Available online at http://www.journalijdr.com

IJDR

ISSN: 2230-9926

International Journal of Development Research
Vol. 07, Issue, 11, pp.16990-16994, November, 2017

ORIGINAL RESEARCH ARTICLE **OPEN ACCESS**

THE QUALITY OF ORTHODONTIC WIRES OF NICKEL-TITANIUM: A SHORT REVIEW.

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ARTICLE INFO

Article History:

Received 14th August 2017
Received in revised form
20th September, 2017
Accepted 18th October, 2017
Published online 29th November, 2017

Key Words:

Orthodontic wires. Nickel-Titanium. Shape Memory. Dynamic mechanical analysis (DSC) -wires, Differential Scanning Calorimetry (DMA) –wires, Three-point bend test -wires.

ABSTRACT

In light of the importance of studying instruments that assess the quality of Orthodontic wires of Nickel-Titanium thermoactivated, this manuscript sought to conduct a systematic review of the techniques used to study of the Orthodontic wires of Nickel-Titanium thermoactivated and duly analyzed its methodology and results. The aim of this manuscript was to review the different techniques of analysis used to study the quality of orthodontic wires and their implications in the thermo-mechanical properties of these materials. The major electronic databases were used for the selection of studies. After the searches with the key words, twenty two a manuscripts were included in this review. Methodological issues of articles were evaluated and discussed. Some common results were highlighted among the studies such as transition of temperature of wires. Among the articles that address the DMA, or DSC and/or three-point bend test, it has been found that the qualities of the strands are still contradictory among researchers. The DMA technique is still little used to disrupt the properties of orthodontic wires.

Citation: Tatiana S. Spini, Pedro Gregol da Silva, Elaine Silva de Pádua Melo, Daniel Araujo Gonçalves, Rita de Cássia Avellaneda Guimarães and Valter Aragão do Nascimento, 2017. "Assessment of frailty and related factors among the elderly cared at a reference center", *International Journal of Development Research*, 7, (11), 16990-16994.

INTRODUCTION

The use of orthodontic wires of Nickel-Titanium (NiTi) in Clinical Orthodontics was consolidated due to the important mechanical properties of shape-memory alloys (SMAs) and superelasticity, resistance to corrosion, high ductibility, ease of application and low cost (Santos et al, 2007). Ideal properties allow such materials to exert light and continuous forces even at high levels of deflection. The force exerted by an orthodontic wire should promote a physiological response to the bone, preventing bone hyalinization, root resorption and great discomfort to the patient. Thus, many efforts have been made to improve the memory characteristics of orthodontic wires. In the market there are several commercial brands of thermo activated orthodontic wires, but the mechanical properties are not always specified in the labels, which hinders the orthodontist in choosing the ideal brand to be used in the treatment of their patient. Properties are strongly influenced by several factors at the time of their production, such as the heat treatment to which the alloy is subjected and addition of elements as Copper (kapila *et al.,* 1989). Some orthodontists choose the orthodontic wires based on clinical impressions. However, the correct one would be to use only the wires that have good mechanical properties (Quintão and Brunharo, 2009). Mechanical tests are effective in determining the properties of orthodontic wires of various brands, however, such methods do not reflect the clinical reality. There are several factors in the patient's mouth that are not reproduced in mechanical tests and that significantly affect the mechanical behavior of orthodontic wire. Factors not reproduced by equipments are the interbracket distance, the size of the bracket slots relative to the wire, the angulation of bracket, the activation direction, the curved shape of the arc and especially the curvature of the wire and the friction between the arc and

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the bracket. There are standards for experimental conducting tests in orthodontic wires, we can highlight the International Standardization Organization (ISO) standards for Orthodontics wires ISO 15841:2006 that specifies requirements and test methods for wires to be used in fixed and removable orthodontic appliances (ISO, 2006). There are the ADA (American Dental Association) 32 and ASTM D3418-08 which stipulate the standards of analysis and experimental parameters (ASTM, 2008). The standards cited above stipulate experimental techniques such as DSC thermal analysis and three-point bending technique. However, there are no standards requiring the use of DMA. The objective of this study was to perform a literature short review of the main mechanical tests for Nickel-titanium orthodontic wires, capable of predicting the mechanical behavior of these alloys, namely: orthodontic wires and Three-point bend test, Mechanical Dynamic Analysis (DMA) and Differential Scanning Calorimetry (DSC).

MATERIALS AND METHODS

We used the electronic databases Medline (National Library of Medicine, USA), SciELO (Scientific Electronic Library Online) and PubMed considering the last fourteen years of publication. The review looked for studies that evaluated the quality of orthodontic wires using as technical instruments: Dynamic mechanical analysis (DMA), Differential Scanning Calorimetry (DSC) and Three-point bend test. The words used as descriptors were: orthodontic wires, materials testing, nickel, titanium, elasticity, nickel-titanium endodontic, nickel-titanium endodontic-mechanical analysis (DMA), Shape Memory Alloys; NiTi Alloys; DMA, Nickel-titanium alloy wires in three-point bending tests. Once the inclusion and exclusion criteria have been established, the articles of literature review were excluded, as well as dissertations and theses. Journals that charge for access to the manuscripts were excluded from this study, which is a limitation of our work**.**

Concepts about Dynamic mechanical analysis, Differential scanning calorimetry and three-point bending tests

Dynamic mechanical analysis (DMA) is a technique used to study and characterize materials solids as polymer and melts. This allows the materials response to stress, temperature, frequency and other values to be studied. These data allow the calculation of the damping or tan delta (δ) as well as complex modulus and viscosity data. However, there is no standardization for DMA analysis for orthodontic wires (Beverly *et al*, 1986). On the other hand, Differential Scanning Calorimetry (DSC) is a technique used to characterize the stability of a protein, biomolecule, polymers and metalic alloys (Beverly *et al*, 1986). This technique is used to measure melting temperature, heat of fusion, latent heat of melting, reaction energy, ortodontic wires transition temperature, precipitation energy and temperature, denaturization temperatures, oxidation induction times, and specific heat or heat capacity. Austenite-finish temperature by differential scanning calorimetry is standardized according to the instructions ISO 15841:2006 for the instrument. The three point bend test is a classical experiment in mechanics, used to measure the Young's modulus of a material in the shape of a beam. The beam, of length L, rests on two roller supports and is subject to a concentrated load P at its centre. Elastic modulus in bending (i.e., flexural modulus), stress-strain behavior, and failure limits in bending all can be obtained using the simple sample geometry of a 3-point bend test. Orthodontics wires ISO 15841:2006 covers flexural properties for wires for use in orthodontics (ISO, 2006).

RESULTS

Table 1 contains the list of twenty two a manuscripts that were selected in our bibliographic search. Some manuscripts use the DMA or DSC technique and/or 3-point flexion to analyze the quality of the orthodontic strands. We can observe in the Table 1 that there is no author who has worked with the three techniques simultaneously to evaluate the properties of the orthodontic wires. According to manuscript of Brantley *et al.* (2003), the differential scanning calorimetry results showed that structural transformations of the wires are complex. Thus, the mechanical properties depend on the initial state and need to be known the dependence ot temperature if NiTi archwires are to be used to optimal effect in clinic (Fischer-Brandies *et al*., 2003). In the year 2003, studies showed that there was a large variation between the three types of thermally active wire (Parvizi and Rock, 2003). Mechanical properties such as stiffness appears to vary with wire size but depends on the ratio of volume of martensitic transformation. During martensitic transformation, the elastic modulus of the alloy is nonconstant (Garrec and Jordan, 2004).

From the clinical view point, some wires increase at least twofold the stiffness as temperature increased (Kusy and Whitley, 2007). On the other hand, other studies emphasize that a significant fraction of the tested wires showed no or only weak superelasticity. The practitioner should be informed for the on mechanical properties load-deflection characteristics of the orthodontic wires to choose the best products for the given treatment needs (Bartzela *et al*., 2007). Others techniques such as transmission electron microscopy confirmed the low-temperature peak and other phase transformations observed by DSC , and revealed that twinning in martensite is the mechanism for the low-temperature peak in wires of Copper nickel–titanium (Brantley *et al*., 2008). In fact, the phase transformation temperatures and transformation behavior varied among different commonly used NiTi orthodontic arch wires, leading to variability in shape memory effect (Ren *et al*., 2008). Stress increased the corrosion rate in nickel-titanium and beta-titanium orthodontic wires. Alterations in stress/strain associated with phase transformation in superelastic nickel-titanium might alter the corrosion rate in ways different from wires not undergoing phase transformation.

According studies, alterations in stress/strain associated with phase transformation in superelastic nickel-titanium might alter the corrosion rate in ways different from wires not undergoing phase transformation (Segal *et al*., 2009). However, others studiesson DMA results show that the stiffness value means of the four NiTi alloys are similar (Ardeshna *et al*., 2010). On the other hand, repeated temperature fluctuations do not impart significant mechanical property changes in 35^{o}C CuNiTi orthodontic wires (Berzins and Roberts, 2010). It is important to know the specific changes in force levels induced for each individual archwire with heat-treatment. According to Brauchli *et al*., (2011), archwire shape can be modified by using either chair-side technique (Memory-Maker, cold forming) because the superelastic behavior of the archwires is not strongly affected.

Table 1. Manuscripts that were found and that used the DMA or DSC technique and/or -point bend test to analyze the quality of the orthodontic wires

	Manufacturer	DMA	DSC	Three-point bend test	Author/year
1	Neo Sentalloy (GAC International, Islandia, NY), 35 degrees C Copper Ni-Ti (Ormco, Glendora, Calif) and Nitinol SE (3M Unitek, Monrovia, Calif).	-	x	-	Brantley *et al.,* 2003.
2	Neo Sentalloy F80™ (GAC, Central Islip, NY, USA), 35 °C Thermo-Active Copper NiTi™ (A-Company/Ormco, Glendora, CA, USA), Rematitan® "Lite" (Dentaurum, Pforzheim, Germany), Titanol® SE S (Forestadent, Pforzheim, Germany) and Titanal™ (Lancer, San Marcos, CA, USA).	-	x	-	Fischer-Brandies *et al.,* 2003.
3	Regency Thermal (Direct Ortho, Bristol, UK), Orthoform (3M Unitek, Bradford, UK), and Eurotherm (Ortho Care, Bradford, UK). The control was Memory wire (3M Unitek).	-	-	x	Parvizi and Rock, 2003.
4	Ni-Ti orthodontic alloy (Thermo NITIt, produced by Ortho-Force, Paris, France).			x	Garrec and Jordan, 2004.
5	Cu-Ni-Ti 40 (SDS/Ormco, Glendora, Calif).	x	x	-	Kusy and Whitley, 2007.
6	Different Wire Types Tested : Forestadent ,Ormco, Ortho Organizers , 3M, Dentaurum.	-	-	x	Bartzela *et al.,* 2007.
6	Variants (27C, 35C, and 40C) of CuNiTi orthodontic archwires (Ormco, Glendora, Calif).	-	x	-	Biermann *et al*., 2007.
7	35 °C Copper nickel–titanium wire (Ormco).	-	x	-	Brantley *et al*., 2008.
8	Smart, Ormco and 3M NiTi wires, Youyan I NiTi wires, Smart, L&H, Youyan II Ni-Ti wires, Damon CuNiT.	-	x	-	Ren *et al*., 2008.
9	Nickel-titanium (Sentalloy, GAC International, Bohemia, NY) and beta-titanium (TMA, Ormco, Orange, Calif) archwires.	-	x	x	Segal *et al*., 2009.
10	GAC Lowland (Martensite Stable), GAC NeoSentalloy (Martensite Active), ORMCO Cu-NiTi (Martensite Active), ORMCO Align SE 200 (Austentic Active), Unitek TMA (Titanium Moybdenum), ORMCO Stainless Steel.	x	x	-	Ardeshna *et al.,* 2010.
11	M-NiTi (Nitinol Classic, NC), A-NiTi (Optimalloy, OPTI) and T-NiTi (Neo-Sentalloy, NEO).		x	x	Yu-Hyun Lee., *et al*., 2010.
12	35°C Copper NiTi (Ormco).	-	x	-	Berzins and Roberts, (2010).
13	Copper NiTi 35C [Ormco, Glendora, Calif], Neo Sentalloy F 80 [GAC International, Bohemia, NY], and Titanol Low Force [Forestadent, Pforzheim, Germany].	-	x	x	Brauchli *et al.,* 2011.
14	Gum Metal (Toyota Central R&L Labs., Inc.), TMA (ORMCO), 35°C Copper NiTi (SDS ORMCO), Thermalloy Plus (Rocky Mountain), Nitinol SE (3M Unitek), and NiTi (SDS ORMCO).	x	x	-	Laino e*t al.,* 2012.
15	Nitinol Termo-Ativado (Aditek, Dravinhos, São Paulo, Brasil), NeoSentalloy F200 (GAC, Bohemia, NY, USA), Thermo Plus (Morelli, Sorocaba, São Paulo, Brazil), Cooper Niti 35°C (Ormco, Glendora, CA, USA), Flexy Termal 35°C (Orthometric, Marilia, São Paulo, Brazil), Superthermal Nickel Titanium Arches (OrthoSource, Matão, São Paulo, Brazil).	-	-	x	Figueiredo *et al.,* 2012.
16	Thermal NiTi: American Orthodontics, Sheboygan, Wisconsin, USA; 3M Unitek, Monrovia, California, USA; GAC, Bohemia, New York, USA; Rocky Mountain Orthodontics, Denver, Colorado, USA.	-	-	x	Gatto *et al.,* 2013.
17	Nitinol Termoativado (Aditek, Cravinhos, SP, Brazil); NeoSentalloy F200 (GAC, Bohemia, NY, USA); Thermo Plus (Morelli, Sorocaba, SP, Brazil); Copper Ni-Ti 35°C (Ormco, Glendora, CA, USA); Flexy Thermal 35°C (Orthometric, Marília, SP, Brazil); Superthermal Nickel Titanium Arches (Orthosource, Matão, SP, Brazil) and Heat Activated NiTi (Highland Metals, San Jose, CA, USA).	-	x	-	Spini *et al*., 2014.
18	NiTi shape memory alloy wires (Ni 49.3, Ti 50.4 at.%) were obtained commercially (NDC, Fremont, CA).	x	x	-	Naghashian *et al*., 2014.
19	Orthodontic wires from different producers included in the analyses: CuNiTi , Thermo-Active (NiTi), NiTi 4 NiTi, Thermo (NiTi), NiTi.	-	x	-	Ferec et al., 2014.
20	Rematitan® LITE DIMPLE (Dentaurum, Ispringen, Germany) and Niti Preformed Archwires (Ormco, Glendora, Calif, USA).	-	x	x	Braz Fernandes *et al.,* 2015.
21	Ni-Ti wires from three different manufacturers (Ah Kim Pech, 03100 Mexico City, Mexico; Borgatta, 15700 Mexico City, Mexico; TP Orthodontics Inc., 46350-9672 La Porte, IN, USA).	-	-	x	Garro-Piña *et al*., 2017.
22	Rematitan® Lite ematitan®, FLI® Coated Orthonol® and Orthonol®	-	-	x	Alobeid *et al*, 2017.

- The research did not use the technique: DSC, DMA, Three-point bend test; x The research used some of the techniques: DSC, DMA, Three-point bend test;

Results from experimental tests have highlighted that superelastic wires are very sensitive to temperature variations occurring in the oral environment, while the proposed model seems to be reliable to predict the Young's modulus allowing to correlate calorimetric and mechanical data. Furthermore, Gum Metal wire behaves as an elastic material with a very low Young's modulus, and it can be particularly useful for the initial stage of orthodontic treatments (Laino *et al.,* 2012). Evidence of experimental results has showed that superelastic wires are very sensitive to temperature variations occurring in the oral environment. In this case, the proposed model seems to be reliable to predict the Young's modulus allowing to correlate calorimetric and mechanical data (Laino *et al*., 2012). According to Figueiredo *et al*., (2012), there are differences in deactivation forces among types of thermally actived nickel-titanium archwires tested.

According to Gatto *et al*., (2013), it is necessary to take into account the biomechanics used. However, thermally activated NiTi archwires present great variability in the transition temperature range and the elastic parameters of each NiTi archwire should be provided by the manufacturers (Spini *et al*., 2014). Theoretical models have been developed to aid in the interpretation of results obtained from DMA and DSC analyzes. In fact, experimental results of actuation showed reasonable agreement with the model (Naghashian *et al*., 2014).

Behavior such as wire slippage inside the brackets and friction bending and pulling tests (Braz Fernandes *et al*., 2015), as well as the addition of an esthetic coating to new Ni-Ti wires produced change in mechanical properties (Garro-Piña *et al.*, 2017). Alobeid *et al*., (2017) studied the mechanical properties of different aesthetic and conventional orthodontic wires and brackets using bending tests. In its conclusions it forces of investigated NiTi wires are very high and in part above clinically recommended values. The elastic behavior of nickel-titanium alloys is atypical when compared to other alloys; most metal materials can be deformed elastically by up to 0.5%. Ni-Ti alloys can be deformed in up to 8% or 10% of their initial length and still return completely to their original shape (Rodriguez and Brown, 1975). In the nickel-titanium alloys, from 2% elastic deformation (Miura *et al*, 1986), the relationship between tension and deformation is not more linear and the force instead of increasing as the material deforms, remains almost constant. The Ni-Ti alloy as the deformation increases or decreases has a behavior called a hysteresis curve (Li *et al*, 2000). In fact, physical properties of an NiTi alloy vary according to the amount of each phase present in the material and this in turn is a function of the temperature of the alloy (Hogdson *et al*, 2000).The thermal transformation interval of the NiTi alloys correlates directly with the composition of the alloy and the thermal treatments to which it was subjected in the manufacturing process (Thompson, 2000; Hodgson *et al*., 2000; Libenson *et al*.,1993).

Conclusion

It can be concluded from this study that:

- The use of techniques such as DMA, DSC and three-point bending, reveals that some manufacturers of orthodontic wires produce materials that have no shape memory in buccal temperature and superelastic properties. Over the years, several studies have shown that the quality of some yarns can be compromised during manufacturing.
- Current classification and quality of Niti alloys may need to be reviewed and take into account their working properties, which are clinically relevant for orthodontist and patients.
- Few orthodontists and students know the physical properties of orthodontic strands.
- There are standards for tests in three-point bending and differential scanning calorimetry (DSC) (ISO 15841, 2014) for orthodontics wires. However, there is so far no standardization of tests using DMA.
- Dynamic mechanical analysis has been shown to be more efficient than DSC analysis because it has high sensitivity, especially for non-pure materials..

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