexão²⁸ em fios retos. Isto pode não representar o comportamento real das diferentes ligas β -Ti quando dobras são inseridas no fio ou quando desenhos mais elaborados são utilizados, tais como as molas "T".

Além disso, na maioria dos materiais, deformação plástica ocorre se a tensão excede seu limite de elasticidade⁴⁸. O que é frequentemente esquecido é que a deformação plástica também é tempo-dependente^{17,48}. Quando um determinado material é submetido a uma carga ou estresse constante dentro

do seu limite elástico, este pode sofrer uma deformação progressiva denominado de fluência (*creep*)^{1,17,43,48}. A partir de uma perspectiva microscópica, fluência em metais é o resultado de deslocamentos na estrutura cristalina do material. Este fenômeno microscópico pode ser observado experimentalmente como um aumento da deformação associado com um estresse constante (*fluência - creep*) ou uma diminuição do estresse associado com um deformação constante (*stress relaxation - alívio de tensão*). A fluência é dependente da intensidade do estresse e da temperatura, visto que altas tensões e temperaturas favorecem os deslocamentos. Na maioria das aplicações de engenharia, a fluência em metais se torna uma preocupação somente em temperaturas de pelo menos 30% do ponto de fusão do material, visto que os componentes estruturais são normalmente submetidos a altas tensões durante a formação para uma aplicação específica^{17,43,48}.

No caso das molas ortodônticos, dobras agudas são geralmente introduzidas para dar forma ao fio. Estas dobras concentram o estresse e causam espaçamentos e deslocamentos instáveis na estrutura cristalina nos pontos de alta tensão⁴⁸. Ortodontistas têm tentado superar este problema aplicando tratamento térmico em aparelhos ortodônticos de aço inoxidável, para promover o rearranjo da estrutura cristalina, aliviando as tensões residuais^{30,31,37}. Outra estratégia muito utilizada é a de aproveitar o efeito Bauschinger¹¹. Este consiste em sobreativar o fio e realizar simulações de ativações, até que o fio assuma a forma desejada para a aplicação do sistema de força.

Como citado anteriormente, a liga de β -Ti apresenta uma moderada memória de forma, entre o aço e o NiTi, ou seja, capacidade do fio retornar a

sua forma e estrutura original, dispersando a energia (estresse) acumulado^{7,22}. Sendo assim, quando se confecciona uma mola “T” de β -Ti é necessário simular sua ativação para que os estresses incorporados no fio durante a confecção das dobras sejam liberados anteriormente à sua instalação na boca do paciente, fazendo com que os sistemas de forças gerados sejam adequados para a movimentação dentária desejada. Para que essa liberação de estresses residuais aconteça é feita uma simulação de ativação. Esta consiste em posicionar a mola em posição neutra, ou seja, simular sua instalação nas canaletas dos bráquetes, colocando as duas extremidades da mola em posições paralelas, antes de qualquer ativação horizontal. A partir deste ponto, ainda fora da boca do paciente, aplica-se uma força horizontal de forma que as hastes verticais da mola fiquem abertas 5 mm^{11,36}.

Porém, mesmo realizando a simulação de ativação, as molas “T” (ou qualquer outro tipo de mola) quando sujeitas a uma deformação constante continuam apresentando algum grau de estresse residual que tende a ser liberado ao longo do tempo, o que faz com que a mola possa perder parte de suas pré-ativações, alterando assim o sistema de força original.

Este efeito tempo-dependente tem sido estudado em outras ligas metálicas de uso ortodôntico^{10,22,24,26,34,49}, contudo, ainda foi pouco avaliado para os fios de β -Ti^{22,26,49}, assim como, existe apenas um registro na literatura sobre este efeito nas molas “T”¹³.

Caldas et al.¹³ (2011) avaliaram este efeito sobre o sistema de força gerado por molas “T” simétricas. A amostra foi constituída de 90 molas de dimensões 6 X 10 mm, confeccionadas com fios de dimensão 0,017” x 0,025” de TMA®, pré-ativadas por dobras e divididas aleatoriamente em 9 grupos de

10 molas. As molas de um grupo (imediato) foram avaliadas logo após a pré-ativação e simulação de ativação, enquanto as molas dos demais 8 grupos (24, 48 e 72 horas, 1, 2, 4, 8 e 12 semanas) foram avaliadas após serem mantidas ativadas por 5 mm durante os períodos supracitados. O grupo imediato apresentou uma intensidade da força horizontal e momento maior (267,6 gf / 1932,6 gf.mm) que os demais grupos (200,7 a 181,7 gf / 1471,3 a 1696,6 gf.mm), sendo esta redução significativa nas primeiras 24 horas. A proporção MF foi semelhante entre os grupos. Os autores concluíram que ocorreu uma deformação progressiva das dobras de pré-ativação, o que promoveu uma redução da força e dos momentos gerados, em torno de 15 e 17%, respectivamente, mas que não alterou a proporção MF a longo prazo.

Porém, ainda existe uma carência de estudos que avaliem o mesmo efeito quando as molas "T" forem pré-ativadas por curvatura. Neste caso, a ausência de um ponto crítico de estresse, uma curvatura gradual é utilizada para pré-ativação, o estresse é distribuído pela extensão da curvatura fazendo com que o efeito do alívio de tensão estrutural possa ser menor do que nas molas pré-ativadas por dobra.

Portanto, diante das carências científicas anteriormente citadas, o objetivo do trabalho é avaliar o comportamento biomecânico das molas "T" confeccionadas com diferentes marcas comerciais de β -Ti e avaliar a estabilidade do sistema de força das molas "T" pré-ativadas por curvatura quando submetidas ao alívio de tensão estrutural a longo prazo, assim como, comparar seus resultados com as molas pré-ativadas por dobras.



2 PROPOSIÇÃO

2 PROPOSIÇÃO

2.1 OBJETIVO GERAL

Avaliar o comportamento biomecânico das molas "T" confeccionadas com diferentes marcas comerciais de beta-titânio (β -Ti) e avaliar a estabilidade do sistema de força das molas "T" pré-ativadas por curvatura quando submetidas ao alívio de tensão estrutural a longo prazo, assim como, comparar seus resultados com as molas pré-ativadas por dobras.

2.2 OBJETIVOS ESPECÍFICOS

Capítulo 1 Force system delivered by different beta-titanium wires in elaborate designs.

Artigo a ser enviado para publicação no periódico European Journal Of Orthodontics.

Capítulo 2 Stability of beta-titanium T-loops springs preactivated by gradual curvature.

Artigo a ser enviado para publicação no periódico American Journal of Orthodontics and Dentofacial Orthopedics.

Capítulo 3 Effect of stress relaxation in the preactivation of beta-titanium T-loops.

Artigo a ser enviado para publicação no periódico European Journal Of Orthodontics.



3 CAPÍTULOS



CAPÍTULO 1

Force system delivered by different beta-titanium wires in elaborate designs

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Force system delivered by different beta-titanium wires in elaborate designs

ABSTRACT

Objective: Evaluation of the force system produced by four brands of beta-titanium (β -Ti) wires bent into an elaborate design (T-Loop spring). **Materials and Methods:** Forty T-Loop springs (TLSs) hand bent from 0.017 x 0.025-in β -Ti were randomly divided into four groups according to wire brand: TMA (G1), BETA FLEXY (G2), BETA III WIRE (G3) and BETA CNA (G4). Forces and moments were recorded by a moment transducer coupled to a digital extensometer indicator adapted to a testing machine every 0.5 mm of deactivation from 5 mm of the initial activation. The moment-to-force (MF) ratio, the overlapping of the vertical extensions of the TLSs and the load-deflection (LD) ratio were also calculated. To complement the results, the Young's module (YM) of each wire was determined by the slope of the load-deflection graph of a tensile test and also, the surface chemical composition was evaluated by an energy dispersive X-ray fluorescence spectrometer. **Results:** All groups, except by G2, produced similar force levels initially. The G3 produced the highest LD rates and G1 and G4 had similar amounts of overlap of the vertical extensions of the TLSs in "neutral position". The G1 and G3 delivered the highest levels of moments and G2 and G3 produced the highest MF ratios. The β -Ti wires from G3 produced the highest YM and all groups showed similar composition, except from G2. **Conclusions:** The four beta-titanium wires analyzed produced different force systems when used in a more elaborate design due to the fact that each wire responds differently to bends.

KEYWORDS: Beta-titanium; T-loop spring; Group B anchorage; Biomechanics.

INTRODUCTION

Beta-titanium (β -Ti) was introduced in dentistry the late 70's [**Goldberg, J. and Burstone, C.J. 1979**] and since then it has been widely used in orthodontics due to its excellent mechanical properties, such as high spring-back, low stiffness, high formability, and good weldability [**Burstone, C.J. and Goldberg, A.J. 1980, Donovan, M.T., Lin, J.J., et al. 1984, Goldberg, A.J. and Burstone, C.J. 1982, Kapila, S. and Sachdeva, R. 1989, Verstrynge, A., Van Humbeeck, J., et al. 2006**]. After the expiration of the patent [**Verstrynge, A., Van Humbeeck, J., et al. 2006**] on the first commercial brand of β -Ti (TMA[®], Ormco Co., Glendora, USA) the use of this alloy expanded drastically with a wide range of prices and quality. Even though there are several brands available to the clinician, only a few studies [**Johnson, E. 2003, Juvvadi, S.R., Kailasam, V., et al. 2010, Verstrynge, A., Van Humbeeck, J., et al. 2006**] have been done in order to compare different β -Ti commercial brands.

These studies, however, compare mechanical properties of the β -Ti alloys either through tensile [**Juvvadi, S.R., Kailasam, V., et al. 2010, Verstrynge, A., Van Humbeeck, J., et al. 2006**] or through 3 point bending tests [**Johnson, E. 2003**] on straight pieces of wire. This might not represent the true behavior of the different β -Ti alloys when bends are placed in the wire or when more elaborate designs are used, such as loops.

It has been established that the T-loop spring (TLS) has the greatest ability to produce high moment-to-force (MF) ratios in order to control tooth movement, when compared to other designs of springs. Several parameters of

TLS have already been studied, such as the spring's height [Burstone, C.J. and Koenig, H.A. 1976, Chen, J., Markham, D.L., et al. 2000, Faulkner, M.G., Fuchshuber, P., et al. 1989, Martins, R.P., Buschang, P.H., et al. 2008a, Viecilli, R.F. 2006], the location of the spring within the interbracket distance [Burstone, C.J. and Koenig, H.A. 1976, Hoenigl, K.D., Freudenthaler, J., et al. 1995, Kuhlberg, A.J. and Burstone, C.J. 1997, Martins, R.P., Buschang, P.H., et al. 2008a, Viecilli, R.F. 2006], the intensity and type of preactivation [Caldas, S.G.F.R., Martins, R.P., et al. 2011a, Faulkner, M.G., Fuchshuber, P., et al. 1989, Manhartsberger, C., Morton, J.Y., et al. 1989, Martins, R.P., Buschang, P.H., et al. 2008b, Viecilli, R.F. 2006], horizontal activation [Faulkner, M.G., Fuchshuber, P., et al. 1989, Viecilli, R.F. 2006], alloy wire type [Burstone, C.J. and Goldberg, A.J. 1980, Lim, Y., Quick, A., et al. 2008, Rose, D., Quick, A., et al. 2009], and stress relaxation [Caldas, S.G.F.R., Martins, R.P., et al. 2011b], all of which can alter the MF ratio and force produced. However, differences between TLS manufactured by different β -Ti have not yet been systematically studied and are not completely understood. Thus, it is suggested that these alloys may present different biomechanical behavior, affecting the force system released by the springs.

The purpose of this study was to evaluate if the behavior of four different brands of beta-titanium bent into an elaborate design (T-Loop spring) are similar, when forces, moments and MF ratios produced are compared.

MATERIALS AND METHODS

Force System

Sixty 6 x 10 mm T-Loop springs (TLSs) were blindly bent out of four different commercial brands of 0.017 x 0.025-in β -Ti, using a "Marcotte" plier (Hu-Friedy dental instruments, Chicago, USA), using a custom template (Fig. 1) and divided into 4 groups of 15 springs, made of the same wire brand. The groups were previously labeled to assure impartiality of the results. The wires used in the groups were TMA (Ormco Co., Glendora, USA) (G1), BETA FLEXY (Orthometric Imp.Exp.Ltda, Marília, Brazil) (G2), BETA III WIRE (Morelli Ortodontia, Sorocaba, Brazil) (G3) and BETA CNA (Ortho Organizers, INC., San Marcos, USA) (G4). (Table 1) TLSs were hand-bent in a random order and out of the 15 TLSs bent, 10 were randomly selected for testing.

An universal testing machine (EMIC, São José dos Pinhais, Brazil), equipped with a load cell of 0.1 kN, was coupled to a moment transducer and a digital extensometer indicator (Transdutec, São Paulo, Brazil) for the tests. The test speed was 5 mm/min and the digital extensometer's excitation and sensitivity was 5 V and 0.5 mV/V, respectively **[Caldas, S.G.F.R., Martins, R.P., et al. 2011a, Caldas, S.G.F.R., Martins, R.P., et al. 2011b]**.

Prior to the test, concentrated bends were used to preactivate the TLSs **[Marcotte, M. 1990]**, which were positioned symmetrically in an interbracket distance (IBD) of 23 mm, and at this distance, checked with a digital caliper, the testing device was zeroed. To assure the correct activation and the centralization of the TLSs, nine millimeters were measured from the center of the loop towards each extremity of the horizontal extensions, and were marked

with a permanent marker (Fig. 2). Those markings would allow the TLS to be correctly secured in place, centralized and with the correct horizontal activation.

After a horizontal activation of 5 mm, the horizontal force and moment developed were recorded for every 0.5 mm of deactivation, at the extremity of the TLSs attached to the testing machine, and the MF ratios were calculated. Furthermore, the amount of overlap of the vertical extensions of the TLSs in “neutral position” (deformation assumed when the loop’s extremities are placed parallel to the position that they will be once installed, producing only moments) was calculated by linear interpolation. The load-deflection (LD) ratio of each TLS was obtained by calculating the slope of the respective deactivation graph (Fig. 3A).

Wire dimensions

The height and width of each wire were measured to the nearest 0.001 mm with a digital micrometer accurate to $\pm 1 \mu\text{m}$ (Mitutoyo, Kyoto, Japan). Five wires were taken from each group, totaling 20 readings and the mean was used in the subsequent calculations (Table 1).

Mechanical Properties

The sample consisted of five 30 cm segments of each of the wires and divided as above mentioned (Table 1). The tensile test was performed on universal testing machine (EMIC, São José dos Pinhais, Brazil) equipped with a load cell of 5 kN and speed of 2 mm / min until rupture of the wire. The Young’s module (YM) was determined by the slope of the LD graph of the tensile test .

Chemical Composition

An energy dispersive X-ray fluorescence spectrometer machine, model EDX-800, (Shimadzu Corporation, Kyoto, Japan) was used to determine the surface chemical composition of the wires in each group, using different wires from the same batch. Based on this analysis, it was assumed that the bulk composition was similar to the surface compositions within the limits of accuracy. A fractographic image was obtained, and the chemical composition was determined automatically in percentages.

Statistical analysis

The SPSS v.16.0 (SPSS Inc., Chicago, USA) statistical analysis software was used in this study. The Kolmogorov-Smirnov test indicated normal distributions of the data, and an ANOVA one-way test was used to identify differences among the groups. Tukey post hoc test at a significance level of 5% was used to compare the groups' differences.

RESULTS

Force system

The TLSs measured produced horizontal forces ranging from 116.7 gf to 498.9 gf (G1), -15.9 gf to 311.4 gf (G2), 35.8 gf to 452.6 gf (G3) and 121.9 gf to 463.7 gf (G4) between 0.5 and 5mm of activation. TLSs from G2 produced the lowest initial forces of deactivation compared to the other 3 groups (Table 2 and Fig. 3A). The TLSs from G3 showed the highest LD rates (93.7 gf/mm), followed by G1 (85.5 gf/mm), and by G2 and G4 (72.7 and 76.0 gf/mm, respectively), which showed similar LD rates.

The amount of overlap of the vertical extensions of the TLSs (in neutral position) was different between G2 (0.72 mm) and G3 (0.13 mm), which on the other hand were different from the similar overlap that occurred between G1 and G4 (-0.86 mm and -1.13 mm, respectively) (Table 2 and Fig. 4).

The TLSs delivered moments that ranged from 1452.0 gf.mm to 2030.7 gf.mm (G1), 919.0 gf.mm to 1482.0 gf.mm (G2), 1366.1 gf.mm to 1992.1 gf.mm (G3) and 1276.9 gf.mm to 1721.3 gf.mm (G4) between 0.5 and 5mm of activation. G1 and G3 produced the highest levels of moments initially, while G4 produced lower moments than G1 but the values were similar to G3 and G2. G2 was different from all other groups (Table 3 and Fig. 3B).

G2 and G3 showed the highest MF ratios initially (4.9 and 4.4 mm, respectively), followed by G1 (4.1 mm) which was similar to G3 and G4 (3.7 mm). From 1.5 mm of deactivation on, there was no difference among the groups (Table 4 and Fig. 3C).

Wire dimensions

Significant differences were found among the sizes of the wires. (Table 1) Groups 1, 3 and 4 had the same height (0.0165-in), which were larger than the dimension of G2 (0.0161-in). Regarding the width of the wires, G1, 2 and 4 had the same dimensions (0.024-in; 0.024-in; 0.0242-in, respectively), while G3 (0.0244-in) was different from all of them, except from G4.

Mechanical Properties

The β -Ti wires from G3 showed the highest YM at 56.5 GPa, which was similar to G1 (51.0 GPa) and G2 (50.3 GPa). G4 showed the lowest YM (48.1 GPa), which was different from G3, but similar to G1 and G2 (Table 5).

Chemical Composition

The wires from all groups showed similar composition regarding Titanium (Ti), Molibdenium (Mo), Zirconium (Zn), Sulfur (S), Tin (Sn) and Phosphorus (P), except the wires from G2, which had a higher concentration of Ti and a lower concentration of Mo (Table 6).

DISCUSSION

All groups produced similar force levels at 5 mm of deactivation, except for G2, which showed lower forces. Even though there were differences found in the dimensions of the wires, these differences were small (ranging from 0.0004 - 0.0002), probably unable to influentiate the results significantly. The neutral position of the loops is probably the factor that can best explain these differences. The amount of overlap of the vertical extensions of the loops when they are in neutral position may create an over or underactivation of the loop initially, what is the consequence of the shape of preactivation of the loop [Caldas, S.G.F.R., Martins, R.P., et al. 2011a, Caldas, S.G.F.R., Martins, R.P., et al. 2011b, Martins, R.P., Buschang, P.H., et al. 2008b]. In this study, however, the groups tested had the same preactivation shapes, what doesn't explain the differences found on neutral position. Chemical differences among the wires, in the other hand, could influentiate how each particular brand of β -Ti

responds to the bends made to design the loop, and could therefore play a major role in causing these differences **[Burstone, C.J. and Goldberg, A.J. 1980]**.

All groups had similar composition, except for G2, which showed a higher percentage of Ti and a lower percentage of Mo. Even though this could explain only partially the differences found (G2 produced lower forces initially), it can't explain why all groups, but G1 and G4, were different among themselves regarding neutral position. The differences might, finally, be explained by other factors, such as the manufacturing process, which can alter the wires properties **[Burstone, C.J. and Goldberg, A.J. 1980]**.

Throughout deactivation, the TLSs from all groups acted differently, except for G1 and G4. This result can be substantiated by the differences found in LD rate. These differences can be explained by the design **[Burstone, C.J. and Koenig, H.A. 1976, Chen, J., Markham, D.L., et al. 2000, Faulkner, M.G., Fuchshuber, P., et al. 1989, Martins, R.P., Buschang, P.H., et al. 2008a, Viecilli, R.F. 2006]**, method of preactivation **[Caldas, S.G.F.R., Martins, R.P., et al. 2011a, Faulkner, M.G., Fuchshuber, P., et al. 1989, Manhartsberger, C., Morton, J.Y., et al. 1989, Martins, R.P., Buschang, P.H., et al. 2008a, Martins, R.P., Buschang, P.H., et al. 2008b, Viecilli, R.F. 2006]**, and chemical composition of the wire **[Burstone, C.J. and Goldberg, A.J. 1980, Lim, Y., Quick, A., et al. 2008, Rose, D., Quick, A., et al. 2009]** and finally, by method of manufacture of the wires **[Burstone, C.J. and Goldberg, A.J. 1980]**. In this study, the design, method of preactivation, and size of the wire were controlled. The similar chemical composition among the groups except for G2, could explain only partially the differences, because it doesn't explain the different

behavior of G3. The physical properties of the wires due to manufacturing process might play a role on the subject, as well as how each beta-titanium wire brand responds to bends in the wire and stress relief, since the tensile test made found similar LD rates (young's modulus) among all groups **[Burstone, C.J., van Steenberg, E., et al. 1995, Caldas, S.G.F.R., Martins, R.P., et al. 2011b, Marcotte, M. 1990]**.

The differences found in the moments among the groups were similar as the ones found in the force levels. In this study, the groups' differences were probably due to neutral position and stress relief differences among them **[Burstone, C.J., van Steenberg, E., et al. 1995, Caldas, S.G.F.R., Martins, R.P., et al. 2011b, Marcotte, M. 1990]**. This was expected since the residual moment, or the moment produced by the concentrated bends, is related to the way each wire will behave to those particular bends **[Caldas, S.G.F.R., Martins, R.P., et al. 2011a, Faulkner, M.G., Fuchshuber, P., et al. 1989, Manhartsberger, C., Morton, J.Y., et al. 1989, Martins, R.P., Buschang, P.H., et al. 2008a, Martins, R.P., Buschang, P.H., et al. 2008b, Vieceilli, R.F. 2006]**. The effect of the bends in the behavior of the wires can be confirmed if the data is mathematically adjusted to the neutral position, as already shown in the literature, because it can subtract the effect of how the wires respond to bends (Fig. 5A and B) **[Caldas, S.G.F.R., Martins, R.P., et al. 2011a, Martins, R.P., Buschang, P.H., et al. 2008b]**. This can be done by transposing the x-intercept of each line of the graph to the origin of the graph, along with every point of the line, isolating the effects of horizontal overlapping of the vertical extensions of the TLSs. One can see on the charts that the relation of force among the groups is very similar to the relation of moments among them, if

neutral position is not taken into consideration, and the TLSs behavior is pretty similar among the groups.

The MF rates were very variable among the groups, since it is a proportion between the already variable force levels and moment levels. The fact that the G1 and G4 produced similar MF rates is consistent to the similar behavior that they showed on neutral position (Table 2). G2 and G3 showed an inconsistent MF ratio on the last 2 mm of deactivation (G2) and very close to complete deactivation (G3) because of their positive neutral position (vertical extensions of the TLSs were apart). If the way each wire behaves in regards to neutral position was isolated (Fig. 5C) and removed experimentally, the MF ratios of all wires would be the same, unfortunately, that is something that would not occur clinically. This, however, doesn't mean that the wires from G2 and G3 shouldn't be used clinically. They can be used, but a different approach is needed when those wires are used in loops. If a TLS is to be used, the clinician should compensate the differences in the overlapping of the vertical extensions of the loop by opening less the inner “ears” of those two wire brands than what is normally recommended for the G1 (TMA) [Burstone, C.J. and Koenig, H.A. 1976, Marcotte, M. 1990].

CONCLUSIONS

It can be concluded from the TLSs tested:

1. When they are produced from different β -Ti wires, the TLSs produce different forces, moments and LD ratios;
2. The cause of these differences is the way each wire behaves in relation to bends, producing different shapes in neutral position;

3. Groups 1 (TMA) and 4 (CNA) showed a more consistent MF ratio throughout deactivation.
4. Even though Group 2 (BETA-FLEXY) and 3 (BETA III TIMO) behaved differently from 1 and 4, this does not mean that shouldn't be used clinically, but a different approach is needed when loops are used.

ACKNOWLEDGEMENTS

The authors would like to thank Orthometric and Ortho Organizers for the donation of their β -Ti wires for this study.

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FIGURE LEGENDS

Figure 1 - Template developed in the Loop software (dHAL Orthodontic Software, Athens, Greece) used for the design of the TLS. The software allows the template to be printed in 1:1 ratio. Each square measures 1 mm².

Figure 2 - **(A)** Loop horizontal dimensions stops were marked to assure the correct activation and TLS centralization; **(B)** Neutral position of the TLS simulated by the Loop Software; **(C)** TLS shape simulated by the Loop Software when positioned symmetrically in an IBD of 23 mm and activated 5 mm. Colored areas reflect stress distribution over the wire, going from red, being high stress areas to dark blue being low stress areas.

Figure 3 - **(A)** Horizontal force (in grams-force) produced on deactivation by the four groups of β -Ti TLSs over a range of 5 mm. **(B)** Moments produced by the β -Ti TLSs over a range of 5 mm of deactivation. **(C)** MF ratio produced by the β -Ti TLSs over a range of 5 mm of deactivation.

Figure 4 - Figure 3A modified: the x- intercepts of the lines, pointed by the arrows, depict the amount of horizontal overlap of the vertical extensions of the TLSs in “neutral position” (deformation assumed when the loop’s extremities are placed parallel to the position that they will be once installed, producing only moments) and were calculated by linear interpolation.

Figure 5 - **(A)** Figure 3A mathematically adjusted in order to isolate the effect of the overactivation on the force produced by the groups caused by the overlapping of the vertical extensions. **(B)** Figure 3B mathematically adjusted in order to isolate the effect of the overactivation on the moments produced by the groups caused by the overlapping of the vertical extensions. **(C)** Figure 3C

mathematically adjusted in order to isolate the effect of the overactivation on the MF ratios produced by the groups caused by the overlapping of the vertical extensions The force systems developed by the groups was quite similar.

Table 1. β -Ti wires used in the study.

GROUP	WIRE	MANUFACTURER	BATCH	MEASURED DIMENSIONS (inches)							
				Height				Width			
				Mean	SD	Range	p (95%)	Mean	SD	Range	p (95%)
1	TMA	Ormco Corporation	03F2F	0.0165	0.0	A	0.0	0.024	0.0	B	0.0
2	BETA FLEXY	Orthometric Imp. Exp.	148	0.0161	0.0	B	0.0005	0.024	0.0	B	0.0
3	BETA III TiMo	Morelli Ortodontia	1072448 100004	0.0165	0.0	A	0.0	0.0244	0.0	A	0.0005
4	CNA	Ortho Organizers	401682D06	0.0165	0.0	A	0.0	0.0242	0.0	AB	0.0005

different letters indicate group differences

Table 2. Means and standard deviations for forces (gf), neutral position (mm), LD ratio (gf.mm) and ANOVA results over a range of 5 mm of deactivation.

	G1		G2		G3		G4		p (95%)
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
5 mm	498.9	18.7	311.4	79.92	452.58	26.73	463.65	13.8	<0.001
4.5 mm	453.74	18.78	273.67	72.85	406.47	24.43	424.35	13.91	<0.001
4 mm	414.1	18.41	238.37	68.59	362.21	24.27	388.57	14.05	<0.001
3.5 mm	373.93	18.3	203.04	64.58	317.58	24.1	352.48	14.22	<0.001
3 mm	333.22	18.18	167.3	60.78	272.42	24.29	315.85	14.48	<0.001
2.5 mm	291.66	18.16	131.48	57.3	226.65	24.4	278.65	14.92	<0.001
2 mm	249.29	18.29	95.34	54.15	180.0	24.58	240.77	15.5	<0.001
1.5 mm	206.05	18.51	58.55	51.22	132.61	24.82	201.93	15.94	<0.001
1 mm	161.89	18.86	21.53	48.83	84.48	25.06	162.28	16.4	<0.001
0.5 mm	116.66	19.42	-15.87	47.1	35.77	25.31	121.94	17.29	<0.001
Neutral position	-0.86	0.22	0.72	0.62	0.13	0.29	-1.13	0.27	<0.001
LD	85.5	3.04	72.7	12.51	93.71	2.59	75.96	3.01	<0.001

different letters indicate group differences

Table 3. Means and standard deviations for moments (gf.mm) and ANOVA results over a range of 5 mm of deactivation.

	G1		G2		G3		G4		p (95%)
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
5 mm	2030.7	290.16	1482.0	278.8	1992.1	179.27	1721.3	110.65	<0.001
4.5 mm	1977.8	282.51	1430.7	272.23	1941.5	177.57	1677.7	113.48	<0.001
4 mm	1934.9	276.38	1382.3	269.75	1891.9	170.27	1641.3	116.98	<0.001
3.5 mm	1874.7	265.35	1329.43	268.39	1837.9	169.29	1601.4	117.46	<0.001
3 mm	1812.1	253.31	1271.4	267.33	1761.0	148.82	1557.1	119.2	<0.001
2.5 mm	1745.3	236.17	1211.3	268.41	1687.6	125.73	1507.7	117.62	<0.001
2 mm	1683.3	224.98	1149.1	269.11	1615.6	124.93	1455.7	114.46	<0.001
1.5 mm	1597.2	180.45	1075.8	267.83	1538.2	126.97	1402.0	112.18	<0.001
1 mm	1527.8	174.18	1000.2	265.97	1459.4	131.14	1339.2	106.87	<0.001
0.5 mm	1452.0	169.17	919.0	265.91	1366.1	132.17	1276.9	106.35	<0.001

different letters indicate group differences

Table 4. Means and standard deviations for MF ratios (mm) and ANOVA results over a range of 5 mm of deactivation.

	G1		G2		G3		G4		p (95%)
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
5 mm	4.07	0.55	4.86	0.72	4.4	0.33	3.72	0.28	<0.001
4.5 mm	4.36	0.59	5.35	0.86	4.78	0.37	3.96	0.33	<0.001
4 mm	4.67	0.64	5.98	1.06	5.23	0.41	4.23	0.37	<0.001
3.5 mm	5.02	0.69	6.83	1.43	5.8	0.49	4.55	0.42	<0.001
3 mm	5.44	0.73	8.12	2.16	6.48	0.5	4.94	0.49	<0.001
2.5 mm	5.99	0.77	10.4	4.02	7.48	0.74	5.43	0.58	<0.001
2 mm	6.77	0.89	17.25	13.64	9.09	1.15	6.08	0.7	0.003
1.5 mm	7.79	1.01	-3.03	49.35	11.91	2.18	6.99	0.9	0.537
1 mm	9.53	1.42	13.76	29.44	18.74	6.21	8.35	1.26	0.425
0.5 mm	12.71	2.35	3.09	71.76	23.65	131.1	10.71	2.1	0.927

different letters indicate group differences

Table 5. Means and standard deviations for YM and ANOVA results over a tensile test.

GROUP	Mean Young's modulus (GPa)	SD	Range	p (95%)
1	51.0	1.7	3.9	
2	50.3	2.9	7.3	
3	56.5	6.2	14.6	0.012
4	48.1	0.7	1.6	

different letters indicate group differences

Table 6. Composition of β -Ti wires used in the study (in % of total composition).

GROUP	Ti	Mo	Zr	S	Sn	P	I	Sum (%)
1	68.4	13.6	6.1	4.7	3.4	3.2	0.6	100.0
2	72.6	11.3	6.2	4.0	2.9	2.5	0.4	100.0
3	68.1	13.0	5.5	5.8	4.0	3.6		100.0
4	69.7	13.3	5.9	4.2	4.0	2.8		100.0

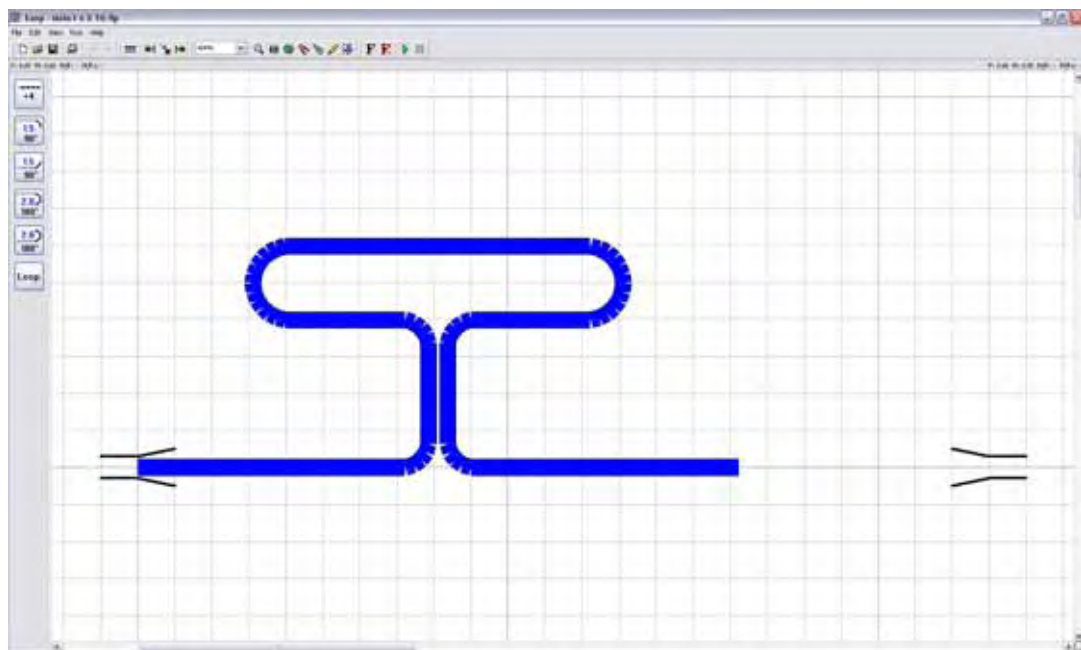
Figure 1

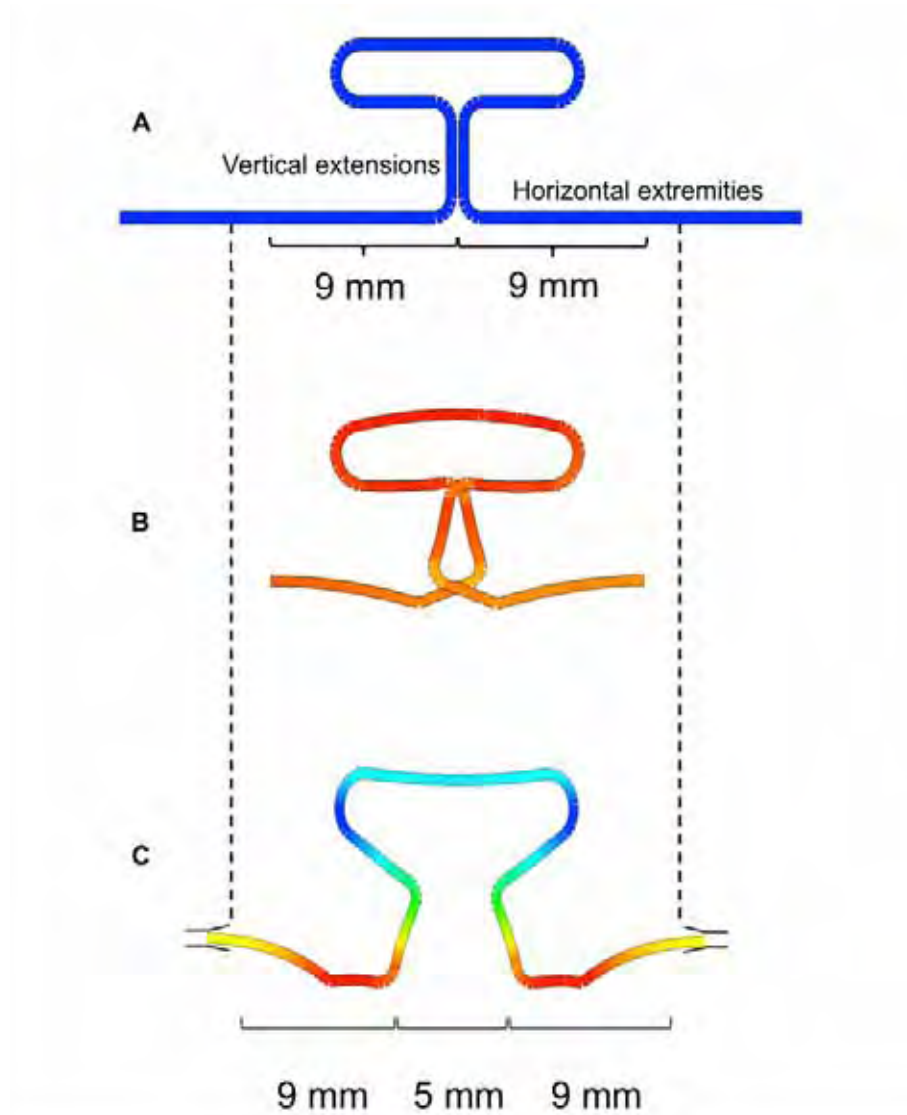
Figure 2

Figure 3

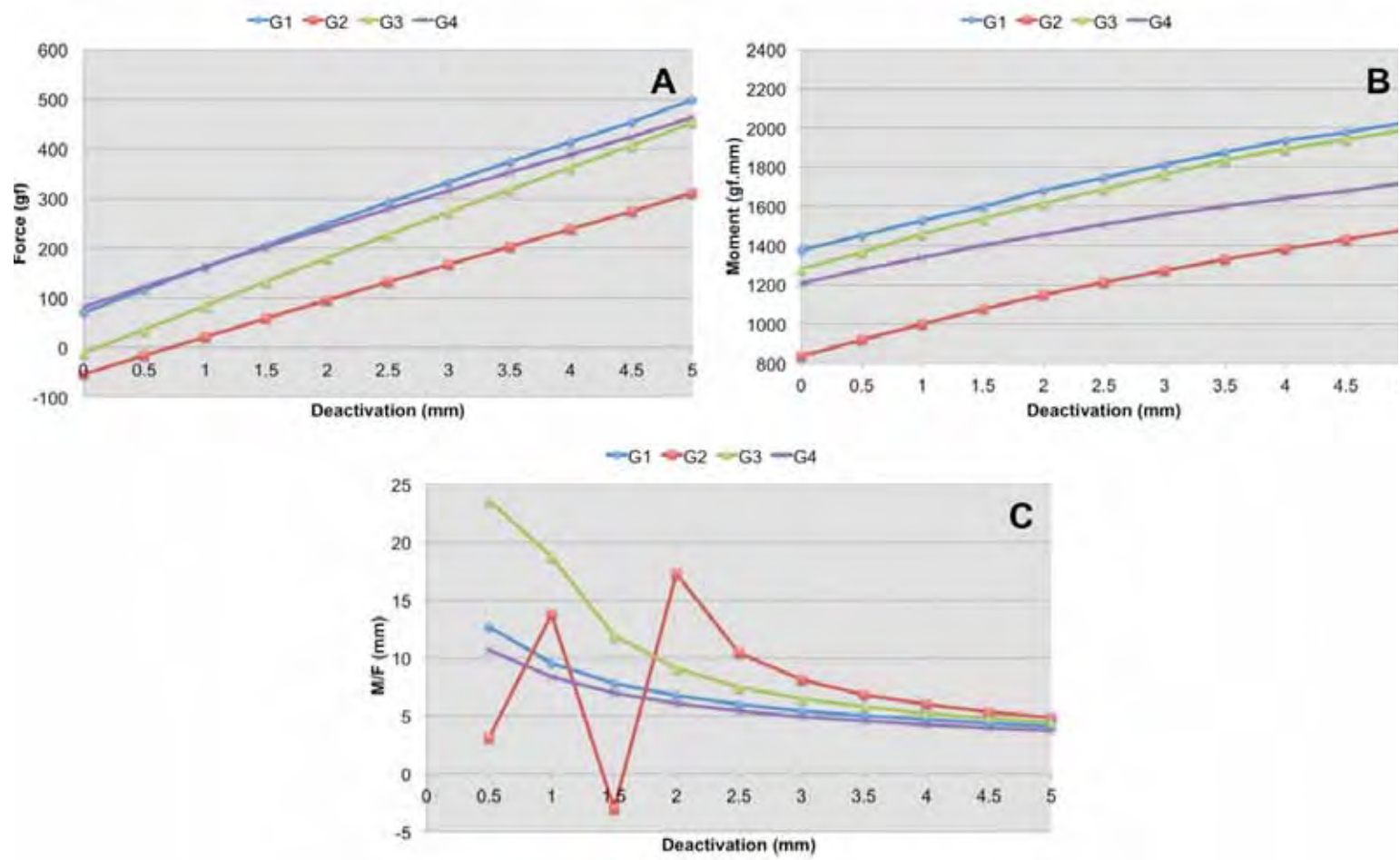


Figure 4

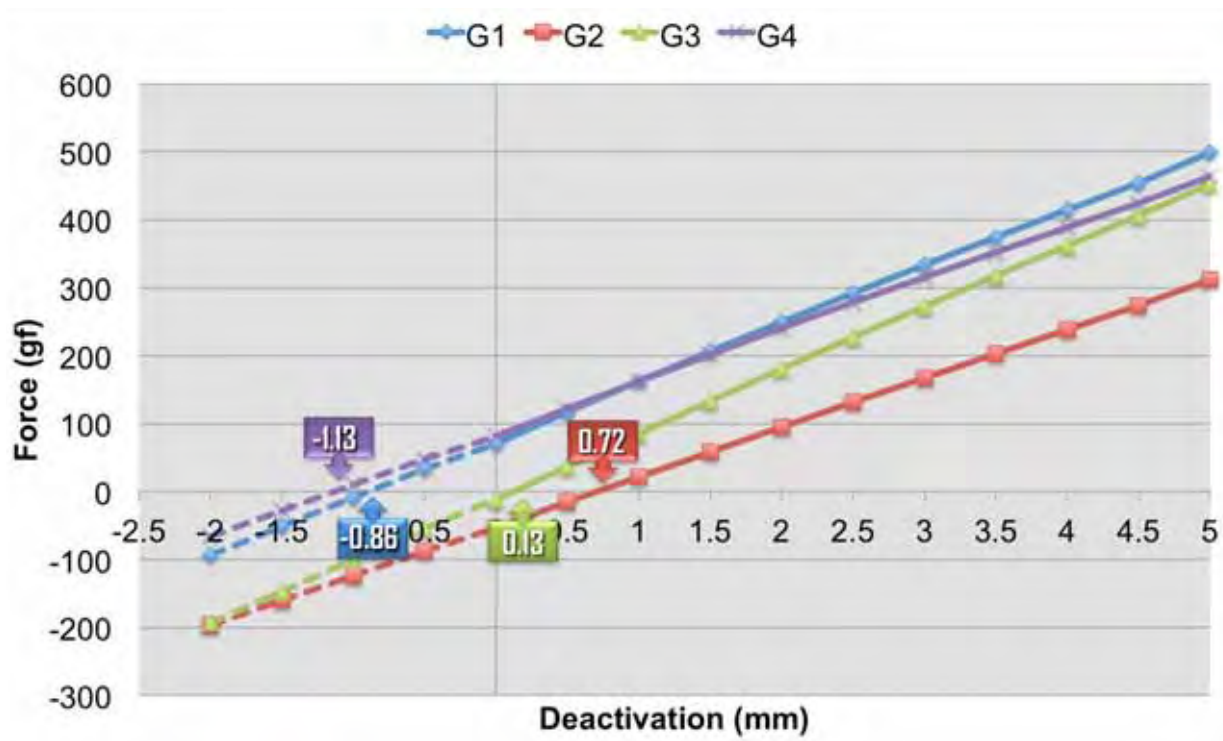
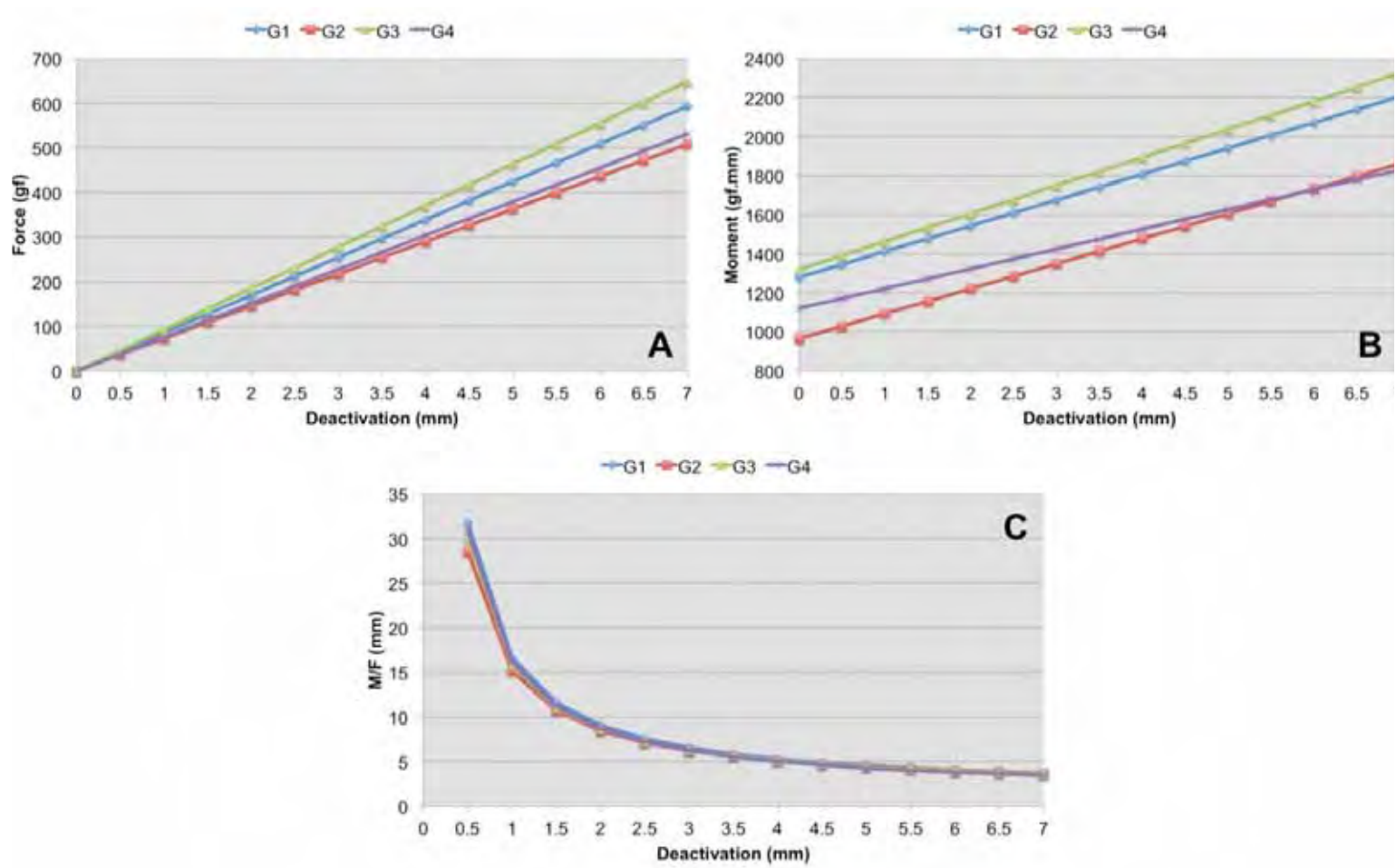


Figure 5





CAPÍTULO 2

Stability of beta-titanium T-loops springs preactivated by gradual curvature

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Stability of beta-titanium T-loops springs preactivated by gradual curvature

ABSTRACT

Objective: Evaluate changes in the force system of TLSs preactivated by curvature due to stress relaxation. **Materials and Methods:** Ninety TLSs with dimensions 6 x 10 mm, produced out of .017" x .025" TMA[®] and preactivated by gradual curvature, were randomly distributed into nine groups according to time point of evaluation. Group 1 was tested immediately after the spring preactivation and stress relief by trial activation. The other 8 groups were tested after 24, 48 and 72 hours, 1, 2, 4, 8 and 12 weeks and divided into groups accordingly. Using a moment transducer coupled to a digital extensometer indicator adapted to a universal testing machine, the amount of horizontal force, moment and moment-to-force (MF) ratios were recorded every 0.5 mm of deactivation from 5 mm of the initial activation in an interbracket distance (IBD) of 23 mm. **Results:** The horizontal forces decreased gradually among the groups ($P<.001$) and the moments showed a significant and slow decrease due to time among the groups when the total profiles of the TLSs were compared ($P<.001$). All groups produced similar MF ratios ($P=.532$), with no influence of time. **Conclusions:** The TLSs preactivated by curvature suffered a gradual deformation over time, which affected the force system, specifically moments, which affected the horizontal forces produced.

INTRODUCTION

The β -Ti T-loop spring (TLS) has been used since the 80's for space closure due to its alloy and design advantages.^{1,2} Even though its specific design produces a high moment of activation, this moment might not be enough to move teeth by translation. Thus, the addition of a residual moment is needed by increasing the angulations of the extremities of the loops, in a procedure known as preactivation.³ Templates⁴ and other methods⁵ of preactivation have been developed to produce specific forces and enough moment-to-force (MF) ratios, allowing different types of tooth movement.

Upon engagement to the brackets, loops are normally loaded in the opposite direction of its preactivation which could over time cause progressive deformation and force reduction (Fig. 1).^{6,7} This time-dependent effect is called stress relaxation and has been thoroughly studied in the alloys used in orthodontics.⁸⁻¹³ Besides the fact that this effect has only been superficially evaluated for β -Ti,^{9,11,13,14} it has never been studied on TLs preactivated by gradual curvatures, which might be less sensitive to stress relaxation.

Thus, the aim of this study was evaluate changes in the force system of TLSs preactivated by curvature due to stress relaxation.

MATERIALS AND METHODS

Ninety TLSs, of 6 by 10 mm were bent using a "Marcotte" plier (Hu-Friedy dental instruments, Chicago, USA) out of .017" x .025" β -Ti (TMA[®],Ormco

Corporation, Glendora, USA) wires and preactivated by gradual curvature following a template (Fig. 2).

The TLSs were randomly divided into nine groups according to the time of evaluation. Group 1 was tested immediately after preactivation and stress relief by trial activation. The other 8 groups were maintained at 5 mm activation for different times in an interbracket distance (IBD) of 23 mm after the same procedures were made to them. A custom made device was specifically made to keep the TLSs in position on a similar way that they would remain clinically (Fig. 3). Groups 2, 3, 4, 5, 6, 7, 8 and 9 were kept restrained for 24 hours, 48 hours, 72 hours, and 1, 2, 4, 8 and 12 weeks, respectively.

An universal testing machine (EMIC, São José dos Pinhais, Brazil), equipped with a load cell of 0.1 kN, was coupled to a moment transducer and a digital extensometer indicator (Transdutech, São Paulo, Brazil) for the tests. The speed used for the test was 5 mm/min and the digital extensometer's excitation and sensitivity was 5V and 0.5 mV/V, respectively.^{14,15} For the test, the TLSs were positioned symmetrically in an IBD of 23 mm.

Horizontal force and moments were recorded for every 0.5 mm of deactivation after 5mm of initial activation, and MF ratios were calculated. The amount of horizontal overlap of the vertical extensions of the TLSs in "neutral position" was also calculated by linear interpolation. The LD ratio (the slope of the deactivation graph) was also obtained based in the graph.

SPSS v.16.0 (SPSS Inc., Chicago, USA) statistical analysis software was used in this study. The Kolmogorov-Smirnov test indicated normal distributions

and Levene's test showed that all variables had similar variances, except the MF ratios.

The multivariate profile analysis using the procedure for analysis of repeated measures was used in order to detect differences of forces, moments and MF ratios among the groups. This analysis compares the total profile, or deactivation pattern, of a whole group in relation to time and deactivation. In order to identify the differences among the groups the post-hoc Tukey test was used with the averages generated by each time (total profiles average).

ANOVA was used, at level of 5%, to detect differences among the groups on LD ratio and the amount of overlapping of the vertical extensions of the TLSs in "neutral position". Post-hoc Tukey test, at level of 5%, was used to identify the groups' differences.

RESULTS

There was a significant decrease of force due to time among the groups when the total profiles of the TLSs were compared ($P<.001$) (Table I). The total profiles horizontal forces decreased gradually among the groups, (Table II and Fig. 4) with values of 228.4gf, 197.3 gf, 191.4 gf, 184.5 gf, 185.9 gf, 189.9 gf, 167.8 gf, 161.4 gf to 143.7 gf from groups 1 through 9. Also, there was significant interaction of the time on the rate of force decrease of the loops ($P=.006$) among the groups (Table I), meaning that the load-deflection rate of the loops also decreased with time. The values (Table III) ranged from 78.1 to 72.1 gf per .5 mm and did not obey a linear decrease.

The amount of overlap of the vertical extensions of the TLSs (addressed as “neutral position” on table III) decreased gradually from group 1 (-0.18 mm) to group 9 (0.85 mm) ($P<.001$).

There was a significant and slow decrease of moment due to time among the groups when the total profiles of the TLSs were compared ($P<.001$) (Table I). The total profile average moments produced throughout the deactivation were similar among group 1 (1941.0 gf.mm) to 7 (1713.3 gf.mm), being different only from group 8 (1506.8 gf.mm), which was similar to group 7 (1713.3 gf.mm) and group 9 (1486.4 gf.mm) (Table II). There was also a significant interaction between evaluation time and deactivation ($P<.048$) (Table I and II and Fig. 5).

All groups produced similar total profile average MF ratios ($P=.532$), ranging from 12.7 mm, -5.8 mm, 17.3 mm, 3.7 mm, 20.9 mm, 24.8 mm, 13.3 mm, -3.5 mm to 18.8 mm, from groups 1 through 9, respectively. No interaction was found between time evaluation and deactivation. (Table I and II and Fig. 6).

DISCUSSION

There was a gradual force decrease among the groups over time, critical in group 4 (72 hours) and 9 (12 weeks), which can be explained by the stress relaxation phenomenon. This decrease of force over time is in agreement to several other reports that have measured this effect on straight wires, showing it to be time dependent.^{9,11,13} There was only one study¹⁴ that looked upon this effect in more elaborate configurations, evaluating stress relaxation on TLSs preactivated by bends, where a decrease of 15.5% on the force levels of TLSs

was shown in the first 24 hours. Our results also show a decrease over time, but with a different behavior, this is probably due to the gradual curvature that was used for preactivation, distributing stress over the entire extent of curvature. The structural area of the TLS that was affected and responsible for relaxation was the angle between the vertical and horizontal extremities of the spring, which is a concentrated bend. This was found by scanning the TLSs of groups 1, 4 and 9 immediately before testing and measuring the TLS's structural angles with the Screen Protractor 4.0 software (ICONICO, New York, USA). Method error assessed through intraclass correlation coefficient (ICC) showed high reliability (0.996) (Table IV and Fig. 7)

Time had a significant effect on LD ratio, which was not constant throughout the evaluation as demonstrated by the interaction between time and deactivation (force variation or LD ratio) (Table I). This effect, although significant, shows very small differences (6 gf/.5mm) (Table III) which may be clinically insignificant. Since shape of a device can influence LD ratio,¹⁶ this differences could have happened due to shape differences in the TLS, as different places in its structure go through stress relaxation, causing slightly different LD ratios overtime.

Moments were also affected by time, however, there was a significant decrease on the moments produced by the TLSs over time only in group 8 and 9. It is known that an increase in the intensity of preactivation increases the moments produced, so a decrease in the preactivation due to stress relaxation of the gable could explain a decrease in the moment values.^{3,17-20} In our results, the

behavior of overactivation caused by “neutral position”, due to the overlap of the vertical extensions of the TLSs, decreased over time and was consistent to the gradual decrease on the horizontal forces, since it has an effect on it. The clinician should be aware that when these changes occur in the shape of the TLS, this can decrease the horizontal force produced due to a reduction of the overlap of vertical extensions,²¹ and if therefore this effect should be compensated.¹⁴

As the horizontal force, there was a significant interaction of time on the rate of variation of the moments with deactivation ($P<.048$). With time, smaller decreases of moments are expected, since some relaxation of the TLS already took place. The moment levels during deactivation on the first four weeks can be fit on a relatively straight line, which over time, turns out to be a slight curvature (Fig. 5). This effect has already been shown on the literature and is explained by deformations in specific parts of the loop.¹⁴

The MF ratios did not change and there was not interaction of time on the rate of the MF ratios levels with deactivation. This was probably due to fact that the stress relaxation in the wire happened quietly on moments, causing a gradual decrease on the overlapping of the vertical extensions of the TLSs, which proportionally decreased the force levels.

CONCLUSIONS

The TLSs preactivated by curvature suffered a gradual deformation over time, which affected the force system, specifically moments, which affected the horizontal forces produced.

Even though a gradual curvature distributes stress over the wire, the structure of the TLS relaxes in an area of sharp bend inherent of the T shape. Either the TLS should be adjusted over time or a more gradual bend should be made on that region when producing the TLS.

ACKNOWLEDGMENTS

This work was supported by FAPESP (Process number 2008/07258-5, Fundação de Amparo à Pesquisa do Estado de São Paulo, SP, Brazil).

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FIGURE LEGENDS

Figure 1 - (A) TLS in passive form; (B) TLS preactivated by gradual curvature; (C) TLS engaged to brackets (loaded in an opposite direction to its preactivation).

Figure 2 - Template developed in the Loop software (dHAL Orthodontic Software, Athens, Greece) used for preactivate of the TLS. The software allows the template to be printed in 1:1 ratio. Each square measures 1 mm².

Figure 3 - Custom made device in order to keep the TLSs activated 5 mm.

Figure 4 - Chart depicting the average forces produced, during deactivation from 5 to 0.5 mm, for the groups and subgroups tested.

Figure 5 - Chart depicting the average moments produced, during deactivation from 5 to 0.5 mm, for the groups and subgroups tested.

Figure 6 - Chart depicting the average MF ratios produced, during deactivation from 5 to 0.5 mm, for the groups and subgroups tested.

Figure 7 - TLSs structural angles measured for find the deformation location. The angle γ is formed by the intersection of horizontal extremities of the TLS.

Table I - Multivariate profiles test significance for force, moment and M/F variable.

<i>Variation</i>	Force		Moment		M/F	
	<i>P value</i>		<i>P value</i>		<i>P value</i>	
Time	<0.001		<0.001		0.532	
Deactivation	<0.001		<0.001		0.124	
Deactivation x Time	0.006		0.048		0.159	

Table II - General profiles means and standard deviations for forces and moments within groups (different letters indicate group differences).

	Force			Moment			M/F	
	Mean	SD		Mean	SD		Mean	SD
Group 1	228.4	A	115.1	1941.0	A	272.9	12.7	13.3
Group 2	197.3	AB	112.8	1919.9	A	336.8	-5.8	180.1
Group 3	191.4	AB	110.3	1922.0	A	301.9	17.3	42.3
Group 4	184.5	B	107.4	1912.9	A	317.5	3.7	100.2
Group 5	185.9	B	109.7	1840.7	A	286	20.9	61.7
Group 6	189.9	B	110.9	1775.4	A	288.9	24.8	90.8
Group 7	167.8	BC	112.9	1713.3	AB	286.7	13.3	40.2
Group 8	161.4	BC	110.1	1506.8	B	287.8	-3.5	245.3
Group 9	143.7	C	112.2	1486.4	B	256	18.8	49

Table III - Means and standard deviations overlapping of the vertical extensions of the TLSs and LD ratio.

Time	Neutral Position* (mm)		L/D** (gf/0.5mm)#		
	Mean	SD	Mean	SD	
Group 1	-0.18	A	78.1	A	3.8
Group 2	0.11	AB	75.5	AB	4.4
Group 3	0.18	AB	74.3	AB	3.4
Group 4	0.19	AB	72.2	B	3.6
Group 5	0.17	AB	72.1	B	3.2
Group 6	0.23	AB	75.5	AB	3.4
Group 7	0.54	BC	76.1	AB	3.0
Group 8	0.59	BC	74.7	AB	2.9
Group 9	0.85	C	75.7	AB	3.9

* $P < .001$

** $P = .008$

in order to acquire the L/D per mm, multiply the values times 2

Table IV - ANOVA and post-hoc Tukey test to identify which angle suffer a deformation due to time.

Angle	Neutral Position		Post Period		Post Period		P
	Group 1		Group 4		Group 9		
	Mean	SD	Mean	SD	Mean	SD	
1	20.65	2.42	20.85	2.28	20.60	2.66	0.097
2	20.21	2.01	21.65	2.82	23.13	2.95	0.063
3	92.10	2.98	92.34	2.55	92.69	1.48	0.864
4	92.60	2.26	94.38	3.10	94.32	2.16	0.226
5	60.37	4.39	A 74.74	4.88	B 73.11	8.29	B <.001
6	64.66	3.88	A 71.47	4.20	B 79.46	5.48	C <.001
7	87.00	5.30	A 107.85	14.93	B 113.24	12.26	B <.001

Figure 1

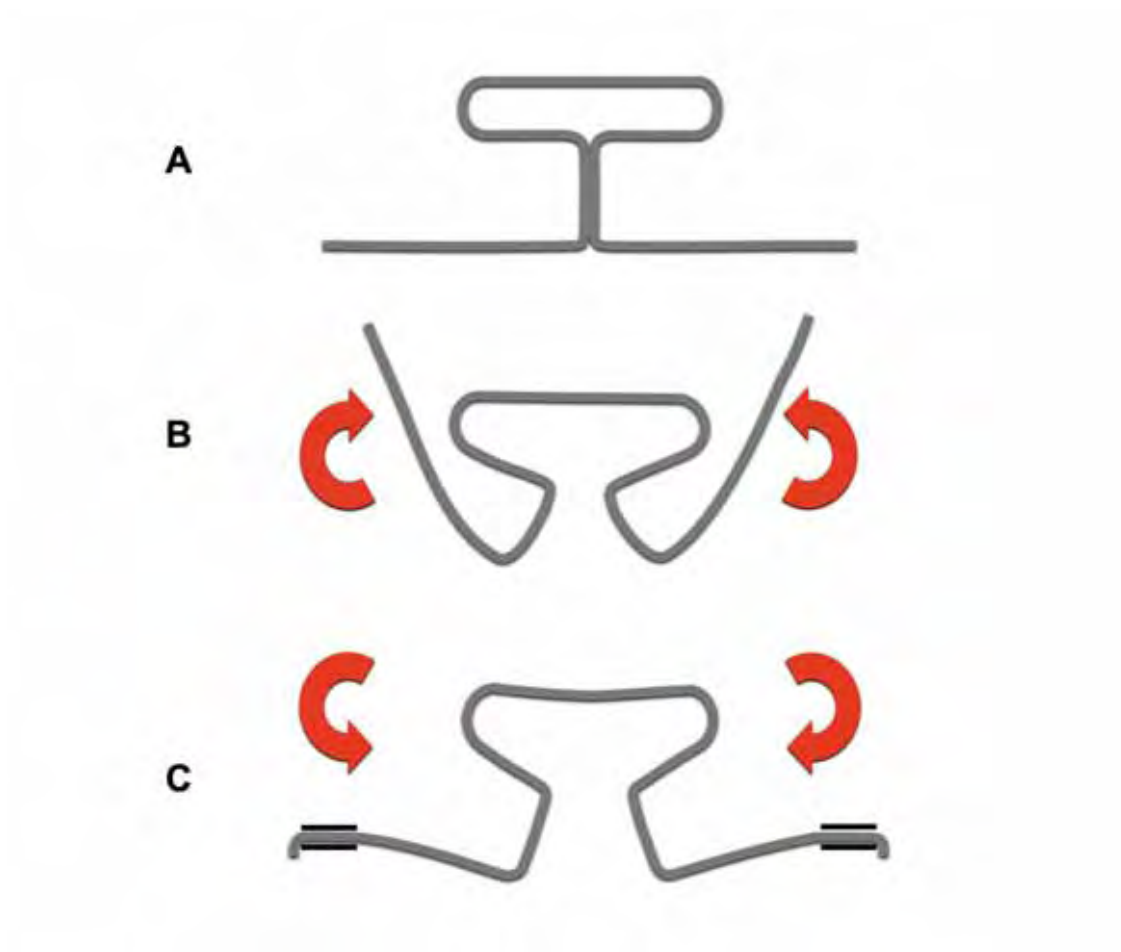


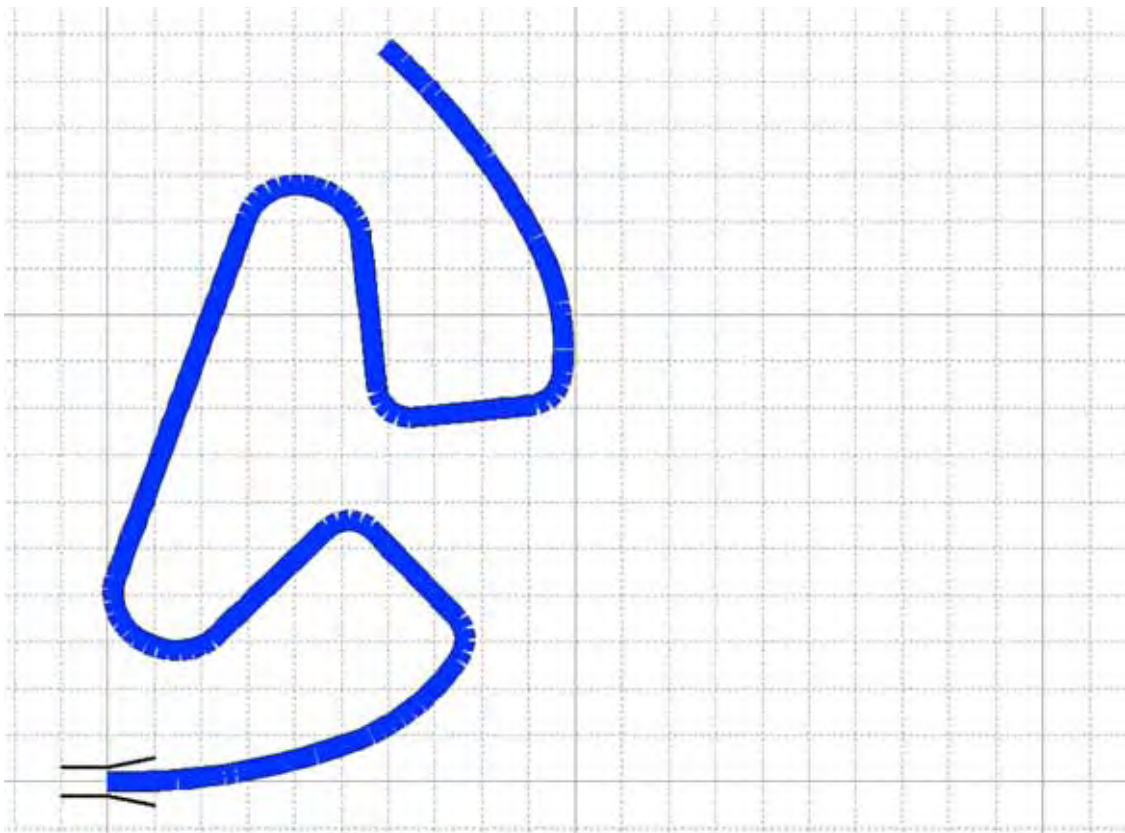
Figure 2

Figure 3

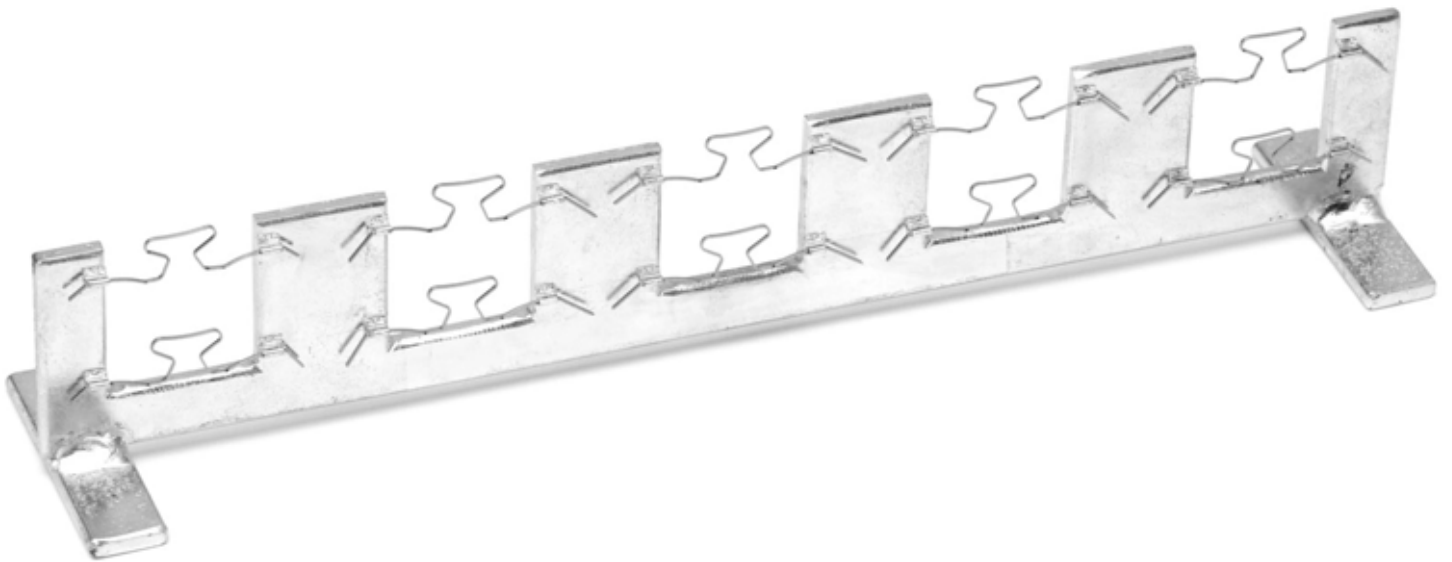


Figure 4

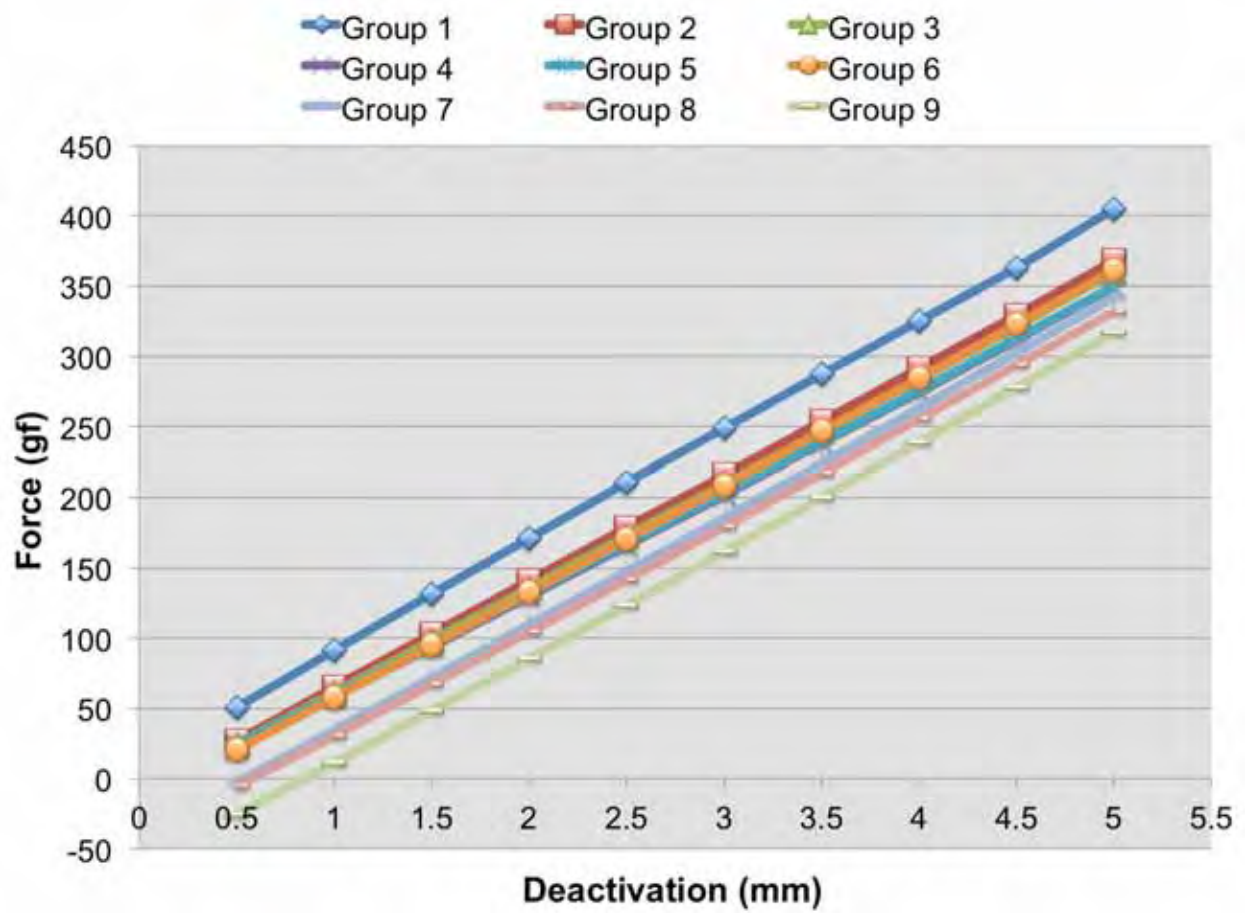
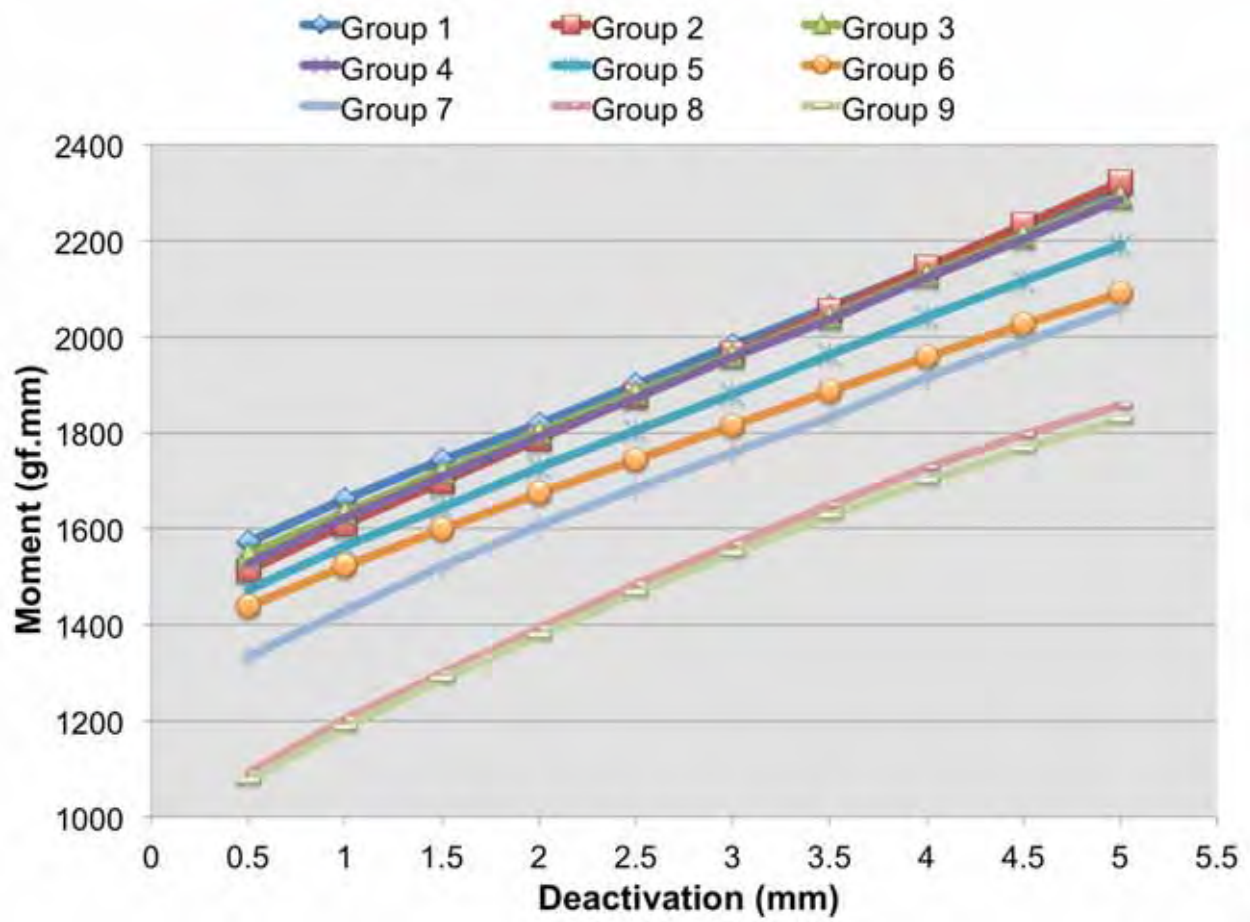


Figure 5



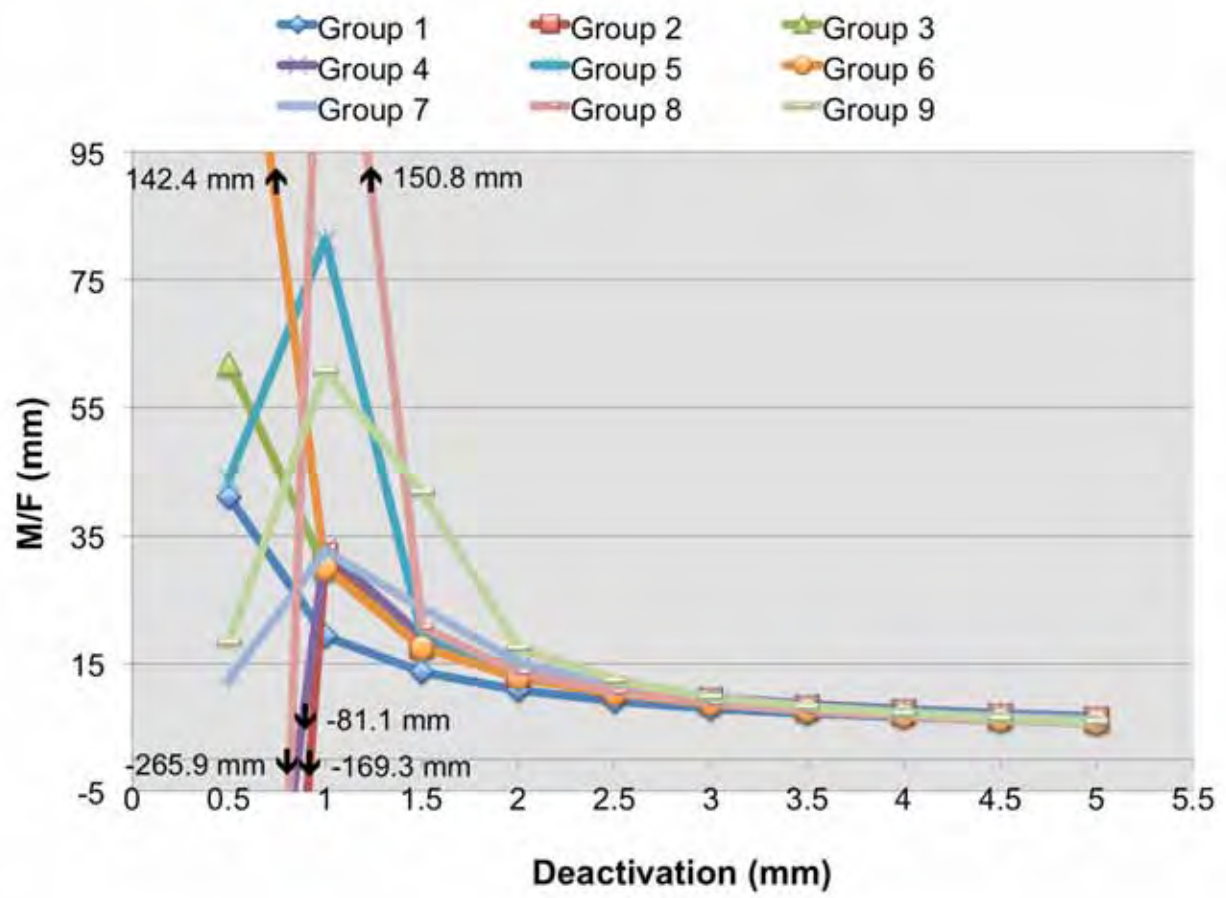
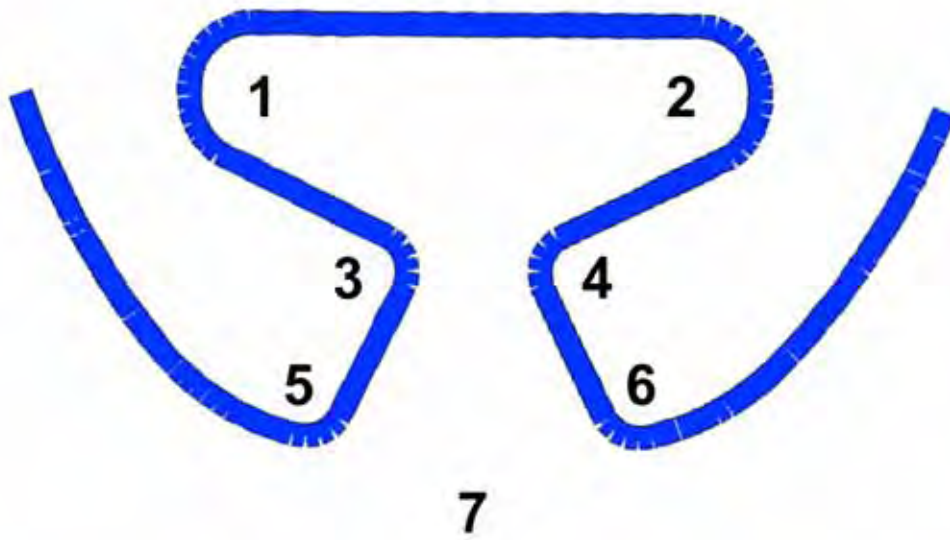


Figure 7



CAPÍTULO 3

Effect of stress relaxation in the preactivation of beta-titanium T-loops**Sergei Godeiro Fernandes Rabelo Caldas**

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Effect of stress relaxation in the preactivation of beta-titanium T-loops

ABSTRACT

Objective: Assess the changes in the force system of TLSs preactivated by bends and curvature, when secured in place with a constant strain over time.

Materials and Methods: One hundred and twenty TLSs with dimensions 6 x 10 mm, produced out of .017" x .025" TMA[®], were randomly divided into two groups of sixty TLSs each according to what preactivation was going to be used, concentrated bends or gradual curvature. Subgroup 1 was tested immediately and the remaining subgroups were tested after they were secured at 5 mm activation for different periods of time in an interbracket distance of 23 mm. Subgroups 2, 3, 4, 5 and 6 were kept activated for 24, 48 and 72 hours, 1 and 2 weeks, respectively. Using a moment transducer coupled to a digital extensometer indicator adapted to a universal testing machine, the amount of horizontal force, moment and moment-to-force (MF) ratios were recorded.

Results: Both groups showed a decrease in force levels over time ($P<.001$ and $.005$ for bend and curvature preactivation, respectively), but with different behaviors. The group preactivated by bends showed a reduction in moments over time ($P<.001$), whereas the group preactivated by curvature didn't ($P=.410$). The MF ratio has not changed over time in either group.

Conclusions: The stress relaxation effect is more evident on group preactivated by bends.

KEY WORDS: Stress Relaxation; Preactivation; T-loop; Beta-titanium.

INTRODUCTION

Orthodontists often use sliding or loop mechanics for space closure resulting from the extractions sites. Among the loops normally used, some may be simple such as the vertical loop [Burstone, C.J. and Koenig, H.A. 1976, Faulkner, M.G., Lipsett, A.W., et al. 1991] or more elaborate, such as the T-Loop Spring (TLS) [Burstone, C.J. 1982]. Nowadays, the TLS are preferred to be produced from β -Ti wires, what improves greatly the physical properties of these springs [Burstone, C.J. 1981, Burstone, C.J. and Goldberg, A.J. 1980].

A TLS with normally used sizes (6-7 by 10 mm) can't produce MF ratios that are high enough to produce translation out of their activation moment [Burstone, C.J. 1982, Burstone, C.J. and Koenig, H.A. 1976], thus, more moment is required, which could be produced by gable bends [Caldas, S.G.F.R., Martins, R.P., et al. 2011a, Caldas, S.G.F.R., Martins, R.P., et al. 2011b, Faulkner, M.G., Fuchshuber, P., et al. 1989, Manhartsberger, C., Morton, J.Y., et al. 1989, Marcotte, M. 1990, Martins, R.P., Buschang, P.H., et al. 2009a, Martins, R.P., Buschang, P.H., et al. 2009b, Martins, R.P., Buschang, P.H., et al. 2008a, Martins, R.P., Buschang, P.H., et al. 2008b] or curvature (residual moment) [Burstone, C.J., van Steenberg, E., et al. 1995, Caldas, S.G.F.R., Martins, R.P., et al. 2011a, Hoenigl, K.D., Freudenthaler, J., et al. 1995, Kuhlberg, A.J. and Burstone, C.J. 1997, Manhartsberger, C., Morton, J.Y., et al. 1989, Martins, R.P., Buschang, P.H., et al. 2008b, Viecilli, R.F. 2006]. These adjustments made prior to engaging the TLS to the brackets in order to increase the MF ratio are called preactivation. Both preactivations, by

bends or by curvature, have specific techniques for standardization allowing them to replicate the system of forces desired which were previously measured **[Burstone, C.J., van Steenbergen, E., et al. 1995, Marcotte, M. 1990]**.

Regardless of which preactivation is used, these springs are attached to the brackets in the patients' mouth over a long period of time and are subjected to a constant strain. This strain what could cause a permanent deformation (Fig. 1), which has been named by stress relaxation **[Anusavice, K.J. and Brantley, W.A. 2003, Earthman, J.C. 2000, William, D. and Callister, J. 2006]**. This phenomenon can cause changes in the original shape of the spring, changing the original preactivation, thus changing the system of forces planned for tooth movement. This effect has already been reported in TLSs preactivated by concentrated bend **[Caldas, S.G.F.R., Martins, R.P., et al. 2011b]**, but there is no evidence that both preactivations (bends and curvature) respond the same way to stress relaxation. While bends tend to concentrate stress on specific areas of the wire, causing spacing and unstable displacement of the crystal structure to be dissipated over time **[Anusavice, K.J. and Brantley, W.A. 2003, Caldas, S.G.F.R., Martins, R.P., et al. 2011b, William, D. and Callister, J. 2006]**, a gradual curvature could distribute these stresses throughout the entire wire, what could reduce the effect of stress relaxation.

Thus, the aim of this paper is to assess the changes in the force system of TLSs preactivated by concentrated bends and curvature, when secured in place with a constant strain over time.

MATERIALS AND METHODS

One hundred and twenty TLSs were bent by one of the authors (SGFRC) using a “Marcotte” plier (Hu-Friedy dental instruments, Chicago, USA) out of straight pieces of .017” x .025” β -Ti (TMA[®],Ormco Corporation, Glendora, USA) wires, following a custom template (Fig. 2). The TLSs had dimensions of 6 mm in height by 10 mm of length and were randomly divided into two groups of sixty TLSs each according to what preactivation was going to be used, concentrated bends or gradual curvature (Fig. 3).

After preactivation was done with the help of a template, both groups were stress relieved by trial activation, and each group was subdivided into six subgroups according to the time of evaluation. Subgroup 1 was tested immediately and the remaining subgroups were tested after they were secured at 5 mm activation for different periods of time in an interbracket distance (IBD) of 23 mm, mimicking a clinical situation, on a custom made device specifically made for this purpose (Fig. 4). Subgroups 2, 3, 4, 5 and 6 were kept activated for 24, 48 and 72 hours, 1 and 2 weeks, respectively.

An universal testing machine (EMIC, São José dos Pinhais, Brazil), equipped with a load cell of 0.1 kN, was coupled to a moment transducer and a digital extensometer indicator (Transdutec, São Paulo, Brazil) for the tests. The speed used for the test was 5 mm/min and the digital extensometer’s excitation and sensitivity was set to 5 V and 0.5 mV/V, respectively. This same set up has been used previously in recent publications [Caldas, S.G.F.R., Martins, R.P., et al. 2011a, Caldas, S.G.F.R., Martins, R.P., et al. 2011b]

For the test, the TLSs were positioned symmetrically in an IBD of 23 mm, and at this distance (confirmed with a digital caliper) the device was zeroed. To assure correct horizontal activation and centralization of the TLSs, nine millimeters were measured from the center of the loop towards each extremity of the horizontal extensions, and were marked with a permanent marker (Fig. 5). Those markings would allow the TLS to be correctly positioned.

After a horizontal activation of 5 mm, the horizontal force and moment developed were recorded for every 0.5 mm of deactivation; at one extremity of the TLSs and the MF ratios were calculated.

Statistical analysis

SPSS version 16.0 (SPSS Inc., Chicago, USA) statistical analysis software was used in this study. The Kolmogorov-Smirnov test indicated normal distributions and Levene's test showed that all variables had similar variances, except the MF ratios.

The multivariate profile analysis using the procedure for analysis of repeated measures was used in order to detect differences of forces, moments and MF ratios among the subgroups (G1 to G6) within each group (concentrated bend and curvature). This analysis compares the total profile, or deactivation pattern, of a whole group in relation to time and deactivation, and should not be mistaken by a comparison of the springs' behavior in a specific activation. If a difference was found, Tukey post-hoc test was used to identify them among the subgroups.

Independent T test was used to identify differences between the two groups in changes force, moments and MF ratios with time.

RESULTS

Both groups showed a decrease in force levels over time, but with different behaviors. In the bends preactivation group, subgroup 1 had an overall force intensity greater than the other five subgroups ($P<.001$), which did not show differences among them. For the group preactivated by curvature, the force decrease occurred more gradually, and was significantly changed only from the third subgroup on ($P=.005$). Regarding the amount of horizontal force lost over time, the difference between the preactivations was significant ($P<.047$) only between times 1 and 2. With that exception, both groups showed similar behavior over time (Table I and Fig. 6).

The group preactivated by bends showed a reduction in moments over time ($P<.001$), whereas the group preactivated by curvature didn't ($P=.410$). In the group preactivated by bends, the moments produced in subgroup 1 were higher than the other five subgroups, which were not different among them. Similar to what happened with the force levels, the amount of moment loss over time was significant ($P<.002$) only between the first and second time periods. From that point on, both groups showed similar behavior over time (Table II and Fig. 7).

The MF ratio has not changed over time in either group, and no differences were found between the two groups (Table III and Fig. 8).

DISCUSSION

Horizontal force decreased in both groups but with different behaviors. The group preactivated by concentrated bends showed a decrease in the level of the horizontal force within the first 24 hours, while the group preactivated by curvature the reduction was more gradual, being significant only after 48 hours. This difference can be explained by the preactivation's behavior in relation to stress relaxation over time. When concentrated bends are subjected to a constant strain, they will converge stress to specific places in the wire, causing dislocations and unstable displacements in the crystalline structure of the alloy, all of which tend to rearrange themselves over time due to stress relaxation [Anusavice, K.J. and Brantley, W.A. 2003, Caldas, S.G.F.R., Martins, R.P., et al. 2011b, Earthman, J.C. 2000, William, D. and Callister, J. 2006]. On the other hand, when a gradual curvature is used, stress is distributed over the entire extent of curvature, diminishing the effect of stress relaxation. Previous reports have shown that when the preactivation intensity is increased (without proper adjustments to the TLS), a greater amount of overlap of the vertical extensions of the TLS in neutral position can happen, producing a greater activation and higher horizontal force [Burstone, C.J. and Koenig, H.A. 1976]. Thus, the faster and larger relaxation of the preactivation by bends causes a faster and larger decrease in force (Table I). A clinical relevant aspect of these findings is that the curvature preactivation allows a smaller decrease (38.5 gf) in the total force produced by the TLS (by subtracting force values from subgroup 1 from 6) caused by the stress relaxation when compared to the bend preactivation group

(81.4 gf), producing a more constant force. This force differences, however, were only significant in the first 24 hours, becoming similar after that period.

There was a reduction in intensity of the moments produced over time in the group preactivated by concentrated bends, while the moments in the group preactivated by curvature remained stable. Stress relaxation can also explain this behavior, since the lower moments are produced by decreasing the angulation of the TLS's horizontal extremities (and vice-versa) [**Burstone, C.J. and Koenig, H.A. 1976, Chen, J., Markham, D.L., et al. 2000, Faulkner, M.G., Fuchshuber, P., et al. 1989, Lim, Y., Quick, A., et al. 2008, Rose, D., Quick, A., et al. 2009**]. The differences between groups were quite similar to the horizontal force, since the relaxation was different in the first 24 hours and then became negligible.

The MF ratio was stable in both groups and insensitive over time. There could be differences among the subgroups, however the power of our analysis was too low (.29 and .47 for concentrated bends and curvature groups, respectively) to detect any differences.

CONCLUSIONS

In regards to the period of observation of this research:

- 1- Both preactivations tested suffer stress relaxation over time, modifying the horizontal force. The preactivation by concentrated bends showed an abrupt load decrease during the first 24 hours, while the preactivation by curvature shows a more gradual decrease;

- 2- The curvature preactivation was insensitive to changes in the moments produced, while in the bend preactivation, the decrease of the moments was abrupt in the first 24 hours;
- 3- The MF ratio was insensitive to the stress relaxation.

ACKNOWLEDGMENTS

This work was supported by FAPESP (Process number 2008/07258-5, Fundação de Amparo à Pesquisa do Estado de São Paulo, SP, Brazil).

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FIGURE LEGENDS

Figure 1 - TLS engaged to brackets (loaded in an opposite direction to its preactivation).

Figure 2 - Template developed in the Loop software (dHAL Orthodontic Software, Athens, Greece) used for the design of the TLS. The software allows the template to be printed in 1:1 ratio. Each square measures 1 mm².

Figure 3 - Templates developed in the Loop software (dHAL Orthodontic Software, Athens, Greece): (A) For the preactivation of the TLSs by concentrated bends and (B) for the preactivation of the TLSs by gradual curvature.

Figure 4 - Custom made device in order to keep the TLSs activated 5 mm.

Figure 5 - (A) Loop horizontal dimensions stops were marked to assure the correct activation and TLS centralization; (B) Neutral position of the TLS simulated by the Loop Software; (C) TLS shape simulated by the Loop Software when positioned symmetrically in an IBD of 23 mm and activated 5 mm. Colored areas reflect stress distribution over the wire, going from red, being high stress areas to dark blue being low stress areas.

Figure 6 - Chart depicting the average forces produced, during deactivation from 5 to 0.5 mm, for the groups and subgroups tested.

Figure 7 - Chart depicting the average moments produced, during deactivation from 5 to 0.5 mm, for the groups and subgroups tested.

Figure 8 - Chart depicting the average MF ratios produced, during deactivation from 5 to 0.5 mm, for the groups and subgroups tested.

Table I. General profiles and subgroup differences means for force developed by both groups and subgroups.

Force											
Group		Concentrated bend		Curvature		Subgroup Difference	Concentrated bend		Curvature		P value**
Subgroup		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Subgroup 1	267.6	A	105.2	228.4	A	1-2 2-3 3-4 4-5 5-6	66.9	42.0	31.1	32.2	0.047
Subgroup 2	200.7	B	111.5	197.3	AB		2.9	49.2	5.9	45.6	0.89
Subgroup 3	197.8	B	107.8	191.4	B		-2.7	38.0	6.9	37.6	0.578
Subgroup 4	200.5	B	111.1	184.5	B		14.4	41.1	-1.4	45.2	0.425
Subgroup 5	186.1	B	104.8	185.9	B		-0.1	31.1	-4.0	38.6	0.808
Subgroup 6	186.2	B	110.4	189.9	B						
P value*			<0.001		0.005						

* Multivariate profile analysis (column intragroup)

** Independent T test (line intergroup)

Table II. General profiles and subgroup differences means for moment developed by both groups and subgroups.

Moment											
Group		Concentrated bend		Curvature		Subgroup Difference	Concentrated bend		Curvature		P value
Subgroup		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Subgroup 1	1932.6 A	259.2		1941.0	272.9	1-2 2-3 3-4 4-5 5-6	394.7	208.4	21.2	251.5	0.002
Subgroup 2	1537.9 B	249.9		1919.9	336.8		66.6	278.7	-2.1	270.2	0.583
Subgroup 3	1471.3 B	239.3		1922.0	301.9		-145.2	294.5	9.1	278.4	0.244
Subgroup 4	1616.5 B	250.0		1912.9	317.5		52.8	150.8	72.2	312.7	0.861
Subgroup 5	1563.1 B	206.7		1840.7	286.0		-72.7	171.2	65.2	164.7	0.083
Subgroup 6	1636.4 B	236.3		1775.4	288.9						
P value	<0.001		0.410								

* Multivariate profile analysis (column intragroup)

** Independent T test (line intergroup)

Table III. General profiles and subgroup differences means for MF ratio developed by both groups and subgroups.

MF ratio									
Group	Concentrated bend		Curvature		Subgroup Difference	Concentrated bend		Curvature	
	Mean	SD	Mean	SD		Mean	SD	Mean	SD
Subgroup 1	8.3	3.2	12.7	13.3	1-2	-2.9	3.5	18.6	57.6
Subgroup 2	11.2	18.2	-5.8	180.1	2-3	-15.5	53.1	-23.1	58.4
Subgroup 3	26.7	166.7	17.3	42.3	3-4	14.5	55.3	13.6	31.5
Subgroup 4	12.2	34.5	3.7	100.2	4-5	-1.9	11.4	-17.2	37.4
Subgroup 5	14.2	13.7	20.9	61.7	5-6	4.2	9.4	-4.0	37.2
Subgroup 6	10.2	33.4	24.8	90.8					
P value	0.509		0.220						

* Multivariate profile analysis (column intragroup)

** Independent T test (line intergroup)

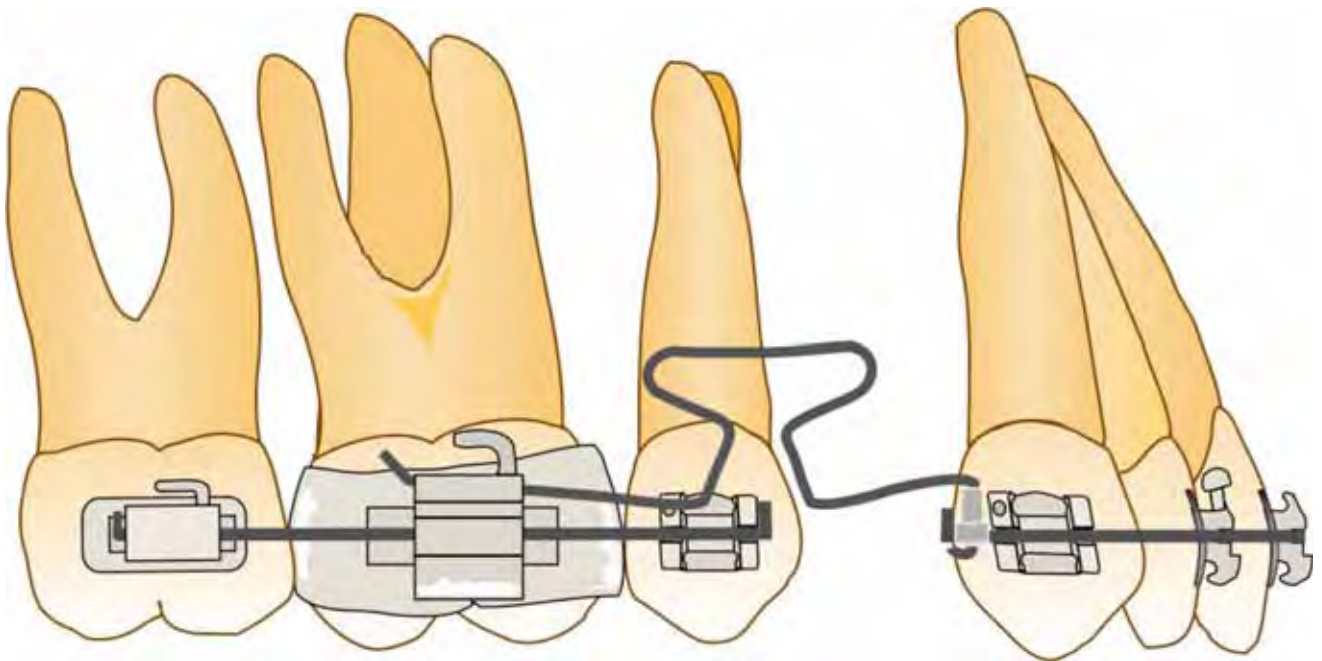
Figure 1

Figure 2

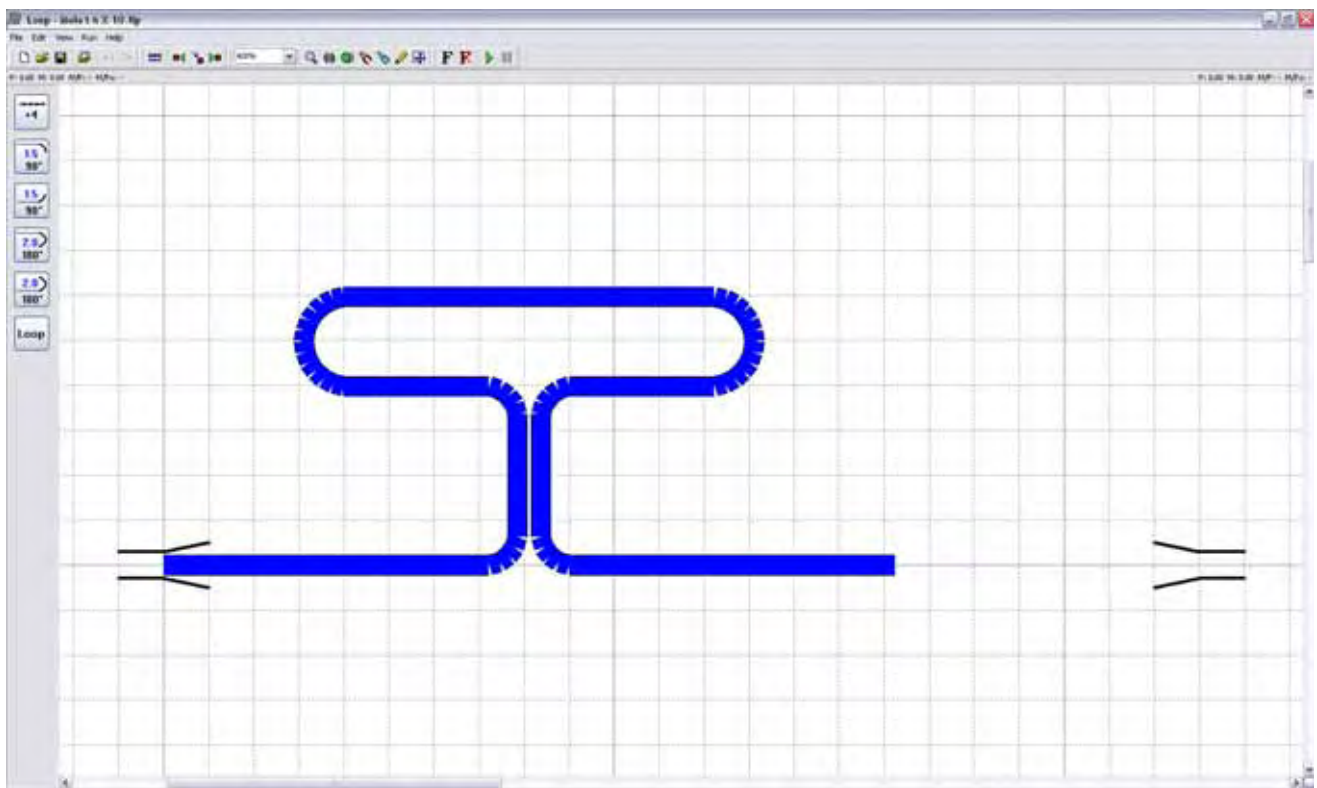


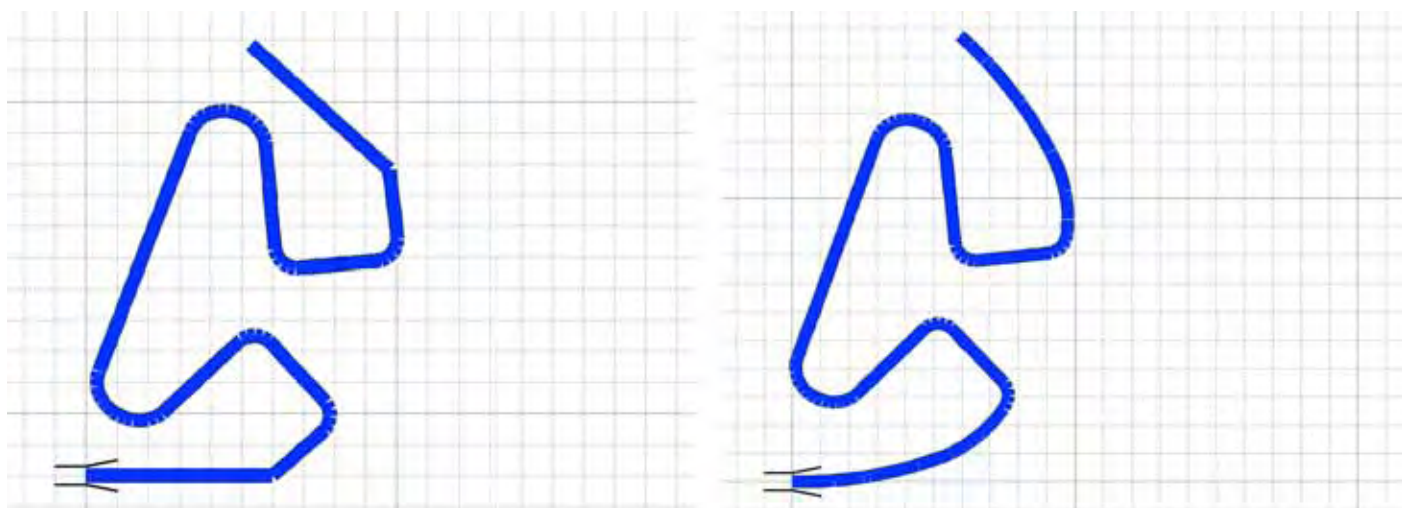
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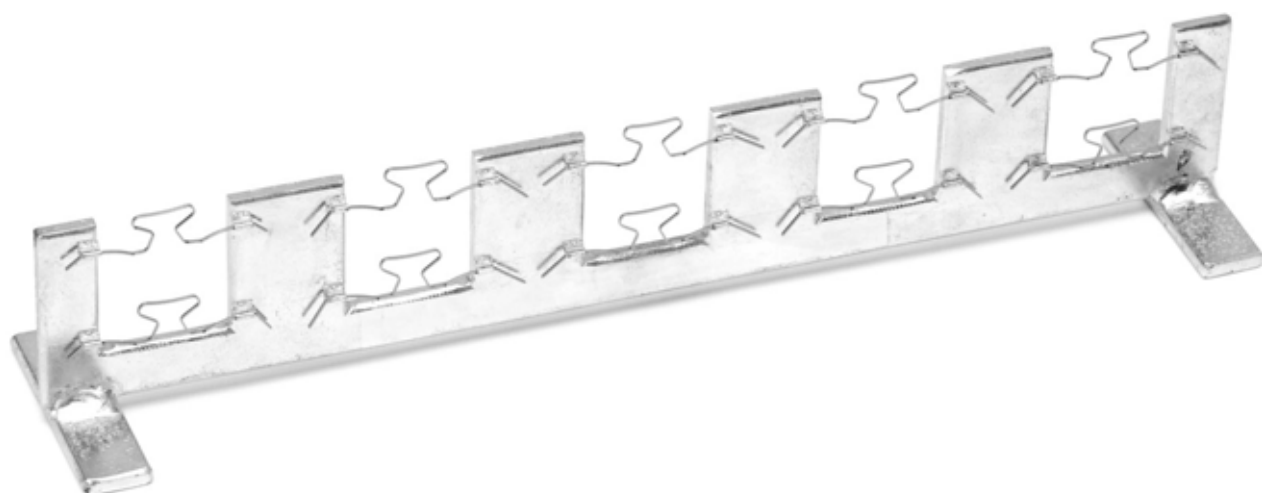
Figure 4

Figure 5

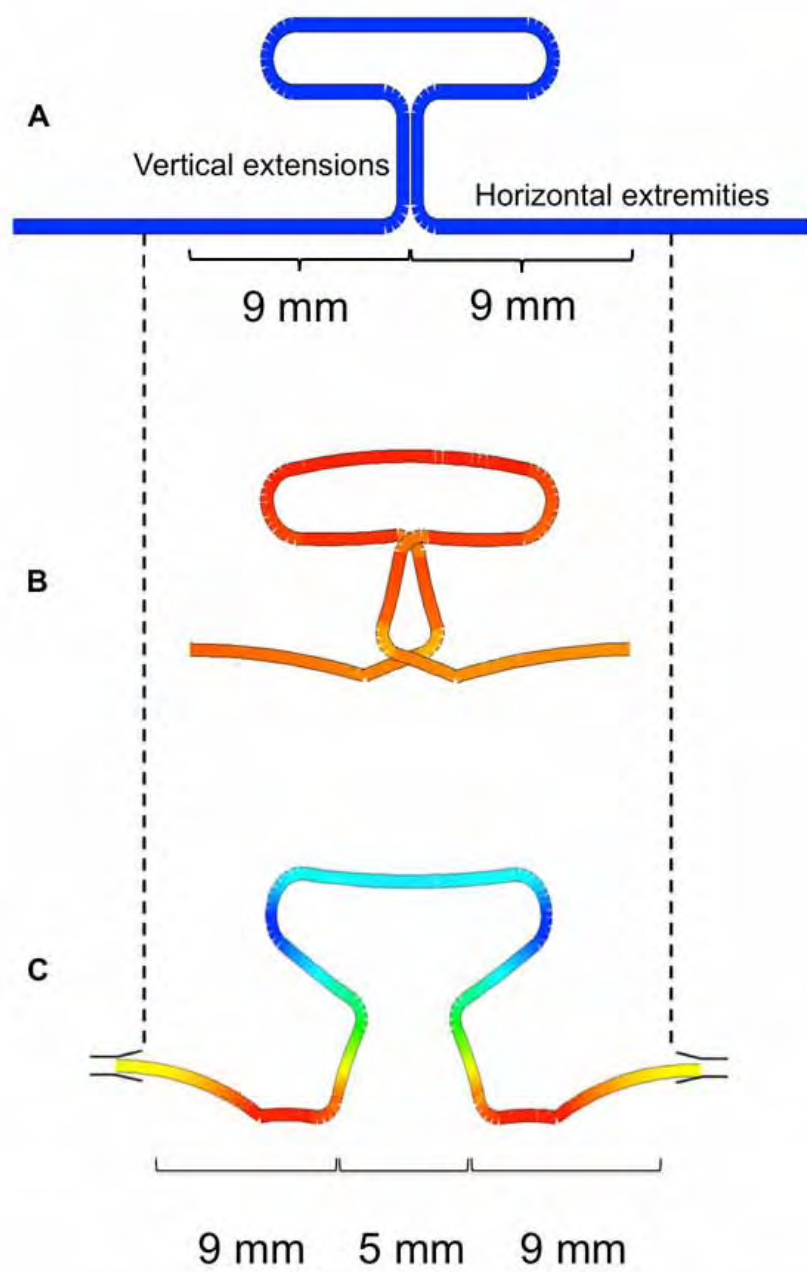


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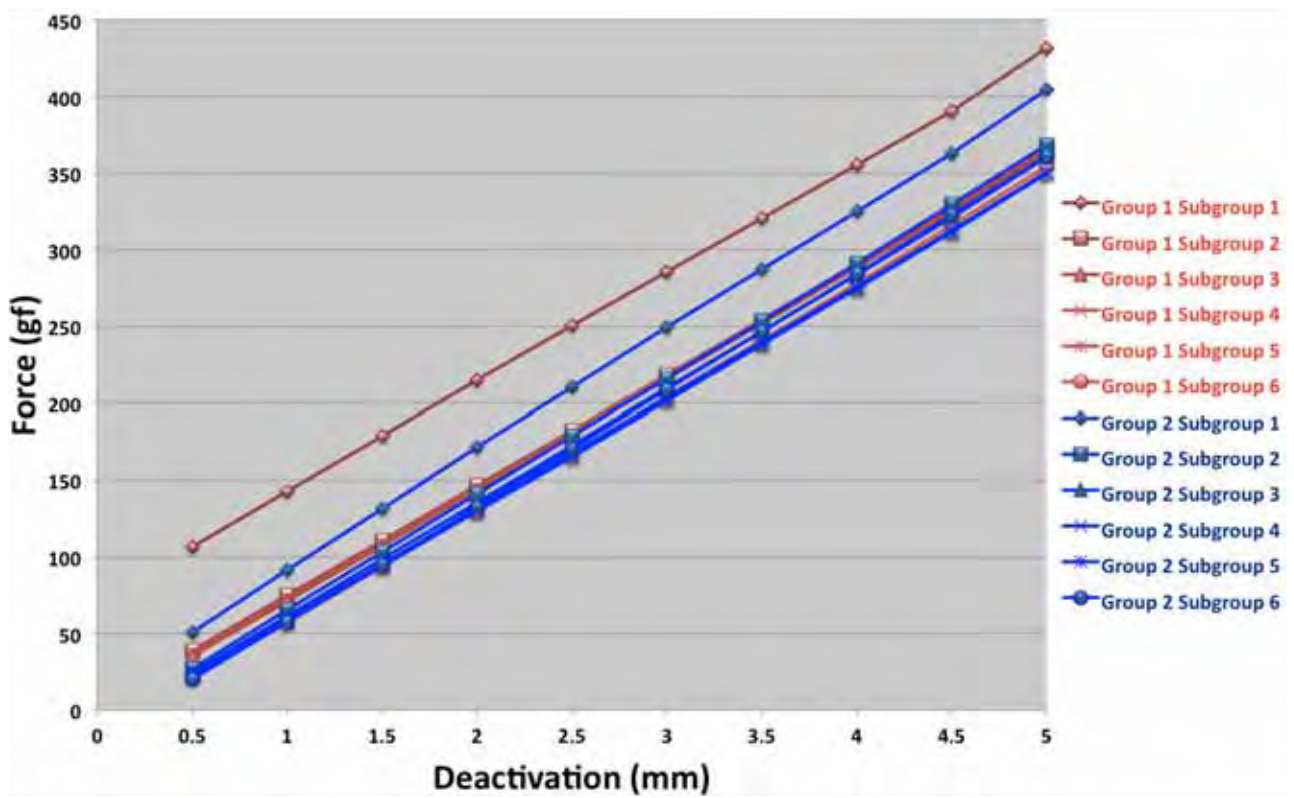


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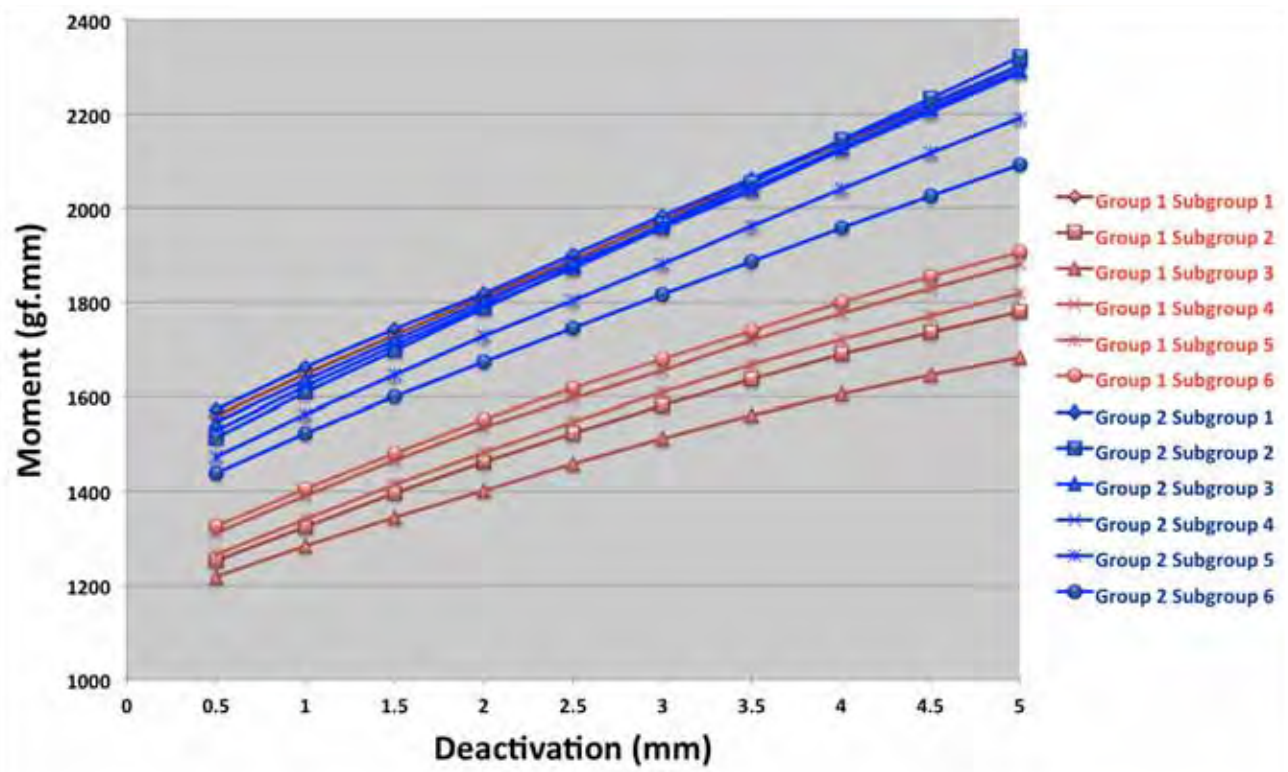
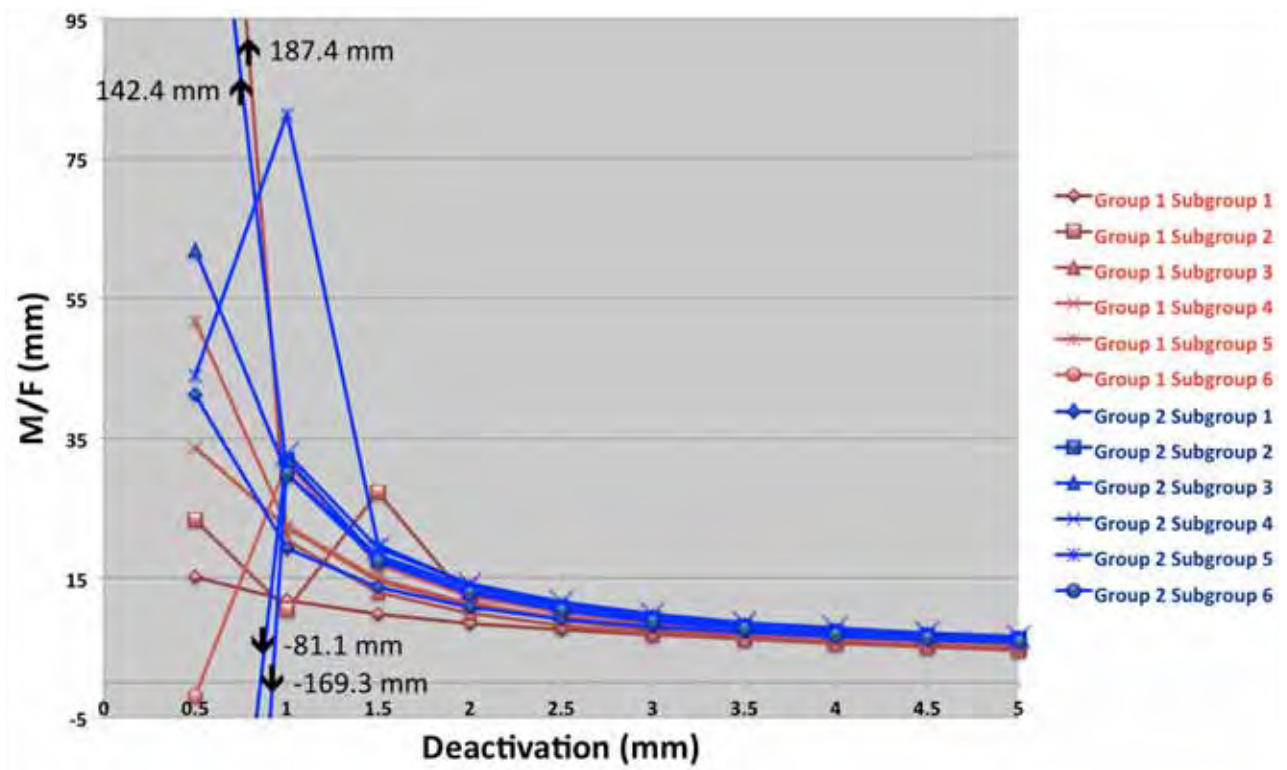


Figure 8





4 CONSIDERAÇÕES

FINAIS

4 CONSIDERAÇÕES FINAIS

Baseado nos resultados e conclusões apresentados pelos artigos, podemos tecer as seguintes considerações finais:

1. Quando confeccionadas com diferentes marcas comerciais de β -Ti, as molas "T" produzem diferentes forças, momentos e relação CD;

2. A causa destas diferenças é o modo como cada fio se comporta em relação às dobras, produzindo formas diferentes de posição neutra;

3. O G1 (Ormco) e G4 (Ortho Organizers) mostraram uma proporção MF mais consistente em toda a desativação;

4. O G2 (Orthometric) e G3 (Morelli) tiveram comportamento diferente do G1 e G4, porém, isto não significa que não devem ser utilizados clinicamente, mas uma abordagem diferente é necessária quando as molas são usadas com estes fios;

5. As molas "T" pré-ativadas por curvatura sofreram uma deformação gradual ao longo do tempo, o que afetou o sistema de forças, especificamente os momentos e consequentemente as forças horizontais produzidas;

6. Mesmo a curvatura gradual distribuindo o estresse sobre o fio, a estrutura da mola "T" alivia o estresse ao longo do tempo em uma área de dobra aguda inerente da forma do "T". As molas "T" devem ser ajustadas ao longo do tempo ou uma dobra mais gradual deve ser realizada na região onde ocorre o maior relaxamento;

7. Ambas os tipos de pré-ativação testados sofreram o alívio de tensão estrutural ao longo do tempo, modificando o sistema de força. A pré-ativação por

dobras concentradas produziu uma diminuição abrupta da força e momentos durante as primeiras 24 horas, enquanto que a pré-ativação por curvatura apresenta uma diminuição mais gradual;

8. A proporção MF não foi alterada devido ao alívio de tensão estrutural em ambos os tipos de pré-ativação.



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Araraquara, 18 de Janeiro de 2013.

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