A current trend in the orthodontic literature is to identify new methods for increasing the efficiency of orthodontic treatment, from the development of brackets and wires to the use of devices or surgical methods to accelerate tooth movement. It is still possible, however, to improve treatment efficiency by using basic biomechanical principles to create predictable force systems while controlling anticipated side effects.

This two-part overview will focus on the
Clinical Applications of Predictable Force Systems

most fundamental of biomechanical principles: one-couple force systems. In Part 1, the advantages of the one-couple system are reviewed, accompanied by cases illustrating simple methods for incorporating it into daily practice. In Part 2, we will present new applications of these principles using skeletal anchorage.

Intrusion and Utility Arches: One-Couple vs. Two-Couple Systems

Deep overbite, a problem frequently encountered in patients seeking orthodontic treatment, can have implications in terms of both normal function and smile esthetics. A key to the diagnosis of deep-bite malocclusions is to determine the etiology: overextrusion of the anterior teeth, undereruption of the posterior teeth, or a combination of the two. The incisor display should be examined on smiling and at rest to determine the best approach to orthodontic management. If excessive incisor and gingival display are evident, treatment should be planned to intrude the maxillary incisors.

While an intrusion arch and a utility arch appear to be similar, they exert significantly different effects, since the intrusion arch is a one-couple system and the utility arch is a two-couple system. The intrusion arch, as described by Burstone, is a rectangular TMA* overlay wire inserted into the auxiliary tube of the first molar and ligated to the base archwire at a single point between the central incisors or between the lateral and central incisors. The rigid stainless steel base archwire consists of two posterior segments and an anterior segment that bypasses the canine, allowing the anterior and posterior dental segments to function as distinct units with a collective center of resistance (CRes) that can be approximated. From a sagittal perspective, this setup produces a one-couple system with a distal tipback (clockwise) moment, an extrusive force on the molar, and an intrusive force on the incisors (Fig. 1A). It should be noted that because the point of attachment of the intrusion arch to the base archwire is anterior to the CRes of the incisors, it will generate a small counterclockwise moment. This can be controlled by using a tight cinch-back of the intrusion wire to fix the length of the wire or by using a three-piece intrusion arch (described later).

The utility arch, as developed by Ricketts, differs from the intrusion arch in that it extends from the molars and is inserted directly into the incisor brackets. This setup results in a two-couple system, with a clockwise moment on the molars and an intrabracket couple at the incisors resulting in a counterclockwise moment and incisor flaring (Fig. 1B). The force system can change dramatically if, for example, the incisors are inclined palatally or labially. The inclination of the incisors can cause the utility arch to twist upon insertion into the bracket slot, adding lingual or labial root

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torque in addition to the expected forces and moments. The torque within the bracket prescription and the material properties of the wire can also affect the force system. If lingual root torque is incorporated due to the bracket or tooth inclination, the resulting extrusive force will impede the objective of intruding the anterior segment. Since the force system of the utility arch is considerably more complex and difficult to predict than that of the intrusion arch, it clearly needs to be used with caution when correcting vertical problems.

The placement and size of the V-bend, as well as the material properties of the archwires, can significantly impact the forces and moments generated by either the intrusion arch or the utility arch. Classically, the V-bend position has been described using a “two-tooth” model of the posterior molar and the anterior incisor. In clinical scenarios, however, segments of teeth are more commonly ligated together, so that they function as posterior and anterior units. This adds complexity in predicting where each unit’s CRes is located and how that unit will respond. From the traditional two-dimensional, sagittal perspective, with the V-bend placed at the midpoint between the molar and incisor, two equal and opposite moments are generated at the incisor and the molar when both brackets are engaged. When the V-bend is moved distally to one-third the distance from the molar, a moment and vertical force are generated at the molar, with a single vertical force (and no moment) in the opposite direction at the incisor. This “one-couple system” will occur only when the two brackets are passive and the bend is placed at one-third the distance from the molar. The cantilever is an example of a one-couple system, since it is typically inserted into the molar tube with a single point of attachment to the anterior tooth. It is important to reemphasize that to generate a force without a moment, the wire must not be inserted into the anterior brackets, but rather ligated on top of the base wire segment, below or above the bracket wings. In this case, the location of the bend becomes secondary in regard to the moments and forces generated. Because additional forces and moments are present in the transverse dimension, however, we need further studies to examine these force systems in three planes of space.
The objective of any system for correcting deep overbite is to apply forces low enough to achieve intrusion while avoiding deleterious side effects such as root resorption. Although the intrusion and utility arches were initially designed with stainless steel wires, new materials like beta titanium (including TMA) and nickel titanium provide the elasticity and force-deflection ratios needed to reduce the force exerted by the V-bend and allow easier engagement into the molar and incisor attachments.\textsuperscript{8-10} Compared to Elgiloy\textsuperscript{**} and TMA utility arches of the same size in a three-dimensional model, TMA intrusion arches have been shown to generate less force at the incisors as well as lower forces and moments at the molar.\textsuperscript{11,12}

A typical indication for using a continuous intrusion arch is when overextruded upper incisors are accompanied by excessive gingival display. Figure 2A illustrates the treatment of a 12-year-old female patient presenting with this scenario. An intrusion arch fabricated from Connecticut New Arch (CNA\textsuperscript{***}) wire was overlaid and tied at the lateral incisors. Figure 2B indicates the amount of incisor intrusion achieved in five months; note the step between the upper lateral incisors and canines, indicating effective intrusion of the incisors.

\textbf{One-Couple Systems for Controlling Vertical Incisor Positions}

\textbf{Three-Piece Intrusion Arch}

For a case where even minimal proclination of the incisors is undesirable, a three-piece intrusion arch can be used (Fig. 3). In this modification, cantilevers are placed bilaterally and attached in line with the CRes of the incisors. This allows the line of force to be directed vertically through the CRes, thus minimizing the anterior moment produced by the one-couple system of a continuous intrusion arch.\textsuperscript{13,14} A light distal force can also be applied with an elastomeric chain between the molar and the anterior segment, redirecting the path of intrusion through the CRes along the long axis of the incisor instead of a true vertical.\textsuperscript{13}

Figure 4A shows a 67-year-old male patient who presented with overerupted lower incisors and a deep bite. Because the lower incisors were proclined and further flaring had to be avoided, a three-piece intrusion arch was used. Anterior and posterior stainless steel segments were placed, with the anterior segment extending distally to the level of the canines. CNA cantilevers were attached to the anterior segment distal to the incisors to approximate the CRes of the lower incisors. Note the difference in the incisor positions compared to the posterior dentition after four months of intrusion (Fig. 4B).

\textbf{Asymmetrical Intrusion Arch}

A common technique for correcting a cant of the anterior occlusal plane is to use unilateral seating elastics to extrude the undererupted dentition. Because the elastics are anchored between the arches, however, the opposing dentition may be extruded, which is not always a desirable effect.\textsuperscript{15} Moreover, the cant may require intrusion of one side rather than extrusion of the contralateral side, which is not possible to achieve with intermaxillary elastics. A more predictable method is to tie a continuous intrusion arch to the anterior segment on the side requiring intrusion. Again, the base archwire is segmented into posterior and anterior components to allow the anterior segment to

\textsuperscript{**}Registered trademark of Rocky Mountain Orthodontics, Denver, CO; www.rmortho.com.

\textsuperscript{***}Trademark of Henry Schein Orthodontics, Carlsbad, CA; www.henryscheinortho.com.
terior dentition. To create a more predictable force system, anterior and posterior wire segments were placed, and a cantilever extending from the molar tube was attached distal to the left lateral incisor. Figure 5B shows the patient seven months later, with the anterior segment leveled and ready for placement of a continuous wire.

**Extrusion Arch**

As its name implies, the extrusion arch is similar to the intrusion arch, but with the wire move freely. One drawback is that the free, untied side of the intrusion arch can extend or bow toward the vestibule, potentially causing irritation for the patient. A modification of this one-couple system is to extend a unilateral cantilever anteriorly from the molar auxiliary tube and hook it onto the anterior base-wire segment.

Figure 5A illustrates a case in which a unilateral cantilever was used to correct an anterior cant with overerupted upper left incisors. Initial placement of a continuous wire would have extended the cant distally by extruding the left posterior dentition. To create a more predictable force system, anterior and posterior wire segments were placed, and a cantilever extending from the molar tube was attached distal to the left lateral incisor. Figure 5B shows the patient seven months later, with the anterior segment leveled and ready for placement of a continuous wire.
inverted for incisor extrusion. Although anterior box elastics are often used for the correction of anterior open bites, they can also cause undesirable extrusion of the opposing incisors. An extrusion arch is a more reliable method for extruding the incisors in a single arch. To prevent any posterior extension of the open bite, the stainless steel base archwire is again segmented. The overlaid extrusion arch extends from the molar and is tied at a single point to the anterior base arch. The V-bend is placed adjacent to the molar attachment, producing a counterclockwise moment and intrusive force at the molar and an extrusive force at the incisor.

Fig. 6 Force diagram of extrusion arch.

Fig. 7 A. Initial placement of extrusion arch with intermaxillary elastics to control posterior segment in 14½-year-old male patient. B. Bite closure noted two months later. C. Placement of continuous wire after four months of extrusion-arch treatment.
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Class II elastics were used to control the counterclockwise moment on the posterior segment and thus prevent development of a lateral open bite. Two months later, some bite closure could be seen (Fig. 7B); after another two months, a continuous wire was placed (Fig. 7C).

One- and Two-Couple Torquing Arches

The classic torquing arch, extending from the molar tube and engaged directly into the incisor brackets, is another example of a two-couple system with intrabracket couples at both the molar...
and incisor segments.17 The V-bend is placed adjacent to the incisor segment to allow for a large anterior moment. As discussed previously, however, it is challenging to predict the sizes of both moments in a two-couple system. If the torquing arch can move freely, the system will result in a counterclockwise moment and extrusion at the incisor segment and intrusion at the molar (Fig. 8A). If incisor crown tipping needs to be avoided, a tight cinch-back of the torquing arch can be placed distal to the molar to generate a distal force against the incisors.17

The torquing arch can also be designed as a one-couple system: a point contact is created on the posterior base archwire by means of a hook, and only the incisor brackets are engaged. When the V-bend is placed closer to the incisor segment, a counterclockwise moment and extrusive force are generated at the incisors, and an intrusive force is exerted on the posterior segment (Fig. 8B).

Figure 9A shows a case in which the maxillary central incisors needed lingual root torque. The central incisors were co-ligated, and a rigid stainless steel base archwire was engaged through the posterior dentition, bypassing the incisors. The base archwire was designed to lie flush against the labial surfaces of the incisor crowns and directed beneath the bracket wings to control flaring and extrusion of the crowns. Note the improvement in central incisor torque after five months (Fig. 9B).

![Fig. 10 A. Force diagram of cantilever for extrusion of maxillary canine (red cantilever indicates occlusal activation), with remaining teeth bracketed and base archwire used for anchorage. B. Force diagram of cantilever with posterior anchorage from fiber-reinforced composite (FRC).](image)

![Fig. 11 A. Limited treatment of 47-year-old female patient requiring extrusion of upper left canine, showing initial placement of cantilever and FRC bonding of posterior segment. B. Canine extrusion after three months of treatment.](image)
One-Couple Systems for Controlling Movement of Single Teeth

Cantilevers for Extrusion and Intrusion

The intrusion and extrusion arches described above are used to control segments of teeth, whose centers of resistance can vary in all three dimensions. The CRes of a single tooth may be less variable and easier to predict, making a cantilever the simplest one-couple system. Lighter forces can also be applied to move single teeth, thus reducing unwanted side effects on the anchorage segment.

Figure 10A illustrates one of the most common applications of a cantilever, for extrusion of a maxillary canine. The cantilever is fabricated with a V-bend mesial to the molar, then inserted into the molar auxiliary tube, activated with an occlusal bend, and engaged with a single-point contact at the canine. This setup produces a vertical extrusive force on the canine and a vertical force and moment on the molar. A rigid stainless steel base archwire on the remaining dentition counteracts side effects at the molar. Alternatively, the posterior segment can be reinforced as a unit by bonding brackets only to the posterior teeth with a segmented base archwire or by bonding the entire unit with fiber-reinforced composite (FRC, Fig. 10B).

Figure 11A shows a patient who required limited treatment to force eruption of the upper left canine and increase its biological width for crown preparation. After endodontic treatment of the canine, the premolar-to-first-molar segment was secured with FRC. A CNA cantilever was extended from the molar bracket to a point of contact on the superior surface of the canine bracket. Figure 11B demonstrates the stability of the posterior segment after three months. The patient then had a new crown restoration placed without further orthodontic treatment.

In a case where a single tooth has overextruded, an initial phase of cantilever mechanics can be utilized to level the tooth with the adjacent dentition before engaging it with a continuous archwire (Fig. 12). This will help limit extrusive side effects on the adjacent teeth.
Figure 13A shows a patient in whom the lower right canine was overextruded. The remaining dentition was leveled with a rigid stainless steel archwire, leaving the canine free. An intrusive cantilever was extended from the canine to the molar tube. With the rest of the mandibular arch serving as a rigid anchorage unit, minimal side effects would be expected from the clockwise moment at the molar. Figure 13B shows the difference in the canine bracket level two months later. At five months, the canine was nearly level with the adjacent dentition, and a continuous nickel titanium archwire was placed (Fig. 13C).

### Cantilevers for Transverse Correction

Another application of the cantilever is for transverse corrections such as buccal movement of a single tooth. The same force system described from a sagittal perspective can be converted to an occlusal view (Fig. 14). The cantilever is inserted into the molar tube, with a V-bend extending buccally in the transverse plane. This will produce a clockwise (mesial-in) moment or 1st-order rotation and a lingual force at the molar and a labial force on the tooth to be brought into the arch. A rigid, continuous stainless steel base archwire can be used in conjunction with a transpalatal arch to prevent rotation and lingual displacement of the molar.

Figure 15A illustrates a case in which the upper right canine had erupted palatal to the remaining dentition. Engagement of a continuous wire would have been difficult and would have caused significant palatal tipping of the adjacent teeth. Instead, stainless steel wire segments were placed, and an .032” TMA transpalatal arch was attached to the first molars. A CNA cantilever was extended buccally from the molar and tied at a single point to the canine bracket. Figure 15B shows the patient seven months later, when a continuous nickel titanium archwire was placed to incorporate the canine.

### Uprighting Spring

While it is often advantageous to apply a single force and no rotational moment to a single tooth, there are cases in which such a moment is actually desirable. In another application of the cantilever—commonly referred to as an uprighting spring—a force and a couple are applied to a single tooth.
tooth for uprighting. A bracket is bonded to the tooth, and the cantilever is hooked to the base archwire and engaged in the bracket, resulting in 2nd-order movement of both the crown and the root (Fig. 16). Crown movement can be controlled by applying a light force in the opposite direction with an elastomeric chain or by co-ligating the tooth to the adjacent teeth.

Figure 17A shows a patient with a severely tipped lower left canine prior to orthognathic surgery. A predictable force system was needed to upright the canine and minimize the duration of presurgical orthodontic treatment. First, a light elastomeric chain was applied to derotate the canine by applying a distal force with anchorage from the posterior segment. Two months later, an uprighting spring was placed to produce distal root tip and mesial crown rotation (Fig. 17B). At four months, the crown position had improved but further root correction was required. An elastomeric chain was then extended from the posterior segment to apply a distal force to the canine and thus restrict further mesial crown tipping (Fig. 17C). Once sufficient uprighting was seen, the surgical archwires were placed. Note the canine correction after mandibular advancement surgery, 12 months into treatment (Fig. 17D).

![Figure 16](image1.png)  
*Fig. 16 Force diagram of uprighting spring for mandibular canine correction.*

![Figure 17](image2.png)  
*Fig. 17 A. Presurgical 46-year-old female patient requiring considerable uprighting of lower left canine. B. Placement of uprighting spring two months into treatment, after initial derotation of canine. C. Improved inclination of canine after two months of treatment with uprighting spring (four months of total treatment). D. Patient following orthognathic surgery, 12 months after initiation of orthodontic treatment.*
Conclusion

This article has described conventional methods by which one-couple systems can be utilized to achieve predictable and efficient effects. It should be noted that the biomechanical principles described here have been a review of the classic literature regarding these force systems. A major limitation of the classic models is that they have all been described from a two-dimensional perspective, whereas many changes are often noted in other dimensions. For this reason, studies using both in vivo measurements and well-designed three-dimensional models need to be conducted to better understand how archwires function in all three planes of space, so that clinicians will be able to use these techniques with optimal efficiency and predictability.

(TO BE CONTINUED)

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REFERENCES