Nickel-Titanium alloys (developed by U.S. Naval Ordnance Lab. & Battelle Memorial Institute in 1962) have been in and out of my life since the 1960’s when one of my materials science professors showed me a “magic” trick. He made some intricate bends in a new NiTi wire, then submerged it in warm water; the wire straightened to return to its original shape! Then, it was a wire without an application. The “novelty” aspect of this wire lasted for several years until an application was developed for an orthodontic wire around the 1970’s.

THE INTENT OF THIS ARTICLE IS TO DISCUSS NITI WIRES USING PLAIN ENGLISH AND KEEPING TECHNICAL TERMS TO A BARE MINIMUM

I will use parentheses (...) to enclose technical information – so, unless you are interested in following a technical path, it should not affect my story.

The alloy itself is a combination of one atom each of Nickel and Titanium (stoichiometric amounts). Because atoms have different weights, the alloy, by weight %, is 55% Nickel and 45% Titanium. One variation of this alloy composition is removal of 5 atoms of Nickel, replaced by 5 atoms of Copper. The resulting wire was called: Copper Ni-Ti. Understanding NiTi wires starts with two measurable concepts: 1) Transformation Temperature and 2) Tooth moving force.

During the manufacturing of NiTi wires, a brand can be processed to set the Transformation Temperature at any point between 0°C and 100°C. For application as an orthodontic
wire, useful transformation temperatures are office temperature (20°C) and open mouth temperature (35°C). For NiTi wires, Transformation Temperature has a unique meaning. It separates two structures (also called phases, the internal arrangement of atoms in its lattice). Think of a thermometer; Transformation Temperature would be a constant temperature line drawn on the thermometer. The internal structure of NiTi differs from below the constant temperature line to above the line. The terms: martensite (M) and austenite (A) are simply names given to a structure for a specific material – such as, NiTi. The actual structures differ among alloys. For example, martensite and austenite phases in stainless steel are not the same structures in NiTi. The structure below the constant temperature line (Transformation Temperature) is called martensite (M), and the structure above that line is called austenite (A). The important concept here is that the structure below the line differs from that above the line. Associated with different structures are differences in properties between martensite and austenite.

Bends can be placed in NiTi archwires in the martensite phase; the wire does not return to its original arch form until the temperature exceeds the Transformation Temperature. This is the case for a heat activated NiTi wire (also called: shape memory) as-received by the doctor. Its Transformation Temperature should be close to mouth temperature (35°C), so that the martensite-austenite transition occurs in the mouth, not in the office. However, a NiTi wire in the austenite phase is “springy” – if you try to bend it, it immediately returns to its original arch shape. This is one characteristic of a superelastic (also called: pseudoelastic) NiTi wire. The doctor receives it in its austenite phase; its Transformation Temperature is below room temperature, so that when received in the office it has already transformed.

Tooth moving forces are determined from a three-point bend test at body temperature (ISO International Standard 15841-Wires for use in orthodontics). Nearly every NiTi orthodontic wire will have transformed to the austenite structure at 37°C. The test itself calls for a 10mm length of wire that is supported at its ends. A probe is applied in a downward direction above the midpoint of the wire and then released, causing the wire to bow slightly more than 3mm and recover. The applied and return forces are monitored and graphed as load vs. deflection in the forward (loading) and return (unloading) directions. See Figure 1. The loading force simulates the engagement force of the archwire in the bracket slots. The return force (unloading) is reported as the tooth-moving force. The unique property of NiTi is that

---

**FORCE MEASURED FROM:**

**THREE-POINT BEND TEST ISO 15841:2006 (E), ORTHODONTIC WIRES**

---

**LOADING FORCE:** FORCE THE DOCTOR EXERTS TO ENGAGE THE WIRE INTO BRACKET SLOTS IN THE MOUTH.

**UNLOADING FORCE:** AFTER WIRE PLACEMENT, FORCE THAT HAD BEEN APPLIED TO ENGAGE THE WIRE IS NOW AVAILABLE TO MOVE TEETH; CALLED TOOTH-MOVING FORCE.

**FIGURE 1**
the curves for loading and unloading are flat, nearly over the entire deflection length. This behavior led to using the term: superelastic (the wire behaves similar to an elastic wire in three-point bend). Clinically, this means that the tooth moving force is constant over a wide deflection range (approximately 1 – 2.5 mm). Brands are compared by tooth moving forces (unloading curve).

Early claims for Copper containing NiTi wires were that the gap (hysteresis) between the loading and unloading curves is very small. This implies that most of the energy applied to engage the wire by the doctor is available to move teeth. Other brands of NiTi wires are now available with small gaps between loading and unloading, so this feature is not unique to Copper containing NiTi wires.

**AT FIRST, YOU MIGHT EXPECT THAT THERE ARE ONLY MINOR DIFFERENCES IN TOOTH MOVING FORCES AMONG BRANDS BECAUSE THE COMPOSITIONS ARE BASICALLY THE SAME (OTHER THAN: COPPER NI-TI). THIS IS NOT TRUE.**

There are many factors that affect the archwire you receive; all are controlled by the manufacturer. These factors include: purity of raw materials to make the alloy, minor type and amounts of elements in the alloy, whether the alloy is optimized for producing a heat activated or superelastic archwire, mechanical processing and heat treatment.

Manufacturers generally sell 2-3 lines of NiTi wires. About 10 years ago, when I first became involved with wire manufacturing, there was an emphasis among doctors on the heat activation properties of NiTi wires. Doctors like the “feel” of the wire and the ability to pre-bend an archwire before engaging it in brackets; a wire characteristic very useful for a patient that presents a large misalignment of teeth in an arch. Bends can be made and remain (unlike superelastic NiTi) until the wire is engaged in the mouth, where the wire transforms to its original arch shape moving teeth with it.

Typically, heat activated wires deliver low forces (40-100 grams, depending on wire size). Clinicians who follow Dr. Ricketts’ philosophy of tooth movement – low, continuous forces to move teeth bodily – use this type of wire. However, some doctors who first started using low force round wires as the initial wire for alignment asked for wires having greater forces as a first wire. RMO® responded by producing a third line of NiTi wires, Thermaloy Plus, having the “feel” of a heat activated wire with higher tooth moving forces. This line delivers moderate forces, between heat activated (low force) and superelastic (high force) wires.

RMO®’s three lines of NiTi wires are: THERMALOY (heat activated; low force); THERMALOY PLUS (heat activated “feel”; moderate force), and ORTHONOL (superelastic; high force). Wires are processed, by design, so that for any
wire size, the tooth moving forces delivered increase from: THERMALOY to THERMALOY PLUS to ORTHONOL. This greatly increases the number of choices of NiTi wires available. For a specific wire size, RMO offers three different force levels. A doctor can choose a wire based on the tooth moving force that he/she desires. Forces range from 40 – 500 grams. Today, heat activated wires are often used in clinical situations where low forces are needed, for example, in periodontal-compromised teeth.

How can you compare wires among brands? Brand marketing makes it difficult for the doctor to compare NiTi wires because wires are marketed in several ways:

1) TYPE OF WIRE (HEAT ACTIVATED OR SUPERELASTIC) – RMO®: THERMALOY, THERMALOY PLUS, ORTHONOL; 3M UNITEK: HA, SUPERELASTIC


3) FORCE DELIVERED - GAC: SENTALLOY ROUND WIRES - LIGHT, MEDIUM, HEAVY; NEOSENTALLOY SQUARE/RECTANGULAR WIRES – 80, 100, 160, 200, 240, 300 GRAMS

Marketing according to: 1) & 2) does not indicate actual tooth moving forces; 3) does not indicate heat activated or superelastic wires; Transformation Temperatures are not called-out.

Because the orthodontic literature has very limited reported data on NiTi wire brand comparisons, we did in-house testing to compare tooth-moving forces among brands. Three-point bend test results revealed inconsistencies among brands. For example, results showed some larger wires deliver smaller forces than smaller wires for the same brand. RMO wires are processed so that there is a logical and predictable sequence of forces – within a wire type (THERMALOY, THERMALOY PLUS, or ORTHONOL), a larger wire delivers a larger force. For the same wire size, the low force wire is THERMALOY, the moderate force wire is THERMALOY PLUS, and the high force wire is ORTHONOL.
Brand comparison by tooth moving forces is shown in Figure 2. Both RMO® in-house data and data available in the literature were used to categorize forces delivered by various brands. Figure 2 can be used as a starting point to compare brands. Brand comparison will become easier in the future as manufacturers meet the requirements of the ISO International Standard, which calls for reporting three-point bend data for all wire sizes.

**WHAT IS THE DIFFERENCE BETWEEN ORMCO COPPER NI-TI & RMO® FLI® COPPER NICKEL-TITANIUM WIRES?**

Copper containing NiTi alloys were patented (Sachdeva et al.: US Patent No. 5,044,947) and assigned to Ormco Corp.; the patent expired in 2010. During the 20-year period of patent protection, Ormco sold and marketed the brand it called: Copper Ni-Ti. Many doctors believed there was nothing either as good as, or better, on the market. When I first learned about the characteristics of NiTi wires, I was influenced by the many doctors who considered Copper Ni-Ti to be the “gold standard” for NiTi wires. However, although these same doctors used the wires effectively, they had a limited understanding of the wire properties. Not all doctors realized the wire packaging has a labeled temperature that has a meaning. Each Copper Ni-Ti wire is labeled by its $A_f$: 27°C, 35°C, or 40°C, and Damon Optimal-Force Copper Ni-Ti is 25°C. When asked what wire they used, the frequent response was Copper Ni-Ti, without knowing the designated temperature or the force delivered. Copper Ni-Ti 27°C is a high force, superelastic wire; Copper Ni-Ti 35°C is a moderate force wire. Copper Ni-Ti 40°C is a low force wire; however, if its $A_f$ is accurate, the austenite transformation occurs above body temperature. The manufacturer’s literature states that this brand delivers intermittent forces, when body temperature spikes above 40°C.

Usually a heat-activated NiTi wire has the lowest relative force for a particular wire size from one manufacturer. The Damon Optimal Force Copper Ni-Ti wire has been described by its manufacturer as a low-force wire. This is not the case. Results from in-house force testing of all sizes of Damon Optimal-Force Copper Ni-Ti wires compared to Copper Ni-Ti 27°C do not show significant differences between corresponding wire sizes. Results imply that Damon Copper Ni-Ti wires are high-force superelastic wires, not low-force wires. Since the manufacturer reports $A_f$ for the Damon wires as 25°C, there is only a 2°C difference between types (superelastic Copper Ni-Ti is reported as 27°C), which is within the experimental variation of measuring transformation temperatures. Results suggest that the only difference between these wires is arch form.

All Copper Ni-Ti wires are labeled with $A_f$ values greater than room temperature (20°C). The question is, shouldn’t they all have the same martensite structure at room temperature? Part of the answer to this question is the wide temperature range determined during Transformation Temperature testing (ISO International Standard 15841- Differential Scanning Calorimetry; DSC). Between the austenite start ($A_s$) and finish ($A_f$) values; the range could be 20-30°C. At office temperature much of the transformation of martensite to austenite has already occurred, whereas the expectation is that the transformation entirely happens within a couple of degrees in the mouth. Ormco’s marketing focus suggests that control of the austenite finish temperature is the major manufacturing criterion. A consequence that arises when processing a wire to control $A_f$ is that the tooth moving forces for these wires are not necessarily consistent.

With the expiration of the Copper containing NiTi wire patent, RMO® initiated a development program to produce a 2nd generation wire. The major development goal was to produce wires with consistent forces, which is not achievable when the manufacturing focus is $A_f$. See Figure 3.

<table>
<thead>
<tr>
<th>BRANDS</th>
<th>FORCE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BRANDS</strong></td>
<td><strong>LOW</strong></td>
</tr>
<tr>
<td>RMO</td>
<td>Thermaloy</td>
</tr>
<tr>
<td>FLI CuNiTi &quot;40°C&quot;</td>
<td>FLI CuNiTi &quot;35°C&quot;</td>
</tr>
<tr>
<td>GAC</td>
<td>Sentalloy Light</td>
</tr>
<tr>
<td>Neo Sentalloy 80/100</td>
<td>Neo Sentalloy 160/200</td>
</tr>
<tr>
<td>ORMCO</td>
<td>Copper Ni-Ti 40°C</td>
</tr>
<tr>
<td>3M Unitek</td>
<td>HA</td>
</tr>
<tr>
<td>G&amp;H</td>
<td>M5</td>
</tr>
</tbody>
</table>

**WIRE BRAND AND FORCE EQUIVALENT**

**FIGURE 2**
**WIRE COMPOSITION:** 49% Ni - 45% Ti - 6% Cu

---

**ORMCO: COPPER NI-TI**

**MANUFACTURING FOCUS:** $A_f$

**VARIATION IN F VALUES**

---

**RMO: FLI COPPER NICKEL-TITANIUM**

**MANUFACTURING FOCUS:** FORCE

**CONSISTENT F VALUES**

---

**RMO® FLI COPPER NICKEL-TITANIUM WIREs**

RMO®s 2nd generation of Copper containing NiTi wires was developed with a specific focus to assure consistency of tooth moving forces. Processes were established to assure manufacturing consistency among wire production lots. The result for the doctor is that all wires within a package deliver the same tooth moving force, and that the force delivered from the wire you use today will be the same as in the future. You can always expect the same force delivery from a specific wire which assures predictability during clinical application.

Three lines of RMO® FLI Copper Nickel-Titanium were developed as consistent force alternatives to Ormco Copper Ni-Ti lines. The temperature designations for RMO® FLI® Copper Nickel-Titanium: 27°C, 35°C, and 40°C are meant to indicate alternative wires to the respective three lines of Ormco Copper NiTi; the temperatures are not the actual $A_f$ values. Actual $A_f$ values of RMO® FLI® Copper Nickel-Titanium wires are within a 4°C difference from the respective Copper Ni-Ti alternatives.

The major outcome from a wire processing focus on $A_f$ is that the forces developed in same size wires are not consistent among production lots. RMO® has overcome this problem by developing manufacturing processes for a 2nd generation of Copper containing NiTi to assure consistency in tooth moving forces.