Advanced Chinese NiTi alloy wire and clinical observations

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In original research, Bueler[1] and Andreasen[2-4] introduced a nickel-titanium alloy wire for orthodontic usage. At mouth temperature, this wire is work-hardened martensite and, hence, does not rely on shape memory characteristics in clinical application. Nevertheless, its very high springback and low stiffness characteristics have won wide clinical acceptance. Chinese NiTi alloy wire, a new, superelastic orthodontic wire, was originally developed by Dr. Hua-Cheng Tien and colleagues at The General Research Institutes for Non-Ferrous Metals in Beijing, China in 1978.[5]

Continuing their research, Dr. Tien[5] and colleagues have further improved Chinese NiTi material. Its mechanical properties have been extensively studied by Dr. C.J. Burstone and associates.[6] Studies by Tien and Burstone[5,6] have indicated that Chinese NiTi archwire has several unique characteristics: 1) It has more than 4.4 times the springback of stainless steel wire, and more than 1.6 times the springback of nitinol wire in all modes of deformation, tension, bending and torsion. 2) It exhibits small differences at varying temperatures because the material components have lower transition temperatures. 3) It exerts a nearly constant force magnitude regardless of the amount of deflection. Chinese NiTi wire deformation is not particularly time-dependent.[6] More specifically, it is clinically acceptable because of its efficiency in moving teeth into alignment from extreme positions.

Moving teeth rapidly without discomfort to the patient and with minimal loosening of the teeth is the concept of light continuous orthodontic forces first introduced by Smith and Storey.[7-9] Light forces bring about uninterrupted tooth movement without occluding the periodontal blood vessels. Bone on the side of pressure is continually and rapidly resorbed, and new bone is simultaneously formed on

Abstract

Chinese NiTi wire was studied on the bench with six other nickel-titanium-alloy wires. Bending and torsional tests were conducted and temperatures of phase transformation compared. The Chinese NiTi wire was found to have a low stiffness, high springback and constant bending and torsional moments on unloading, in a very large deformation region. It can produce a gentle, nearly constant force. These factors make it desirable for clinical application.

Included in this paper are clinical observations of cases selected from over 100 patients in current treatment with Chinese NiTi wires. Chinese NiTi wire reduced the leveling and alignment phase of treatment without discomfort to the patient. Chinese NiTi wire can be used in both children and adults.

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Key Words

Chinese NiTi alloy • Superelasticity • Shape memory

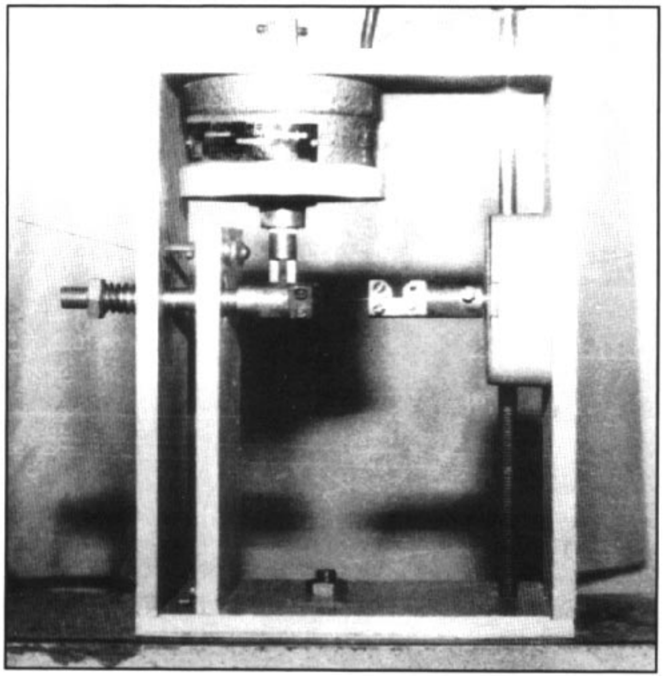


Figure 1

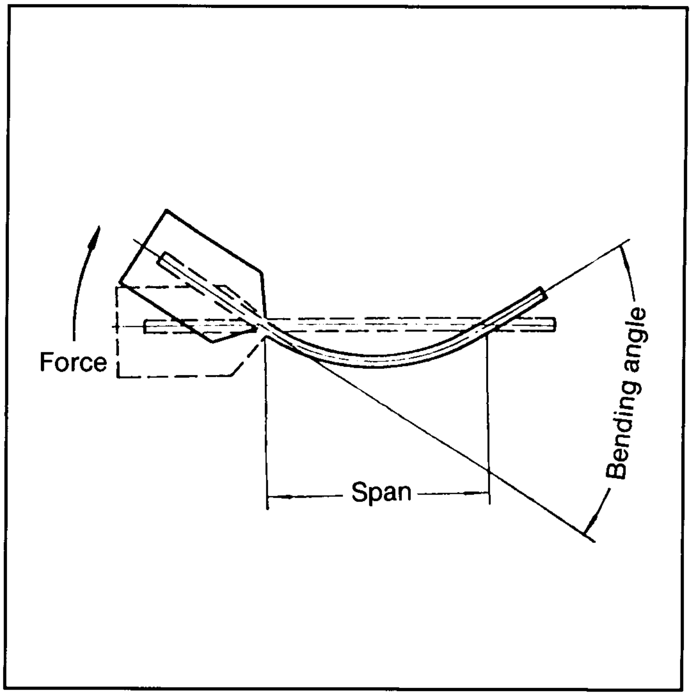


Figure 2

Figure 1
MBTR-1 micro-type of cantilever bending and torsional test machine with an automatic recording device.

Figure 2
The schematic diagram of bending test. The span of testing wire is 12.5 mm. The bending angles are from 0° to 90°.

the side of tension, with elimination of the negative effects of undermining resorption. Since 1985, Chinese NiTi wires have been used clinically in the United States. These wires have reduced the leveling and alignment stage of orthodontic treatment with minimal discomfort to the patients.

In this study, physical and mechanical properties of archwires marketed by six companies (Ormco, Masel, Unitek, Lancer, Ortho-source and GTi)* and Chinese NiTi wire are measured and compared.

Materials and methods

Six nickel-titanium-alloy wires and Chinese NiTi wire were tested by General Research Institute for Non-Ferrous Metals in China.[5,10] Three tests were performed on each of seven 0.016″ diameter nickel-titanium-alloy wires.

Temperatures of phase transformation tests were determined by the electrical-resistance method.[9] In order to demonstrate mechanical behavior of the alloys during bending, the permanent and recovery deformations of the wires were measured after imposing 90° bends (Figures 1,2). The bending tests were performed to determine wire stiffness, springback, and maximum bending moments. A 12.5 mm span of each wire was used for the bending test. When the bending angle reached 90°, the tested wire was unloaded until the bending moment was equal to zero. The bending moment-versus-deformation curves were automatically recorded for both loading and unloading.

In order to demonstrate the mechanical behavior of the alloys in the condition of torsion, the permanent and recovery deformations of the wires were measured after twisting through 720°. The activation/loading and recovery curves for all seven wires were recorded. Mechanical properties were measured on an MBTR-1 micro type of cantilever bending and torsional machine with an automatic recording device. For the torsional test, a 25.4 mm span of each wire was used. During the experiment, the wires were fixed at one end and the other end was rotated at a speed of 180° mm^{-1} with a maximum torsional angle of 720°; it was then unloaded until the torsion moment reached zero. The torsion-moment versus angle-of-twist curves were automatically recorded for both loading and unloading. Six replications of these tests were performed on the seven NiTi wires from each company.

In the treatment of clinical patients, Chinese NiTi wires were used initially after the placement of straight wire appliances. Photographs were taken at the time of initial wire insertion and at intervals of several weeks.

Results

The electrical resistance method[11] was used for measuring the starting temperature of R phase transformation (R_s), the starting temperature of martensite phase transformation (M_s),

*Ormco, Glendora, Calif.; Masel, Bristol, Penn.; Unitek, Monrovia, Calif.; Lancer, Carlsbad, Calif.; Ortho-source, N. Hollywood, Calif.; GTi, Sarasota, Fla.

Table 1
The Temperatures of Phase Transformation

Material	R_s (°c)	SD	M_s (°c)	SD	M_f (°c)	SD	A_s (°c)	SD	A_f (°c)	SD
Chinese NiTi	35	±3.0	-60	±2.5	-105	±2.5	-1	±2.0	37	±3.0
Ormco NiTi	20	±2.0	-42	±3.0	-95	±2.5	6	±2.5	22	±3.0
Elastinol (Masel)	29	±2.5	-63	±1.5	-110	±5.0	7	±3.0	30	±4.0
Nitinol (Unitek)	59	±1.0	-43	±1.5	-110	±3.5	27	±3.0	62	±2.0
Titanal (Lancer)	40	±2.0	-105	±2.5	-110	±3.5	-5	±3.0	31	±3.0
Super Nitane Ortho-source)	43	±1.5	-60	±5.5	-128	±3.5	2	±6.0	50	±3.0
Marsenol (GTi)	72	±2.5	-30	±2.5	-180	±4.0	10	±2.5	50	±6.5

*Ormco, Glendora, Calif.
Masel, Bristol, Penn.
Unitek, Monrovia, Calif.
Lancer, Carlsbad, Calif.
Ortho-source, N. Hollywood, Calif.
GTi, Sarasota, Florida

Table 2
Bending Properties

Material (0.016" wire, 12.5 mm span)	After bending to 90°: Permanent deformation (degree)	After bending to 90°: Recovery (%)
Chinese NiTi	0.0	100.0
Ormco Ni-Ti	3.0	96.7
Elastinol (Masel)	1.5	98.3
Nitinol (Unitek)	2.5	97.2
Titanal (Lancer)	5.0	94.4
Super Nitane (Ortho-source)	1.5	98.3
Marsenol (GTi)	2.9	96.8

Table 3
Torsional Properties

Material (0.016" wire, 25.4 mm span)	After torsion to 720°: Permanent deformation (degree)	After torsion to 720°: Recovery (%)
Chinese NiTi	19	97.4
Ormco Ni-Ti	26	96.4
Elastinol (Masel)	23	96.8
Nitinol (Unitek)	36	95.0
Titanal (Lancer)	71	91.4
Super Nitane (Ortho-source)	36	95.0
Marsenol (GTi)	17	97.6

the ending temperature of martensite phase transformation (M_f), the starting temperature of austenite phase transformation (A_s), and the ending temperature of austenite phase transformation (A_f) in the present study. The results are listed in Table 1.

The foregoing research and clinical applications indicate that the temperature at A_f of half of the wires is between 28°C and 38°C, which is approximately the temperature of the human body, with the exception of Super Nitane (50°C), Marsenol (50°C) and Nitinol (62°C) wires. In clinical situations when the wires are used at room temperature, stress induced martensite transformation can occur after deformation.[12] Therefore, the superelasticity and the effect of shape memory can be obtained.[13-16] Shape memory is very useful in orthodontic applications. The three wires with higher A_f temperatures are not as suitable for orthodontic treatment

Figure 3A-C
Bending moment/deflection characteristics of Chinese NiTi and six other nickel-titanium alloy wires. Both loading and unloading curves are shown. Note the constant force of unloading over a long range of deflection recovery of Chinese NiTi wire.

Figure 4A-C
Torsion moment/deflection characteristics of Chinese NiTi and six other nickel-titanium wires. Both loading and unloading curves are shown. Note the constant force of unloading over a long range of deflection recovery of Chinese NiTi wire.

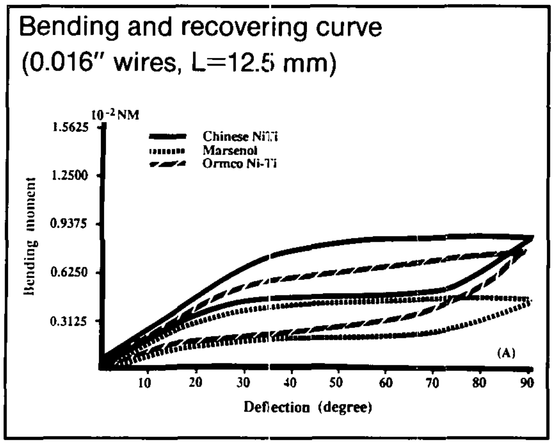


Figure 3A

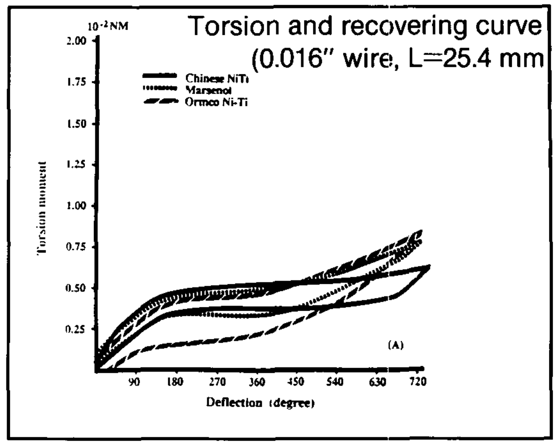


Figure 4A

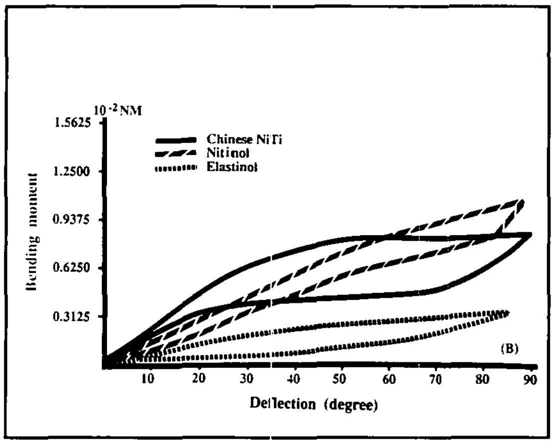


Figure 3B

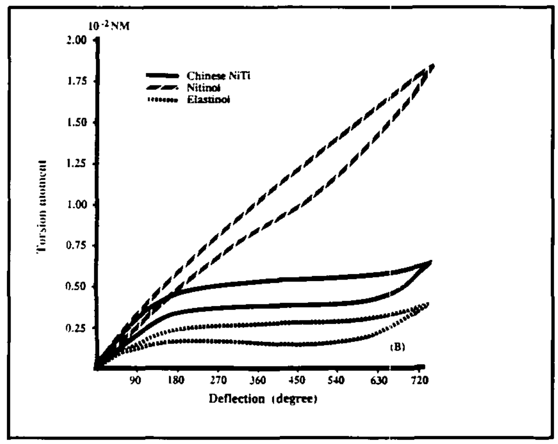


Figure 4B

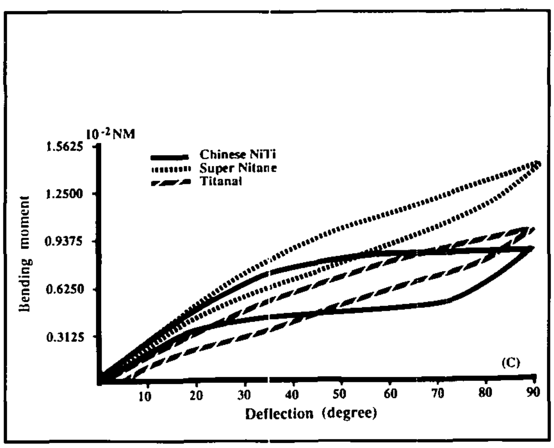


Figure 3C

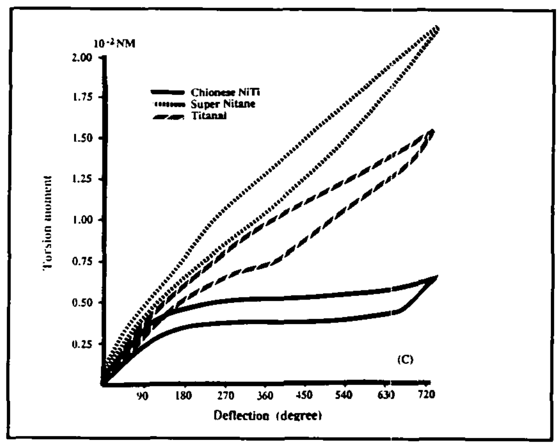
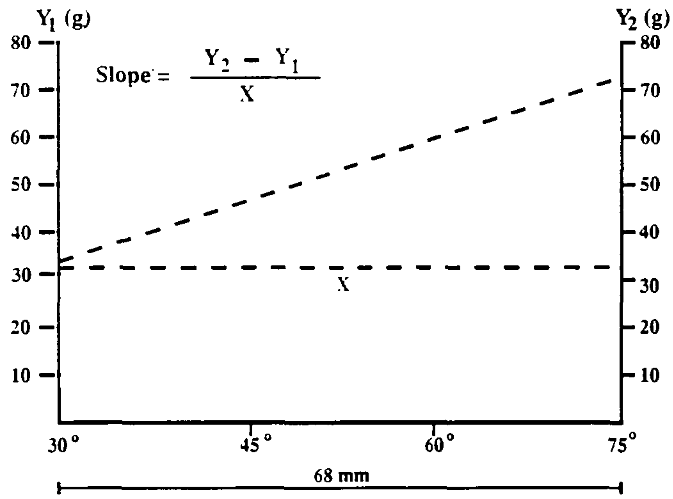


Figure 4C

due to the lack of shape memory effect.

In clinical application, it is more important that the wire has constant unloading properties. In Figures 3A-C and 4A-C, the curves are typical. The first curve (flag shaped) is described by Chinese NiTi wire (Figures 3 and 4) and represents superelasticity. At the beginning and end of unloading, during bending and torsional tests, there is no rapid reduction of force magnitude. The slope of the hysteresis curve of the Chinese NiTi in unloading approaches zero in the mid-range of deflection. Chinese NiTi wire also remains at nearly unchanged force level in the mid-range of unloading (Figures 3A-C and 4A-C). Recovery of the bending angle to 90° is nearly 100%. This superelasticity is valuable in clinical practice for efficient tooth movement.

The second typical curve (leaf shaped) is represented by Nitinol and also includes Super Nitane wire (Ortho-source) and Titanol (Figures 3C,



Samples	Value of Y-axis (g) at 75° (Y_2)	Value of Y-axis (g) at 30° (Y_1)	Slope x 68 mm
Chinese NiTi	52	43	9
Marsenol	24	10	14
Ormco Ni-Ti	42	22	20
Nitinol	74	34	40
Elastinol	14	4	10
Super Nitane	67	30	37
Titanal	103	59	44

Figure 5

Figure 5
Comparison of the slopes between 75° to 30° of bending recovering curves among seven wires. The force values of 75° are shown at Y_2-axis and the force values of 30° are shown at Y_1-axis. The value differences between 75° and 30° are listed in the upper table of the figure. The lower chart shows a schematic diagram of the slopes measurement. The X-axis represents the distance between 75° and 30° bending recovering curves as recorded on the paper of the automatic recording apparatus. Y_2-Y_1 represents the difference of the force value between 75° and 30° as described.

4B-C). The relationship between stress and strain during loading and unloading is linear in these wires, making them less effective in tooth movement because the force is not constant.

An illustration of this constant force in unloading can be seen by comparing the slopes of the bending recovery curves of the seven wires between 30° and 75°. As shown in the bending test, the unloading curves are quite level for bends between 30° and 75°. A constant force between 30° and 75° of deflection is more favorable for tooth movement and Chinese NiTi is a typical example of this.

Standard nickel-titanium-alloy wires, which included Nitinol, Titanol and Super Nitane, displayed leaf shaped stress-strain curves (Figures 3B-C and 4B-C). The bending angle increased rapidly with the increase of the bending moment. This was also shown on the loading and unloading curves. The bending angle and bending moment increased and decreased rapidly.

Clinical observations

Uprighting: Figures 6A and 6B show Chinese NiTi wire uprighting teeth. In Case 1, the mandibular left canine was located at an extremely low labial position with the crown of the tooth tipped mesially. A 0.016″ Chinese NiTi wire was easily tied into the brackets (Figure 6A). The initial wire was completely engaged in a straight-wire canine bracket which allowed for the immediate expression of the machined angulations of the bracket slots. The wire delivers a gentle force without permanent deformation, to upright and extrude the canine. In this case, a 0.016″ Chinese NiTi wire was used in the maxillary arch. At the same time, an elastic chain was placed from maxillary left canine to maxillary left first molar to begin retraction (Figure 6B).

Labial and lingual movement: In Case 2 (Figures 7A and 7B), with first mandibular premolar extractions, the mandibular arch displays anterior crowding. A 0.016″ Chinese NiTi wire was

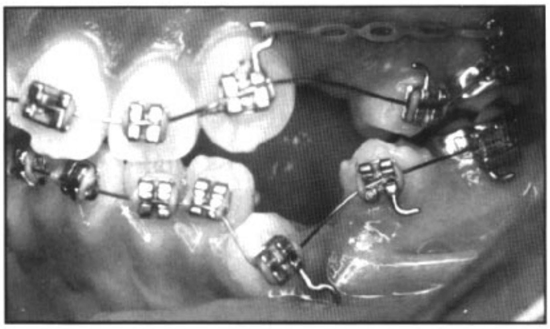


Figure 6A

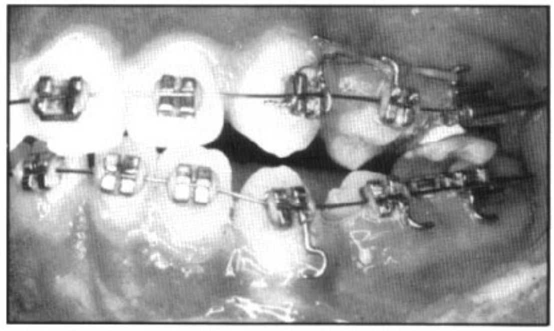


Figure 6B

Figure 6A-B
Case 1: An initial 0.016" Chinese NiTi wire was inserted in this patient after extraction of the first premolars. The wire was completely engaged in the canine straight-wire brackets allowing for immediate uprighting. An elastic chain from maxillary left canine to left first molar was added. The uprighting and distalization of the canines were achieved in nine weeks.

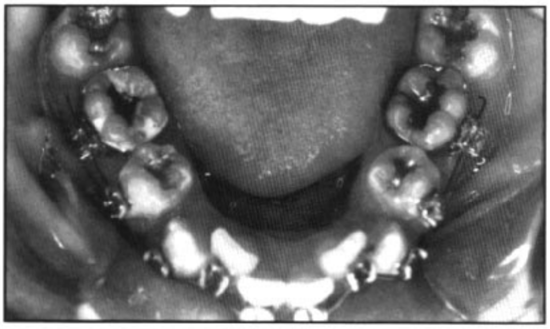


Figure 7A

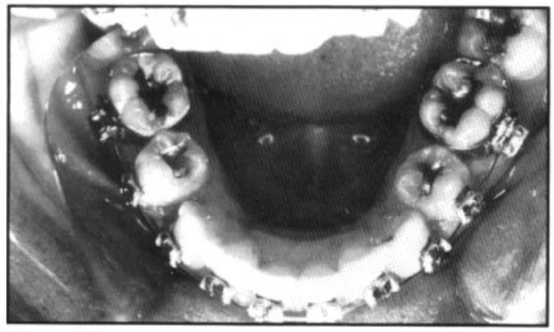


Figure 7B

Figure 7A-B
Case 2: This patient exhibited mandibular anterior crowding. The 0.016" Chinese NiTi wire was inserted and Class I elastic mechanics were added from first molars to the canine hooks (Figure 7A). The next photo was taken 4.5 weeks later displaying relief of anterior crowding and canine retraction.

inserted in the mandibular arch (Figure 7A). The wire moved the mandibular lateral incisors labially; at the same time, the mandibular canines moved distally with Class I elastic mechanics from first molars to the canine hooks. The narrow mandibular arch became a normal arch shape (Figure 7B).

Discussion

Chinese NiTi wire possesses super-elasticity and shape memory. The possible uses of Chinese NiTi wire are many in that it offers low-stiffness and high-springback for tooth alignment. Because of its high range of action or springback, Chinese NiTi wire is applicable in situations where large deflections are required. The wire produces a constant force and maintains a higher magnitude of force level over the range of activation.

At the high temperature range, the crystal structure of NiTi alloy is in an austenite phase, which is a body-centered cubic lattice. At the low temperature range, the material is in the martensitic phase, a close-packed hexagonal lattice. By controlling the low and high temperature ranges, a change in crystal structure called martensitic transformation can be produced. NiTi alloy, a nearly equi-atomic intermetallic compound, incorporates a variety of properties that can be controlled by manufacturing technique. In the low temperature, martensitic phase NiTi alloy is ductile. In austenite phase in the high temperature range, it is more difficult to induce deformation.

NiTi alloy has the property of shape memory, meaning the alloy can return to its previous shape. Martensitic transformation can be reversed by heating the alloy to return to the austenite phase. This shape memory is produced by temperature difference.

This NiTi alloy also has the property of superelasticity. This is produced by stress and is called stress-induced martensitic transformation. If the stress is diminished, the NiTi alloy returns to the previous shape without retaining the permanent deformation. This is due to the fact that it returns to the austenite phase within a given temperature range.

There are two types of superelasticity among various NiTi wires. A flag shape curve is formed when stress deforms the alloy wire, inducing the martensite stage of transformation which results in superelasticity. At A_f temperatures below or near the body temperature, the alloy is easily transformed to its martensitic state; in the mouth, the wire becomes activated, thus using the shape memory effect.[14-17] Chinese NiTi is an example of this type of superelasticity.

The second type of superelasticity is represented by the leaf shape curve of Nitinol, Titanol and Super Nitane. The A_f temperature of Nitinol and Super Nitane is above body temperature. The martensite structure of these types of wires in mouth temperature is not completely transformed. This affects the shape memory of these wires.[14]

Conclusions

Chinese NiTi wire was bench tested and compared to six other nickel-titanium wires. Various clinical orthodontic applications of Chinese NiTi wires were also presented.

(1) In this study, Chinese NiTi wire demonstrated 100% recovery at a 90° bending angle in a bending test based on a 12.5 mm span, and 19% permanent deformation in a torsional test after a 720° twist over a 25.4 mm span.

(2) Chinese NiTi wire demonstrated excellent retentive memory among the memory wires. This quality is represented by the table of the temperatures of phase transformation.

(3) Chinese NiTi wire has a long constant range of bending and torsional moments. It offers a nearly constant force which is desirable in orthodontic applications.

(4) Chinese NiTi wire possesses unique low stiffness, high springback and superelasticity. At subsequent visits, the wire is simply retied to the brackets.

(5) In clinical practice, Chinese NiTi wire has been successful in the treatment of patients with a variety of malocclusions. Chinese NiTi wire is capable of maintaining a gentle, nearly constant force. Teeth move efficiently during leveling and alignment in both children and adults.

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References

1. Buehler WJ, Gilfrick JV, Wiley RC. Effects of low temperature phase changes on the mechanical properties of alloys near composition TiNi. J Appl Physics 1963; 34:1475-1477.
2. Andreasen GF, Hilleman TB. An evaluation of 55 cobalt substituted nitinol wire for use in orthodontics. J Am Dent Assoc 1971; 82:1373-1375.
3. Andreasen GF, Bigelow H, Andrews JG. 55 Nitinol wire: force developed as a function of "elastic memory." Aust Dent J 1979; 24:146-149.
4. Andreasen GF, Morrow RE. Laboratory and clinical analysis of nitinol wire. Am J Orthod 1978; 73:142-151.
5. Tien HC, Yang FZ, Liu H, Guo JF. Orthodontic TiNi wire. J Rare Metals, China 1982; 29:69-75.
6. Burstone CJ, Qin B, Morton JY. Chinese NiTi wire — a new orthodontic alloy. Am J Orthod 1985; 87:445-452.
7. Smith R, Storey E. The importance of force in orthodontics. Austral J Dent 1952; 56:291-304.
8. Storey E, Storey R. Force in orthodontics and its relation to tooth movement. Austral J Dent 1952; 56:11-13.
9. Gua YL. A multi-functional apparatus for the measurement of shape memory alloys and its application. The second Asian thermophysical properties conf. (ATPC '89). Sapporo, Japan. Sept. 1989.
10. Zhang JP. Bending and torsion machine with an automatic recording device and its application. J Rare Metal, China 1985; 6:71.
11. New American Dental Association specification No. 32 for orthodontic wires not containing precious metals. J Am Dent Assoc 1977; 95:1169-1171.
12. Otsuka K, Shimizu K. Stress-induced martensitic transformations and martensite-to-martensite transformations. AIME Pittsburgh conference 1982; 1267-1286.
13. Otsuka K, Shimizu K. Memory effect and thermoelastic martensite transformation in Cu-Al-Ni alloy. Scr Met 1970; 4:469-472.
14. Wayman CM. Mechanical effects in thermoelastic transformations. Physical Metallurgy, Elsevier Science Publishers B.V. 1983; 1059-1065.
15. Saburi T, Wayman CM. Crystallographic similarities in shape memory martensites. Acta Metall 1979; 979-995.
16. Niyazaki S, Wayman CM. The R-phase transition and associated shape memory mechanism in NiTi single crystals. Acta Metall 1988; 181-192.