Revista Odontológica Mexicana

Facultad de Odontología

Vol. 20, No. 3 ● July-September 2016

pp e162-e169

ORIGINAL RESEARCH

Clinical importance of austenitic final point in the selection of nickel-titanium alloys for application in orthodontic-use arches

Importancia clínica del punto austenítico final en la selección de las aleaciones de níquel-titanio para su aplicación en arcos utilizados en Ortodoncia

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ABSTRACT

There are many nickel-titanium alloy wires available in the market. Nevertheless not all of them possess the ideal characteristics of shape memory and super-elasticity to be used in orthodontic treatment. The aim of the present study was to find austenitic final temperature of these archwires so as to determine the transformation phase in order to better use them in orthodontics. **Methods:** Eleven nickel-titanium orthodontic wires were selected. Transformation phase was assessed using differential scanning calorimetry method. **Conclusions:** The present study illustrates how some orthodontic Ni-Ti wires elicit results contrary to those advertised.

RESUMEN

Existe en el mercado una gran cantidad de alambres de aleaciones de níquel-titanio; sin embargo, no todos poseen las características ideales de memoria de forma y superelasticidad para ser utilizados en ortodoncia. El objetivo de este estudio fue encontrar la temperatura austenitica final de estos arcos con la finalidad de determinar la fase de transformación para su mejor uso clínico en Ortodoncia. **Métodos:** Se estudiaron once alambres de níquel-titanio más utilizados en Ortodoncia y se evaluó la fase de transformación utilizando la prueba de calorimetría de barrido diferencial. **Conclusiones:** Este estudio muestra cómo algunos arcos de NiTi en Ortodoncia presentan resultados contrarios a los que promocionan.

Key words: Austenitic final point, nickel-titanium alloys, phase transformation, differential scanning, calorimetry.
Palabras clave: Punto austenítico final, aleaciones de níquel-titanio, fase de transformación, calorimetría de barrido diferencial.

INTRODUCTION

At the beginning of the 1970's Andreasen[1,2] introduced the first nickel-titanium (Ni-Ti) wire in orthodontics. This can be attributed to William F Buehler[3,4] who discovered this alloy. He named this wire NITINOL, as acronym of the two most important elements composing the alloy: nickel (Ni), titanium (Ti) and NOL for Naval Ordnances Laboratory in Silver Springs, Maryland, USA where the alloy was discovered.

According to Miura[5-8] Ni-Ti alloys possess two main characteristics that render them unique in orthodontics: shape memory and super-elasticity. Shape memory refers to the ability of the material to return to its original shape through temperature transformation phases. Super-elasticity means the possibility of generating constant forces for a long period of time; tension being the force to cause this property.

Transformation phases

The unique characteristics exhibited by Ni-Ti alloys are mainly due to the transformation phases they undergo. The first one is the high temperature phase, also called austenitic phase, the other low temperature phase is called martensitic phase *(Figures 1 A-B)*, these phases do not appear at a given temperature, rather, they possess different temperatures where these changes gradually appear. Ni-Ti alterations apparent in austenitic and martensitic phases are basically at three temperatures: initial, peak and

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Received: August 2015. *Accepted: October 2015.*

This article can be read in its full version in the following page: http://**www.medigraphic.com/facultadodontologiaunam**

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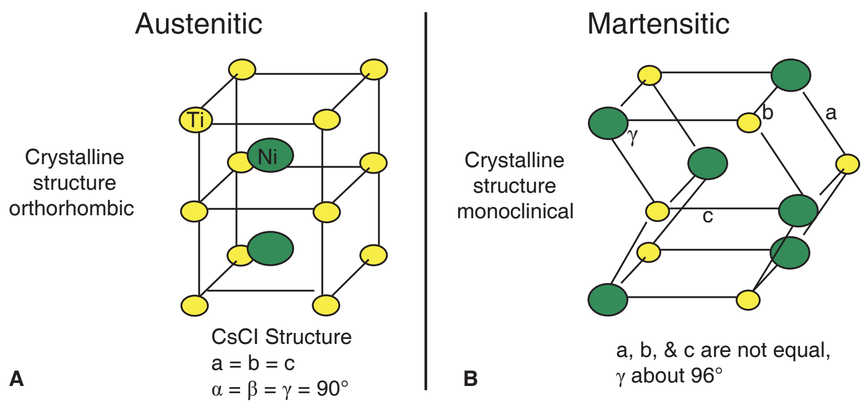
http://dx.doi.org/10.1016/j.rodmex.2016.08.012



Figures 1 A-B.

A) Austenitic phase: shape of orthorhombic crystal, angles exhibit 90° angle, **B)** Martensitic phase: shape of monoclinic crystal, angles displace braking their original 90°.

final. Depending on the final application for which the product manufactured with this alloy is intended, it will be important to determine transformation temperature. This can be clearly observed in the graphs known as thermograms which are generated during the differential scanning calorimetry test *(Figure 2)*. Austenite final (AF) is the most important temperature to determine from the clinical and manufacturer´s point of view. It is considered the most important since, at this phase, the alloy is stable and exhibits the final, work-suitable shape.

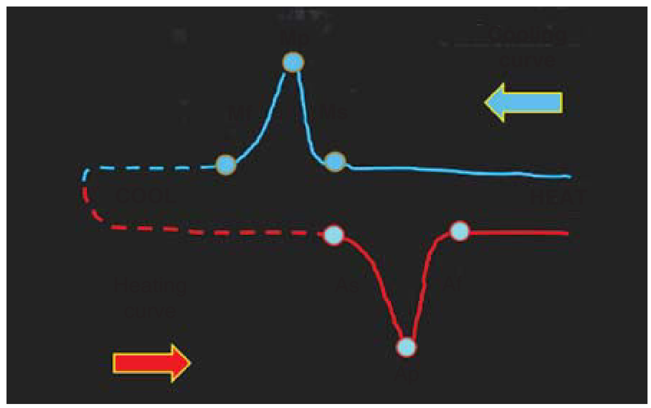


Figure 2. Transformation phases of NiTi alloys in heating and cooling curves represented in the thermograms.

Ni-Ti alloys classification

Kusy[9] made up a classification by dividing these orthodontic alloys in three main groups: the first one is passive (passive martensitic) the other two are active (austenitic and martensitic). All of them are practically composed of 50% Ni and 50% Ti (with small composition variants). They possess the unique characteristic of returning to their original shape (shape memory). Differences between them mainly lie in two aspects: the first one is that active forces generate constant load during the phases, and the second difference, also found between active forces lies in the temperature at which this transformation phase is generated.

According to Kusi, the first alloy to be used in orthodontics was martensitic passive. This alloy possessed the shape memory property only in name. This was due to the fact that errors incurred upon during manufacturing process when stretching the material to shape it caused incapacity to generate continuous forces, only preserving the ability to return to its original shape. Nevertheless, forces generated by these alloys when compared to other archwires such as stainless steel, were lesser by one fifth. In 1971 this alloy appeared for the first time in Orthodontics with the commercial name of NITINOL (UNITEK Co) *(Figure 3)*.

With time, a second generation of nickel titanium was generated, under the name of active austenitic. When describing this material, Kusi mentioned as its main characteristic the fact that, differing from passive martensitic, the wire did not only generate mild force, it also presented the unique characteristic of generating continuous forces at both the activation and deactivation phases., and this was mainly due to the performance they exhibited at the austenitic phase (high temperature phase) and the martensitic phase (low temperature phase) in the process of mechanical transformation between both phases.

In this austenitic-active alloy both phases can be clearly observed: the beginning is with a lineal force three times greater than the force generated by a passive martensitic archwire. This linear force disappears and brings about a curve where the archwire generates a continuous force for a long period of time; this is known as the activation phase *(Figure 4 A-B)*. The archwire experiences a transformation from martensitic phase to austenitic phase; once this latter is completed, the archwire once more experiences

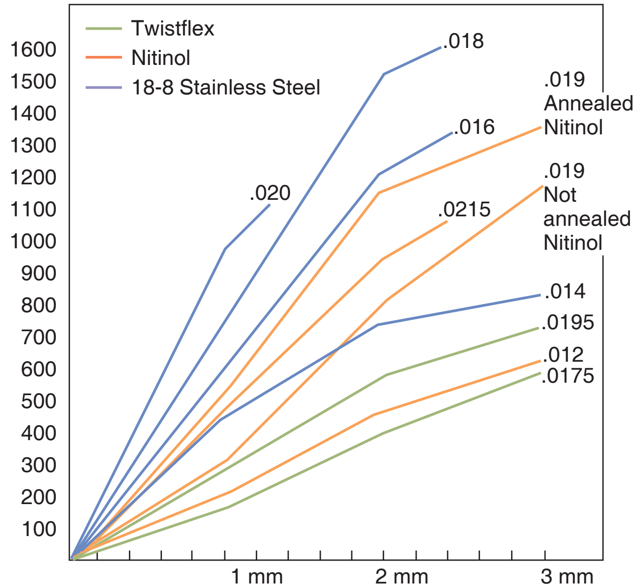


Figure 3. Martensitic passive: Archwires return to original shape but exhibit linear behavior. Force generated when compared with other traditional archwires such as stainless steel and NiCrCo is of one third.

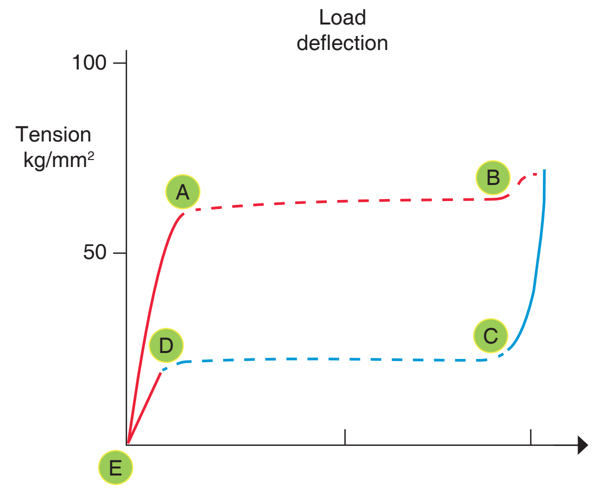


Figure 4. Active Austenitic and Martensitic. Just like the passive form, they return to original shape but force generated in the activation phase (B-C) and deactivation phase (C-D) present a vale which generates continuous forces for a long period of time. Difference between both lies in the temperature at which these changes take place.

a linear fall for a short period, to then generate a continuous force for a long period which is expressed in the curve of the graph. This phase, encompassing from point C to D, and from D to F is considered the most important from the orthodontic clinical standpoint *(Figure 4)*, since it is in this deactivation phase where dental movement is generated. (B-C-D-E). Nevertheless, this austenitic-active alloy suffers from a great disadvantage, since the temperature at which the archwire experiences this transformation (AF austenitic final) is far removed from body temperature.

Finally, active-martensitic alloys, whose most important characteristic is the fact that, besides preserving activation and de-activation phases of active austenitic alloys, their transformation phase is mechanically generated within the mouth since it is close to body temperature; therefore, they generate a continuous force for long periods, favoring thus ideal cell activity for dental movement in Orthodontic treatments. Miura introduced this type of alloys in Orthodontics.[10]

Assessment of physical properties

There are several methods to assess the physical properties of these alloys: electrical resistance measurement[11] and X-ray diffraction.[12] Nevertheless, there are some difficulties with respect to sample preparation. Moreover, these tests do not accurately provide all phases related to material transformation. On the other hand, presently, differential scanning calorimetry[13] (DSC) is the method most used for these tests. It is a thermo-analytical technique in which differences between heat in one sample and a reference are measured as a temperature function. Sample and reference are preserved at approximately the same temperature in the experiment. This is the method most frequently employed to assess transformation characteristics which exhibit a beginning, peak and end. One of the advantages of these tests is that small sections of sample are required which are placed in test containers where materials are easily heated or cooled in a strictly controlled manner. Thus, this test allows us to precisely determine phases of temperature transformation of nickel titanium alloys.

The aim of the present research paper was to determine the austenitic final transformation point of eleven nickel titanium archwires used in Orthodontics and to establish whether the phase transformation does or does not take place at temperatures which are close to body temperature.

MATERIAL AND METHODS

Eleven archwires from different commercial brands were used for the present study *(Table I)*, cuts were executed at the areas corresponding to premolars, since this area is the area presenting lesser tension

Table I. Orthodontic NiTi wires researched in the present study.

	Product	Measurement	Manufacturer (inches)
1	Bioforce anterior	.016 × .022	Dentsply GAC. Islandia N.Y. USA
2	Bioforce posterior	.016 × .022	Dentsply GAC. Islandia N.Y. USA
3	NeoSentalloy F80	.016 × .022	Dentsply GAC. Islandia N.Y. USA
4	NeoSentalloy F160	.016 × .022	Dentsply GAC. Islandia N.Y. USA
5	NeoSentalloy F240	.016 × .022	Dentsply GAC. Islandia N.Y. USA
6	LH Titan	.016 × .022	Tomy International. Tokio Japón
7	Cu NiTi 40°	.016 × .022	Ormco, Glendora CA. USA
8	Cu NiTi 35°	.016 × .022	Ormco, Glendora CA. USA
9	Cu NiTi 27°	.016 × .022	Ormco, Glendora CA. USA
10	Nitinol HA	.016 × .022	3M Unitek, Monrovia CA. USA
11	Nitinol SE	.016 × .022	3M Unitek, Monrovia CA. USA

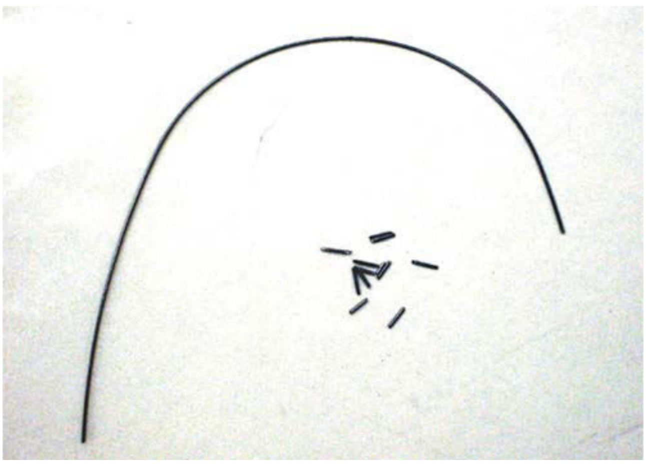


Figure 5. Archwire cuts in premolar areas.

Figure 6. Weight of each of the samples.

during arch manufacturing. Approximate length of all samples was 4 mm *(Figure 5)*; to this effect a low speed diamond disk was used; the area was cooled in order to avoid overheating of material and results alteration. Finally, all samples were weighed in order to achieve the greatest possible similarities in the size of all samples *(Figure 6)*. Only in the case of Bioforce, the sample was divided in two sections, since this archwire, differing from all others, generates a mild force for anterior teeth, a moderate force for premolar zone, and heavy force in the posterior section, in this case the sample was not taken in the premolar area.

Differential scanning calorimetry was the method used to assess temperature phases of Ni-Ti alloys. The appliance used for this study was manufactured by Seiko SII-DSC6220, Seiko Instruments, Japan *(Figure 7)*. All eleven samples were subjected to three measurements.

Samples were placed in sealed containers and were subjected to a controlled temperature cycle; changes in phases of materials were recorded according to energy absorption or production. Samples' temperature was recorded in a range of -100 °C to 100 °C; liquid nitrogen was used as coolant *(Figure 8)* at a 10 °C per minute speed, this was used to acquire both heating and cooling curves. All samples exhibited a thermogram which was duly printed for later assessment.

RESULTS

Five different thermogram patterns were observed. They mainly indicated transformation phases of each sample, In some cases they presented ill defined peaks and intermediate phases (phase R) between austenitic and martensitic phases. In the case of CuNiTi archwires, all of them presented one peak in both the heat and cold curve *(Figure 9A)*; NeoSentalloy 80, 160, Bioforce Anterior and Nitinol HA exhibited one cold peak and two heat peaks *(Figure 9B)*; Nitinol SE presented two heat peaks and one cold peak *(Figure 9C)*; Neosentalloy 240 and Bioforce posterior presented two heat peaks and two cold peaks *(Figure 9D)*, finally LH Titan exhibited three heat peaks and three cold peaks *(Figure 9E)*.

Results of mean and standard deviation of austenitic final (AF) temperature of all samples can be seen in *table II*.

In the present study several aspects were taken into account in order to determine oral temperature. We know as a rule that temperature in the mouth changes constantly due to intake of hot or cold foods. For the present study 35 °C was taken as base oral temperature, since it was considered as ideal for this type of tests[14]; 25 °C was taken as environmental temperature (room temperature). *Figure 10* indicates the values of samples and shows how these approach or move away from the 35 °C value. Only two samples out of the total sample number exhibited values above 35 °C: LH Titan (38.2 °C) and Nitinol SE (60.4 °C).

AF point of Bioforce Posterior, CuNiTi 27° and Nitinol archwires exhibited values below environmental temperature. Bioforce Anterior, NeoSentalloy 80 g, 160 g, 240 g, LH Titan and CuNiTi 40° and 35° archwires exhibited AF very similar to oral temperature, finally, Nitinol SE archwires presented AF well above oral temperature.

Figure 7. Appliance used for Differential Scanning test (Seiko Sil-DSC6220).

Figure 8. Nitrogen-based cooling system used in the test.

DISCUSSION

Nickel Titanium alloys possess unique characteristics in their transformation phases; they have the consequence of generating light and constant forces when passing from one phase to the other. Nevertheless, from the clinical point of view, it is of the utmost importance that this transformation take place at a temperature very similar to oral temperature, so as to be able to obtain maximum

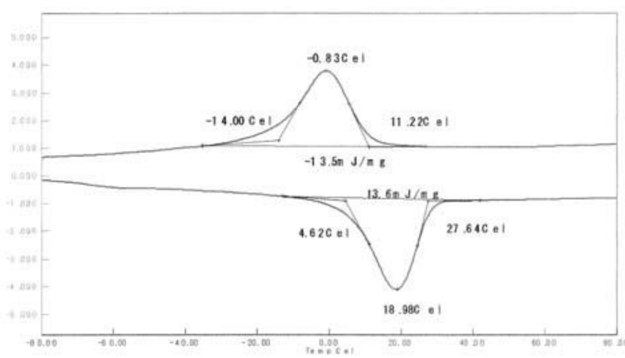


Figure 9A. CuNiTi 35 Pattern.

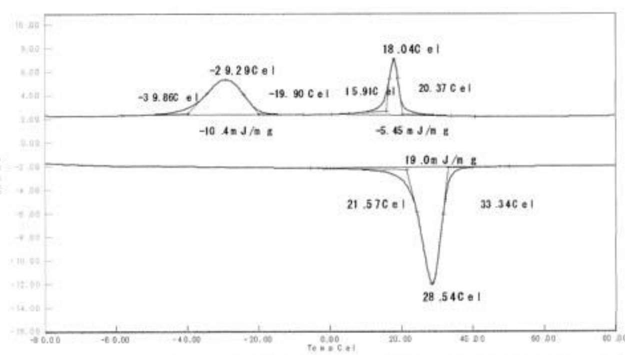


Figure 9B. NeoSentalloy 80 pattern.

benefits when using these alloys in Orthodontics treatments.

In the manufacturing of different appliances using NiTi alloys, the active range of NiTi alloys is determined by the AF point; thus we have, as an example, in the catalogue of metal companies specialized in the production of these products, that point AF range can vary from 0 °C to -20 °C (Group N) up to 95 °C to 115° (Group H) *(Figure 11)*. In this particular case, all final products which are going to be used in the human body must be manufactured with alloys whose point AF active range is found in Group B (20 °C to 40 °C).

These materials are later subjected to a new process to be suitably formed and shaped. To this effect they are subjected to a new thermal treatment, where AF point of each new product is altered. Depending on the quality control and manufacture of the same product this point will be closer or farther from body temperature, and thus, its transformation phase might exhibit the following variables in the mouth with their corresponding secondary effects:

1) AF point below oral temperature

There is no transformation phase. Changes take place before the archwire is placed in the oral environment. Sometimes, when attempts are made

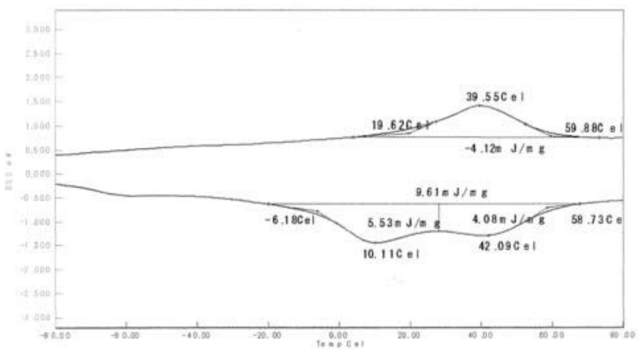


Figure 9C. Nitinol SE pattern.

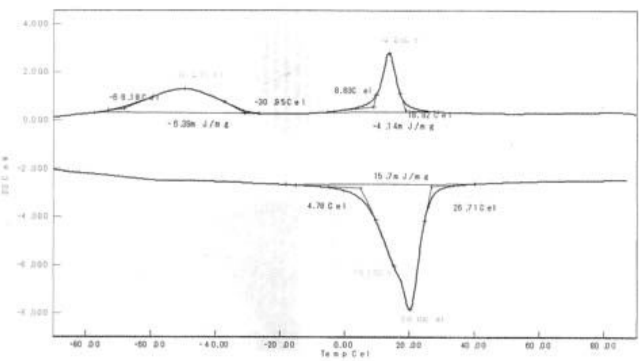


Figure 9D. 4 Bioforce post pattern.

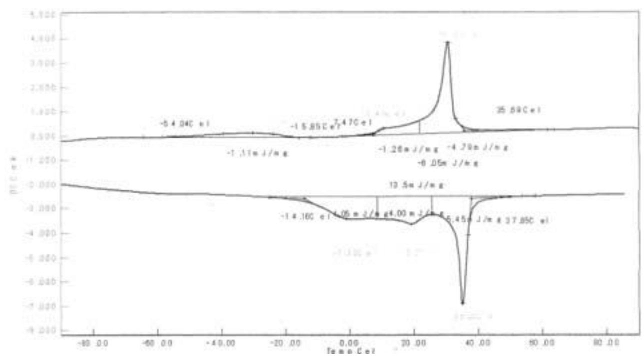


Figure 9E. 5 LH titan pattern.

Table II. Transformation temperatures of orthodontic wires (°C).

Product	MF °C Martensitic		MI °C Martensitic		AF °C Austenitic		AI °C Austenitic	
	Final	SD	Initial	SD	Final	SD	Initial	SD
Bioforce ant.	-38.8	(1.7)	-19.2	(0.8)	32.5	(0.6)	20.4	(0.4)
Bioforce post.	-66.7	(1.2)	-29.9	(0.9)	26.4	(0.6)	5.7	(0.6)
NeoSentalloy F80	-39.3	(1.1)	-19.9	(0-8)	32.7	(0.7)	21.1	(0.5)
NeoSentalloy F160	-52.3	(1.1)	-24.6	(0.4)	29.1	(0.5)	12.3	(0.8)
NeoSentalloy F240	-68.0	(0.9)	-24.7	(7.1)	28.3	(0.8)	6.8	(0.3)
LH Titan	-44.2	(5.1)	-17.5	(1.7)	38.2	(0.3)	-12.4	(1.0)
Cu NiTi 40°	-1.3	(1.7)	12.9	(0.7)	32.7	(0.9)	18.2	(0.5)
Cu NiTi 35°	-13.5	(1.3)	10.6	(0.9)	29.1	(0.7)	6.5	(1.1)
Cu NiTi 27°	-24.9	(2.4)	7.7	(0.6)	22.6	(0.8)	-2.7	(2.2)
Nitinol HA	-63.6	(3.0)	-42.3	(1.7)	21.5	(2.3)	2.7	(1.4)
Nitinol SE	-13.7	(3.3)	-58.8	(0.8)	60.4	(1.3)	-3.2	(1.2)

to insert a heavy caliber wire , use of ethyl chloride is recommended to insert it, since these alloys already presented their transformation at room temperature and thus do not possess Shape Memory which is fundamental for suitable clinical use. Archwires exhibiting these values were Bioforce Posterior, CuNiTi 27° and Nitinol HA.

2) AF point above oral temperature

In these cases, since AF point is above oral temperature, archwires are at the martensitic phase. The archwire is extremely malleable, but there is no transformation phase since this phase would only appear in cases when oral temperature would reach the AF temperature of the archwire, that is to say, these changes would only appear when ingesting hot foods, in which case a temperature would be

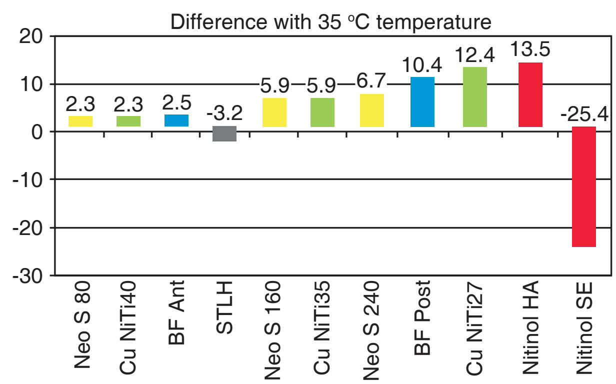


Figure 10. Values of all samples taking as base a temperature of 35 °C.

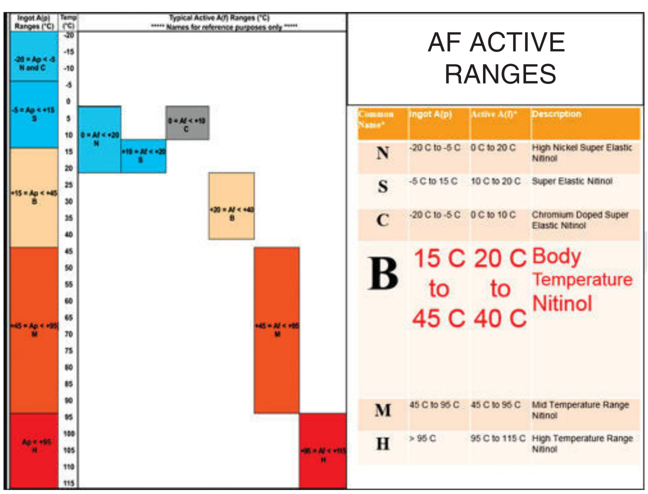


Figure 11. Table of AF point of all materials depending on the final application of NiTi alloy.

reached where changes from martinsitic phase to austenitic phase were possible. In our study, the only archwire corresponding to this group was Nitinol SE.

3) AF point close to oral temperature

In these circumstances, the archwire is at room temperature in a phase between austenitic and martensitic; the archwire is extremely malleable; a martensitic to austenitic transformation phase is initiated when the archwire is taken into the mouth and internal temperature is increased,. The archwire hardens in an attempt to recover its original shape, and at this point this force moves the teeth to the desired place. Most of these archwires possess an AF point slightly below oral temperature, since this is a manner of being sure that they will present Shape Memory property in the mouth, and will thus generate a continuous force for a prolonged period of time. In our study, arches corresponding to this group were: Bioforce anterior, NeoSentalloy 80, 160, 240, LH Titan and CuNiTi 40 and 35.

Special care must be taken when using CuNiTi40 archwires. Manufacturer's publicity mentions that they generate intermittent forces which are ideal for cases with periodontal problems, but since these archwires exhibit 38 °C AF, at this temperature their behavior indicates that transformation phase is closer to that of an active martensitic wire. This is possibly due to the fact that incorporation of hysteresis-reducing elements such as Copper and other elements such as Chrome to stabilize transformation temperature, hinder control of these materials´ homogeneity, and, when compared to results of other studies[15] they show great variability in AF temperature values.

Moreover, another low hysteresis arch such as LH Titan exhibits 38 °C AF. This will render it, on the one hand, malleable and easy to manipulate to be introduced in the mouth, since it presents a transformation phase slightly above body temperature, this arch is also suitable for patients with periodontal problems.[16-18]

CONCLUSIONS

In the present study of eleven archwires, we can estimate that seven were found to be in a range close to oral temperature. For this reason we can expect them to exhibit Shape Memory property, and generate continuous and light forces for a period of time ideal for orthodontic treatment. Nevertheless, in our study we discovered that some archwires did not possess the Shape Memory that would enable them to be clinically used in the mouth as advertised by their manufacturers. Further research will be necessary so as to determine possible causes for these discrepancies.

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