MBT™ ARCH FORM AND ARCHWIRE SEQUENCING

ARCH FORM

For over a century, the subject of arch form has been discussed in the dental and orthodontic literature. A review of this literature reveals that three contradictory themes dominate the clinical observations and research presented on this subject. These themes consist of the following:

1. The persistent search for the ideal arch form for the human dentition
2. The observation that changes made in initial arch form are subject to a proportionate amount of instability and subsequent relapse
3. The awareness that a great deal of variation is present in human arch form

THE SEARCH FOR THE IDEAL ARCH FORM

In 1885, Bonwill[1] noted the tripod shape of the lower jaw and declared that it formed an equilateral triangle with the base extending from condyle to condyle and the sides extending from each condyle to the midline of the central incisors. He stated that this triangle existed for the proper functioning of the teeth. Importantly, he noted that the bicuspids and molars formed a straight line from the cuspids to the condyles. In 1905, Hawley[2] employed some of Bonwill's principles in proposing a geometric method for constructing the ideal arch form. Hawley suggested that the six anterior teeth be made to lie along a circle whose radius equaled their combined widths. From this circle he created an equilateral triangle, the base of which represented the inter-condylar width. It was proposed that the bicuspids and molars should be aligned along these extended straight lines. Hawley did, however, advised against the strict use of this method for determining arch form, and that it be used only as a guide in establishing arch form.

Numerous authors described other shapes for the dental arches. In 1902, Black[3] stated that the upper teeth are arranged in a semi-ellipse and that the lower teeth were arranged similarly on a smaller curve. Broomell,[4] in the same year, said that "the teeth are arranged in the jaws in the form of two parabolic curves, the superior arch describing the segment of a larger circle than the inferior, as a result of which the upper teeth slightly overhang the lower".

In 1907, Angle[5] discussed in detail the "line of occlusion", which he defined as being "the line with which, in form and position according to type, the teeth must be in harmony if in normal occlusion". The form of this line was said to resemble a parabolic curve but one that varied greatly due to race, type, temperament, etc. of the individual. Because of these variables, Angle did not consider the Bonwill-Hawley arch form to be useful for anything more than a general approximation of the true line of occlusion. In describing the first order bends needed in the arch

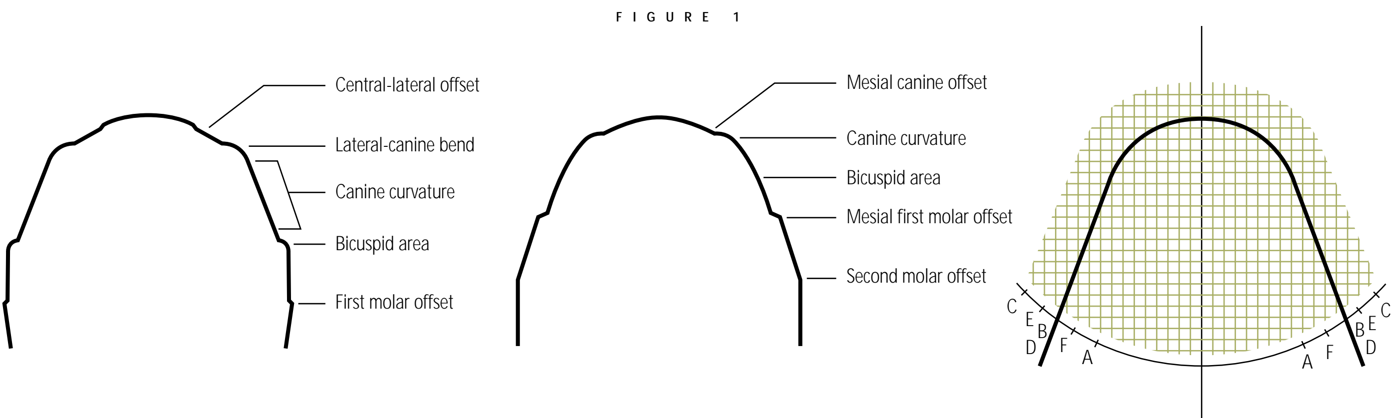
form for proper tooth positioning, Angle objected particularly to the straight line proposed from cuspid to third molar. Angle stated that a straight line existed from the cuspid to the mesio-buccal cusp of the first molar, however, there was a natural curvature needed in the molar region.

In 1942, Gray's Anatomy[6] stated the following about human arch form: "The maxillary dental arch forms an elliptical curve…The mandibular dental arch forms a parabolic curve". In 1934, Chuck[7] noted the variation in human arch form and pointed out that arch forms had been referred to as square, round, oval, tapering, etc. He stated that while the Bonwill-Hawley arch form was not suitable for use in each patient, it could serve as a template for the construction of individualized arch forms. Chuck superimposed this arch form on a millimeter grid and used this template for archwire construction according to Angle's method. Chuck suggested that the bicuspid regions should be wider than the cuspids to prevent excessive expansion of the cuspids. In 1963, Boone[8] proposed the similar superimposition of the Bonwill-Hawley arch form on a millimeter template for construction of the individualized edgewise arch form.

Thus, over the years the Bonwill-Hawley arch form has been the most consistently used arch form as a beginning template for edgewise orthodontists. It is the "standard" arch form offered by most orthodontic manufacturers today.

In 1949, MacConaill[9] stated that, in considering the line of occlusion, it would be impossible for an ellipse and a parabola to meet one another

FIGURE 1



Boone Arch Form and traditional wire bending with the Edgewise Appliance. (from Stoner[44]).

FIGURE 2

The catenary curve is formed by extending a chain from two fixed points.

at every point. He concluded that the ellipse-parabola description of the two dental arches, although elegant, had no immediate relation to function. He stated that a certain simple and well known curve, the catenary curve, fit so many cases with exactness that it could be taken as the "ideal curve" of common occlusions. The catenary curve was formed simply by suspending a chain of appropriate length from two points of varying width (for example width of the most distal molars in the arch form).

In 1957, Scott[10] also supported the concept of the catenary curve as the shape of the human arch based on the developmental anatomy of the dental arches and surrounding anatomic structures. He pointed out that the basal bone of the maxilla and mandible remains much more constant in form in all mammals and forms a foundation on which a great deal of variation in form of alveolar processes are constructed. In man, the dentition maintains the primordial catenary form because alveolar process growth does not show a regional differentiation but remains more or less equal in amount and constant in direction in all parts of the arch.

Burdi and Lillie[11] in 1966 further stated that the basic bony arch is established as early as 9.5 weeks in utero and that this form was that of the catenary curve. However, their research actually demonstrated numerous arch forms outside the catenary form. Musich,[12] in 1973, supported the concept of the catenary curve as the ideal arch form and suggested the use of the catenometer as a reliable device for construction of arch perimeter. The catenary curve creates a rather tapered arch form and many of the tapered arch forms provided by orthodontic manufacturers today are based on the catenary curve.

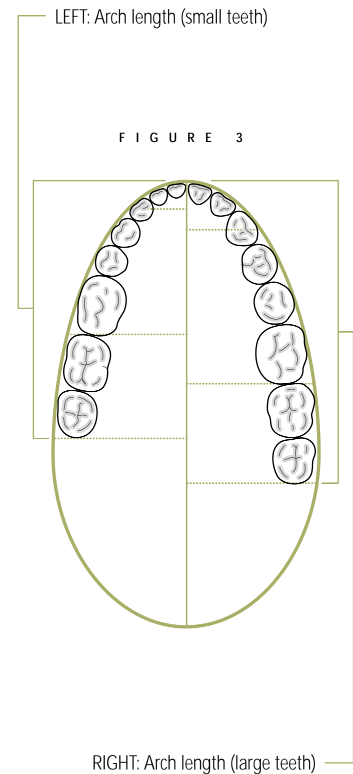
The last major publication attempting to establish the "ideal" arch form was presented by Brader[13] in 1972. He stated that dental arch form was made up of teeth which assume unique positions along a compound curve representing an equilibrium at all points and delimited by the counterbalancing forces of the tongue and circumoral tissues. The geometry of the curve of the dental arch form was said to be best

approximated by a closed curve with the curvilinear properties inherent in the trifocal ellipse, with the teeth occupying only the portion at the constricted end of the curve.

Brader recommended an arch guide with five arch forms. The selection of the proper arch form was based on arch width at the second molars as measured at the facial, gingival surface. The maxillary arch form was selected one size larger than the mandibular arch form. While the Brader arch form provided a convenient method of archwire selection, many clinicians found that this arch form created excessive narrowing in the cuspid region of many patients and led to excessive wear of the incisal portion of the cuspids.

THE RELAPSE TENDENCY INHERENT IN ARCH FORM CHANGES

In 1969, in a chapter on retention in Graber's text, Riedel[14] reviewed the literature on previous studies concerning stability of arch form. He cited numerous authors[15-29] who had reported that when inter-cuspid and inter-molar width had been changed during orthodontic treatment, there was a strong tendency for these teeth to return to their pre-treatment position. He cited only one author, Walter,[30-31] who reported the maintenance of slight increase in mandibular inter-cuspid width after all retention had been removed for what was termed an adequate period. Steadman[32] also reported similar results. Arnold[37] later pointed out that at least five years must elapse before an apparent maintenance of increase in inter-cuspid width could be accepted. For example, in one of his patients an increase inter-cuspid width of 4.2 mm had occurred during treatment and had relapsed only 1 mm after a year of retention. However, after 5 years of retention inter-cuspid width had effectively increased only .7 mm. Riedel presented a number of postulates concerning retention. One of these postulates was that "arch form, particularly in the mandibular arch, cannot be permanently altered during appliance therapy." The above comments were made primarily in reference to non-extraction cases. Concerning extraction cases, Strang[33-34] and Howes[35] felt that inter-molar width was normally



Brader utilized the anterior portion of a trifocal ellipse to establish arch form.

decreased during extraction treatment, however, that if cuspids were moved distally into extraction sites, they could be expanded buccally to limits offered by their new distal location. Contrary to this, other authors[36-39] reached the conclusion that with regard to extraction cases, inter-molar width decreased post-treatment, but the inter-cuspid width which retained its original dimension did not show an increased arch width as was previously thought.

In 1974 Shapiro[40] studied changes in arch length, inter-cuspid width and inter-molar width in 22 non-extraction cases and 58 extraction cases after treatment and post-retention. Shapiro's conclusions were as follows:

1. Mandibular inter cuspid width demonstrated a strong tendency– to return to its pre-treatment dimension in all groups with the exception of the Class II, division 2 group, which demonstrated a significantly greater ability to maintain treatment inter-cuspid width expansion than did Class I and Class II, division 1 groups. (This could possibly be due to the fact that Class II, division 2 cases normally show a deep bite with lower cuspids inclined lingually in relation to the palatal surface of the upper cuspids. Once the bite is opened, while the incisal edges of the incisors may move labially, the apex of the roots of these teeth may actually move lingually with the body of the tooth remaining in the same position. This may also occur in many deep bite cases that are opened orthodontically).
2. Mandibular arch length decreased substantially in every group during post-retention period.
3. Arch length reduction in Class II, division 2 groups was significantly less than in the Class I and the Class II, division 1 groups during treatment.
4. From pre-treatment to post-retention, mandibular inter-molar width decreased more in extraction cases than in non-extraction cases. Much of the treatment inter-molar width expansion was maintained in the non-extraction group, although the trend was to return toward the pre-treatment dimension. In the extraction group inter-molar width was decreased during treatment and continued to decrease during the post-retention period.

In 1976 Gardner[41] studied inter-cuspid, inter-first bicuspid, inter- second bicuspid and inter-molar widths, as well as arch length changes and 103 cases, 74 of which were treated non-extraction, and 29 of which were treated with extraction of four first bicuspids. His conclusions were as follows:

1. Inter-cuspid width was expanded during treatment but had a strong tendency to return to or close to its original pre-treatment width in both non-extraction and extraction cases.
2. It would appear that the inter-first bicuspid width showed the greatest treatment increase in width with only a minimal amount of post-treatment width decrease.
3. Second bicuspid width for non-extraction cases showed a significant amount of increase with a slight tendency for

post-retention decrease.

4. Second bicuspid width for extraction cases showed a decrease with treatment and a slight continued decrease post-retention.
5. The inter-molar width of non-extraction cases showed significant increase in width with treatment and the extraction cases showed a significant decrease with treatment, However there were no changes in either extraction or non-extraction cases post-retention.
6. The incisor to inter-molar distance decreased with treatment and had a slight tendency to continue to decrease post-retention.

In 1987 Felton, et al.,[42] carried out a computerized analysis of the shape and stability of mandibular arch forms. Concerning the retention and post-retention aspect of the study (30 Class I and 30 Class II cases) the authors concluded that 70% of the dental arches returned to their original shape during the post-treatment period.

In 1995 De La Cruz, et al.,[43] studied the long term changes in arch form of 45 Class I and 42 Class II Division 1 cases after orthodontic treatment and a minimum of 10 years post retention. They concluded that arch form tended to return toward the pre-treatment shape after retention and that the greater the treatment change, the greater the tendency for post-retention change. They did point out that individual variations were considerable in the study. They suggested that the patient's pre-treatment arch form appeared to be the best guide for future arch form stability, but emphasized that minimizing treatment change was no guarantee of post-retention stability.

Thus, there is overwhelming support in the orthodontic literature confirming that when arch form is changed during orthodontic treatment, there is a strong tendency for relapse to the original dimensions. This is particularly true of inter-cuspid width. The most recent evidence does indicate that changes in inter-molar width seem to be more stable than those of inter-cuspid width.

THE VARIATION IN HUMAN ARCH FORM

Over the years the great majority of authors on the subject of arch form have recognized that there is variability in the size and shape of human arch form. Angle,[5] for example, stated that the arch form varies within the limits of the normal, according to race, type, temperament etc., of the individual. Because the form of the arches was considered dependent on these variables, Angle did not consider Hawley's method of arch predetermination useful for more than a general approximation as a true line of occlusion. Over the years, however, the majority of edgewise orthodontists used the Bonwill-Hawley arch form as a beginning template for the construction of the edgewise archwire. These construction methods were described by Angle,[5] Chuck,[7] Boone,[8] Stoner[44] and others.

Hellman[45] investigated the skulls of apes and human beings, and found no relation between the size of teeth and the form and shape of the dental arches. Therefore, he did not accept the theories of arch predetermination based on measurements of certain teeth. He concluded that mathematical

methods for dealing with the question of arch form were unsatisfactory.

Stanton[46] carried out extensive investigations on arch form and pointed out the error in the Bonwill-Hawley method of arch predetermination. He utilized "arthrographic map makers" to study occlusions, and concluded that arch forms are open and closed, that is ellipse, parabola, and other kindred curves. Izard[47] based his method of arch predetermination on ratios between arch width and facial depth. He concluded that approximately 75% of arch forms were represented by an ellipse, 25% by a parabola and 5% by a U shape. While Wheeler[48] observed that dental arches generally conform to the shapes of parabolic curves, he stated that nothing anatomic could be reduced to the mathematical exactitudes of geometric terms.

Sicher[49] wrote that the shapes of the dental arches vary considerably, but that the upper arch generally took on the appearance of an ellipse, and the lower arch a parabola. Remsen[50] studied various arch predetermination methods by comparing them with the arches of a sample of "normal" occlusions. He observed that the parabola best represented the anterior curvature of the dental arch, but stated that an arch which fits a precise pattern was the exception rather than the rule.

White[51] reviewed the accuracy of various standardized arch designs to 24 untreated ideal adult occlusions. His findings were as follows:

1. The Bonwill-Hawley arch form had a good fit with 8.33% of the cases, a moderately good fit with 39.58% of the cases, and a poor fit with 52.08% of the cases.
2. The Brader arch form had a good fit with 12.50% of the cases, a moderately good fit was 43.75% of the cases, and a poor fit was 43.75% of the cases.
3. The Cantinary curve showed a good fit with 27.08% of the cases, a moderately good fit in 45.82% of the cases, and a poor fit with 27.05% of the cases.
4. The Rocky Mountain data computer derived arch design which is based on measurements of inter-molar width, inter-cuspid width and arch depth, showed a good fit with 8.3% of the cases, and a moderately good fit with 81.57% of the cases. No cases showed a poor fit.

White also pointed out that most theories on arch form consider arch form to be symmetrical. He observed that there was a great deal of asymmetry in the arches and felt that should be considered in arch design. Because of the variability that White found in arch form, he suggested that an occlusal "map maker" be used to construct the shape of the arch for the individual and used throughout orthodontic treatment.

In order to determine whether a particular ideal orthodontic arch form could be identified, Felton[42] et. al., studied the mandibular casts of 30 untreated normal cases, 30 Class I non-extraction cases, and 30 Class II non-extraction. After computerized digitizing and the use of a mathematical function called a polynomial of the fourth degree, they determined that no particular arch form predominated in any of the three samples. They therefore stated that customizing arch forms appeared to be necessary in many cases to obtain optimum long

term stability, because of the great variability in arch form observed in the study.

The overall result of these clinical observations and research papers is that, because of the extensive variations in human arch form, there does not seem to be any single arch form that can be used in all orthodontic cases. Also, when the patients original arch form is modified, there is a strong tendency (in approximately 70% of cases) for the arch form to return to it's original shape after appliances are removed.

THE PROBLEM AND PRACTICAL SOLUTIONS

The use of preformed archwires, even though some modifications are necessary, is of obvious value to the orthodontist. Approximately 90% of the archwire bending has already been completed with these archwires and there is less of a tendency for change or distortion of this form after placement. However, does the overwhelming evidence in the literature concerning the variation in human arch form and the instability of arch form change mean that preformed archwires are of no value and that archwires need to be customized for each patient in the busy orthodontic practice? The authors do not believe this to be the case and the following steps are recommended to reduce the need for the tedious process of customizing each archwire for every orthodontic patient:

1. It is not recommended that patients progress from rectangular wires directly to retainers, without a phase of settling in lighter wires. The authors prefer the use of a .014 Nitinol lower archwire and an upper 2x2 .014 stainless steel sectional wire, in combination with light triangular elastics near the completion of treatment. The patient is checked at two week intervals for a period of approximately six weeks. During this period, not only is vertical tooth settling allowed to occur, but the upper and lower arch form is allowed to settle, so that a balance between the tongue and peri-oral musculature is allowed to occur. Additions or modifications to this general process are as follows:
   A. When the case is treated on an extraction basis, extractions sites are stabilized with figure 8 ligature wires during the settling process.
   B. When the maxillary arch is expanded in the early stages of treatment, a removable palatal plate can be used during settling to maintain upper expansion.
   C. With Class II Division 1 cases, where anterior relapse of incisors is anticipated, a full .014 archwire bent back behind the most distal molars is indicated. This will slow settling, however, it is necessary.
2. Lower bonded retainers are recommended to minimize the strong tendency for lower incisors to relapse in nearly all types of cases.
3. If the lower arch appears to be narrowing relative to the fully retained upper arch, the upper removable retainer can be left out for a period of two to four weeks. This normally results in a very satisfactory settling of the upper arch in relation to the lower arch. After this an adjusted or new upper retainer can be placed.

If the above techniques are carried out, allowing for stabilization of the arch form, then a preformed archwire system can be used effectively. This system is designed in the following way. There are four basic components to the arch form as follows:

The anterior curvature

It has been generally observed by all authors that there is some curvature in the anterior segment. This curvature is largely influenced by the inter-canine width.

Inter-cuspid width

This appears to be the most critical aspect of arch form, since significant relapse occurs if this dimension is changed. Thus, the preformed archwire should be selected based on the desired width of the cuspids in the area of the bracket slots of these teeth.

Inter-molar width

Changes in this dimension appear to be slightly more stable than changes in inter-cuspid width, especially if expansion is carried out at an early age and retained for a number of years. Arch form width in this dimension can be standardized in the preformed archwire and then widened or narrowed depending on the needs of the individual case.

The curvature from cuspids to second molars

This dimension has been described as a straight line (the Bonwill-Hawley arch form) to a significant curvature (the Brader arch form). The consensus seems to be the selection of a curvature that represents the mid-range of these two arch forms with a gradual curvature incorporated between cuspids and second molars.

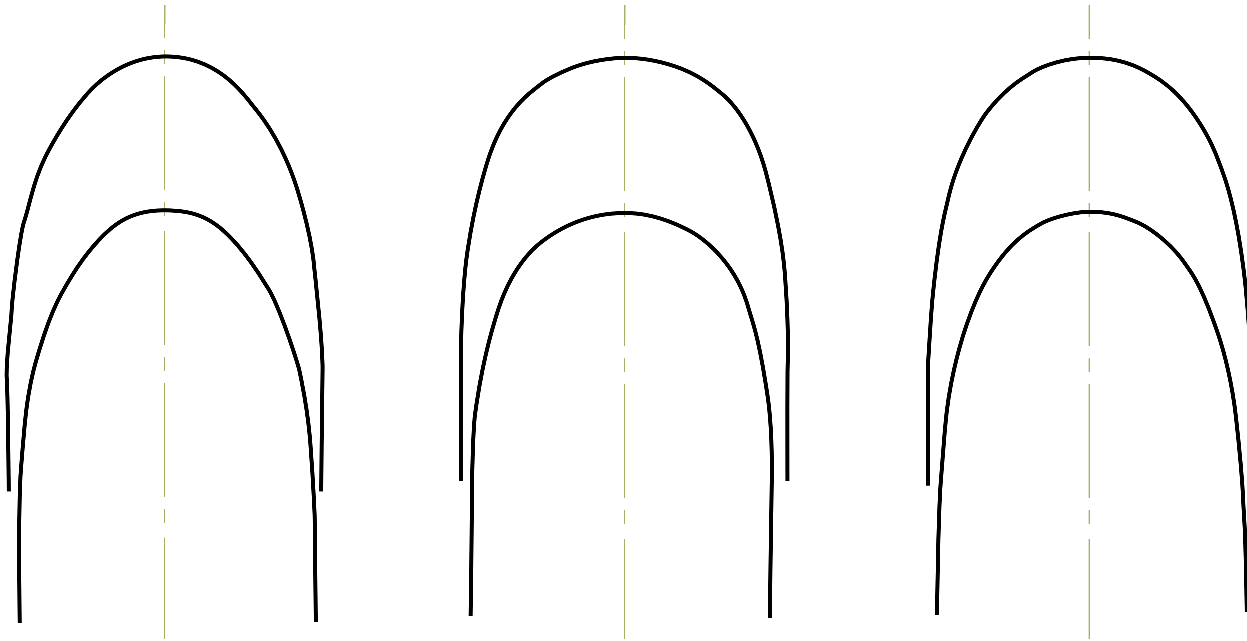
In addition to these general arch form components, the above review of the literature revealed that three basic arch forms have been described by many clinicians. These include Tapered, Ovoid and Square arch forms. Felton et all.[42], in particular, evaluated arch forms from several orthodontic companies. These arch forms fell quite closely into the above three shapes. These basic arch forms are shown below. When superimposed they vary primarily in inter-cuspid width, with a range of approximately 5 mm. Inter-molar widths are quite similar and the posterior aspects of the archwires can be widened or narrowed as needed. These arch forms are illustrated as shown in figure 4.

The general guidelines for the selection of the appropriate arch form for each individual case are as follows:

The Tapered Arch Form

This arch form provides the most narrow inter-cuspid width and is indicated in patients with narrow, tapered arch forms. It is particularly important to use this arch form in patients with narrow arch forms and gingival recession in the cuspid and bicuspid regions. This situation occurs most frequently in adult orthodontic cases. Also, cases with tapered arch forms undergoing partial treatment in one arch only benefit from this arch form, so that no expansion occurs in the treated arch. The posterior aspect of this arch form can be easily modified to conform to the inter-molar width of the patient.

FIGURE 4



Tapered Arch Form — OrthoForm™ I Modified *Square Arch Form — OrthoForm™ II* *Ovoid Arch Form — OrthoForm™ III*

The Square Arch Form

This arch form is indicated in cases with broad arch forms. It is also indicated, at least in the first portion of treatment, in cases that require buccal uprighting of the lower posterior segments and expansion of the upper arch. In such cases, if over expansion has been achieved, it may be beneficial to change to the ovoid arch form in the latter stages of treatment.

The Ovoid Arch Form

This arch form has been used by the authors most frequently in their cases over the past fifteen years. By using this arch form, along with the above settling and retention procedures, a minimal of post-treatment relapse has occurred in the majority of treated cases.

Because of the potential inventory concerns when using three arch forms, The authors prefer to use the Ovoid arch form when using multistrand wires, .014 and .016 stainless steel round wires, and all Nitinol Heat-Activated nickel titanium wires. When using .018, .020 round stainless steel wires and rectangular stainless steel wires (wires that significantly influence arch form) one of the above three arch forms is selected.

Note: 3M Unitek provides these arch forms as follows:

- The **Tapered Arch Form** is available as **OrthoForm™ I**, however this arch form needs to be narrowed in the anterior segment and rounded in the molar regions to fit the tapered arch form.
- The **Square Arch Form** is available as **OrthoForm II**
- The **Ovoid Arch Form** is available as **OrthoForm III**

ARCHWIRE SEQUENCING

The archwires used with the standard edgewise appliance and during the early years with the pre-adjusted appliance were round and rectangular stainless steel wires. Round wires were available in sizes .014, .016, .018, and .020. Rectangular wires were available in a number of sizes, with .018x.025, .019x.025 and .0215x.025 being the most popular wires used with the .022 bracket slot (the authors prefer the .022 slot over the .018 slot primarily because of the rigidity needed in the archwire during space closure with sliding mechanics).

The authors prefer to use the above round wire sequence followed by the .019x.025 rectangular wire. This wire allows for efficient sliding mechanics (unlike the larger .0215x.025 wire which creates excess friction during space closure) without significant archwire deflection (unlike the more flexible .018x.025 wire).

One of the earlier attempts at producing greater archwire flexibility was accomplished by twisting strands of very small stainless steel wires into what have been referred to as multistrand wires. These wires in sizes .015 and .017 were used as initial wires, prior to the use of the .014 round wire, in cases with significant tooth malalignment. The introduction of Nitinol wires provided a possible substitute for multistrand and round wires during the leveling and aligning stage of treatment. Their flexibility provided for a substitution of approximately two sizes of stainless steel wires. Given their higher cost, their significance was therefore considered questionable by many clinicians. They were also mistakenly used during procedures that required the rigidity of a rectangular stainless steel wire, such as complete arch levelling and overbite control, space closure, overjet reduction with intermaxillary elastics.

The development of heat-activated nickel titanium wires, provided a wire with significantly greater flexibility. As a result these wires could be used as a substitute for three of the traditional stainless steel wires in certain situations, which was a significant improvement! Instead of replacing wires on a per visit basis during levelling and aligning, a coolant can be applied to the wire in the areas where full bracket engagement has not been achieved and the wire can be retied for complete engagement. Prior to the following visit, the normal warmth of the oral cavity allows for significant activation of the wire and very efficient tooth movement. Surprisingly, patients do not seem to complain of added discomfort, most likely due to the light forces that are introduced.

The substitution sequence shown at the right has been employed by the authors. This sequence has dramatically reduced chair time and has significantly increased the efficiency of tooth movement due to the minimizing of permanent archwire deflection.

Because of their flexibility, there are clinical situations where heat-activated wire substitutions are not recommended or where some stainless steel wires should also be used. These clinical situations can be described as follows:

As initial wires in cases with severe malalignment of teeth

It is a service to the patient to place a multistrand wire as the first wire in such cases. The permanent deflection that occurs with these wires reduces the overall force levels and provides for less discomfort during this initial "experience with braces". Also, some wire bending in addition to the normal arch form may be required and is easily accomplished with multistrand wires.

When using lacebacks for cuspid retraction in crowded extraction cases

The use of lacebacks minimizes the tipping of the cuspids into the extraction sites. However, with the continued use of flexible heat-activated wires, some tipping can occur. To reduce this possibility, an .018 or .020 stainless steel wire should be used as early as possible when using lacebacks.

When using open coil spring in the anterior or posterior segments to create space for blocked out teeth

Because of the flexibility of heat-activated wires, the use of open coil springs on these wires can cause significant distortions in arch form. Thus, open coil springs should not be used until .018 or .020 round wires are in place.

SUBSTITUTION SEQUENCE

.015 Multistrand	.016 NITINOL HEAT-ACTIVATED
.017 Multistrand	
.014 Round (SS)	
.016 Round (SS)	.0195 X .025 NITINOL HEAT-ACTIVATED
.018 Round (SS)	
.020 Round (SS)	
.0195 X .025 Rectangular(SS)	.0195 X .025 RECTANGULAR(SS)

Nitinol Heat-Activated wires can replace a number of traditional stainless steel wires.

For complete arch levelling and overbite control

While heat-activated wires are excellent for individual tooth alignment, they are not effective for complete arch levelling and subsequent bite opening. Hence, the transition from even the rectangular heat-activated wire to the rectangular stainless steel wire is sometimes impossible. An .020 round wire is often required prior to the use of the rectangular stainless steel wire.

For torque control

While rectangular heat-activated wires do initiate the process of torque control, this difficult tooth movement is best completed with a rectangular stainless steel wire.

For the treatment stages of space closure and overjet reduction

The major tooth movements that occur during these stages of treatment require the rigidity of a rectangular stainless steel wire, as opposed to the flexibility of a heat-activated wire.

In summary, the introduction of heat-activated wires has provided a beneficial substitute for a number of traditional stainless steel wires and can dramatically improve the efficiency of orthodontic treatment. This substitution is, however, beneficial for initial tooth alignment procedures only. Their excellent flexibility can actually be detrimental in a number of other clinical situations as described above. It is important that the orthodontist separate the situations that require archwire flexibility from those in which archwire rigidity.

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