Force Control in Orthodontia*

Cecil C. Steiner, D.D.S.

Los Angeles, California

Lately, much has been written about the relative virtues of various orthodontic appliances. Considerable criticism has been voiced against orthodontic procedures in general and certain appliances in particular but, to my knowledge, an analytical discussion of the mechanical principles of these problems, from the point of view of force control and of jiggling, has not been given.

As far as I am capable of doing and as space will permit, it is my intention, herein, to trace out the meaning behind these powerful and mysterious words which we use so fluently, too often as mystic wands to brush aside problems that are deserving of more serious consideration.

Webster gives us the following definitions:

Jiggle: To move in an affected or awkward manner; to move unsteadily up and down or backward and forward; to rock or jerk lightly or rapidly.

Force: Any cause that produces, stops, changes or tends to produce, stop or change the motion of a body.

Control: To exercise a directing, restraining or governing influence; to direct; regulate; manage.

This all seems very simple and easy to understand and, from the definition, it becomes obvious that jiggling in an orthodontic appliance is unphysiological and so undesirable. Let us, therefore, see where it might occur. For the purpose of discussion we will admit that, mechanically, an ideal appliance should deliver to a tooth a continuous, unrelenting, measured force of constant and uniform intensity in the direction in which it is desired to move the tooth. To avoid jiggling, as we understand it, it should do one thing more. It should resist the movement of the tooth in the opposite direction by a force which has sufficient margin of safety to prevent any possible recurrent movement of the tooth by any other forces brought to bear upon it during treatment. Nothing so far conceived can meet this latter requirement better than the jackscrew, as Dr. Angle applied it, for it certainly delivered a positive force in a given direction without back-lash. But how about its meeting the other requirements? Was this force contin-

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uous and unrelenting and was it continuously of equal intensity? It was mechanically possible that these conditions could have been met if the screw could have been advanced continuously during all of the time the case was being treated. But this was not practicable. Actually, the screw was advanced about once a week, which meant that the force which, theoretically, should have been portioned or doled out to the tooth or teeth over a week's time, was all given out during, let us say, one minute; no additional force was added until the following week. Theoretically, the jackscrew embodied force control and the elimination of jiggling better, probably, than anything else so far conceived. Practically, its clinical application brought forth difficulties which made impossible the taking advantage of these possibilities. Intermittent force, therefore, is the price generally paid for stability and lack of jiggling.

What is the requirement, then, lacking in the jackscrew and, hence, necessary to supply in another appliance to make it more ideal? My first answer would be,—a store-house of power. But it is more than that. It is a store-house in which power can not only be stored but also doled out or fed back to the teeth, evenly and continuously, in a measured and constant intensity.

How about rubber, then, either under compression or stretched as a band, say from molar to bicuspid, as previously discussed before this Society? Here, probably, is the store-house of power, which gives a measured force back to the teeth most evenly, as clinically applied, because of its extreme elasticity. It acts more evenly over a greater distance than anything else so far employed for the purpose. The direction of its applied force is ideal for it operates continuously between given points and certainly can be applied in a relatively unrelenting manner. But how about our last requirement, stability? Even though the force is active, ideally, in the desired direction because of this perfect elasticity, yet rubber probably falls shortest of any material in achieving stability. In its use, back-lashing or a reverse movement of the tooth is resisted only by the same force that acts to move the tooth in the desired direction and this, necessarily, leaves it totally unsupported in other directions. Therefore, other forces, acting upon the tooth in opposed directions, predominate over the force active in the desired direction, as soon as they exceed the pull of the rubber in this direction. This, then, is the price paid for elasticity, for it must be remembered that there are tremendous natural forces, normally working on and about the teeth through occlusion, and these forces are constantly redirected as the teeth are moved.

How about metal as a store-house of force? Of course certain metals or combinations of metals possess elasticity and can be made to serve our purpose. But, clinically, because of other requirements to make them practical for use in the mouth, the group of such metals is restricted to the precious metal alloys. How, then, is elasticity gained in this limited group?

First, by properly combining certain metals into an alloy which has the property of elasticity. Second, by so distributing and proportioning this alloy, in the creation of the appliance,—in other words, by so designing it—that the forces applied to its various parts will so distort its resting form that power, in proper proportion, will be imprisoned within its various parts. This brings us to a consideration of what are the requirements or design for this assumption and distribution of force. First, the elasticity of a metal is not dependent upon the distribution of the metal. Its elasticity is a constant factor. When a metal wire can be bent and will recover its original size and shape, we say it possesses elasticity. Fashion it into a round ball and apparently we can not bend it, but the metal still possesses its original degree of elasticity. The amount of possible distortion of the elastic metal, then, is dependent upon the relation of force to resistance in the various parts of the metal, in accordance with the laws of elasticity, a knowledge of which we must here grant, for lack of space. The amount of resistance to distortion, in a given alloy, is dependent upon the distribution or design, size and shape in which the alloy is used. Force in orthodontia is generally applied through levers and these vary in resistance to distortion according to design. For instance, a round wire of given length and diameter can be bent twice as far with the same amount of distortion of the metal within the wire, as a wire of the same length and of twice the diameter. In such bending the metal on the inside of the bend is compressed and that on the outside stretched, plus a slight diagonal distortion in the cross section. The same length of wire of twice the diameter necessitates twice the amount of compression and elongation of the opposite sides to accomplish the same degree of bend, because of the laws of levers. In like manner, a wire of a given diameter and length will bend a given distance with half the compression and elongation of the two opposite sides as one of the same diameter and of one-half the length, because the compression and elongation of the two sides are distributed over twice the length of wire.

Now, if we recall that, in orthodontic procedures, the power stored in the metal, through such distortion, is fed back, generally, through principles of leverage, we immediately see how complex this storing and releasing of force may become and how easily force *control* may give way to jiggling.

In actual use, particularly during the acts of mastication, many forces are generated outside of the appliance and are brought to bear upon it. As this happens, further distortion of the wire takes place in the appliance in such manner that the combined forces acting upon it become balanced, by resistance, and this resistance must be generated by distortion in the metal itself, plus resistance carried through the appliance and teeth to the supporting tissues. This external pressure is variable and therefore brings a variable pressure upon the teeth. This, according to our definition, produces jiggling. But this is not all. As the appliance itself absorbs and releases this force, through distortion and relaxation of the metal, not only a variable pressure is carried through it to the teeth, but, because of this distortion, the direction of the forces, from the appliance to the teeth, becomes variable. Actually, this power is delivered and released in such a complexity of curves that it is difficult to completely analyze them. This is, undoubtedly, the most destructive type of jiggling, for, not only is the pressure variable but the direction, as well, and this certainly must be most destructive to the affected tissues.

Archimedes once said, "Give me a lever long enough and a place to stand and I will move the earth." He could have said, "Give me enough leverage on a bar of metal, I care not how big it is, and I will bend it." The principle of leverage is such an integral part of an orthodontic appliance and may be so intimately associated with jiggling that this paper would not be complete without a consideration of it. It is difficult to conceive of the application of force in any orthodontic appliance that does not bring the laws of levers into play. "To every action there is an equal and opposite reaction," is a first principle of physics. In an orthodontic appliance, for every force applied there is an equal and opposite force exerted. Both of these forces are generally exerted through levers and the levers are generally of unequal length. Because of the action of levers, these forces are often shifted back and forth until they are absorbed and offset in a maze of various directions.

Take, as an example, a simple elastic round archwire to which all of the teeth in the jaw are passively fastened with ligatures, with the exception of the central incisors, which are lingually displaced. Now, tie the archwire to these centrals and see what happens. The wire is resisted from moving bodily lingually by contact with the two lateral incisors. These resisting teeth thus become the fulcrum of a lever, the archwire, for the force also passes through the archwire to the cuspids, but there it acts in the opposite direction. As the cuspids begin to give way, the force passes to the first bicuspids and so on until, through tooth movement in the various parts, the archwire again finds its position of rest. Now, the point is, that as the laterals are displaced lingually, the resistance is thrown backward onto the adjoining teeth. At the same time, the centrals are being displaced forward.

Eventually the time arrives when the load of the levers, the centrals, has so moved forward that the fulcra, formerly the laterals, have moved backward and the cuspids have become the fulcra. The centrals and laterals are now both load, and the laterals change their direction of movement and move forward. This change is passed backward from tooth to tooth until all of the power stored in the archwire has been delivered. This means that probably all of the teeth, except the centrals and the last molars, have been moved in at least two directions and these directions are nearly opposite. This is jiggling in the true sense.

Now complicate this little example by fixing the archwire to the various teeth with stationary attachments as is done with the ribbon arch and brackets. As soon as the archwire is displaced into the lingually placed central brackets, in addition to the various results just outlined, rotation of the laterals will also come into play to bring the centrals forward. The leverage to cause this rotation is the length of the archwire from the attachment of the centrals to the attachment of the laterals. This is further complicated by the fact that the attachment is not in the center of the long axis of the tooth. As this anchorage gives way, the lateral will be rotated mesially and immediately the direction of force eminating from the archwire beyond, is changed. It will then act to rotate the cuspids, but in the opposite direction and, as they give way, the bicuspids will receive the stress again, but in the opposite direction. Thus the force passes backward in a zigzag manner to the cuspids and bicuspids. These teeth are then not only being jiggled back and forth, but around and around, as well.

Under leverage, loops and coils deserve consideration, for they are created and employed in order to apply the laws of leverage upon the metal to distort it for the purpose of storing power and changing the direction of its action.

The word loop, like the words, "jiggle" and "force control", too often sends our minds scampering to a hasty decision of condemnation without due consideration. A true loop is a complete folding back upon itself. The term "loop", as commonly applied in orthodontia, is really a partial loop. Remember, then, that an archwire of any type commonly used, in present orthodontic procedures, is purely and simply a loop in principle, as we have applied it. Every time an archwire is distorted, by fastening it to a misplaced tooth, force is stored in it by the creation of a minor loop. The common procedure of tipping teeth back in single or mass movement is possible only through the principles of single and multiple loops. Therefore, loops are deserving of serious thought.

Take a piece of round wire four inches long, as an example. In all of its parts it possesses equal elasticity. It would take varying degrees of pressure to distort it in various directions because of the fact that pressure would be brought to bear on various parts of the metal, generally through the laws of leverage, and this leverage would vary tremendously in the various parts. For instance, a given pressure applied along the long axis of the metal would distort it only microscopically, since no leverage would be brought into play. With one end fixed and this pressure applied to the other end at right angles to the long axis of the wire, a four-inch-to-the-wire-diameter lever would be brought to bear on the metal at the sides of the wire, at its periphery, and a four-inch-to-zero mean lever at the center. Distortion would occur in a diminishing eccentric arc, beginning with a four-inch radius.

With the two ends fixed and pressure applied in the middle of the wire at right angles to its long axis, a two-inch-leverage-to-the-diameter-of-the-wire would be created, with proportionate distortion. Because of double lever action, distortion at this point would be a straight line in the direction of force application.

With one end fixed and with torque at the other, leverage would be diameter-to-diameter at the periphery, graduating to diameter-to-zero at the center.

Now let us introduce a downward loop into the middle two inches of this four-inch wire. If the sides of the loop approximate, we will have shortened the wire, horizontally, by two inches, with a loop one inch high. Fix one end and apply pressure at right angles through the long axis of the wire. There will now be only a two inch-leverage to distort the wire, but four inches of wire to distort. In other words, in the same space length, we have introduced twice as much wire, therefore the end must be displaced twice as far before the wire would store the same amount of force as would occur with a straight two-inch wire. Likewise, the same amount of force would be fed back over twice the distance. This, then is a means of increasing elasticity in a given distance, though accompanied by compensating ills. Now apply pressure, horizontally, through the long axis of the two ends. There will be no leverage on the end portions, therefore practically no distortion there. In the loop portion, there will be a one-inch leverage on two inches of wire. This is a means of storing force in the direction of the long axis of an arch. Let us now open the loop. By so doing, the vertical height is diminished and the leverage in the loop portion is reduced proportionately, but the length over all is increased so that lateral leverage is increased. Apply pressure through the long axis of the end portions and the loop is distorted by closing; as it does so its vertical height is increased.

In addition, the end portions change their directions and by so doing become an extension of the loop, further increasing the vertical height over-all with kindred changes of leverage upon the metal of the various parts of the wire.

It can be easily seen that power is thus stored efficiently because of the great amount of distortion due to stress through leverage brought to bear on the metal. It is likewise apparent, however, that, though this power is so stored as to enable it to be fed back, it is not fed back in straight lines but in complex eccentric curves. Also, that because of the great amount of elasticity, it, of course, permits back-lash and lacks stability.
increased and force control diminished.

Coils are but a series of loops by which the laws of levers are brought to bear upon the metal of the wire in such a way that pressure will distort the loops laterally, thus storing power. Because of these loops, greater flexibility of the wire is gained and power storage and delivery is accomplished in the direction of the long axis of the coil. Because of its extreme elasticity, it, of course, premits back-lash and lacks stability.

In all of these examples we have considered the bending, power-storing and power-releasing principles of a round wire which possesses resistance to distortion at right angles to its long axis equally in all directions. Let us now consider a square, and then a rectangular wire and mentally apply these additional principles to the foregoing examples.

We have seen that elastic round wire bends because force is brought to bear upon it through the laws of levers. Also, that length to cross-section establishes the amount of this leverage. In a round wire, the cross section or diameter is equal in all directions. Therefore, the leverage is the same in all directions.

A wire, say .022″ square, is, in cross section, .022″ each way. Therefore, in bending such a wire, the leverage on the metal at the periphery is length-to-.022″ each way upon its flat sides, which causes equal distortion of the sides of the metal in both directions, causing equal resistance to force. In cross section, diagonally from corner-to-corner, the distance is not .022″, but .031″, and, therefore, in bending, the leverage upon the metal at the periphery in this direction is length-to-.031″, and also, in this dimension, the relative distribution of metal is not the same. It is obvious, then, that this wire offers varying resistances to bending in the various directions. Therefore, a force brought to bear upon it in one direction is liable to be perverted into another direction because of a lesser resistance in that particular direction.

If we now consider rectangular wire, we will see that, because of its form, the laws of levers create a still greater variance in the resistance to bending in the various directions and as a consequent, there is a greater tendency for the wire to bend in the line of least resistance rather than in the exact direction in which the force is applied.

It is obvious that these principles are of great importance in the consideration of force control. Not only do they complicate the storage and delivery of force, but they can be used to direct its distribution as well.

I have presented this necessarily superficial consideration of some of the principles underlying the mechanical procedures, first, to call to mind the complexities of these principles in order to stimulate deeper thought upon them; second, to show that in the consideration of appliances we must not condemn, condone or accept, as perfect, anything without looking for all that is good as well as all that is bad as measured by the yard-stick Dr. Angle gave us,—physiology, dynamics and art. It seems obvious that, dynamically or mechanically, the most ideal appliance so far conceived is not necessarily one which possesses each individual desirable quality 100%, but rather one in which these qualities are so blended and balanced, by concession on the one hand to accomplishment on the other, that the greatest possible efficiency is gained in the whole.

1014 Roosevelt Bldg.