UNESP - Universidade Estadual Paulista
“Júlio de Mesquita Filho”
Faculdade de Odontologia de Araraquara

TATYANE RIBEIRO MESQUITA

AVALIAÇÃO IN VITRO DA SOLDA ELÉTRICA EM FIOS DE NÍQUEL-TITÂNIO

Araraquara

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Dissertação apresentada ao programa de Pós-Graduação em Ciências Odontológicas, Área de Ortodontia, da Faculdade de Odontologia de Araraquara, da Universidade Estadual Paulista para título de Mestre em Ciências Odontológicas.

Orientador: Profa. Dra. Lídia Parsekian Martins.
Co-orientador: Prof. Dr. Renato Parsekian Martins

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AVALIAÇÃO IN VITRO DA SOLDA ELÉTRICA EM FIOS DE NÍQUEL-TITÂNIO

Dissertação para obtenção de grau de Mestre

COMISSÃO JULGADORA

Profa. Dra. Lídia Parsekian Martins

Prof. Dr. Ary dos Santos-Pinto

Prof. Dr. Sergei Godeiro Fernandes Rabelo Caldas

Araraquara, 25 de novembro 2016

DADOS CURRICULARES

TATYANE RIBEIRO MESQUITA

NASCIMENTO: 10 de janeiro de 1985 – Aracaju/SE.

FILIAÇÃO: Ricardo Morais de Almeida Mesquita
Maria de Fátima Ribeiro Mesquita.

2006/2011: Graduação em Odontologia – Universidade Federal de Sergipe.

2012/2013: Curso de Pós-Graduação em Ciências Odontológicas, Nível de Aperfeiçoamento em Curso Teórico e Prático de Aperfeiçoamento em Ortodontia, Associação Brasileira de Odontologia, Seção Sergipe.

2013/2016: Curso de Pós-Graduação em Ciências Odontológicas, Nível de Especialização em Ortodontia – Gestos- Grupo de Estudos Ortodônticos e Serviços – Araraquara/SP.

2014/2016: Curso de Pós-Graduação em Ciências Odontológicas, Nível Mestrado– Área de Ortodontia, Faculdade de Odontologia de Araraquara – UNESP- Araraquara/SP.

DEDICATÓRIA

À Deus,

Pelo dom da vida e benções recebidas.
Pela saúde e força que me ajudou a alcançar meu objetivo.
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Mesquita TR. Avaliação in vitro da solda elétrica em fios de níquel-titânio [Dissertação de Mestrado]. Araraquara: Faculdade de Odontologia da UNESP; 2016.

RESUMO

OBJETIVO: Determinar a potência mais adequada para a solda elétrica em fios de NiTi; mensurar a resistência à tração desta solda; avaliar a superfície da solda microscopicamente e com um rugosímetro digital. **MATERIAIS E MÉTODOS**: Cento e oitenta pares de fios de NiTi foram divididos em grupos de acordo com seus fabricantes: GI (Orthometric, Marília, Brazil), GII (3M OralCare, St. Paul, CA) e GIII (GAC,York, PA); e soldados por uma máquina de solda elétrica. Cada grupo foi subdividido em subgrupos com soldas de diferentes potências. O estudo foi dividido em duas partes: a primeira parte testou noventa pares de fios soldados desde a potência mínima de união até a potência 0.5 menor àquela que provocou a fratura dos fios durante a solda, de modo que o GI e GII compreendem 6 subgrupos (potências 2.5, 3, 3.5, 4, 4.5 e 5) e o GIII 4 subgrupos (potências 2.5, 3, 3.5 e 4), sendo que cada unidade de potência da máquina utilizada representa 500W. Os pares de fios soldados foram testados em uma máquina de ensaios mecânicos até a ruptura e os valores de resistência máxima foram registrados. Análise de variância (ANOVA) e teste de Tukey foram realizados para determinar qual potência dentro de cada grupo apresentava a melhor resistência à tração. A segunda parte do estudo utilizou a potência mais adequada para cada fabricante, obtida no estudo anterior, e variou a potência 0.25 para mais e para menos em cada grupo, assim o GI e GII testou as potências 3.75, 4 e 4.25 e o GIII as potências 3.25, 3.5 e 3.75. De maneira análoga à primeira parte do estudo, mais noventa pares de fios foram soldados de acordo com seu grupo e testados até a ruptura. Adicionalmente, foi realizado microscopia eletrônica de varredura com feixe de emissão de campo e testes de rugosidade superficial para refinar os resultados sobre a potência mais adequada. ANOVA e teste de Tukey foram realizados para definir qual subgrupo dentro de cada grupo obteve a maior resistência, e testes de Friedman e Wilcoxon foram utilizados para os resultados da rugosidade. **RESULTADOS:** No primeiro estudo, a potência 2.5 exibiu a menor resistência à tração (43.75N GI, 28.41N GII e 47.57N GIII), enquanto que a potência 4 apresentou melhor performance nos GI e GII (97.90N e 99.61N, respectivamente), e a potência 3.5 no GIII (79.28N). No segundo estudo, houve diferença entre as resistências à ruptura apenas nos GI e GII. A potência 4 apresentou uma resistência de 95.37N (GI) e 101.90N (GII), entretanto semelhantes às potências 3.75 e 4.25 para seu respectivo grupo. O diâmetro da área de solda e o extravasamento do material aumentaram conforme as potências foram aumentadas nos três grupos. A rugosidade mostrou-se diferente no GII, já no GI e GIII as potências mais altas apresentaram rugosidades semelhantes (1.15Ra e 1.47Ra no GI, e 0.54Ra e 0.71Ra no GIII). **CONCLUSÕES:** A potência mais adequada para solda elétrica a ponto em fios de NiTi das marcas Orthometric e 3M foi 4 e para a marca GAC 3.5.

Palavras-chaves: Soldagem. Titânio. Ortodontia. Topografia.

Mesquita TR. In vitro evaluation of welding nickel-titanium wires [Dissertação de Mestrado]. Araraquara: Faculdade de Odontologia da UNESP; 2016.

ABSTRACT

OBJECTIVE: To determine the most appropriate power for the electric welding of NiTi wires; measure the weld tensile strength; asses the weld surface microscopically and by a digital profilometer. **MATERIALS AND METHODS:** One hundred and eighty pairs of NiTi wires were divided into groups according to their manufacturers: GI (Orthometric, Marília, Brazil), GII (OralCare 3M, St. Paul, CA) and GIII (GAC, York, PA); and welded by a welding machine. Each group was divided into subgroups with different powers welding. The study was divided into two parts: the first one tested ninety pairs of welded wires from the minimum power up to a 0.5 below that of the weld fracture, such the GI and GII incluses 6 subgroups (powers 2.5, 3, 3.5, 4, 4.5 and 5) and GIII 4 subgroups (powers 2.5, 3, 3.5 and 4), where in each power unit of the machine is 500W. The welding were tested in a mechanical testing machine until failure and maximum resistance values were recorded. Analysis of variance (ANOVA) and Tukey tests were performed to determine which subgroup showed the best tensile strength. The second part of the study used the most appropriate power for each manufacturer, obtained in the previous study, and varied 0.25 power to up or down in each group, so the GI and GII tested the powers 3.75, 4 and 4.25 and GIII the powers 3.25, 3.5 and 3.75. In a similar way, ninety pairs of wires were welded according to their group and tested to fracture. Scanning electron microscopy with field emission beam and surface roughness testing were made to refine the results on the most appropriate power. ANOVA and Tukey tests were conducted to determine which subgroup within each group had the highest strength and Friedman and Wilcoxon tests were used for the roughness results. **RESULTS:** In the first study, the 2.5 power exhibited the lower tensile strength (43.75N GI, GII and 28.41N 47.57N GIII), while the 4 power showed better performance in GI and GII (97.90N and 99.61N, respectively) and 3.5 power in GIII (79.28N). In the second study, there was a difference between the tensile strengths only in GI and GII. The 4 power showed a resistance of 95.37N (GI) and 101.90N (GII), but similar to the 3.75 power and 4.25 for these groups. The weld area diameter and material leakage increased as the power was increased in all three groups. At GI and GIII the higher powers had similar roughness (1.15Ra and 1.47Ra in GI and 0.54Ra and 0.71Ra in GIII), while was different in the GII. **CONCLUSIONS**: The most suitable power to electric spot welding of NiTi wires of Orthometric and 3M brands was 4 and 3.5 to GAC brand.

Keywords: Welding. Titanium. Orthodontics. Topography.

SUMÁRIO

1 INTRODUÇÃO

O movimento ortodôntico é obtido pela aplicação de forças sobre os dentes que resultam no processo de remodelação óssea (Arciniegas et al.[3], 2013; Sevilla et al.[22], 2008). As forças devem ser de baixa magnitude e natureza contínua para um movimento fisiológico e controlado dos dentes e estruturas adjacentes (Gravina et al.[8], 2013; Krousbroeck et al.[14], 1982). Isso minimiza a destruição tecidual e produz estresse relativamente constante no ligamento periodontal (Andreasen, Morrow[1], 1978; Andreasen, Zwanziger[2], 1980; Sevilla et al.[22], 2008).

Os fios em forma de arco representam a unidade básica da terapia ortodôntica (Juvvadi et al.[11], 2010; Krishnan, Kumar[13], 2004), sendo que a deformação elástica deste arco e a sua consequente resiliência irão originar as forças corretivas para o movimento ortodôntico (Krousbroeck et al.[14], 1982; Sevilla et al.[22], 2008).

O níquel titânio (NiTi) foi descoberto em 1959, mas sua aplicação comercial é mais recente, pois o entendimento sobre seu comportamento vem sendo aprimorado (Tam[24], 2010). Assim, por volta de 1965, o pesquisador metalurgista William F. Buehler, no Laboratório da Artilharia Naval (Naval Ordinance Laboratory –NOL) da marinha dos Estados Unidos, desenvolveu uma liga metálica com memória, que foi chamado de Ni-Ti-Nol (Andreasen, Morrow[1], 1978; Kauffman, Mayo[12], 1997).

O NiTi é definido como um composto intermediário (IMC) equiatômico ou aproximadamente equiatômico de níquel e titânio. E ao contrário dos convencionais IMCs, a liga pertence a uma classe de materiais especiais denominadas de ligas com memória de forma (Shape Memory Alloys- SMA) (Tam[24], 2010).

A liga de NiTi apresenta um conjunto de pequenas regiões de cristais simples, chamados grãos ou grânulos, todos com tamanho, forma e orientação aleatórias. O aquecimento reestrutura a rede atômica dentro dos grãos individuais, e os átomos adotam a fase austenítica (átomos ordenados), que tem uma estrutura atômica em que cada átomo de níquel é cercado por oito átomos de titânio nas arestas do cubo. Cada átomo de titânio é igualmente rodeado por um cubo de átomos de níquel (Kauffman, Mayo[12], 1997).

O NiTi apresenta propriedades funcionais como superelasticidade, boa resistência à fadiga e à corrosão, baixo custo e biocompatibilidade, o que permite várias possibilidades de utilização (Andreasen, Morrow[1], 1978; Lin et al.[15], 2007; Tamada et al.[25], 2012). Estas particularidades facilitaram o uso na clínica ortodôntica, já que a liga permite uma boa distribuição de forças com um menor desconforto ao paciente (Andreasen, Morrow[1], 1978; Andreasen, Zwanziger[2], 1980). O resultado é um movimento efetivo em um tempo menor quando comparado com as demais ligas, como por exemplo o aço inoxidável (Arciniegas et al.[3], 2013; Sevilla et al.[22], 2008).

A base da elasticidade e da memória de forma do NiTi são dois aspectos do mesmo efeito, ambos intimamente ligados à transformação de fase cristalina reversível que ocorre no estado sólido do material, conhecida como transformação martensítica (Delobelle et al.[6], 2012; Tam[24], 2010). Esta transformação se inicia quando a liga é resfriada- por uma temperatura denominada Ms (martensite start), e se completa em Mf (martensite finish), quando o material é considerado martensítico. No sentido oposto, a transformação reversa ou austenítica, se inicia, com o aquecimento- na temperatura As (austenite start) e termina em Af (austenite finish), quando então o material é austenítico (Buehler, Wang[4], 1967; Kauffman, Mayo[12], 1997).

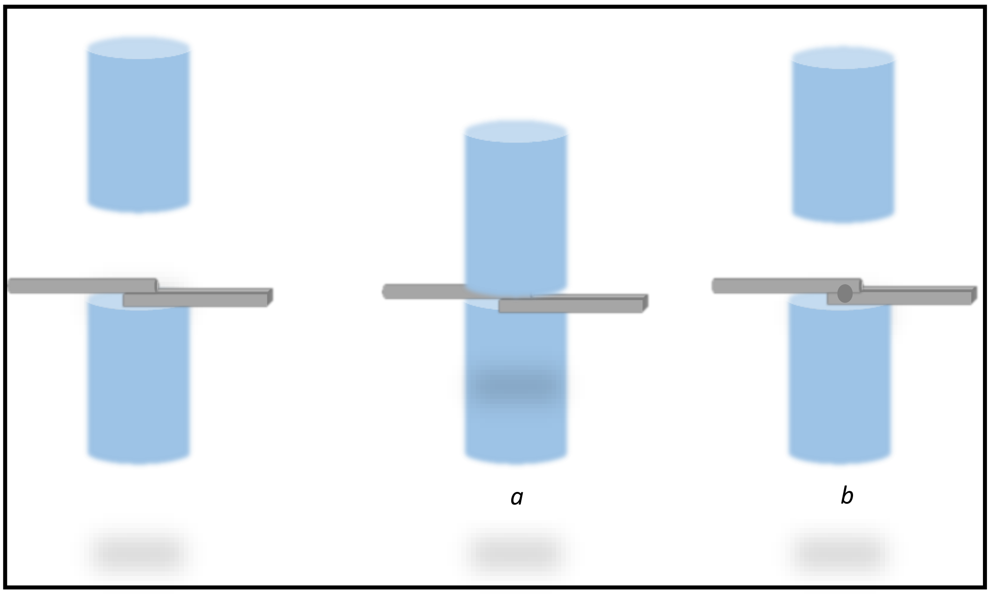
Todavia, mesmo com as características já mencionadas, a necessidade de realizar soldas de acessórios ou fragmentos de fio em ligas de NiTi ainda existe e traz consigo novas possibilidades de mecânicas ortodônticas (Iijima et al.[10], 2008). Por isso, a união de acessórios em fios de arco ortodônticos com a finalidade de proporcionar forças adequadas tem fascinado os clínicos (Vijayalakshmi et al.[28], 2009).

A soldagem é um processo metalúrgico de união de superfícies, que consiste na fusão dos metais, com ou sem metal de preenchimento, para formação da junta (Tambasco et al.[26], 1996; Wang, Chang[29], 1998; Wang, Welsch[30], 1995), que pode ou não ter sofrido aquecimento. Para ocorrer a solda, deve existir uma quantidade de energia capaz de unir dois metais similares ou não (Wiskott et al.[32], 2001), sem causar distorção na peça. Uma solda satisfatória não deve ter sofrido oxidação nem ter sido comprimida durante a fusão (Philips[19], 1991). Este processo é importante, pois a qualidade das soldagens diminui o tempo final de tratamento e os custos, porque evita desperdício de tempo ao repetir o procedimento.

A solda prata é bastante utilizada na clínica ortodôntica, no entanto pesquisas demonstram que alguns íons podem ser liberados a partir dela (Oh, Kim[18], 2005; Sestini et al.[21], 2006; Vande Vannet et al.[27], 2007) e isto pode levar a efeitos colaterais que causam alterações tóxicas ao ser humano, como interferência na diferenciação dos osteoblastos, viabilidade dos fibroblastos e crescimento dos queratócitos (Freitas et al.[7], 2009; Sestini et al.[21], 2006). Assim, a solda ponto elétrica tem sido indicada como uma alternativa segura em ortodontia, pois é bem tolerada pelas células (Sestini et al.[21], 2006).

A solda ponto elétrica é um processo em que duas ou mais superfícies são unidas pelo calor gerado por uma corrente elétrica que passa através das amostras mantidas em união pela força aplicada pelos eletrodos (Correr Sobrinho[5], 1997) (Figura 1). Os eletrodos são aquecidos por um rápido pulso de baixa voltagem e alta amperagem para fundir o metal, o que gera a solda (Williams, Stell[31], 2005). Este tipo de solda apresenta menor tempo de confecção, facilidade de trabalho, custo inferior em relação à solda a laser, trabalho laboratorial simplificado, higiene e estética favoráveis. Porém, tem sido evitada onde é necessária uma maior resistência mecânica (Lopes et al.[16], 2000). Dentre os fatores que interferem na qualidade da solda e nas suas características mecânicas devem ser considerados: o tipo de máquina de solda, o formato e pressão dos eletrodos, a liga do fio utilizado, secção transversal dos fios, orientação dos fios na união, resistência à tração, dissipação do calor e condição da superfície (Nelson et al.[17], 1987; Tamada et al.[25], 2012).

Figura 1 - Desenho esquemático do processo de solda elétrica ponto.



a. Eletrodos próximos para a passagem da corrente elétrica.
b. Formação da solda.
Fonte: Elaboração própria

As ligas de NiTi são característicamente difíceis de sofrer a solda, devido ao alto ponto de fusão e reatividade com gases oxigênio, nitrogênio e hidrogênio em altas temperaturas (Iijima et al.[10], 2008; Taira et al.[23], 1989). Entretanto, em diversas situações clínicas, uniões homogêneas ou heterogêneas entre componentes do NiTi são desejadas, o que aumenta o interesse pela influência nas propriedades físico-mecânicas da liga, com destaque ao método de soldagem (Gugel et al.[9], 2008; Qiu et al.[20], 2006).

Assim, o uso clínico das ligas de níquel-titânio poderia ser mais explorado com a utilização de soldas nesses fios. Soldagem de pequenos pedaços de fios de NiTi ao fio principal da mesma liga permitiriam a utilização de ganchos para a uso precoce de elásticos e stops, sem contar que molas de NiTi soldadas aos fios permitiriam trazer a superelasticidade, a memória de forma e a baixa deformação da liga à outras situações clínicas do que as convencionais.

Estes fios são muito úteis ao ortodontista, pois permitem ganho de tempo de atendimento ao paciente, por evitar a confecção de alças ou dobras auxiliares, e podem permanecer ativos na cavidade bucal por um longo período de tempo. A possibilidade de realizar a soldagem por resistência neste tipo de liga traz muitas alternativas mecânicas para os ortodontistas por permitir modificação do sistema de forças e consequentemente apresenta uma grande importância clínica. Diante disso, o objetivo deste estudo é determinar a potência mais adequada para se alcançar uma solda elétrica a ponto suficientemente resistente ao uso clínico e sem alterações significativas na superfície.

2 PROPOSIÇÃO

Serão descritos neste tópico os objetivos gerais e específicos deste trabalho científico.

2.1 Objetivo geral

O objetivo desse estudo é avaliar a solda a ponto elétrica em fios de níquel-titânio e determinar a potência mais adequada para soldar fios 0.018” e 0.017” × 0.025” NiTi de 3 marcas comerciais Orthometric, 3M e GAC.

2.2 Objetivos específicos

1- Mensurar a resistência à tração até a ruptura de soldas elétricas a ponto em fios de NiTi 0.018” e 0.017” × 0.025’’ com o aumento das potências utilizadas, dentro das marcas comerciais testadas;

2- Avaliar microscopicamente a área de fusão de soldas elétricas a ponto em fios de NiTi 0.018” e 0.017” × 0.025’’ com o aumento das potências utilizadas, dentro das marcas comercias estudadas;

3- Comparar a rugosidade superficial da área de soldas elétricas a ponto em fios de NiTi 0.018” e 0.017” × 0.025’’ com o aumento das potências utilizadas, dentro das marcas comerciais testadas.

3 PUBLICAÇÕES

Este trabalho de dissertação de mestrado foi subdividido em dois artigos científicos que serão posteriormente publicados em periódicos.

3.1 Publicação 1

WELDING STRENGTH OF NITI WIRES*

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* Artigo a ser submetido ao periódico American Journal of Orthodontics and Dentofacial Orthopedics.

ABSTRACT

Objective: To identify the appropriate power level for an electric resistance welding of nickel-titanium (NiTi) wires. **Materials and Methods**: Eighty pairs of 0.018" and 0.017"× 0.025" NiTi wires were divided into three groups according to their manufacturers: GI (Orthometric, Marília, Brazil), GII (3M OralCare, St. Paul, CA) and GIII (GAC,York, PA); and welded by electrical resistance. Each group was divided into subgroups of 5 pairs of wires where welding was done with different power levels. In GI and GII, power levels of 2.5, 3, 3.5, 4, 4.5 and 5 were used while in GIII 2.5, 3, 3.5 and 4 were used (each unit of power of the welding machine represents 500W).The pairs of welded wires underwent a tensile strength test on an universal testing machine until rupture and the maximum forces were recorded. Analysis of variance (ANOVA) and post hoc tests were conducted to determine which subgroup within each brand group had the greatest resistance to rupture. **Results**: The 2.5 power exhibited the least resistance to rupture in all groups (43.75N for GI, 28.41N for GII and 47.57N for GIII) while the 4.0 power provided the highest resistance in GI and GII (97.90N and 99.61N, respectively), while in GIII (79.28N) the highest resistance was achieved with a 3.5 power welding. **Conclusions**: The most appropriate power for welding varied for each brand, which is 4.0 for Orthometric and 3M, and 3.5 for GAC NiTi wires.

Key Words: Spot welding, Nickel titanium, Orthodontics.

INTRODUCTION

Electric resistance spot welding allows two or more metallic surfaces to be joined by the heat produced from an electric current conducted by two electrodes that hold both surfaces in tight contact.[1,2] This procedure is routinely in orthodontics with stainless steel and beta-titanium wires, but has not been used with nickel-titanium (NiTi) alloys. The reason for that might be because the orthodontic literature reports that NiTi wires cannot be welded,[3] even though this information diverges from evidences on the field of materials engineering.[4]

NiTi wires could be further explored if welding is used. Short pieces of NiTi wires could be welded to the NiTi leveling wire acting as hooks, allowing early use of elastics, and also as stops, decreasing cost in the orthodontic office. Moreover, springs made of NiTi could also be welded to the main wires allowing use of superelasticity, shape-memory and low deformation of NiTi in nonconventional clinical situations. Thus, an approximate weld of round wires, usually used as initial leveling wire, to rectangular wires might he used for the mentioned situations.

Even though four papers on electrical resistance welding of NiTi wires have been published,[5-8] two of them did not compare the resistance to rupture among the welding power used.[5,6] Moreover, none of them tested the welding configuration of round to rectangular wires and did not use more than one commercial brand of NiTi. If it assumed that different wires might exhibit different responses to heat, an incorrect power level used for the weld may damage the wires.

Therefore, this study aims to test the weld resistance of NiTi wires in order to identify the most appropriate power level to be used on wires produced from three different manufacturers.

MATERIALS AND METHODS

Eighty pairs of 0.018" round and 0.017" × 0.025" NiTi wires were divided into three groups according to their manufacturers. Group I (GI) was made form wires from Orthometric (Marília, São Paulo, Brazil), Group II (GII) from 3M (3M OralCare, St. Paul, CA), and Group III (GIII) from GAC International (GAC, York, PA, United States).

The thinner surface of the rectangular wire of each group was welded by electrical resistance to a respective round wire, (Fig. 1) using a modified spot welding machine (Pontomatic NiTi - Electronic Automatic/Kernit, Indaiatuba, São Paulo, Brazil). Subgroups were created within each group according to the power levels used for the welding. Group I and II were divided into 6 subgroups (5 pairs per subgroup) which were welded with power levels of 2.5, 3, 3.5, 4, 4.5 and 5 (where each power level of the welding machine represents 500W), while Group III wires were divided into 4 subgroups, welded with power levels of 2.5, 3, 3.5 and 4. The tests started at a power level of 2.5 because it was the smallest power capable of welding wires while higher values than the ones tested damaged the wires during welding. The welding machine was calibrated to apply an electric current for 3 milliseconds between two flat electrodes, that produced a force of 12N when joining the wires, according to the manufacturer. The weld switch activated only once per weld by the same calibrated operator.

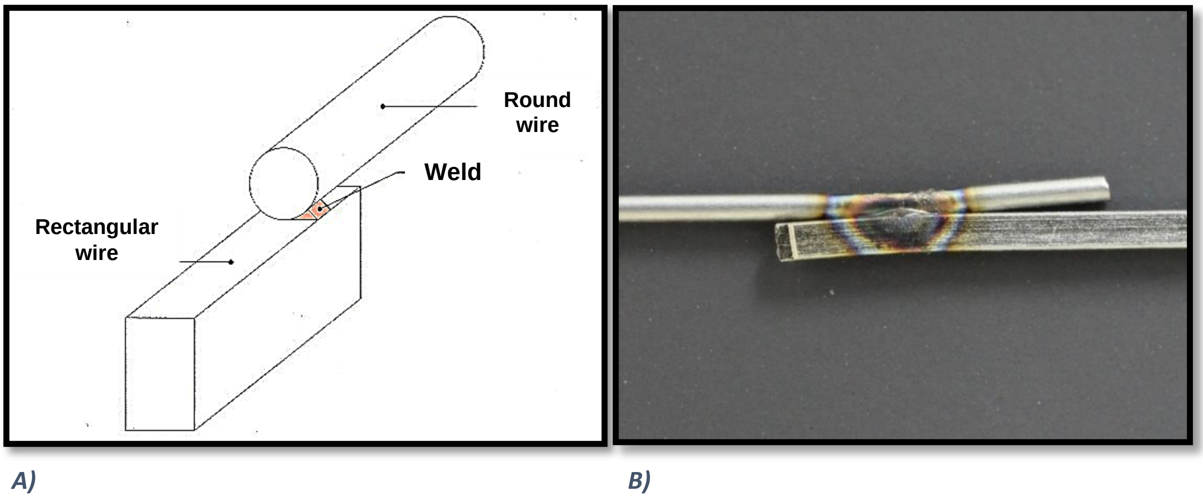

Figure 1 A) Schematics of the electric resistance weld. B) Image of a weld analyzed by this report.

For the tension test, the welded wires were secured with clamps specially made for the study, and subjected to the tensile strength tests using a universal testing machine (EMIC, São José dos Pinhais, Paraná, Brazil), with a 5 kN load cell. The tests were performed with a crosshead speed of 0.5 mm per minute until the rupture of the wires. The dedicated software of the machine recorded the breaking-point force in Newtons (N).

Statistical analysis was performed using SPSS software, version 16.0. (SPSS Inc., Chicago, IL, USA). The data distribution was normal and subgroups were compared using an analysis of variance with a significance level of 0.05 to identify subgroup differences while Tukey post hoc test (p=.05) was used to determine which groups were different.

RESULTS

All the wire ruptures were very close to the weld, in round wire. There was a difference between the forces registered on the subgroups of GI (p<.001) (Table 1). The power levels of 2.5, 3, 3.5 and 5 produced similar forces of rupture, with values of 43.75N, 61.69N, 65.00N and 53.76N, respectively. The power levels of 4 and 4.5 were similar to each other, but different from the remaining welds, with forces of 97.90N and 92.11N, respectively (Fig. 2).

Table 1: Average of the resistance strength (in Newtons) of NiTi wires welded at different powers, standart deviations (SD) and significance of the ANOVA (p>.05). Each unit of power value of the welding machine represents 500W. Different letters in the columns depict groups differences.

Power	GI (SD)	GII (SD)	GIII (SD)
2.5	43.75N[a] (6.10)	28.41N[a] (12.36)	47.57N[a] (4.39)
3	61.69N[a] (9.41)	79.66N[b,c] (7.64)	67.96N[a,b] (4.77)
3.5	64.99N[a] (11.11)	89.75N[c] (12.48)	79.28N[b] (12.62)
4	97.90N[b] (11.59)	99.61N[c] (10.14)	67.69N[a,b] (18.14)
4.5	92.11N[b] (17.51)	93.61N[c] (15.74)	...
5	53.74N[a] (14.39)	58.79N[b] (18.29)	...
Sig.	<.001	<.001	.004

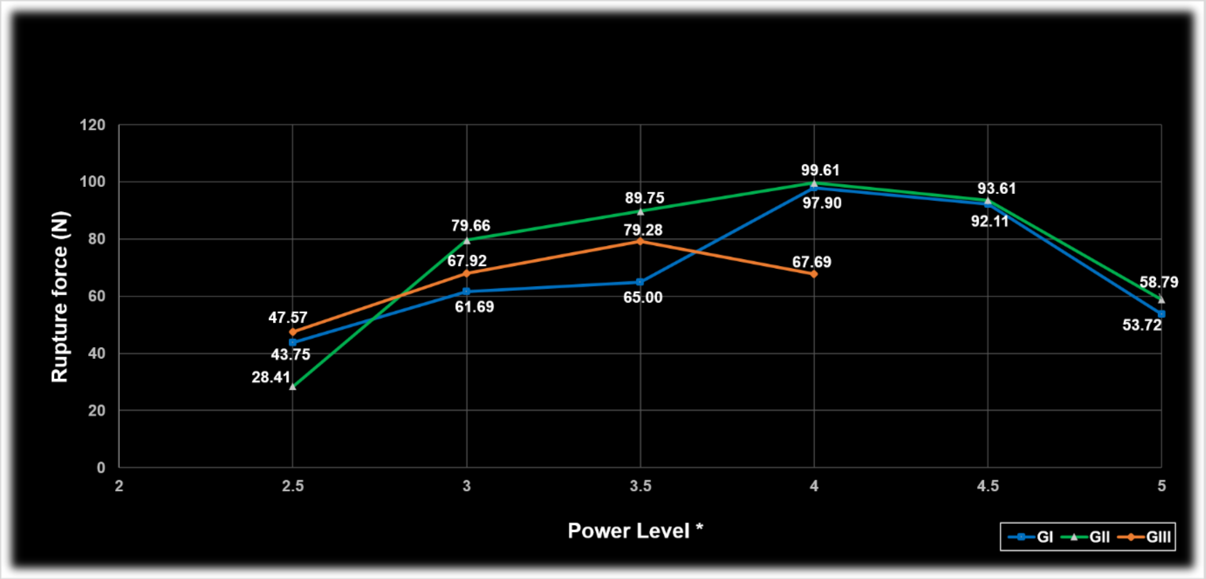

Figure 2 Graph of maximum tensile strength of the electric resistance welds in NiTi wires of the groups tested according to the powers used. * One unit of power of the welding machine represents 500W.

There was also a difference between the force values of GII ($p<.001$). The power level 2.5 resulted in a maximum force of 28.41N different to the other power levels. The power level 5 and 3 (58.79N and 79.66N, respectively) produce similar forces, which were different from the remaining weld powers. The levels 3, 3.5, 4 and 4.5 were similar and produced forces of 79.66N, 89.75N, 99.61N and 93.61N, respectively (Fig. 2).

GIII also showed a difference between the force registered ($p=.004$). The weld with a power level 2.5 produced a maximum force of 47.57N, which was similar to the power levels 3 (67.96N) and 4 (67.69N). The power level 3.5 produced a maximum force of 79.28N, which was similar to the power levels 3 and 4. The power levels 4.5 and 5 were not tested as the wires were destroyed during welding (Fig. 2).

DISCUSSION

The power that produced the strongest weld in the NiTi wires was identified for each of the brands tested. Although there are only four articles in the literature related to electric resistance welds in NiTi wires,[5-8] none of them tested wires of different commercial brands, which is very important, according to our results. Moreover, none of them tested which power was more appropriate to be used according to the resistance of the weld.

The most appropriate power level for each brand was defined as the one that produced a weld with the highest tensile strength. The tests started at a power of 2.5, since a lower power did not weld the NiTi wires, and these power levels were increased in steps of 0.5 until the heat produced by the weld broke the wires during the welding process. Our results show that the maximum tensile strength of the welded wires increased with the power levels up to a certain point only after which the resistance began to decrease. These peaks of resistance (Fig. 2) were at the power 4 for the Orthometric and 3M brands and 3.5 for GAC. The resistance decrease with higher power occurred because the heat produced by the resistance weld anneals of the wire[7] which is sufficient to significantly alter its mechanical properties and sometimes even break the wire, as occurred in the wires of the GAC brand when welded at power levels higher than 4 (and therefore were not used in this study). The difference of power levels which obtained the highest resistance for each group can be explained by variations in the manufacturing process of the wires. Variations in the wires may be due to the composition, as the nickel percentage can vary,[9] or due to the wire drawing machine and cooking processes.

The rupture of the wires never occurred at the weld but very close to it. This was probably due to the heat produced around the weld, which anneals the wire making it less resistant. Welded wires show less maximum resistance to tension than solid wires,[5,10-12] however, they need to be high enough to tolerate orthodontic forces. In this report, we found values ranging from 8 to 10 kilograms-force, which are high enough to support orthodontic forces. This results are lower than the results reported in the literature[5-7] because the wires used in this work had smaller diameters. The clinical implications of welded NiTi orthodontic wires are of great importance as they allow a combination of the advantages of the alloy such as high flexibility, shape memory, superelasticity, the possibility of using hooks for attaching elastics, and the use of omega loops or stops. Additionally, springs may also be welded to alignment the wires to assist in that phase of treatment.

Although these results open up new possibilities for the use of NiTi alloys in orthodontics, further studies should be made to evaluate these welded wires in the long term within the oral cavity where they are subjected to factors, such as corrosion by saliva as well as thermal and mechanical cycling. Additionally, it would be of great value to develop a type of weld, if possible, where there was no annealing of the wire around the weld point, both for NiTi wires and steel wires, which are usually reinforced with a silver alloy weld.

CONCLUSIONS

The most suitable power levels for electric resistance welding of NiTi wires varied for the different brands.

The most appropriate power level to weld the wires with the parameters given by the welding machine used was identified as being 4 (2000W) for the Orthometric and 3M brands and 3.5 (1750W) for GAC.

REFERENCES*

1. Darwish SM, Ghanya A. Critical assessment of weld-bonded technologies. J Mater Process Technol. 2000;105:221-229.

2. Wu KC. Resistance spot welding of high contact resistance for weld-bonding. Weld-bonding J. 1975:436-443.

3. Kapila S, Sachdeva R. Mechanical properties and clinical applications of orthodontic wires. Am J Orthod Dentofacial Orthop 1989;96:100-109.

4. Duerig P. TiNi Shape Memory Alloys. In: Collings EW, Welsch G, editors. Material Properties Handbook Titanium Alloys. Materials Park, OH: ASM International; 1994. p. 1047.

5. Matsunaga J, Watanabe I, Nakao N, Watanabe E, Elshahawy W, Yoshida N. Joining characteristics of titanium-based orthodontic wires connected by laser and electrical welding methods. J Mater Sci Mater Med. 2015;26:5391.

6. Nascimento LE, Santos RL, Pithon MM, Araújo MT, Nojima MG, Nojima LI. The Effect of Electric Spot-Welding on the Mechanical Properties of Different Orthodontic Wire Alloys. Mater Res. 2012;15:409-414.

7. Tam B, Pequegnat A, Khan MI, Zhou Y. Resistance Microwelding of Ti-55.8 wt pct Ni Nitinol Wires and the Effects of Pseudoelasticity. Metall Mater Trans A 2012;43.

8. Fukumoto S, Morikawa S, Yamamoto A. Small-scale resistance welding of crossed TiNi fine wire. Mater. Sci. Forum 2008;580-582:225-228.

9. Kararia V, Jain P, Chaudhary S, Kararia N. Estimation of changes in nickel and chromium content in nickel-titanium and stainless steel orthodontic wires used during orthodontic treatment: An analytical and scanning electron microscopic study. Contemp Clin Dent 2015;6:44-50.

10. Sevilla P, Martorell F, Libenson C, Planell JA, Gil FJ. Laser welding of NiTi orthodontic archwires for selective force application. J Mater Sci Mater Med 2008;19:525-529.

11. Bock JJ, Fraenzel W, Bailly J, Gernhardt CR, Fuhrmann RA. Influence of different brazing and welding methods on tensile strength and microhardness of orthodontic stainless steel wire. Eur J Orthod 2008;30:396-400.

12. Gugel H, Schuermann A, Theisen W. Laser welding of NiTi wires. Mat Sci Eng A-Struct 2008;481-482:668-671.

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* De acordo com as normas do periódico American Journal of Orthodontics and Dentofacial Orthopedics. Disponível em: http://www.ajodo.org/content/authorinfo#idp1856352 .

3.2 Publicação 2

POWER LEVEL FOR ELECTRIC SPOT WELDING OF NITI WIRES: STRESS RESISTANCE, MICROSCOPIC ANALYSIS AND SURFACE ROUGHNESS*

* Artigo a ser submetido ao periódico Dental Materials.

ABSTRACT

Aim: To determine the most appropriate power level for electric spot welding of nickel-titanium wires (NiTi). **Methods:** Ninety pairs of Niti wires (0.018" and 0.017"×0.025") were divided into groups according to their manufacturer: GI (Orthometric, Marília, Brazil), GII (3M OralCare, St.Paul, CA) and GIII (GAC Int., York, PA). Each group was divided into 3 subgroups of 10 pairs of wires, which were welded using three different power levels (3.75, 4 and 4.25 for GI and GII, and 3.25, 3.5 and 3.75 for GIII), where each power level represented 500W on the electric welding machine used. The welded wires were subjected to a tensile test until rupture on an universal machine and the maximum forces were recorded. Weldings were analyzed by scanning electron microscopy and subjected to a roughness test. Analysis of variance and post-hoc Tukey tests were conducted to determine which subgroups produced the highest resistance. Friedman and Wilcoxon tests were used for the roughness data. **Results:** Forces needed for rupture were different within GI and GII, but in GIII. The power level 4 showed a rupture force of 95.37N(GI) and 101.90N(GII), which were similar to the forces produced in power levels 3.75 and 4.25, within these two groups. Nugget and flash increased with the power used in all groups. Roughness increased with the power used in all groups, but did not change on the higher powers in GI and GIII. **Conclusions:** Power level 4 is suggested as the most appropriate for the Orthometric and 3M manufacturers wires tested, while 3.5 is suggested for GAC wires.

Key Words: Spot weld, Nickel titanium, Orthodontics, Topography.

INTRODUCTION

Nickel-titanium (NiTi) based wires are normally the choice of the majority of orthodontists in the initial stages of treatment [1] due to specific characteristics, such as high elastic recovery and low modulus of elasticity. The use of electrical resistance spot welding (ERSW) of these wires would further increase its applications in orthodontics because it would enable the orthodontist to use their properties associated to intermaxillary elastics and to passive and active stops.

Accuracy in defining safe power levels for welding NiTi wires is extremely important, since too much power could result in unwanted annealing of these wires,[2] modifying their mechanical behavior.[3-5] Even tough we have defined a suitable value of power for welding NiTi wires or three manufacturers previously [6] it is not known whether slight differences in power could increase or decrease the weld strength significantly without affecting the wires.

Therefore, this study aims to identify the most appropriate power levels for ERSW NiTi wires from three manufacturers by assessing the forces needed to rupture the wires, by microscopically evaluating changes in the surface topography and by analyzing surface roughness changes using a digital rugosimeter of the wires before and after welding.

MATERIALS AND METHODS

Ninety pairs of 0.018'' and 0.017'' × 0.025'' wires were divided into three groups according to their manufacturer to be welded by ERSW. Group I (GI) wires were manufactured by Orthometric (Marília, São Paulo, Brazil), Group II (GII) were manufactured by 3M Oral Care (St. Paul, CA, USA) and Group III (GIII) wires were manufactured by GAC International (York, PA, USA).

These three groups were further divided into three subgroups, with 10 pairs of wires each, to be welded with different power levels using an appropriate spot welder (Pontomatic NiTi, Kernit, Indaiatuba, São Paulo, Brazil). In GI and GII, the power levels used were of 3.75, 4 and 4.25 (each unit of power is equivalent to 500W) while the GIII the pair of wires were welded with 3.25, 3.5 and 3.75 of power. The groups were tested with different power values since each wire respond differently to the heat produced by welding. The flat electrodes of the welding machine held each pair of wires with a force of 12 newtons (N) while the current was applied for 3 milliseconds, as standardized by the spot welder. All wires were position in a way that the smaller surface of the rectangular wire (0.017'') was the one welded to the round wire (Fig. 1).

Figure 1 Spot electric welding of NiTi wires (0.018" and 0.017" x 0.025").

The specimens were subject to a tensile test using a universal testing machine (EMIC, São José dos Pinhais, Paraná, Brazil) with a 500 N load cell, and load speed of 0.5 mm/min until the wires ruptured. Each of the two wires were held by a clamp attached to testing machine and the dedicated software of the machine recorded the maximum force before rupture of the wires in N.

The round wires were used for the surface topography analysis because they are more likely to be effected by heat during welding due to their transverse geometry and might be, therefore, more susceptible to fracture. The wire surfaces of one sample of each subgroup were examined before and after the welding by a high-resolution scanning electron microscope with field emission beam FEG-SEM (JEOL 7500F model) equipped with an energy dispersive spectroscopy (EDS) and magnifications of 43x. Before taking the images, the samples were cleaned with an acetone solution, placed in an ultrasonic cleaning tank for 10 minutes and dipped in isopropyl alcohol for 10 more minutes. The images obtained allowed a qualitative evaluation of the nugget of the welding area, the flash of the alloy and the interface between the welded wires.

A digital rugosimeter (Mitutoyo Surftest SJ-400, Aurora, Illinois, USA) with a diamond needle along a single axis was used to measure the surface roughness of the wires. An average, in arithmetic roughness (Ra), of the surface roughness in the weld region of the round wires was obtained after 3 needle readings. Ten wires of each manufacturer, of the same batch used in the welding and as received, were similarly measured to allow comparison with the welded wires.

Statistical analysis was performed using SPSS software, version 16.0. (SPSS Inc., Chicago, IL, USA). An analysis of variance with a significance level of p>.05 was used to identify differences between the maximum forces registered with the rupture of the wires within each group. The post-hoc Tukey test was used to determine which power levels were different from the others within each group. For data surface roughness analysis, the Friedman and Wilcoxon test was used with a significance level of p>.05, since they had a non-normal distribution.

RESULTS

Differences were found between the maximum forces registered for the NiTi wire welds in GI (p=.037) (Fig. 2 and Table 1). The welding done with a power level of 4.25 showed a maximum force of 93.65N, which was similar to welds done with power levels of 3.75 and 4 (with values of 81.13N and 95.37N), even though these latter two were different from each other. Differences were also found in GII (p=.004). The welding done with power level of 4.25 showed a maximum force of 89.38N, which was similar to the values found for when the power levels of 3.75 (82.29N) and 4 (101.90N) were used, but the welding done with these two last power levels were different from each other. No differences were found among the maximum force values of the wires in GIII (p=.387).

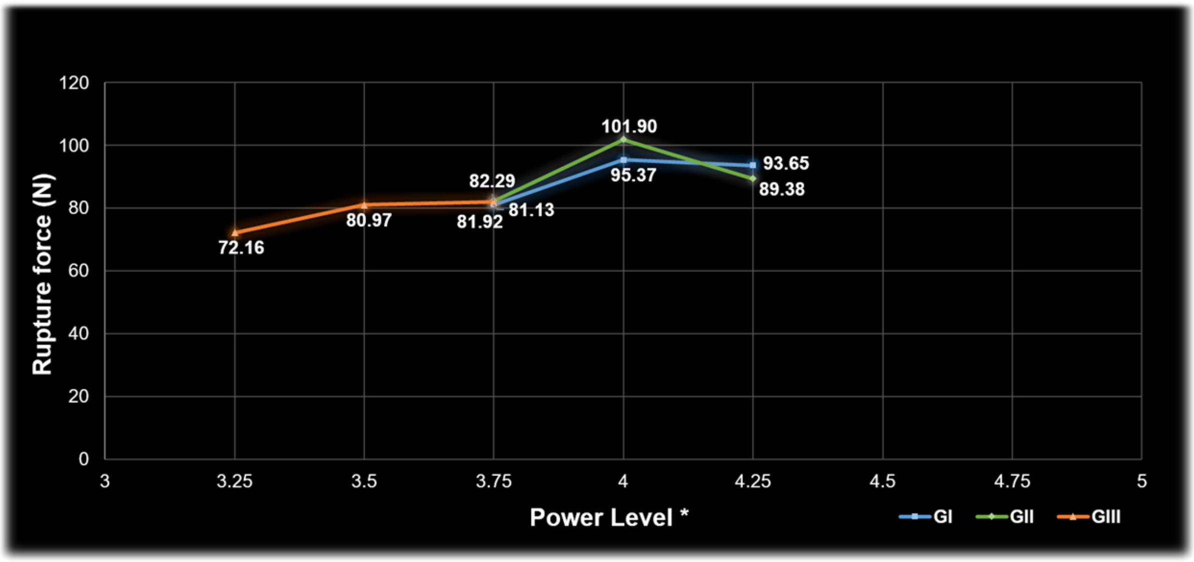

Figure 2 Graph of the maximum force registered before rupture given the power levels used for welding of the three groups tested. *Each power level is equivalent to 500W.

Table 1: Average of the resistance strength (in Newtons) of NiTi wires welded at different powers, standart deviations (SD) and significance of the ANOVA (p>.05). Each unit of power value of the welding machine represents 500W. Different letters in the columns depict groups differences.

Power	GI (SD)	GII (SD)	GIII (SD)
3.25	...	...	72.16 (11.09)
3.5	...	...	80.97 (13.88)
3.75	81.13N^{a} (8.64)	82.29N^{a} (12.87)	81.92 (23.82)
4	95.37N^{b} (13.06)	101.90N^{b} (10.48)	...
4.25	93.65N^{a,b} (15.44)	89.38N^{a,b} (12.15)	...
Sig.	.037	.004	.387

The welded wires clearly showed changes in their surface roughness when compared to as-received wires. Roughness increased as the power levels used for welding increased. GI showed the greatest change in surface roughness followed by GII and GIII. In addition, the GI wires showed a greater increase in roughness between the power levels 3.75 and 4, with no increase in roughness when the power used was raised to 4.25. Groups II and III showed a progressive increase in roughness with increasing power levels.

The size of the weld area (nugget) and the flash of the material increased as the power levels increased in all three groups. In general, it became more difficult to identify the interface between the wires as power levels increased in all groups (Figs. 3, 4 e 5).

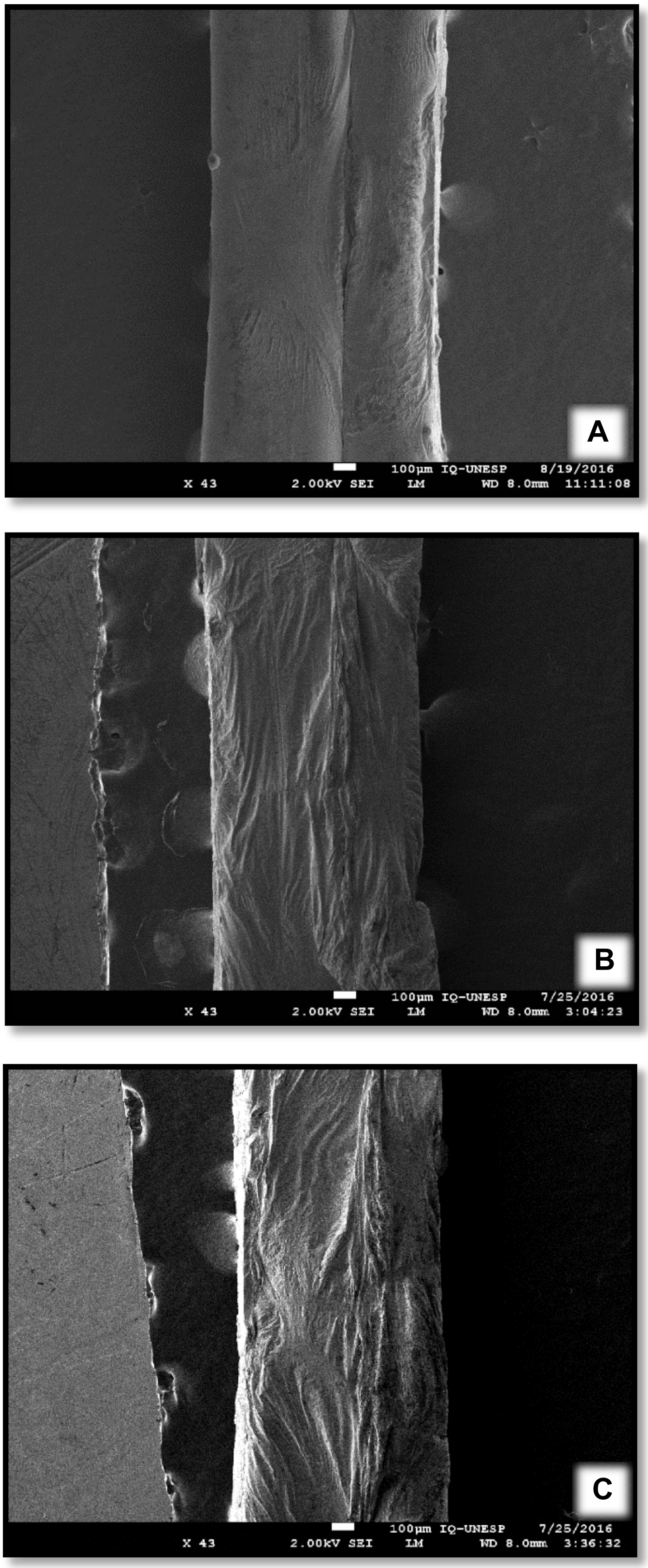

Figure 3 Scanning electron microscopy with a field emission beam and 43 times magnification of the electrical spot welds carried out on the GI wires. A. Welds with power level 3.75; B. Welds with power level 4 and C. Welds with power level 4.25.

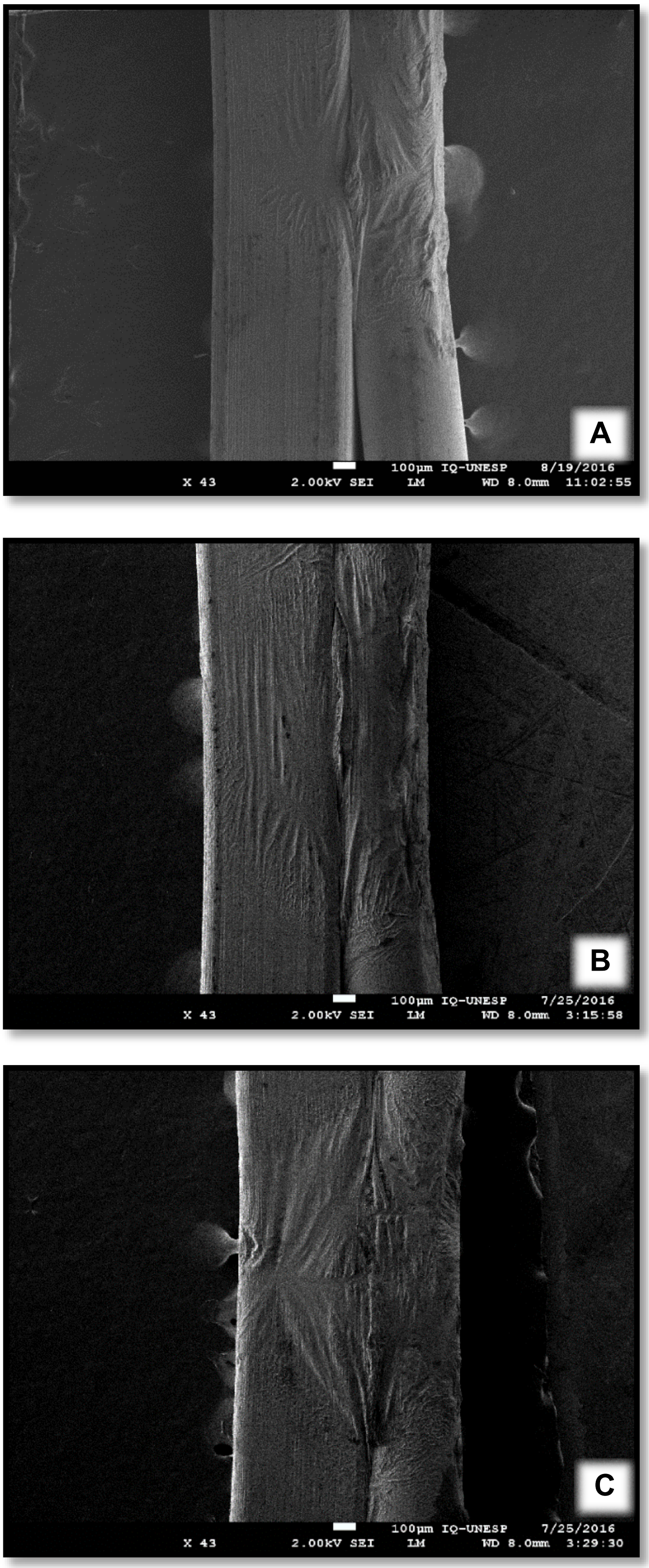

Figure 4 Scanning electron microscopy with a field emission beam and 43 times magnification of the electrical spot welds carried out on the GII wires. A. Welds with power level 3.75; B. Welds with power level 4 and C. Welds with power level 4.25.

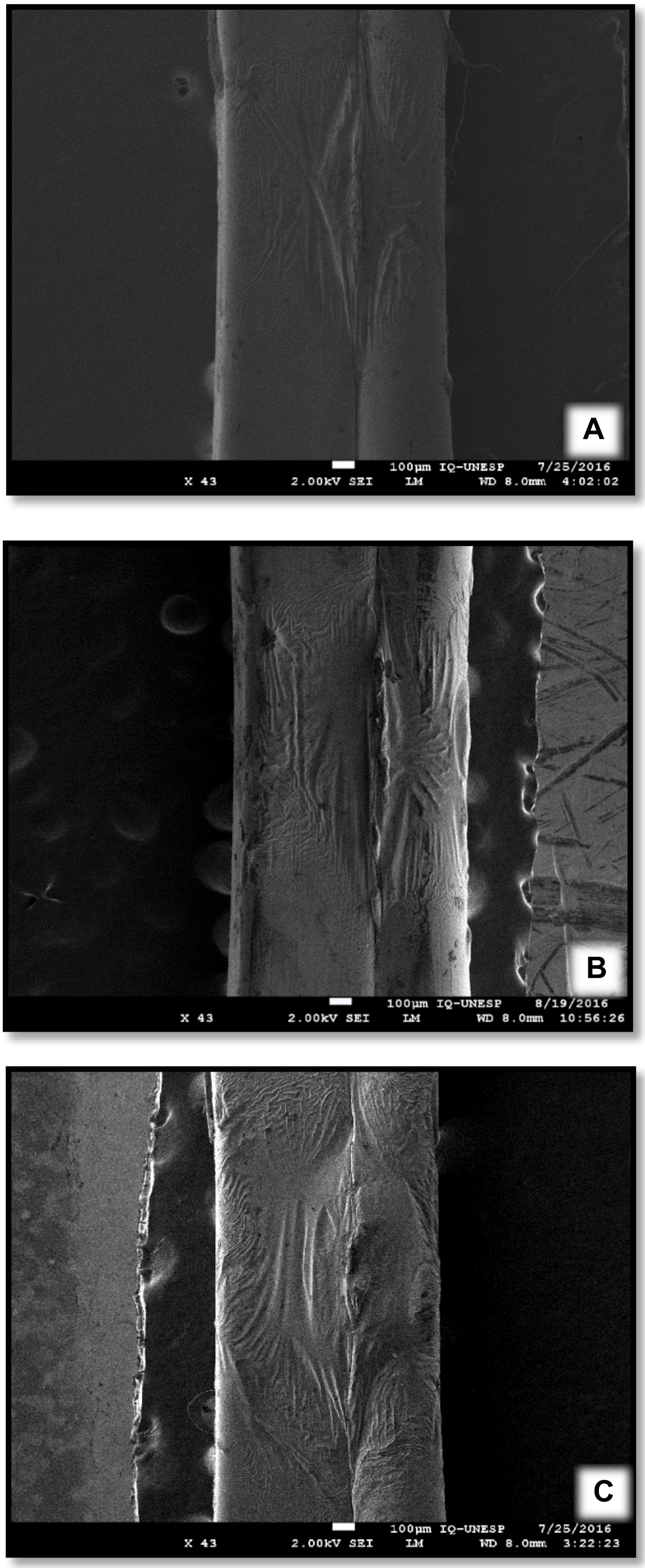

Figure 5 Scanning electron microscopy with a field emission beam and 43 times magnification of the electrical spot welds carried out on the GIII wires. A. Welds with power level 3:25; B. Welds with power level 3.5 and C. Welds with power level 3.75.

The GI wires showed different roughness before (0.10 Ra) and after welding. The wires welded with a power level of 3.75 had a different surface roughness (0.51 Ra) compared to when the powers levels of 4 (1.15 Ra) and 4.25 (1.47 Ra) were used, which on the other hand, produced similar roughness (p=.153) when compared amongst themselves (Table 2). All subgroups within GII showed different roughness, including when the subgroups compared to the non-welded wires (0.13 Ra). The power level of 3.75 produced a roughness of 0.33 Ra, while the power level of 4 produced 0.95 Ra and the power of 4.25 produced 1.34 Ra of roughness. All subgroups of GIII showed different roughness. The power level 3.25 (0.25 Ra) produced a roughness on the wires which was different to the non-welded wires (0.05 Ra) and to the wires welded with the power levels of 3.5 (0.54 Ra) and 3.75 (0.71 Ra), which were similar (p=.093) when compared to each other.

Table 2: Median of the surface roughness of NiTi wires (in Artimetic Roughness) welded at different powers, standart deviations (SD) and significance of the Friedman test (p>.05). Each unit of power value of the welding machine represents 500W. Different letters in the columns depict groups differences.

Power	GI (SD)	GII (SD)	GIII (SD)
As received	0.10 Ra^a (0.02)	0.13 Ra^a (0.04)	0.05 Ra^a (0.02)
3.25	...	...	0.25 Ra^b (0.07)
3.5	...	...	0.54 Ra^c (0.20)
3.75	0.51 Ra^b (0.09)	0.33 Ra^b (0.07)	0.71 Ra^c (0.27)
4	1.15 Ra^c (0.35)	0.95 Ra^c (0.39)	…
4.25	1.47 Ra^c (0.58)	1.34 Ra^d (0.50)	…
Sig.	<.001	<.001	<.001

DISCUSSION

The power level of which provided the best relation between force of resistance, roughness and visual quality of welding was identified in this paper. In a pilot study [6] an appropriate power level for this type of welding, for the same three manufacturers, was identified more broadly, without such precision. Our results bring an improved security to the welding process used, decreasing the risk of changing the mechanical resistance of the wires due to increased temperature [2, 5, 7] and also decreasing the likelihood of the wire breakeage during the welding process. Thus, the previously identified power levels (4 for Orthometric and 3M and 3.5 for GAC) were compared against slightly higher and lower power levels (+/- 0.25) in order to check if resistance would change. The results showed that the slightly higher powers level produced similar resistance while the slightly lower power levels were less resistant in GI and GII, but not in GIII, where the power used did not change the resistance to rupture. Four previous studies which have tested NiTi ERSW presented results which are difficult to compare to ours because two of them did not test orthodontics wires[2, 8] and the remaining two did not compare the effect of power level on the resistance to rupture.[9, 10]

The welding power used changed the surfaces of the wires. The boundaries of the wires could be easily identified in the lower powers used, but on the higher powers the wires could not be told apart. Metallurgical studies on NiTi ERSW have shown this same relationship between the power used and the weld interface, [2, 8] suggesting an increased weld quality with power. Flash and nugget appear to be more evident on the higher power welds, what is also in agreement with the literature.[2, 8] The increase in the nugget area appeared to be connected to an increase in roughness around it, which was measured quantitatively with a rugosimeter in order to evaluate a possible relationship between power and roughness.

The surface roughness increased with the power used for all manufacturers, which is due to an increase in the porosity formed by air bubbles, within the melted region that did not escape before solifidification.[11] Higher electric currents will increase the temperature of the interface, thus increasing the solubility of gases that contribute to the pore formation. An increase in roughness of the surfaces in orthodontic wires might be detrimental because it makes them more prone to corrosion,[12] which could change the mechanical properties of the wires.[13] Additionally, nickel ions released by corrosion of NiTi wires, may be associated to hypersensitivity on interacting with saliva.[14]

The power levels considered the most appropriate in this study provided an appropriate relationship between tensile strength, with a good visual weld, and as low as possible surface roughness. The power level 4 showed the best performance in the 3M wires, producing greater resistance than the lowest power and the same resistance compared to a highest power, but with a good visual union and less roughness. The power level 4 was also the most appropriate for the Orthometric wires. The resistance was greater than the lowest power and similar to the highest power used with the visual analysis of the weld and surface roughness similar to the latter level. Therefore, we considered the power 4 more appropriate than 4.25, in order to have a safety margin since it will show the same properties with a lower power, an thus smaller weld temperature. The welding of the GAC wires showed similar resistance for all three power levels, but the lowest power showed a smaller diameter weld, which may characterize a low quality weld. Thus, the power level 3.5, the medium power level used, was considered by us the one that produced the best benefit weld for the GAC wires, still providing a safety margin.

CONCLUSIONS

The power level 4 presented the best benefit for welding the NiTi wires of Orthometric and 3M manufacturers. For the GAC wires the most appropriate power level was 3.5, according to the parameters of the welding machine used. The scanning electron microscopy and measurements of the digital rugosimeter showed that the changes to the topography of the wires were more evident at the highest power levels tested in the wires from the three manufacturers studied.

REFERENCES*

[1] Keim RG, Gottlieb EL, Vogels DS, 3rd, Vogels PB. 2014 JCO Study of Orthodontic Diagnosis and Treatment Procedures, Part 2: breakdowns of selected variables. JCO 2014;48:710-26.

[2] Tam B, Pequegnat A, Khan MI, Zhou Y. Resistance Microwelding of Ti-55.8 wt pct Ni Nitinol Wires and the Effects of Pseudoelasticity. Metall Mater Trans A 2012;43.

[3] Bourauel C, Fries T, Drescher D, Plietsch R. Surface roughness of orthodontic wires via atomic force microscopy, laser specular reflectance, and profilometry. Eur J Orthod 1998;20:79-92.

[4] D'Anto V, Rongo R, Ametrano G, Spagnuolo G, Manzo P, Martina R, et al. Evaluation of surface roughness of orthodontic wires by means of atomic force microscopy. Angle Orthod 2012;82:922-8.

[5] Miura F, Mogi M, Ohura Y, Hamanaka H. The super-elastic property of the Japanese NiTi alloy wire for use in orthodontics. Am J Orthod 1986;90:1-10.

[6] Mesquita TR, Martins LP, Martins RP. Welding strenght of NiTi wires. Unpublished data.

[7] Krishnan V, Kumar KJ. Mechanical properties and surface characteristics of three archwire alloys. Angle Orthod 2004;74:825-31.

[8] Fukumoto S, Morikawa S, Yamamoto A. Small-scale resistance welding of crossed TiNi fine wire. Mater Sci Forum 2008;580-582:225-8.

[9] Nascimento LEAG, dos Santos RL, Pithon MM, Araújo MTdS, Nojima MG, Nojima LI. The Effect of Electric Spot-Welding on the Mechanical Properties of Different Orthodontic Wire Alloys. Mat Res 2012;15:409-14.

[10] Matsunaga J, Watanabe I, Nakao N, Watanabe E, Elshahawy W, Yoshida N. Joining characteristics of titanium-based orthodontic wires connected by laser and electrical welding methods. J Mater Sci Mater Med 2015;26:5391.

[11] Akman E, Demir A, Canel T, Sınmazçelik T. Laser welding of Ti6Al4V titanium alloys. J Mater Process Technol 2009;209:3705-13.

[12] Widu F, Drescher D, Junker R, Bourauel C. Corrosion and biocompatibility of orthodontic wires. J Mater Sci Mater Med 1999;10:275-81.

[13] Walker MP, White RJ, Kula KS. Effect of fluoride prophylactic agents on the mechanical properties of nickel-titanium-based orthodontic wires. Am J Orthod Dentofacial Orthop 2005;127:662-9.

[14] Eliades T, Athanasiou AE. In vivo aging of orthodontic alloys: implications for corrosion potential, nickel release, and biocompatibility. Angle Orthod 2002;72:222-37.

*De acordo com as normas do periódico Dental Materials. Disponível em: http://www.demajournal.com/content/authorinfo.

4 CONSIDERAÇÕES FINAIS

Estudos in vitro são úteis para avaliar novos materiais, ferramentas ou técnicas, determinando a possibilidade da aplicação in vivo, apesar dos resultados apresentarem algumas limitações. Os objetivos propostos neste estudo foram alcançados, após a execução dos experimentos relatados:

1- A potência mais adequada para solda elétrica a ponto nos fios de NiTi testados variou para as três marcas comerciais do estudo. De acordo com a metodologia desse estudo foi identificada como: 4 para as marcas Orthometric e 3M e 3.5 para a marca GAC.

2- A solda dos fios de NiTi das marcas Orthometric e 3M apresentaram a melhor relação entre resistência à tração e rugosidade superficial com a potência 4, já com os fios da GAC a potência considerada mais adequada foi de 3.5, de acordo com os parâmetros da máquina de solda utilizada.

3- A microscopia eletrônica de varredura e as medidas do rugosímetro digital mostraram que as alterações da topografia dos fios foram mais evidentes nas potências mais altas para as três marcas comerciais estudadas.

REFERÊNCIAS*

1. Andreasen GF, Morrow RE. Laboratory and clinical analyses of nitinol wire. Am J Orthod. 1978; 73(2): 142-51.

2. Andreasen GF, Zwanziger D. A clinical evaluation of the differential force concept as applied to the edgewise bracket. Am J Orthod. 1980; 78(1): 25-40.

3. Arciniegas M, Manero JM, Espinar E, Llamas JM, Barrera JM, Gil FJ. New Ni-free superelastic alloy for orthodontic applications. Mater Sci Eng C Mater Biol Appl. 2013; 33(6): 3325-8.

4. Buehler W, Wang F. A summary of recent research on the Nitinol alloys and their potential application in ocean engineering. Ocean Engng. 1967; 1(1): 4.

5. Correr Sobrinho L. Comparative study of the tensile strength of silver solders and super micro point, used in orthodontics. J Fac Dent UFP. 1997; 45: 51-7.

6. Delobelle V, Delobelle P, Liu Y, Favier D, Louche H. Resistance welding of NiTi shape memory alloy tubes. J Mater Process Tech. 2012; 213: 1139-45.

7. Freitas MP, Oshima HM, Menezes LM, Machado DC, Viezzer C. Cytotoxicity of silver solder employed in orthodontics. Angle Orthod. 2009; 79(5): 939-44.

8. Gravina MA, Brunharo IH, Fraga MR, Artese F, Campos MJ, Vitral RW, et al. Clinical evaluation of dental alignment and leveling with three different types of orthodontic wires. Dental Press J Orthod. 2013; 18(6): 31-7.

9. Gugel H, Schuermann A, Theisen W. Laser welding of NiTi wires. Mater Sci Eng, A. 2008; 481–482: 668-71.

10. Iijima M, Brantley WA, Yuasa T, Muguruma T, Kawashima I, Mizoguchi I. Joining characteristics of orthodontic wires with laser welding. J Biomed Mater Res B Appl Biomater. 2008; 84(1): 147-53.

11. Juvvadi SR, Kailasam V, Padmanabhan S, Chitharanjan AB. Physical, mechanical, and flexural properties of 3 orthodontic wires: an in-vitro study. Am J Orthod Dentofacial Orthop. 2010; 138(5): 623-30.

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*De acordo com o Guia de Trabalhos Acadêmicos da FOAr, adaptado das Normas Vancouver. Disponível no site da Biblioteca: http://www.foar.unesp.br/#biblioteca/manual.

12. Kauffman GB, Mayo I. The story of nitinol: The serendipitous discovery of the memory metal and its applications. J Chem Educ. 1997; 2(2): 20.

13. Krishnan V, Kumar KJ. Weld characteristics of orthodontic archwire materials. Angle Orthod. 2004; 74(4): 533-8.

14. Krousbroeck R, Van Der Perre G, Aernoudt E, Mulier JC. Shape memory effect in biomedical devices. In: Winter GD, Gibbons DF, Plenk H, editors. Advances in biomaterials. New York: John Wiley & Sons; 1982. p. 767.

15. Lin MC, Lin SC, Wang YT, Hu SW, Lee TH, Chen LK, et al. Fracture resistance of Nd:YAG laser-welded cast titanium joints with various clinical thicknesses and welding pulse energies. Dent Mater J. 2007; 26(3): 367-72.

16. Lopes MB, Correr Sobrinho L, Consani S, Sinhoreti MAC, Cangiani MB. Fatigue resistance between point electrical solder and silver solder utilized in orthodontics. Rev Dent Press Ortodon Ortop Facial. 2000; 5(6): 45-9.

17. Nelson KR, Burstone CJ, Goldberg AJ. Optimal welding of beta titanium orthodontic wires. Am J Orthod Dentofacial Orthop. 1987; 92(3): 213-9.

18. Oh KT, Kim KN. Ion release and cytotoxicity of stainless steel wires. Eur J Orthod. 2005; 27(6): 533-40.

19. Philips RW. Physical Properties of Dental Materials: Skinners Science of Dental Materials. 9th ed. Philadelphia: Saunders; 1991. 615 p.

20. Qiu XM, Li MG, Sun DQ, Liu WH. Study on brazing of TiNi shape memory alloy with stainless steels. J Mater Process Technol. 2006; 176: 8-12.

21. Sestini S, Notarantonio L, Cerboni B, Alessandrini C, Fimiani M, Nannelli P, et al. In vitro toxicity evaluation of silver soldering, electrical resistance, and laser welding of orthodontic wires. Eur J Orthod. 2006; 28(6): 567-72.

22. Sevilla P, Martorell F, Libenson C, Planell JA, Gil FJ. Laser welding of NiTi orthodontic archwires for selective force application. J Mater Sci Mater Med. 2008; 19(2): 525-9.

23. Taira M, Moser JB, Greener EH. Studies of Ti alloys for dental castings. Dent Mater. 1989; 5(1): 45-50.

24. Tam B. Micro-welding of nitinol shape memory alloy [Master of Applied Science in Mechanical Engineering]. Waterloo: University of Waterloo; 2010.

25. Tamada M, Nagano O, Tateyama S, Ohmura M, Yae T, Ishimoto T, et al. Modulation of glucose metabolism by CD44 contributes to antioxidant status and drug resistance in cancer cells. Cancer Res. 2012; 72(6): 1438-48.

26. Tambasco J, Anthony T, Sandven O. Laser welding in the dental laboratory: an alternative to soldering. J Dent Technol. 1996; 13(4): 23-31.

27. Vande Vannet B, Hanssens JL, Wehrbein H. The use of three-dimensional oral mucosa cell cultures to assess the toxicity of soldered and welded wires. Eur J Orthod. 2007; 29(1): 60-6.

28. Vijayalakshmi RD, Nagachandran KS, Kummi P, Jayakumar P. A comparative evaluation of metallurgical properties of stainless steel and TMA archwires with timolium and titanium niobium archwires--an in vitro study. Indian J Dent Res. 2009; 20(4): 448-52.

29. Wang RR, Chang CT. Thermal modeling of laser welding for titanium dental restorations. J Prosthet Dent. 1998; 79(3): 335-41.

30. Wang RR, Welsch GE. Joining titanium materials with tungsten inert gas welding, laser welding, and infrared brazing. J Prosthet Dent. 1995; 74(5): 521-30.

31. Williams NT, Stell B. Resistance spot welding. In: ASM Handbook. Volume 6: Welding, brazing and soldering. Materials Park: ASM; 2005. p. 226-9.

32. Wiskott HW, Doumas MT, Scherrer SS, Susz C, Belser UC. Microstructures of brazings and welds using grade 2 commercially pure titanium. Int J Prosthodont. 2001; 14(1): 40-7.

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Tatyane Ribeiro Mesquita