Intrabracket space and interbracket distance: Critical factors in clinical orthodontics

George F. Schudy, DDS, MS, and Fred F. Schudy, DDS
Houston, Texas

The engineers who designed the Houston Astrodome, Walter Moore and Associates, were engaged to study the effect that different edgewise appliances have on the function of orthodontic beams or wires. They were supplied with tooth width, bracket width, wire size, slot size information, and stainless steel wire specifications. With these data their computer was programmed to model each appliance as a simple beam reflecting its different support conditions. In the study the 0.018, 0.022, and 0.016-inch traditionally slotted appliances were tested in single and twin brackets. In addition the 0.016-inch bimetric appliance (0.016 inch on anterior teeth, 0.022 inch on posterior teeth) was tested. The following wires were used for testing: 0.016 x 0.022 inch, 0.017 x 0.022 inch, 0.018 x 0.025 inch (0.018 inch); 0.018 x 0.025 inch, 0.019 x 0.025 inch, 0.022 x 0.028 inch (0.022 inch); 0.014 x 0.018 inch, 0.015 x 0.019 inch, 0.016 x 0.022 inch (0.016 inch and bimetric). The results as stated in the conclusion statement by Rick Horn, PhD, of Walter Moore and Associates, are (1) for a given appliance and wire size, the amount of deflection allowable at permanent set decreases with decreasing size of teeth; (2) for a given appliance and wire size, the force imparted to the teeth at permanent set increases with decreasing size of teeth; (3) for a given appliance, the amount of deflection at permanent set decreases with increasing wire size; (4) for a given appliance, the force imparted to the teeth at permanent set increases with increasing wire size; (5) the amount of deflection allowable at permanent set is larger for single brackets than double brackets and larger for bimetric brackets than single brackets; (6) the force imparted to the teeth at permanent set is smaller for single brackets than double brackets and smaller for bimetric brackets than single brackets; and (7) of the six types of appliances examined, the bimetric appliance is the most flexible, allowing the most deflection at permanent set with the smallest force imparted to the teeth. This study supports the following thesis: the only way to take advantage of smaller wires and thereby have an appliance deliver maximum resiliency with lighter forces and not loose control is through differential slot sizing. (AM J ORTHOD DENTOFAC ORTHOP 1989;96:281-94.)

For years the orthodontic specialty has been drawn toward wire bracket combinations that produce a loose fit around working wires. This intrabracket space around our wires makes chairside operations easier and promotes patient comfort. Even though metallurgy has improved and wires today are more flexible, we still avoid precision finishing with the inevitable stainless steel wire. Unfortunately loose wire bracket combinations compromise control and undermine the pretorquing precision that our appliances possess.

The authors also enjoy the ease of manipulation and patient comfort that is promoted by having intrabracket space around wires. However, the recognition that 0.014 x 0.018-inch, 0.015 x 0.020-inch, and 0.016 x 0.022-inch wires are the largest rectangular wires necessary and that treatment (especially leveling and torquing) proceeds faster and less painfully with these wires called for a change to a 0.016-inch anterior bracket to maintain control.

8/1/16144

Because the value of play or *intra*bracket space around small wires in the buccal segments is thought to be substantial, our appliance remains 0.022 inch (or 0.018 inch if one prefers) in the posterior segment. The terminal area has control with a smaller buccal tube. This *differential slot sizing* for selective control is called the bimetric principle and has been used for 17 years.

Although this concept appears to comply with common sense, some have questioned the rationale and the actual quantitative impact of such a mechanical arrangement. This article will discuss arch wire efficiency from a practical viewpoint and will report on the first quantitative study of the impact of intrabracket space on the function of orthodontic wires. The effect of *inter*bracket distance and the efficiency of the popular edgewise appliances were studied also.

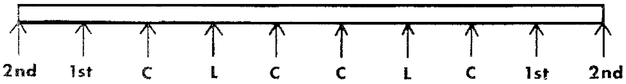

Fig. 1. Occlusogingivally an orthodontic arch wire is analogous to a simple beam supported at various intervals. The analytic technique used accounted for variances in tooth size, wire size, bracket width, and bracket spacing.

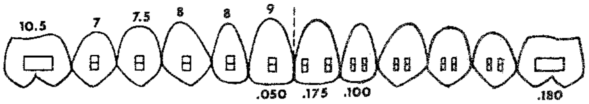

Fig. 2. Specific tooth widths (millimeters) and bracket widths (inches) used in the study.

It is difficult to find unanimity of thought among orthodontists. However, regardless of how different our treatment philosophies or mechanics might be, we should *all* be able to agree on certain desirable characteristics or working effects of the wires we use. We all find it desirable to have our wires as *uncomplicated* and easy *to fabricate* as possible. We also find it desirable to have our bends approach as closely as possible a one-to-one ratio with resultant tooth movement. And we would all like our wires to have the capability of simultaneously performing as many different types of needed orthodontic movements as possible-that is, rotating, leveling, and torquing. This could be described as *integrating treatment* functions. Our profession has forgotten or ignored for some time the importance of interbracket space and intrubracket space and their effect on the achievement of these goals for our wires. In the following pages, we will (1) discuss orthodontic appliance setups in relationship to the above-mentioned goals, (2) report on a computer study of wire function in different models of orthodontic appliances (Figs. 1 and 2), and (3) show some treatment applications with two revolutionary new light wires (0.015 x 0.019 inch and 0.014 x 0.018 inch) used in the bimetric adaptation of the edgewise appliance.

APPLIANCE DESIGNS IN RELATION TO DESIRABLE WIRE CHARACTERISTICS

Uncomplicated, easy to fabricate

The greater the arch length discrepancy present in a malocclusion, the further we are forced to depart from this goal. We must place loops in our wires to bring their forces down to a level that the patient can tolerate and one that permits wire engagement without a permanent set. Loops, of course, decrease the force and increase the range of our wires. Looped arch wires require greater time to bend and, if bent at the chair, consume valuable chairtime. If they are premade indirectly, they still require excess time to bend; and, of more importance, their fabrication requires a much more skilled technician. In addition these looped arches present hygiene and tissue tolerance problems.

There are several conventional ways to minimize phase where good edgewise control is not possessed.

1. We can work our way through a series of round wires, starting with one small enough to be tolerable to the patient. This method avoids loops and is easier on the patient, but it is very slow. It lengthens the period of round wire use and therefore prolongs the treatment phase where good edgewise control is not possessed.

2. We can use the largest slotted edgewise bracket possible and perform much of the treatment with either round wires or small rectangular wires using as much intrubracket space as possible. This practice reduces the total number of arches used and also decreases the necessity for loops, but it has the inherent disadvantage of prolonged lack of precise torque control. Under such conditions the teeth roll around the arch wire, causing a need for unexpected torquing of teeth that were previously thought to be correct. Under these circumstances "routine" high-quality finishing is difficult, often requiring much more treatment time. Positioners frequently are necessary.

3. The use of small wires is another way to avoid loops. By virtue of size alone, smaller wires are more flexible and have a greater range of activity. Smaller wires, however, when used with large brackets have too much intrubracket space and suffer the disadvantage of poor control as noted previously.

4. We may use the newer nickel titanium wires in the initial stages of alignment. These wires certainly offer a great deal of flexibility but generally suffer the serious disadvantages of bending poorly and high cost. Even with the use of this type of wire, it usually is necessary to use stainless steel wires for the last half of treatment.

5. We can avoid loops and keep our wires easy to fabricate with an appliance that interferes as little as possible with the action of our wires. We fail to remember that the bracket itself interrupts the action of wire. Each time a wire is surrounded by a bracket, its action is essentially discontinued, especially in close-fit conditions. The wider the brackets on an appliance, the less the "uncovered" or active wire left to move the teeth. This is why twin brackets are less efficient than single brackets. Any long span of wire is more flexible than a shorter span of a similar wire.[1] The longer span of "active" wire in a single bracket appliance is more flexible and therefore will bend farther before permanent set occurs. As a consequence, single brackets allow use of fewer multilooped wires and less nickel titanium wire.

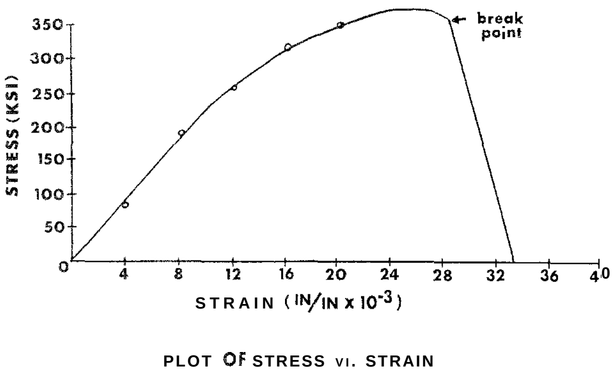

Fig. 3. Stress versus strain curve for stainless steel No. 303. Stress is force divided by area; strain is the amount of elongation divided by the length of the test area. Infinite bending occurs at set or yield point.

In summary, there are primarily two *efficient* ways to minimize the number of multilooped arches we use: (1) use an appliance that automatically has a maximum amount of "working wire" or interbracket distance and (2) use smaller wires where a lack of control is acceptable and take advantage of the maximum *intra*bracket space.

Full mechanical potential

Two conditions must exist for a given bend in an arch wire to reach its full mechanical potential and therefore express itself completely in resultant tooth movement.

1. In the act of "seating" the wire, it must not be stressed past its elastic limits (Fig. 3).
2. The wire must deliver a force that is compatible with the physiology of tooth movement.

This article will deal primarily with the first condition. *Inherent wire properties* and the *mechanical environment* within which the wire functions (since this changes local wire properties) control whether or not our wires work to their full mechanical potential.

Small wires have more range or flexibility than larger wires and therefore bend farther before taking a permanent set. A 0.016 × 0.022-inch wire is 17% more flexible than a 0.017 x 0.022-inch wire, 38% more flexible than an 0.018 x 0.025-inch wire, and 70% more flexible than a 0.022 x 0.028-inch wire. It behooves us to make use of smaller wires whenever possible. The use of the larger wires with less range limits mechanical efficiency since they are frequently stressed beyond their limits by the forces of mastication. In addition their greater force development hurts the patient to the extent that placement of the wires must be delayed until brackets are ideally aligned. To the clinician this means more arch removals and additional arch wires.

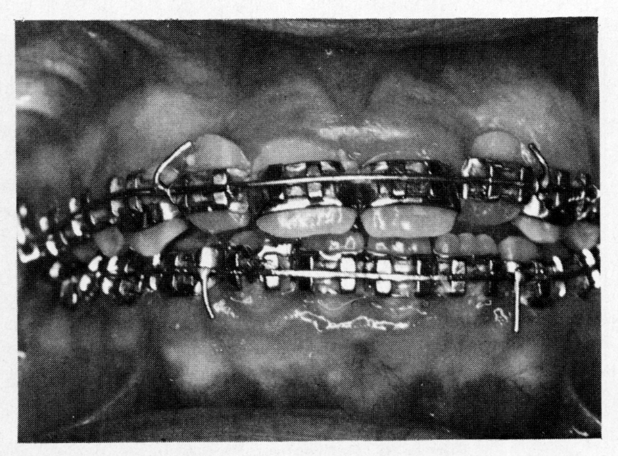

Fig. 4. Brackets shown are so wide that the inactive wire within the brackets is wider than the active wire between the brackets.

The best mechanical environment is created through the use of narrow width brackets because they have the least limiting effect on the action of wire. As noted previously, every time a wire is placed in the confinement of a bracket, its action is interrupted. In essence the bracket is a *dead spot* that functions like an annealed area. Obviously then the wider the appliance's bracket, the greater the "dead area" of its wires and the less active or working area. Note the example of extremely wide brackets in Fig. 4. In this case there is significantly more *dead* wire "in" the bracket than active wire '"between" the brackets. Diminishing the working area diminishes wire effectiveness and makes treatment inefficient and slow. By definition then, any traditional appliance with double width or Siamese brackets has severe limitations in providing an ideal environment for wire function so that more mechanical potential can be realized. A similar effect also applies to any appliance that incorporates the routine use of large rectangular wires.

Integrated treatment functions

In the past we thought of orthodontic treatment as a process that unfolded in rather distinct stages. First, we corrected rotations and did some leveling with round wires, then we continued with round wires until bracket alignment was such that we could use rectangular wires. With these rectangular wires, we finished leveling. After the bite was open, we closed spaces and made finishing arches for final positioning. Such "phase" treatment requires unnecessary arch wires, consumes chairtime, and extends overall treatment time. Integration of anterior alignment, space closure, leveling, and torquing make treatment easier, more efficient, and usually shorter. To achieve more integrated treatment, we need to do two things in particular: (1) use sectional arches on the lower arch in extraction cases to take advantage

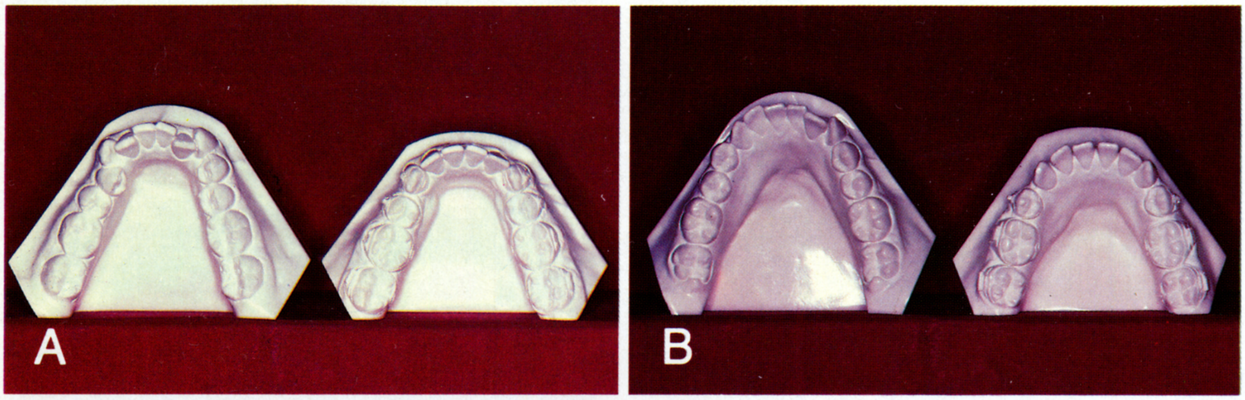

Fig. 5. A, Pretreatment lower teeth of a 27-year-old woman and a 4-month progress model after sectional arch retraction of canines. A light intraoral elastic was used to consolidate some lower anterior spacing. **B,** Pretreatment lower teeth of a 13-year-old girl and a 6-month progress model after sectional arch retraction of the first premolars.

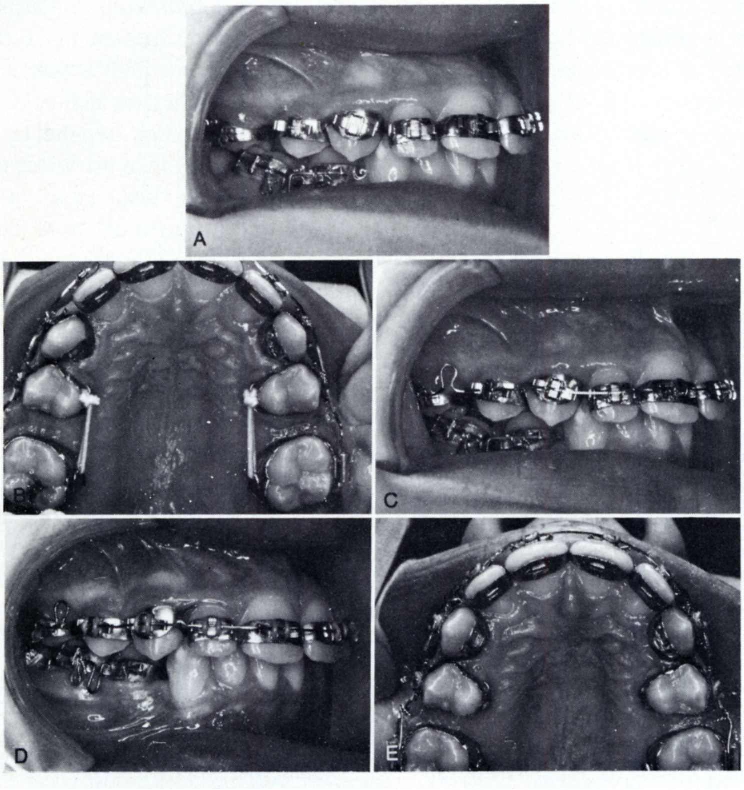

Fig. 6. Treatment sequences showing the early use of rectangular wire with the bimetric appliance. At the time views A, B, and C were taken, the $\underline{3|3}$ were banded and a new 0.014 x 0.018-inch wire was placed. Views D and E show progress 4 months later. During this time the wire was removed once. Note the improvement in axial inclination during rotation of the right canine.

of physiologic drift[2] or migration and (2) advance to a rectangular wire early in treatment.

When sectional arches are used as they were in the case illustrated in Fig. 5, the anterior teeth follow the teeth being retracted and improve their alignment automatically. After sectional therapy the less crowded anterior teeth can be "banded" easily without any separation or bonded with more accuracy. This procedure integrates space closure, alignment, and the correcting of rotations. In short it is more efficient and easier.

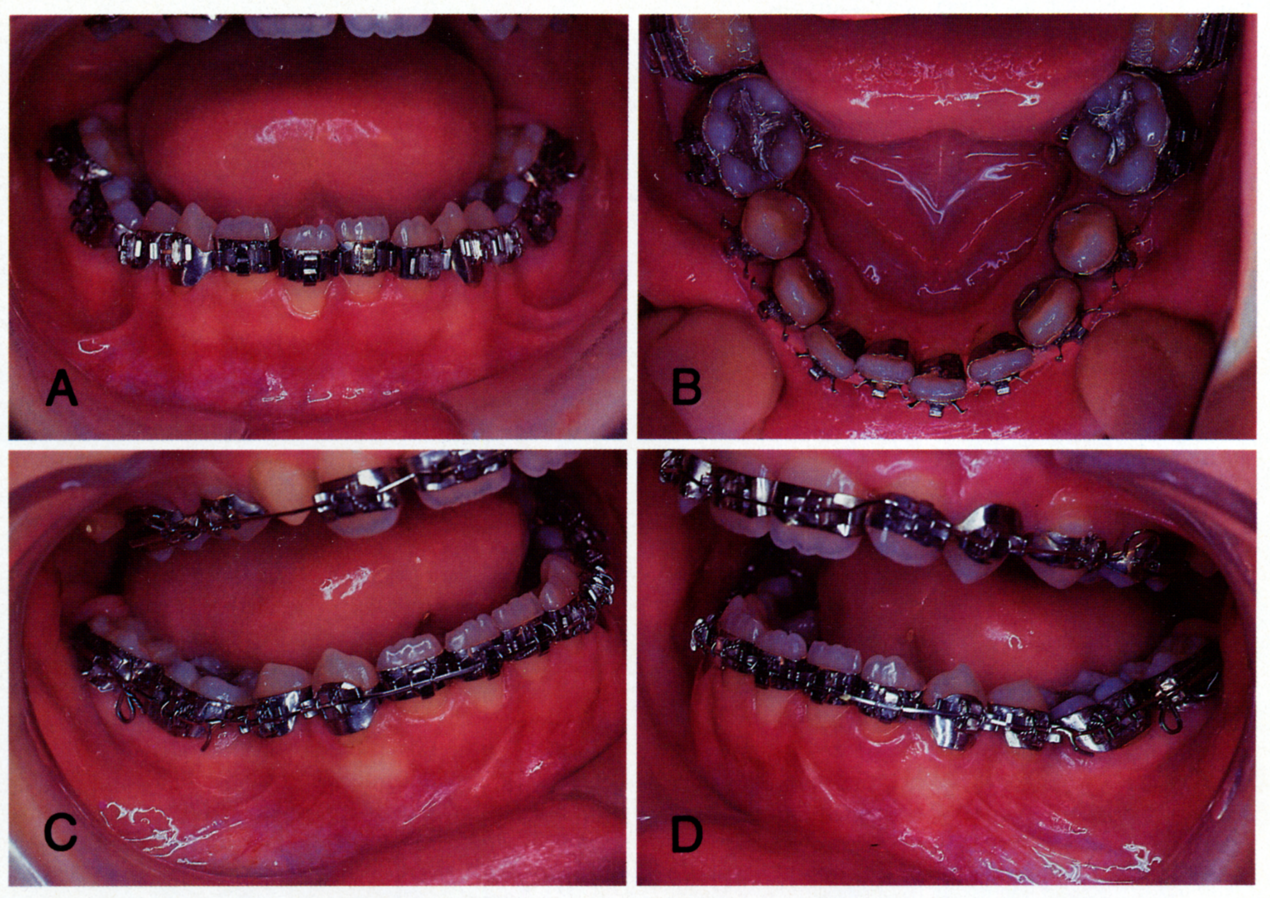

Fig. 7. The four second premolars were congenitally missing in this patient. The entire lower arch was banded at one appointment and a 0.015 x 0.019-inch arch was placed. A and B, Immediately after banding. C and D, After placing the 0.015 x 0.019-inch wire.

Advancing to a rectangular wire early in treatment makes it possible to control axial inclinations while leveling with a positive force (i.e., a reverse curve and second-order bends in the lower arch) and to use Class III or Class II elastics (if necessary) in a controlled environment. Round wires used over a long period of time allow buccal and lingual rolling of posterior teeth and labial dumping of anterior teeth. In addition, as Ricketts[3] and others[4] noted years ago, extended use of round wires usually results in lingual movement of the apices of lower incisors. No benefits are accrued through prolonged use of these wires, especially when all teeth are bracketed. However, to advance to a rectangular wire early without sacrificing patient comfort or constructing elaborate multilooped arch wires, it is necessary to have a proper and *differential* mechanical environment.

First, it is necessary to use small rectangular wires, such as 0.014 x 0.018 inch or 0.015 x 0.019 inch. With the inherent properties of these wires, flexibility is increased so much that rectangular wires are placed with only round wire discomfort. Some rotation also becomes possible with these rectangular wires. Note the alignment and rotation with a 0.014 x 0.01%inch wire in Fig. 6, *D* and *E*. *Second,* there should be as much interbracket distance as possible in the appliance. This allows maximum wire deflection without a permanent set. *Third,* there must be as much intrabracket space as possible. Here again, as with interbracket space, the presence of maximum intrabracket space allows the wires to bend farther without permanent set since more bending can occur within the confines of the bracket. Having such space minimizes the “dead spot” effect that a bracket has on a wire. The desire to have such space around working wires causes many practitioners to continue use of the 0.022-inch slotted edgewise appliance even though they are not satisfied with the heavy wires they are forced to use for finishing control.

The desire for intrabracket space coupled with a similar desire to use smaller wires present the contemporary edgewise orthodontist with a paradox. To be

Table I. Results for the 0.022-inch appliance

	Deflection location							
	Lateral		*Canine*		*First premolar*		*Second premolar*	
Bracket	*Force (lb/kg)*	*Deflection (mm)*	*Force (lb/kg)*	*Deflection (mm)*	*Force (lb/kg)*	*Deflection (mm)*	*Force (lb/kg)*	*Deflection (mm)*
0.022-inch single bracket								
0.018 x 0.025	4.378 1.987	0.486	4.414 2.003	0.488	4.449 2.019	0.519	5.167 2.345	0.478
0.019 x 0.025	5.567 2.527	0.433	5.260 2.388	0.429	5.299 2.405	0.459	5.785 2.626	0.433
0.022 x 0.028	8.584 3.897	0.216	8.163 3.706	0.216	8.261 3.750	0.236	9.185 4.169	0.228
0.022-inch double bracket								
0.018 x 0.025	6.743 3.061	0.222	5.662 2.570	0.268	5.713 2.593	0.290	5.661 2.570	0.280
0.019 x 0.025	7.769 3.521	0.194	6.547 2.972	0.251	6.575 2.985	0.251	6.477 2.940	0.246
0.022 x 0.028	11.921 5.421	0.106	10.077 4.574	0.131	10.214 4.637	0.147	10.135 4.601	0.146

efficient, competitive, and as painless to the patient as possible, the orthodontist must sacrifice some of the control to which he or she has become accustomed. It is this paradox that creates the fourth essential for early use of rectangular wires and greater integration of treatment functions. The fourth essential is the use of two *different* sized bracket slots in one appliance; it is called the bimetric principle. By having a small bracket (0.016 inch) on the six anterior teeth and a larger bracket (0.022 inch) on the posterior teeth, it is possible to accrue the advantages of a large *intra*bracket space and not suffer the disadvantage of lack of control in the critical areas of the mouth. Fig. 7 shows an example of early rectangular wire use and integrated treatment. It is not possible to have control with the previously mentioned small rectangular wires unless 0.016-inch anterior brackets are used. This appliance concept has been thoroughly tested clinically in exclusive use during the past 19 years. However, recently it was quantitatively tested by the computer and some startling facts were disclosed.

COMPUTER COMPARISON OF POPULAR EDGEWISE APPLIANCES

Background

Any orthodontic appliance represents, very simply, a set of mechanical constraints or supports within which a wire functions in bending and torsion (Fig. 1). The efficiency of an appliance then can be measured as a function of wire performance. In other words, how do the environments created by different appliances affect the action of wire? It is a published and accepted fact that interbracket distance has a marked effect on a wire's flexibility. It is possible to make theoretical comparisons of appliances with different interbracket distances using wire property constraints in combination with a ratio of the interbracket distances. Such a comparison was done by Creekmore[5] in 1975. This article was significant because it helped reemphasize to the profession the value of interbracket distance. However, Creekmore credited a great deal more significance to interbracket distance than actually exists because the calculations were made taking only two teeth into consideration. What actually happens at a bracket involves the wire spanning of three teeth. In addition it is not possible on a theoretical basis to compare wires that are not filling the bracket since tbe introduction of a "loose fit" changes the support conditions. The conclusion that, "Bracket width makes more difference in force and tooth movement than the entire range of useable edgewise wires" was a significant overstatement.

Clinically one of the most significant aspects of any appliance is the ability to have play or *intra*bracket space around its wires. The computer study reported in the current article was prompted primarily by a desire to know precisely what effect this "loose fit" in the posterior brackets has on wire capabilities. In addition we wanted to compare single- and double-bracketed appliances in 0.016, 0.018 and 0.022-inch slots with each other and then with the bimetric appliance.

Methods and materials

The engineering firm of Walter Moore and Associates was engaged to perform the study. **This firm was**

Table II. Results for the 0.018-inch appliance

	Deflection location							
	Lateral		*Canine*		*First premolar*		*Second premolar*	
Bracket	*Force (lb/kg)*	*Deflection (mm)*	*Force (lb/kg)*	*Deflection (mm)*	*Force (lb/kg)*	*Deflection (mm)*	*Force (lb/kg)*	*Deflection (mm)*
0.018-inch single bracket								
0.016 x 0.022	3.261 1.480	0.538	3.123 1.417	0.540	3.148 1.429	0.575	3.636 1.650	0.533
0.017 x 0.022	3.900 1.710	0.474	3.765 1.709	0.474	3.759 1.706	0.508	4.271 1.939	0.482
0.018 X 0.025	5.130 2.329	0.264	4.878 2.214	0.264	4.937 2.241	0.288	5.489 2.492	0.278
0.018-inch double bracket								
0.016 x 0.022	4.719 2.142	0.245	3.971 1.802	0.295	4.010 1.820	0.320	3.964 1.799	0.309
0.017 x 0.022	5.502 2.497	0.215	4.651 2.111	0.256	4.662 2.116	0.278	4.586 2.082	0.273
0.018 x 0.025	7.124 3.234	0.129	6.022 2.733	0.160	6.104 2.771	0.179	6.057 2.749	0.178

started in 1.931 and enjoys a strong reputation in the consultant field. As a matter of interest, the firm first gained national attention when they engineered the Astrodome in Houston in 1960. Walter Moore and Associates was provided with basic background information on orthodontics and specific bracket widths, slot sizes, mesiodistal tooth sizes, and wire sizes. The bracket widths used were those found to be rather standard: 0.050 inch for singles, 0.100 inch for intermediate twins, and 0.175 inch for wide twins. The buccal tube length was 0.180 inch. Each bracket and tube were placed exactly in the mesiodistal center of each tooth. The mesiodistal tooth sizes were obtained from Black's text[6] on dental anatomy. Calculations were made on small, medium, and large teeth. The results shown in this article were from the testing on medium teeth. The different bracket width conditions and tooth sizes used are depicted in Fig. 2. Walter Moore and Associates were also supplied by the manufacturer (Fort Wayne Metal Co.) with the specific properties and characteristics of a stainless steel commonly used in orthodontic wires. The material chosen was stainless steel No. 303. The stress-strain graph for this alloy is shown in Fig. 3. This graph is a gentle curve indicating that the wire does not have one specific point where any additional force yields infinite bending or permanent set point. For the study the point of permanent set was determined by using the 0.2% offset method. Such a method is commonly used in engineering to evaluate beams.

The computer was programmed with the different support conditions dictated by the tooth sizes, bracket widths, and bracket slots. With different wires inserted into the different appliance representations, the computer was asked the following question: How far can the wire be deflected gingivally at each tooth (or bracket) before it takes a permanent set? At that point the force generated (lb) and the amount of deflection (mm) were calculated. *

This study tested behavior of wire in bending in six different edgewise appliances: 0.022-inch twin brackets, 0.022-inch single brackets, 0.018inch twins, 0.018-inch singles, 0.016-inch singles, and the bimetric appliance (0.016-inch canine to canine and 0.022-inch posterior teeth). Three wires were tested in each appliance. In the 0.022-inch brackets, these were 0.022 x 0.028-inch wires, 0.019 x 0.025-inch wires, and 0.018 x 0.025-inch wires. In the 0.018-inch brackets, these were 0.018 x 0.025-inch wires, 0.017 x 0.022-inch wires, and 0.016 x 0.022-inch wires. In the 0.016 appliance and the bimetric appliance, the same three wires were tested: 0.016 x 0.222, 0.015 x 0.019, and 0.014 x 0.018.

Results

The results of the study are shown in Tables I through IV. These results show the raw data for the 0.022-inch slot (all teeth), 0.018-inch slot (all teeth), 0.016-inch slot (all teeth), and the bimetric slot (0.016-inch anterior and 0.022-inch posterior teeth), respectively.

The results also demonstrate several general facts concerning the inherent behavior of wire and the effect

*Further details on the particulars of the engineering technique used may be obtained directly from Walter Moore and Associates. Houston, Texas.

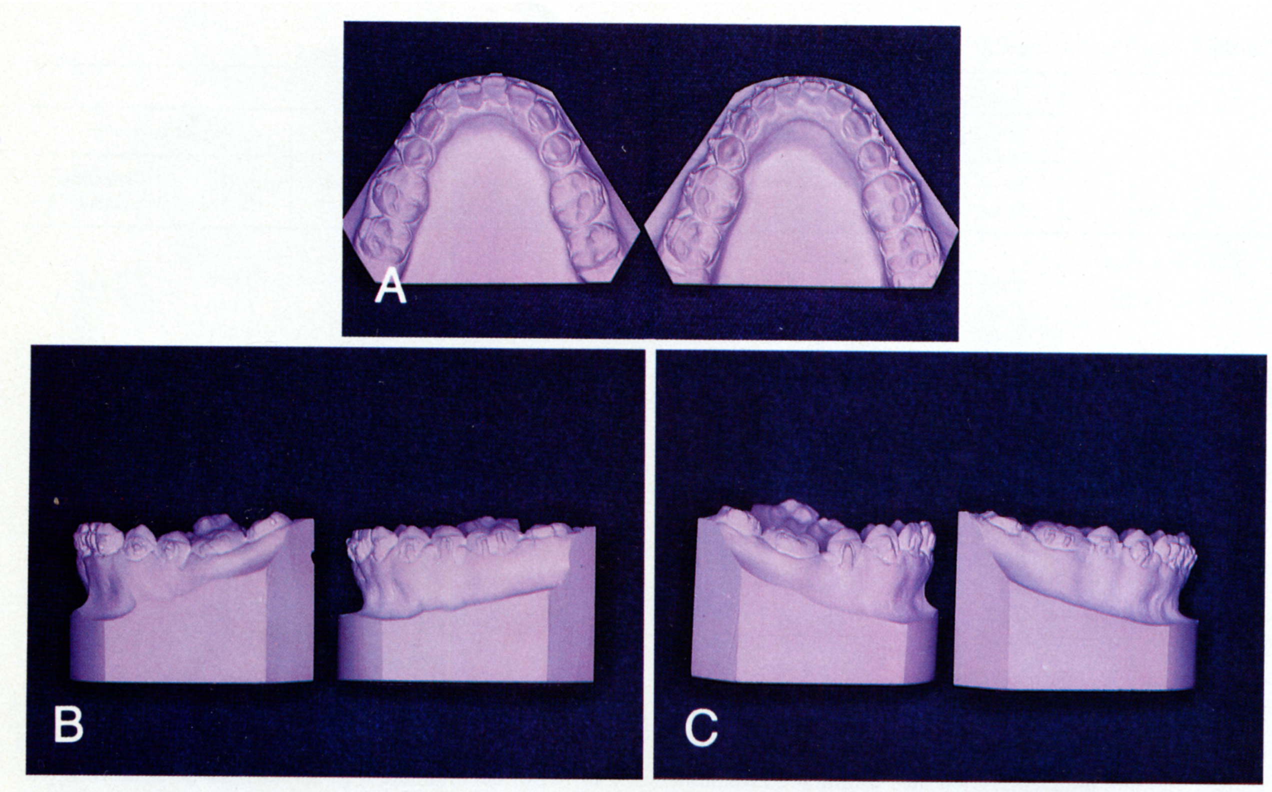

Fig. 8. These models show the leveling that was accomplished with a 0.015 x 0.019-inch arch. During the B-month interval between the models, the arch was removed only once. View A shows the arch development that occurred during the 6-month period.

of appliance modification on that behavior. These are as follows: (1) less force and greater range result from the use of smaller wires, (2) less force and greater range result with single brackets, and (3) less force and greater range result when intrabracket space is increased around the arch wire. These conclusions are supported by examining the traditionally slotted appliances in which all slots are the same size.

Wire size. To study the effects of wire size only, we need to examine the wires under tight-fit conditions. Using the lateral incisor-single bracket area of each table, note that the force falls rather dramatically as we go from 0.022 x 0.028 inch (8.58 lb) to 0.018 X 0.025 inch (5.13 lb) to 0.016 x 0.022 inch (3.56 lb). This is a 40.2% drop in force from 0.022 x 0.028 inch to 0.018 x 0.025 inch and a 30.6% drop from 0.018 X 0.025 inch to 0.016 X 0.022 inch. It is enlightening, if not astounding, to see bow much force is developed when the wires are pushed to yield or permanent set point. Of course, in actual clinical practice the arches are rarely pushed to yield point. It is at the yield point, however, that accurate comparisons can be made.

Range. As the force is reduced with the wire size going from 0.022 x 0.028 inch to 0.018 X 0.025 inch, the range increases 22.2% and increases another 12.5% going from 0.018 X 0.025 inch to 0.016 x 0.022 inch.

Interbracket distance. These same “tight conditions” (i.e., a 0.022-inch wire in a 0.022-inch slot) show the difference that longer spans of wire or narrower brackets make on force and range. We need to examine only one wire since here we are concerned with how different appliance conditions affect wire in general. All wires would be affected similarly.

With the 0.018-inch appliance results (Table IT), the force reduction at the lateral incisor with single brackets was 1.99 lb. This was a 27.9% decrease. The force decrease at the canine, first premolar, and second premolar was 19.1%, 17.5%, and 9.4%, respectively. The increased force or stiffness that is directly attributable to the shorter span of wire between the twin brackets is drastically less than that calculated by Creekmore.[5] In his study the increased stiffness produced by wide twin brackets on 9 mm teeth was found to be 536%. The increased stiffness with intermediate twins on 8 mm teeth was reported to be 320%. These calculations were high because they were made taking a two-bracket span into consideration. In such an arrangement, the results describe what happens at the interproximal as-

Table III. Results for the 0.016-inch (all brackets)

Bracket	Lateral Force (lb/kg)	Lateral Deflection (mm)	Canine Force (lb/kg)	Canine Deflection (mm)	First premolar Force (lb/kg)	First premolar Deflection (mm)	Second premolar Force (lb/kg)	Second premolar Deflection (mm)
0.016-inch single bracket								
0.014 x 0.018	2.074 9.416	0.604	1.983 .900	0.605	1.998 .907	0.644	2.300 1.044	0.602
0.015 x 0.019	2.648 1.202	0.534	2.524 1.145	0.533	2.551 1.158	0.572	2.888 1.311	0.544
0.016 x 0.022	3.568 1.619	0.297	3.393 1.540	0.297	3.434 1.559	0.324	3.818 1.733	0.313
0.016-inch double bracket								
0.014 x 0.018	2.983 1.354	0.275	2.513 1.140	0.330	2.532 1.149	0.358	2.499 1.134	0.348
0.015 x 0.319	3.703 1.681	0.241	3.140 1.425	0.287	3.148 1.429	0.312	3.094 1.404	0.307
0.016 x 0.022	4.955 2.249	0.145	4.189 1.901	0.180	4.246 1.921	0.201	4.213 1.912	0.200

Table IV. Results for the 0.016-inch bimetric appliance

Bracket	Lateral Force (lb/kg)	Lateral Dejection (mm)	Canine Force (lb/kg)	Canine Deflection (mm)	First premolar Force (lb/kg)	First premolar Dejection (mm)	Second premolar Force (lb/kg)	Second premolar Dejection (mm)
0.014 x 0.01%inch wire in 0.016-inch brackets in anterior and	2.074	0.604	1.826	0.664	1.518	0.817	1.783	0.728
0.022-inch brackets in posterior	0.941		0.829		0.689		0.809	
0.015 x 0.019-inch wire in 0.016-inch brackets in anterior and	2.648	0.534	2.320	0.591	1.923	0.743	2.218	0.672
0.022-inch brackets in posterior	1.218		1.053		0.873		1.006	
0.016 x 0.022-inch wire in 0.016-inch brackets in anterior and	3.568	0.297	3.393	0.297	2.809	0.671	3.004	0.617
0.022-inch brackets in posterior	0.161		1.540		1.275		1.363	

pect, rather than at the bracket. To determine what happens at a bracket positioned between two others, three teeth must be considered. This change doubles the span over which the calculations are made and exponentially changes the effect of twin brackets since stiffness is inversely proportional to the cube of the length. While force was decreasing under the single bracket conditions, the range was increasing by 104.7%, 65.0%, 60.8%, and 56.1% at each tooth. At the lateral incisor, the wire was deflected 0.429 mm in twins and 0.264 mm in singles.

Intrabracket space. When trying to assess the effects of adding intrabracket (casually called "slop" or "play") space around the wires, it is necessary to examine several different tables because the *same wire* must be studied under *different* support conditions. Note at the lateral incisor bracket in Table I that an 0.018 *x* 0.025inch wire in a 0.022-inch slot single bracket requires 0.76 lb or 14.8% less force than the same wire in an 0.018-inch slot (Table II). The force reduction is less at the canine, first premolar, and second premolar—9.4%, 9.9%, and 5.8%, respectively. At the lateral incisor, a 0.016 x 0.022-inch wire requires 8.6% less force to deform it to yield when in 0.018-inch single brackets (Table II) as compared to when it is in tight 0.016-inch single bracket conditions (Table III). Range of activation is more dramatically affected by the introduction of space around an arch wire. Again at the lateral incisor, an 0.018 x 0.025-inch wire has an 84.0% greater range in 0.022-inch single brackets (Table I) than it does in 0.018-inch single brackets (Table II). A 0.016 x 0.022-inch wire has an 81.1% greater range when in 0.018-inch single brackets (Table II) as opposed to 0.0 16-inch single brackets (Table III). Of interest is the fact that the reduced force and increased range that go with intrabracket space are minimized when using twin brackets. When twin brackets are used and the conditions just described are analyzed, the range of the 0.018-inch wire in the 0.022-inch slot increases only 72.0% over the 0.0 1 8-inch wire in tight-fit conditions and the force is reduced by less than half as much-namely, 5.3%. Similar observations hold true when comparing a 0.016 x 0.022-inch wire in a tight 0.016-inch slot and in the loose 0.018-inch slot. The force is reduced by only 4.7% and the range increases by 68.9%.

DISCUSSION

In the last few years, the profession has come to realize that heavy forces are not only unnecessary, but most of the time undesirable. The "buzz words" for the 70s and 80s could be "light force and greater range." If this were not so, the new wires, such as twisted, braided, and nickel titanium, would not have been so successful. These wires have been so well accepted because they strike close to the desirable wire characteristics discussed earlier-that is to say, such wires are less complicated to form while working closer to their full mechanical potential and they help make treatment phases more integrated. Interestingly these desirable wire features are summarized by the same phase, "light force and greater range." This verifies the fact that within the profession there is unanimity of thought on desirable wire features. Although these new wires certainly represent a step forward, they are only a partial step toward efficiency. The basic change needs to be *in the appliance more so than in the wires.*

The results of the computer study showed that to receive the greatest range or flexibility and lightest force from a wire three conditions must be present: (1) large interbracket distance, (2) small wires, and (3) as much intrabracket space as possible. The appliance that can meet all of these requirements will come closest to achieving the desirable wire characteristics. The first of these may be met by the use of single-width brackets. The difficulties arise in attempting to achieve the last two. The simple fact is that it is not physically possible to have these last two features (small wires and maximum *intra*bracket space) and still maintain good control with traditional edgewise appliances. The use of smaller wires in large brackets (i.e., 0.015 x 0.019, 0.016 x 0.022, or 0.018 x 0.025 in 0.022) will increase flexibility and range, but good control is abandoned. The use of an 0.018-inch bracket increases control but sacrifices some of the flexibility associated with intrabracket space. In addition the 0.018-inch slot is not small enough to offer good control with 0.014 x 0.018-inch and 0.015 x 0.019-inch wires. It is necessary to use an appliance that incorporates *differential slot* sizing-the bimetric principle (small in front and large in back) to make controlled use of these wires possible and thereby meet the three criteria for wire efficiency. Smaller rectangular wires, such as 0.014 x 0.018 inch, 0.015 x 0.019 inch, offer a whole new vista to the clinician. The lighter forces generated by these wires move teeth with amazing efficiency and the discomfort they cause is minimal. Note that the arch in Fig. 8 was leveled by one 0.015 x 0.019-inch wire that was removed only once in 6 months. As discussed previously, these rectangular wires are capable of affecting rotation as a result of their inherent flexibility (Fig. 7). Their actions are more gentle; however, they have more than enough force to accomplish the orthodontic task.

Comparison of popular edgewise appliances and the bimetric edgewise appliance

When the raw data in Tables I through IV are compared, the differentially slotted bimetric appliance is found to be more mechanically efficient than any of the traditional edgewise appliances. The wires typically used with it will deflect farther before permanent set and develop less force over greater range. Table V shows these comparisons. In this table the amount of increased deflection or range and decreased force at each tooth are expressed as percentages. For example, at the lateral incisor a deflected 0.016 x 0.022-inch wire in the bimetric appliance moves 13% farther with 30% less force than an 0.018 x 0.025inch wire in 0.018-inch brackets. The "overall" column shows the cumulative average increased range and reduced force at each tooth. It should be emphasized that this table

Table V. Overall comparison (0.016-inch bimetric vs. traditional appliances)*

Wire size	Location of deflection									
	Lateral		Canine		First premolar		Second premolar		Overall	
	Deflection	Force	Deflection	Force	Deflection	Force	Deflection	Force	Deflection	Force
Versus single brackets										
16 x 22 vs. 18 X 25	13	30	13	30	133	43	111	42	68%	36%
15 x 19 vs. 17 x 22	13	32	25	38	46	49	39	48	31%	42%
14 x 18 vs. 16 x 22	12	36	23	42	42	52	37	51	29%	45%
16 x 22 vs. 22 x 28	38	58	38	58	184	66	171	67	108%	62%
14 x 18 vs. 19 x 25	39	63	55	65	78	71	68	69	60%	67%
Versus twin brackets										
16 x 22 vs. 18 x 25	130	50	86	44	275	54	247	50	185%	50%
15 x 19 vs. 17 x 22	148	52	131	50	167	59	146	52	148%	53%
14 x 18 vs. 16 x 22	147	56	125	54	155	62	136	55	141%	57%
16 x 22 vs. 22 x 28	180	70	127	66	356	72	323	70	247%	70%
14 x 18 vs. 19 x 25	211	73	187	72	225	77	196	72	205%	74%

*The results are the percentage of increased deflection and percentage of decreased force that resulted when comparing the 0.016-inch bimetric to the traditional appliances.

Table VI. Comparison of 0.016-inch bimetric (singles) with 0.018-inch (singles) using wires with 0.001-inch play

Wire	Dejection location			
	Lateral	Canine	First premolar	Second premolar
0.017 × 0.022-inch wire in 0.018-inch single brackets	↓	↓	↓	↓
0.015 x 0.019-inch wire in 0.016 brackets in anterior and 0.022-inch brackets in posterior	50% less force, 12.7% more deflection	38% less force, 25.5% more deflection	48.6% less force, 48% more deflection	44.6% less force, 38.7% more deflection

compares appliances ***overall,*** not wires, tightness of tit, nor bracket widths. These factors combine to cause impressive differences in efficiency.

Bimetric versus 0.018-inch single brackets

When using full-sized wires (0.016 x 0.022 and 0.018 X 0.025) the bimetric appliance has 68% greater range and 36% less force overall. The advantage is only moderate in the lateral and canine areas, but tremendous in the premolar areas. At the first premolar, there is 133% greater range with 43% less force and at the second premolar there is 111% greater deflection with 42% less force. This is where the shortcomings of the traditionally slotted appliance are the greatest. With the traditional 0.018-inch appliance, overall efficiency is greatly reduced because filling the anterior brackets with an arch wire automatically fills the posterior brackets. The posterior *intra*bracket space (with the bimetric) is very helpful in leveling and reducing wire breakage.

When comparing wires with $^{1}/_{1000}$ of an inch play in the respective appliances (0.015 X 0.019 vs. 0.017 x 0.022), the overall range advantage of the bimetric appliance drops to 31%, but there is a further force reduction to 42% less than the 0.018-inch appliance. This drop in range advantage is indicative of the valuable role that space around the wire plays in creating efficiency. The further gain in force reduction is primarily a function of the inherent advantage of the smaller sized 0.015 X 0.019-inch wire. Table VI shows the specific tooth-by-tooth advantages of the bimetric appliance.

In comparing a 0.016 x 0.022-inch wire in the

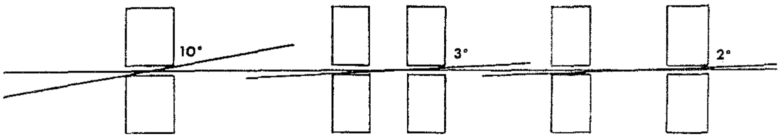

Fig. 9. Wider brackets restrict wire pivoting, which results in more stiffness even when intrabracket space is present. This 0.016-inch wire pivots 10° in a 0.022-inch single bracket, 3" in an intermediate twin bracket (0.022 inch) and 2" in a wide twin bracket (0.022).

Table VII. Comparison of 0.016-inch bimetric vs. 0.018-inch twins using finishing arches*

Wire	*Deflection location*			
	Lateral	*Canine*	*First premolar*	*Second premolar*
0.018 x 0.025-inch wire in 0.018-inch double brackets	↓	↓	↓	↓
0.016 X 0.022-inch wire in 0.016-inch brackets in anterior and 0.022 brackets in posterior	51% less force, 141% more deflection	45% less force, 87% more deflection	52% less force, 294% more deflection	50% less force, 264% more deflection

*Since a great percentage of orthodontists use the 0.018-inch bracket appliance, this is a very realistic example of the advantages of differential slot sizing. The bimetric appliance can be used with 0.018-inch posterior slots. In such a set up, its advantage would be somewhat less.

0.018-inch slot and a 0.014 X 0.018-inch wire in the bimetric slot (giving each appliance 0.002 play), we see a similar pattern of decreasing range advantage for the bimetric appliance with increasing advantage in force reduction. The 0.014 x 0.018-inch wire has 29% more range, but applies 45% less force. As the 0.018-inch appliance gets more space around its wires, it becomes more efficient from a range standpoint. On the other hand, the use of the light 0.014 x 0.018-inch wire in the bimetric appliance improves the gentleness of this appliance.

Bimetric versus 0.018-inch twin brackets

The addition of twin brackets to the 0.018-inch appliance further restricts it and its comparisons with the bimetric appliance are far worse. In tight-fit conditions, the bimetric appliance has an 185% greater range while applying 50% less force. With $^{1}/_{1000}$ play (0.015 x 0.019 vs. 0.017 x 0.022), the bimetric appliance has a 148% greater range and applies 53% less force. With $^{2}/_{1000}$ play, the percent of increased range and decreased force with the bimetric are 141% and 57%, respectively. It is interesting to note the dramatic increases in range that are accrued in the premolar areas in which the bimetric appliance has 0.022-inch slots. This is the principal reason for, and significance of, differential slot sizing.

The O.OlS-inch slot with twin brackets is probably the predominant edgewise appliance in use today. Assuming that those using this appliance finish in a full-sized wire to completely engage and take advantage of pretorque, Table VII is a realistic comparison of the efficiency of this appliance with that of the bimetric appliance during the finishing stage of treatment. With the 0.018-inch appliance, it is all or *nothing* in each bracket; the forces generated are extreme and the range much reduced. With the bimetric appliance, one can have full engagement for angulation and torque in the anterior teeth and on terminal molars while enjoying “play” or loose fit on the remaining posterior teeth.

Bimetric versus 0.022-inch single brackets

At full bracket engagement (0.016 *x* 0.022 vs. 0.022 *X* 0.028), the bimetric appliance averages 108% more in range efficiency at each tooth. While having twice the range, the 0.016 *X* 0.022-inch wire is imparting an average of 62% less force. When comparing working wires of 0.014 *x* 0.018 inches in the bimetric appliance and 0.019 *X* 0.025 inches in the 0.022-inch appliance, the 0.014 *X* 0.018 wire is on the average 61% more flexible while applying 66% less force. Again it is evident that the greatest advantage of the bimetric appliance in range occurs as wires approach full-bracket engagement and its greatest advantage in reduced force is when more intrabracket space is introduced.

Bimetric versus 0.022-inch twin brackets

An appliance that uses large wires and wide brackets such as the 0.022-inch twin bracket would be expected to be the least mechanically efficient. Such was the case. When finishing wires are inserted, the bimetric appliance is 247% more flexible (range) overall and applies 70% less force. When working wires of sizes 0.014 x 0.018 inch and 0.019 x 0.025 inch are inserted in each appliance, the bimetric has 206% more range and applies 74% less force.

The mechanical environment created by a combination of small anterior and larger posterior slots is clearly superior to any of the uniformly slotted edgewise appliances in use today. The efficiency becomes evident to the clinician mainly in the form of fewer wires, less complex wires, fewer arch removals, greater control, and greater patient comfort. Advantages such as these are beneficial and enjoyable in the treatment of any malocclusion, but they are of particular significance in the treatment of the more difficult malocclusion.

Clinical implications of intrabracket space

It is the finding of this study that *intra*bracket space has nearly as much impact on the clinical workings of an orthodontic appliance as does interbracket distance. As was noted previously, placing an 0.018 X 0.025-inch wire in 0.022inch single brackets rather than in 0.018-inch brackets decreases force by 14.6% at the lateral incisor while increasing range 84.0%. In this study a 0.016 x 0.022-inch wire was not tested in the 0.022-inch appliance, but it was tested in the bimetric setup with 0.022-inch slots on the premolars. In these brackets a 0.016 X 0.022-inch wire applied 22.5% less force and had 100% more range than it did when tested in the 0.016-inch slot appliance. *Intra*bracket space produces a greater degree of efficiency or resiliency in single-bracketed appliances. This is because the width of the twin bracket prevents the wire from pivoting very much in the bracket even if a significant amount of space is introduced around the wire. Note in Fig. 9 that a 0.016-inch round wire turns 10.0" in a 0.022 single bracket, but only 3.0" in an intermediate twin bracket and only 2.0" in a wide twin bracket. The many positive manifestations of intrabracket space are (1) less patient discomfort, (2) less complex wires, (3) fewer arch wires, (4) fewer arch removals, (5) faster and more efficient leveling, and (6) a reduction of permanent sets in arch wires due to mastication.

As we have seen, space around wires serves to decrease force as it increases range. The force reduction translates directly into less patient discomfort at each appointment and at home between appointments. Anyone operating with small wires and large slots will notice a very positive reaction from the patient. For years clinicians have recognized this and they frequently dreaded and avoided the use of wires that approach a close bracket fit. This is why so many practitioners using 0.022-inch slots never use wires larger than 0.019 x 0.025 inch and those using 0.018-inch slots frequently finish with 0.016 X 0.022inch wire. This compromises the theoretically precise and quality-oriented control of the pretorqued appliances being manufactured today. This anxiety or hesitancy over the use of tight fitting finishing wires is a testimony to the benefits of intrubracket space.

With the 0.016 bimetric appliance, a finishing arch of 0.016 x 0.022 inch is no more feared by the clinician than an initial small-diameter arch wire. Anterior torque is seated easily and the loose posterior fit produced by the 0.022-inch slots in that area makes seating the wire comfortable there.

In addition to creating more wire flexibility and range, *intra*bracket space reduces friction between the bracket and the wire, which makes leveling faster and easier. As was noted previously,[7] it is necessary for the teeth to move ***horizontally*** somewhat as they move vertically during continuous arch leveling. It is this horizontal shifting that is restricted when we level with too tight a fit between the bracket and the arch wire. With the 0.016 bimetric appliance, the average lower arch is leveled with only one to two arch removals over a period of 3 to 6 months (Fig. 8). Finally, working with *intra*bracket space around arch wires drastically reduces the number of permanent sets in- arch wires due to mastication. Permanent deformation of arch wires has long been a problem in orthodontics. These dead spots in arch wires interrupt movement, thereby slowing treatment and draining efficiency because they necessitate added arch removals. It is quite common in our office to allow an arch wire to work 3 to 4 months and find no deformation at the end of this time. This is, of course, another reason why leveling is so easy with the bimetric appliance. Space or freedom around the wire in the buccal segments allows the wire to bend or reverberate within the slot during chewing. Common sense might indicate that a big, strong wire that filled the posterior brackets would resist biting forces the best, but in actual fact this is incorrect. A small rectangular wire functioning with plenty of play or intrabracket space is far superior.

CONCLUSION

The facts demonstrated in this computer study indicate conclusively that there are three appliance conditions necessary to maximize wire function or efficiency in an orthodontic appliance. These are (1) the use of narrow or single brackets to increase interbracket distance and the amount of working wire, (2) the and of smaller edgewise wires (i.e., 0.014 x 0.018, 0.015 x 0.019, 0.016 x 0.022) with more inherent flexibility, and (3) the use of bracket-wire combinations that provide maximum *intra*bracket space around arch wires. The first two of these conditions may be achieved simply by use of small wires and single-width brackets.

When the smaller rectangular wires (such as 0.014 x 0.018 and 0.015 x 0.019) are used in traditionally slotted edgewise appliances, good control is lost because there is too much *intra*bracket space in the critical areas of anterior teeth and terminal molars. Ever since its invention by Dr. Angle in 1925, the edgewise appliance has been the appliance that possessed the greatest control of tooth movement. It is because of this control that it has come into the widespread usage that we see today. The only way the edgewise clinician can take advantage of the benefits of both intrabracket space and small wires without losing and/or compromising the control on which the appliance was founded is to use *differential* **slot** sizing with the bimetric principle.

We thank our wonderful wives, Judy and Florence Mae, for their support, help, and interest. We also thank our fine office staff with special appreciation to Connie Hubbard. Dr. Rick Horn of Walter Moore and Associates was also of great help to us.

REFERENCES

1. Thurow RC. Edgewise orthodontics. 4th ed. St. Louis: CV Mosby, 1982.
2. Creekmore TD. Physiologic drift. J Clin Orthod 1975;9:749-73.
3. Ricketts RM. Denver: Seventy-second annual session of AAO, 1971.
4. Schudy FF. Cant of the occlusal plane and axial inclination of teeth. Angle Orthod 1963;33:69-82.
5. Creekmore TD. The importance of interbracket width in orthodontic tooth movement. J Clin Orthod 1976;10:530-4.
6. Black GV. Descriptive anatomy of human teeth. 4th ed. Philadelphia: SS White, 1897.
7. Schudy FF, Schudy GF. The bimetric system. AM J ORTHOD 1975;67:57-92.

Reprint requests to:
Dr. George F. Schudy
909 Dairy Ashford
Suite 201
Houston, TX 77079