Evolution of treatment mechanics and contemporary appliance design in orthodontics: A 40-year perspective

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Until the early 1970s, successful treatment with the Begg technique and the Tweed edgewise technique required tedious wire bending. The introduction of Andrews' straight wire appliance changed that, and it was one of the most significant contributions in the history of orthodontics. The straight wire appliance significantly reduced the amount of wire bending and also brought along other options in treatment mechanics. Retraction of the canines with elastic chains and ligature wires became more common. Sliding mechanics in place of closing loops became the method of space closure for a significant number of clinicians. Edgewise force levels were initially used to close spaces; however, it was soon observed that lighter forces were more effective with sliding mechanics. Along with these changes, it became apparent that compensation in the appliance was needed, depending on the type of malocclusion and particularly with varying extraction sequences. Various appliance designs were developed to accommodate changes in mechanics and force levels. These modifications improved tooth positions at the end of treatment as long as the brackets were properly placed. These major changes in appliances, force levels, and treatment mechanics can be traced back to the work of Dr Lawrence Andrews and the straight wire appliances. (Am J Orthod Dentofacial Orthop 2015;147:654-62)

This article presents a 40-year overview of our experience with treatment mechanics and contemporary appliance designs. Fortunately, due to the periodontal ligament and bone biology, teeth move in every direction. Some of these movements are positive and beneficial for the patient, and some are not. Therefore, there have been many ideas on how and how not to move teeth. Countless methods of treatment mechanics have been developed, and experience with these has led to many different appliance designs. This has been the pattern throughout the history of orthodontics. Clinicians have established their ideas on treatment mechanics and then have developed or used appliances to complement their mechanics. With these observations in mind, it is important to clarify that this article is not intended to provide criticism of what others have done with orthodontic appliances, because mechanics have led to many of their decisions. Instead, it discusses the path we chose and how mechanics have driven our appliance modifications.

PRECURSORS TO THE PREADJUSTED APPLIANCE

Before the 1970s, 2 major treatment systems were used in orthodontics: the Begg light-wire technique with the Begg appliance, and the Tweed technique with the edgewise appliance. These treatment systems were developed in response to an orthodontic philosophy of nonextraction treatment in nearly all orthodontic
patients, as recommended by Edward H. Angle. Both P. Raymond Begg and Charles Tweed proposed that it was appropriate to extract teeth when crowding or protrusion was present to an extent that nonextraction treatment would lead to instability and potential periodontal breakdown. They demonstrated numerous extraction cases to support their position. Begg recommended a 3-stage approach to treatment using round wires. Multiple-loop 0.016-in round wires and light force levels were used in stage 1 for early alignment. In stage 2, teeth were tipped into the extraction sites, and spaces were closed. Finally, heavier round wires and auxiliaries were used in stage 3 to upright the teeth and correct the root positions. Orthodontists needed skill and experience to achieve good results, and the treatment method was labor intensive.

Tweed was concerned with the stability of his patients. The greatest area of concern was the mandibular anterior segment, where bone is the thinnest and multiple forces from all directions are brought to bear on these teeth. He proposed that the most stable position for the mandibular incisors was when they were positioned at 90° to the mandibular plane. Tweed believed that the most efficient and effective way to move teeth was in a bodily manner, especially in extraction patients, where the potential to tip teeth into the extraction sites was the greatest. He further believed that the most efficient force level and wire shape for bodily movement was in the 600-g range with rectangular wires. Edgewise brackets were milled (cut from larger pieces of metal). Their bases were formed at 90° angles to the tooth surface, and their rectangular slots, originally at size 0.022 in, were cut at 90° angles. Patients progressed from round wires to rectangular wires, where major tooth movements were carried out. In the early round-wire stages of treatment, horizontal in-and-out and rotational bends (first-order bends) were placed in the maxillary lateral incisors and in the maxillary and mandibular canines and molars. To aid in bodily movement, varying amounts of vertical tip bends (second-order bends) were placed. “Beauty bends” were placed in the incisor areas for tip control and esthetics. “Gable bends” were used in the canine and premolar regions to control tipping, where extractions most frequently occurred, and tipping was the greatest issue. “Tip-back bends” were used in the premolar and molar areas to control forward tooth tipping and to aid in anchorage control (needed to achieve maxillary and mandibular incisor positions). Once elastic chains became available, they were used for canine retraction in the early round-wire stages of extraction cases. Omega loops mesial to the first molars were used to “tie back” the archwires to minimize anterior tooth flaring. In rectangular wires, in addition to first- and second-order bends, torque bends (third-order bends) were placed in the incisor, premolar, and molar areas to correct the patient’s torque needs. Closing loop arches with omega loop tie-backs were used to close spaces. Although the 0.022-in slot was the most popular size during most of the edgewise era, 0.018-in slots were later introduced, with the assumption that a smaller slot and lighter wires would create lighter forces. Since forces are also based on wire deflection, this assumption was questioned by those who used the 0.022-in slot. It was a significant challenge for Tweed to achieve his goals with the edgewise brackets and labor-intensive mechanics. He met this challenge, and his treatment method significantly influenced the development of preadjusted appliances in the future.

**ANDREWS’ STRAIGHT-WIRE APPLIANCE**

It was against this edgewise backdrop that Lawrence F. Andrews developed the first “fully programmed preadjusted” appliance. Andrews, an excellent edgewise orthodontist, thoroughly understood the nuances of edgewise treatment. He began his journey to develop the appliance by collecting 120 nonorthodontic normal models. These were models of patients whom Andrews assessed as having ideal occlusions, and who had never had orthodontic treatment. He studied these models and observed many features but found 6 features or “6 keys” that were consistent in all of the models. He published these observations in his classic article “The six keys to normal occlusion.” These keys included molar relationship, crown tip, crown torque, rotations, lack of spaces, and plane of occlusion, and they are an important part of the American Board of Orthodontics grading system used today. He then measured the in-and-out, tip, and torque values for each tooth on the models. He used 3 references to measure these values: the center of the clinical crowns, the long axis of the center of the clinical crowns, and the thickness of the clinical crowns from a designated position on the teeth to the center of the clinical crowns (Figs 1–3). This allowed him to have consistent measurements on small and larger teeth. Once these data were collected, norms and standard deviations were determined. He then converted this information into a “preamtended” appliance with tip, torque, and in-and-out values built into each bracket for each tooth. He called it the straight-wire appliance (SWA).

Andrews realized that 2 important factors were needed to develop the SWA. First, each bracket needed a “compound contoured” base, which would fit each tooth mesiodistally and occlusogingivally while positioned at the center of the clinical crown and centered in the canine and premolar regions to control tipping, where extractions most frequently occurred, and tipping was the greatest issue. “Tip-back bends” were used in the premolar and molar areas to control forward tooth tipping and to aid in anchorage control (needed to achieve maxillary and mandibular incisor positions). Once elastic chains became available, they were used for canine retraction in the early round-wire stages of extraction cases. Omega loops mesial to the first molars were used to “tie back” the archwires to minimize anterior tooth flaring. In rectangular wires, in addition to first- and second-order bends, torque bends (third-order bends) were placed in the incisor, premolar, and molar areas to correct the patient’s torque needs. Closing loop arches with omega loop tie-backs were used to close spaces. Although the 0.022-in slot was the most popular size during most of the edgewise era, 0.018-in slots were later introduced, with the assumption that a smaller slot and lighter wires would create lighter forces. Since forces are also based on wire deflection, this assumption was questioned by those who used the 0.022-in slot. It was a significant challenge for Tweed to achieve his goals with the edgewise brackets and labor-intensive mechanics. He met this challenge, and his treatment method significantly influenced the development of preadjusted appliances in the future.

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Andrews defined tip (or angulation) as the angle formed by the facial axis (ie, the long axis) of the clinical crown and a line perpendicular to the occlusal plane. This definition applied to incisors, canines, and premolars. He used the buccal groove as a reference for the long axis of molars.

Andrews used the term “inclination” to describe what is commonly known as “torque.” He defined this as “the angle between a line perpendicular to the occlusal plane and a line that is parallel and tangent to the long axis of the clinical crown at its midpoint.”

Andrews defined prominence to describe what is known as “in-and-out,” and he measured it from a line called the “embrasure line.” This was defined as “an imaginary line at the level of the crown’s midtransverse plane that would connect the most facial portions of the contact areas of all crowns in an arch when they are optimally positioned.”

Alignment, Andrews further realized that he needed to vary the angles at the bracket bases from 90° to varying amounts of acute and obtuse angles. This resulted in a feature referred to as “torque in base,” which was patented by Andrews. This required other manufacturers that did not have the patent to place not only tip, but also torque, into the face of the brackets. In the SWA, tip was properly placed into the face of rectangular brackets, and the thickness of the brackets was determined by the in-and-out measurements on the models. The 0.022-in slot was Andrews’ choice of slot size. He decided that the best choice in manufacturing these brackets was to cast the brackets with stainless steel,
similar to the casting of crowns or inlays. The difficulty with casting brackets was that stainless steel had never been cast in this manner. The temperatures to cast stainless steel were much higher than for gold. To accomplish this, he sought out engineers who determined how to carry out this process, and the brackets were constructed. This monumental effort by Andrews was one of the most significant contributions in the history of orthodontics. His work created a baseline reference for all future preadjusted appliances in the specialty.

MECHANICS WITH THE SWA: THE NEED FOR ADDITIONAL APPLIANCE COMPENSATION

A period of mechanics and appliance modification followed the introduction of the SWA. These adjustments centered around methods of canine retraction and space closure, force levels, and compensation needed in the appliance.

Canine retraction: In extraction patients, the canines were retracted on round wires using elastic chains. Without the overcorrection of additional gable bends, teeth tended to tip and rotate into the extraction sites when the chains were overstretched, with associated bite deepening (Fig 5).

Methods of space closure: As stated above, before the SWA, most space closure with the edgewise appliance was accomplished with various types of closing loops. Sliding mechanics were seldom used because of the posterior interferences of omega loops, molar offsets, and tip-back bends (Fig 6). However, with the SWA, sliding mechanics became a feasible option for the first time. Andrews supported and used sliding mechanics as the method of choice for space closure. This was also chosen as the method of space closure by many orthodontists, and it reduced the need for wire bending and the managing of closing loops.

Many other orthodontists continued to use their familiar closing loop mechanics. Dr Ron Roth,6 a friend and professional colleague of Andrews, chose to use double T-loop arches for space closure. Roth was able to answer the criticism of gnathologists concerning extraction treatment. The gnathologic position was that when premolars were extracted, an ideal functional occlusion could not be achieved. Roth studied the work of Drs Stuart and Stallard, the leaders of gnathology. After carefully reviewing their goals, Roth, as well as Andrews, treated numerous extraction patients to centric relation using the SWA. They demonstrated...
conclusively, using both closing loop mechanics and sliding mechanics, that extraction patients (as well as nonextraction patients) could be treated to ideal static and functional goals of occlusion in orthodontics. Roth’s contributions in the area of functional occlusion were also significant to the specialty. Their combined findings and recommendations on static and functional occlusion became a powerful message and a goal of treatment in orthodontics.

Force levels: Typically with the SWA, leveling and aligning and canine retraction were initiated with round wires and elastic chains. These chains have been proven to create approximately 400 g of force when stretched to twice their length, but the force reduces rapidly and becomes half of the initial force after 24 hours. However, their activation length and continuous force created tipping of teeth into the extraction sites and unwanted rotations with level archwires.

Traditional edgewise forces for space closure were approximately 600 g, with single closing loops in rectangular archwires. Roth reduced these force levels using double T-loops for space closure. This did reduce the force levels, but it brought the need for gable bends in the extraction areas to counteract the increased flexibility. Orthodontists who chose to use sliding mechanics were unsure of how much force to use in the process, and there was minimal experience to fall back on. Andrews began using stainless steel coil springs with carefully controlled 600-g force levels to close spaces, the similar force levels he had used with edgewise treatment. These force levels tended to also create some collapse in the extraction sites and some rotational effects in rectangular wires.

During this period, the nickel-titanium alloy group of wires was developed, but orthodontists were unsure about when to use them. The flexibility of these wires was excellent for individual tooth alignment in many clinical situations. However, it was not effective when wire stiffness was needed to retract canines, level arches, and close spaces. These leveling and aligning and space-closure issues led Andrews to add modifications to the SWA.

Appliance compensation: Rather than modifying the force levels or providing compensating bends in the wires to counterfeit these effects, Andrews chose to maintain the “straight-wire” effect of the appliance. He developed a series of “extraction brackets” for the canines and posterior teeth that created additional compensating tip and rotational control. He also added “power arms” to these brackets to move the forces closer to the center of resistance. The amount of additional tip and rotational control in the extraction brackets was based on the edgewise concept of minimum, moderate, and maximum anchorage needs. Dr Roth preferred not
to use the larger inventory involved with extraction brackets and chose to use a “single bracket per tooth philosophy” with Andrews’ minimum anchorage extraction brackets as part of his appliance system. For many orthodontists, this was the state-of-the-art in preadjusted appliance design until the mid-1990s.

OTHER PREADJUSTED APPLIANCE VARIATIONS

With the awareness of the need for compensation in the SWA, and potentially for other preadjusted appliances, the floodgates were opened in orthodontics for variations in preadjusted appliance designs. The goals were to determine the most common irregularity for each tooth relative to the Andrews norms and then to determine how much bracket compensation was needed to correct its position. This was further complicated by the multiple variations in slot sizes, force levels, wire types, and mechanics. Essentially, the top of the bell-shaped curve for each tooth was sought out to establish a given appliance design. We had the opportunity to work with the various mechanical and appliance options of the SWA for nearly 20 years. Over this time, our perspective on the 4 factors discussed above (force levels, method of canine retraction, space closure, and compensation needed in the appliance) can be described as follows.

Force levels: With the edgewise appliance and closing loop mechanics, tip bends (beauty, gable, and tip-back bends) helped to counteract the 600-g forces applied to the archwires and brackets. It became apparent to us that when using the SWA and sliding mechanics, the heavy force levels and the lengths of activation were overpowering the stiffness of the archwires. Adding additional tip and rotational compensations to brackets did not seem to be as helpful as reducing the force levels and the activation lengths. Short activation lengths and lighter forces in the 200-g range proved to be more effective with sliding mechanics.

Canine retraction: The use of elastic chains for canine retraction without compensating bends proved to be too much force in this round-wire stage and caused tipping of teeth into the extraction sites. Nickel-titanium wires placed during this stage of treatment compounded the tipping problem. Instead, passive figure-eight ligature wires, referred to as “lacebacks” (Fig 7), were placed from the first molars to the canines before archwire placement. They provided a short activation length and a rapid reduction in force after initial application. The periodontal space was compressed with minor tipping, as initial minimal tightening of the laceback occurred. The archwire was then placed and had
adequate time (4-6 weeks) to upright the teeth (Fig 8). Gentle tightening of the lacebacks at 4- to 6-week intervals led to bodily movement of the canines and the premolars into the extraction sites.9

Methods of space closure: Lower forces during space closure (200-g range) were eventually used, creating less tipping force against the archwires and, in turn, less archwire deflection. This reduced friction in the system and allowed for more effective space closure. The 200-g forces were created using “tiebacks.”8 The tieback was a single elastic module and a ligature wire attached between hooks on the archwires and the first molars (Fig 9). Nickel-titanium wires were not used during space closure.

Appliance compensation: Because of these mechanical changes to lighter forces, as well as other clinical observations, when the opportunity arose to develop a new preadjusted appliance, 5 changes were introduced to the appliance as follows.

Modified tip in the maxillary and mandibular anterior segments: Over time with the SWA, the force levels with sliding mechanics were reduced from the 600-g range to the 200-g range. Therefore, we determined that it was unnecessary to add compensating tip to the anterior brackets of the newly developed preadjusted appliance.10 Because of the reduced forces used, the anterior tip values collected from Andrews’ nonorthodontic normal models proved to be adequate in combination with these lighter forces. By using these values, the anchorage needs of each patient were significantly reduced, since the apices of the anterior roots did not have to be retracted as far.

Modified torque in the maxillary and mandibular incisors: The rectangular wire of choice for us has been a 0.019 × 0.025-in stainless steel wire. It provided a balance between a larger wire that was difficult to place and did not slide well and a smaller wire that provided less tooth control and showed deflection when activated for space closure. However, this 0.019 × 0.025-in wire, with the SWA incisor torque values, did not provide adequate palatal root torque for the maxillary incisors or labial root torque for the mandibular incisors. Some patients were left with inadequate overjet and overbite. Others finished with slight Class II buccal segments or with extraction spaces in the maxillary arch that could not be closed and could not be explained by a tooth-size discrepancy. It was concluded that these clinical situations were due to the 10° of play with the 0.019 × 0.025-in rectangular wire in the 0.022-in slot. Accordingly, additional palatal root torque was recommended for the maxillary incisors and additional lingual crown torque for the mandibular incisors.10

Modified torque in the mandibular posterior segment: There were concerns about patients being
finished with an excessive curve of Wilson in the occlusion, causing hanging palatal cusps and resulting in interferences during lateral excursions. Correction of these orthodontically required additional lingual crown torque and uprighting of the mandibular posterior teeth. This uprighting torque was added progressively to the mandibular posterior segments of the new appliance.\(^{10}\)

**Modified torque in the maxillary posterior segment:** As Roth had done with his version of the SWA, we added an additional 5° of buccal root torque to the maxillary molar brackets to avoid hanging palatal cusps and the resulting interferences (Fig 10). However, the difficulty of inadequate buccal root torque in this area was frequently due to narrowing of the maxillary posterior segments relative to the mandibular posterior segments. Many times, this was observed along with a posterior dental crossbite. More frequently, there was skeletal narrowing of the maxilla relative to the wide mandibular skeletal base. In these patients, if the maxilla was expanded early in treatment and retained until the rectangular wires were placed, adequate buccal root torque in the maxillary posterior segment was often achieved with relative ease.\(^{10}\)

**Torque options in the maxillary and mandibular canine brackets:** The canines, both maxillary and mandibular, are frequently out of position. The standard maxillary canine bracket that we used featured −7° of torque, creating labial root torque, and tucking in the crowns of these teeth. Inverting this bracket to +7° of torque was helpful for maxillary canines with very prominent roots. As another option, 0° of torque for the maxillary canine brackets was useful in extraction patients to keep the roots away from the cortical plate and in cancellous bone during retraction. Since mandibular canines are most commonly inclined lingually because of contact with the maxillary canines, brackets with 0° of torque were most commonly used. In some cases, brackets with −6° of torque could be used, or they could be inverted to give +6° of torque when the mandibular canine roots were more labially or lingually displaced. In summary, canines are difficult to align, and 2 canine brackets with 3 torque options has been the most effective way to manage these teeth.\(^{9}\)

**Metal injection molding, computer-aided design/computer-aided manufacturing (CAD-CAM), and torque in base:** In the mid to late 1980s, metal injection molding became the process of choice by the major orthodontic companies in making brackets. Although it is efficient for the production of brackets, the construction of the bracket molds was expensive, so changes in bracket design were limited for cost reasons. Also, when these brackets cooled, they reduced in size, which influenced slot size. Tolerances were set so that the brackets were not allowed to be less in slot size than the 0.022-in or 0.018-in traditional sizes. Thus, metal injection molded brackets varied in sizes greater than 0.022 and 0.018 in.\(^{11}\) However, decisions on tip, torque, and in-and-out in appliances were made based on the numbers of 0.022 and 0.018 in.

About the same time, the major orthodontic companies were designing their brackets on computers, and programming machines to construct the brackets. This process was referred to as CAD/CAM. In addition, by the mid 1990s, the patents on torque in base expired, and more companies began making brackets with torque in base.

**Self-ligating appliances:** In the 1990s, self-ligating brackets became popular in orthodontics, along with promises of great efficiency and effectiveness. These were produced in both “passive” and “active” types. In the early stages of treatment, these brackets were effective in the initial alignment of the crowns of teeth. The small initial wires in a larger “closed slot” provided effective movement due to reduced friction (Fig 11). They were also popular with staff members in the initial wires stages because elastic modules and ligature ties were largely eliminated. However, when larger rectangular wires were used during the period of major tooth movement, the brackets proved to be disappointing. When a

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**Fig 10.** As Roth had done with his version of the SWA, we added an additional 5° of buccal root torque to the maxillary molar brackets to avoid hanging palatal cusps and the resulting interferences. Uprighting torque was added progressively to the mandibular posterior segments to prevent the curve of Wilson from becoming too steep during treatment.

CURRENT APPLIANCE VARIATIONS

As an alternative to metal injection molding, and with the aim of achieving greater bracket accuracy, a computerized milling system was developed. This is called computerized numerical control (CNC). With this method, a computer converts the design produced by the CAD software into numbers, and sophisticated milling machines accurately cut brackets from a solid piece of metal. This allows for a more accurate slot size in each bracket.

In-and-out values had slowly been modified over time in all bracket types. In metal brackets, the movement from full size, to midsized, and to low-profile brackets created the situation in which the canine brackets could not be made thin enough to properly match the in-and-out values of more narrow incisor brackets. Esthetic brackets were made stronger and thicker (at the expense of in-and-out values) to prevent the fracturing seen in earlier versions of esthetic brackets. Ceramic materials are much stronger today, and production of esthetic brackets with proper in-and-out values is occurring. With self-ligating brackets, in-and-out values were modified to allow for proper positioning of gates and clips. All of these issues were resolved by the introduction of accurate CNC machines. Another significant feature of CNC bracket production is the ability to make changes in bracket design by adjusting the CNC machines, as opposed to purchasing expensive molds for new bracket designs. Examples of this are maxillary molar brackets for Class II molar positioning and maxillary canine substitution brackets used when the lateral incisors are congenitally missing. These changes are easily done with CNC machines. Another improvement that has occurred along with the CNC machined brackets is the use of heat-treated wires with greater stiffness. These are used with 0.020-in round wires for canine retraction and with 0.019 × 0.025 rectangular wires for bite opening and space closure.

CONCLUSIONS

Many changes have occurred in appliance design since the edgewise and Begg appliances were designed. This has opened the potential for far more efficient treatments with higher-quality results. Attention to diagnosis and treatment planning, bracket positioning, and efficient mechanics can enhance the results along with these appliance improvements.

REFERENCES


Fig 11. We found that self ligating brackets were effective in the initial alignment of the crowns of the teeth. The small initial wires in a larger “closed slot” provided effective movement because of reduced friction. During major tooth movement with rectangular wires, the brackets proved to be disappointing.

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