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A Study of the Regional Load Deflection Rate of Multiloop Edgewise Arch Wire

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ABSTRACT

To quantify the unique mechanical properties of multiloop edgewise arch wire (MEAW), its load deflection rate (LDR) and the LDR of various arch wires in the individual interbracket span were measured and compared. The MEAW arch wires were made out of .016 × .022–inch Permachrome stainless steel wire with L-loops of 4 different sizes. Five samples of each size were prepared for the comparison against wires of plain stainless steel, TMA, and nickel-titanium (NiTi) wires, all of the same dimensions. Five specimens for each of the various wires were used to eliminate the possibility of change in the physical properties of wires caused by the stress from repeated measurement. The LDR was measured by using the Instron model 4466 at a crosshead speed of 1 mm/min and maximum deflection of 1.0 mm. The regional wire stiffness of MEAW was calculated from the LDR in the interbracket spans that were measured by the Instron. The findings were as follows: (1) The LDR of the L-loop of MEAW at an individual interbracket span rate was 1:7.54 of the plain stainless steel wire, 1:1.76 of the NiTi, and 1:2.72 of TMA. (2) The L-loop at an individual interbracket span showed much lower wire stiffness than the entire arch wire, and the value of the stiffness differed according to the region.

KEY WORDS: Regional, Load deflection rate, Multiloop edgewise arch-wire.

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INTRODUCTION Return to TOC

The load deflection rate (LDR) is defined as the external loading needed for the unit deformation and, in orthodontics, signifies the force generated by the unit length deformation. Orthodontic arch wires with high LDR not only apply excessive force on teeth, but their strength decreases quickly with tooth movement. Wires with low LDR, however, generate light and continuous force. In the finishing stages of straight wire appliance technique, stainless steel wires of high stiffness not only express every characteristic feature programmed into the brackets, but they also minimize individual tooth movement. Such a procedure requires a period of retention before debonding.[1] Wires of high stiffness, however, are unsuitable for facilitating precise tooth movements needed in the correction of sagittal and vertical dysplasias, which might be found in the finishing stage of treatment. In contrast, in the multiloop edgewise arch wire (MEAW) technique, multiple L-loops are used to decrease interdental LDR, making it possible to upright posterior teeth, change the inclination of the occlusal planes, and correct sagittal relationships of the occlusion in a significantly shorter time.[2] Other studies have noted that the unique properties of the MEAW are caused by a lower stiffness than is present in plain stainless steel, nickel-titanium (NiTi), and TMA wires.[3, 4] Despite the fact that NiTi and TMA wires possess much lower stiffness than the MEAW, they did not show the independent tooth movement and uprighting characteristic properties that MEAW demonstrated. In other words, the low stiffness of the wires alone in their entirety cannot affect their uprighting of the posterior teeth. The LDR of any wire, for that matter, is not known at the interbracket regional level. This study, therefore, was conducted to determine the LDR of MEAW at the interdental regional level and compare it with stainless steel, NiTi, and TMA wires.

MATERIALS AND METHODS Return to TOC

The single L-loops in 5 different lengths of the horizontal part were made out of .016 × .022–inch Permachrome stainless steel, as described by Kim[5] (Figure 1). The wires were treated thermally at 475°C for 3 minutes and electrically polished for 5 seconds (Big Jane Model E3762). The segments of stainless steel, TMA, and NiTi wires in .016 × .022–inch size were used (Table 1).

The end of the wire to be tested was engaged in the bracket, which was welded to the stainless steel fixture that was fixed by the lower grip. The other end of the wire was fixed in the same manner by the upper grip at various interbracket spans as measured by the dentiform manufactured with the average tooth size on which the standard brackets (Tomy Co) were bonded at the ideal position (Table 2). Instron (model 4466) universal testing machine and the software Series IX were used. The LDR was measured at the crosshead speed of 1 mm/min and maximum deflection of 1.0 mm. The capacity of the load cell was 50 N. Five specimens were tested under each experimental condition to eliminate the possibility of changes in the physical properties of the wires as a result of the stress from repeated measurements. In the case of L-loop, the wire was activated in the direction of closing the loop (Figure 2). The specimens of NiTi and TMA were tested in the thermostatic water bath that was maintained at a temperature of 37°C (Figure 3).

The data (deflection and load) were transmitted from the load cell to the software (Series IX automated Material Testing System) in the computer connected to the Instron. The load-deflection curves were plotted, and the slope of the linear portion of the curve gave the load deflection rates.

RESULTS Return to TOC

Interbracket span of an average-sized dental arch was set as shown in Table 2. The values of LDR at various interbracket spans were obtained as shown in Tables 3 and 4. The results show that the LDRs of the L-loops are approximately one-half of NiTi, one-third of TMA, and one-eighth of plain stainless steel wire.

DISCUSSION Return to TOC

Clinical significance of the LDR

There are various ways of describing the physical properties of orthodontic wires. In the case of elasticity or stiffness, there are 3 areas of measurement: material stiffness, wire stiffness, and appliance stiffness.[6] First, the material stiffness is defined as the ratio of unit stress to unit strain, usually expressed as psi, pascals, or N/mm^2 in accordance with Young's modulus or modulus of elasticity. This describes the inherent elastic properties of the wire material regardless of the length and the cross-sectional geometry.

Second, the wire stiffness describes the inherent stiffness of a given wire as determined by the cross-sectional area, the shape, and the material, but not by the length or wire design. It represents flexural rigidity (N/mm^2; psi) of a wire and depends on its elastic modulus of the wire and the moment of inertia. The advantage of dealing with flexural rigidity rather than elastic modulus is that flexural rigidity is of immediate clinical relevance and, therefore, wires of different shapes, sizes, and constructions can be directly compared.[1]

Third, the appliance stiffness, determined by the length and other design factors (such as a loop) of a wire of specified size and material, is represented by LDR, which measures the load required for a unit length of deflection. In orthodontics, the LDR is the force generated by an orthodontic appliance causing unit deflection. The LDR of an orthodontic appliances is, therefore, dependent on the wire material (material stiffness; N/mm^2) represented by Young's modulus, the cross-sectional geometry (cross-sectional stiffness and moment of inertia), and design factor of wires (appliance design stiffness).[6, 7]

LDR = wire stiffness × design stiffness, where wire stiffness = material stiffness × cross-sectional stiffness.

Waters[1] mentioned that wires with low stiffness were not necessarily advantageous in orthodontic treatment in every instance. Whereas NiTi wires of low stiffness were recommended for severely malpositioned teeth at the early stages of treatment, it would be less suitable for stabilizing components such as buccal sections that have to resist forces such as those exerted by intermaxillary elastics. TMA can be deflected approximately twice as much as stainless steel wire without permanent deformation, and it delivers force values less than half those of stainless steel, so it is better in the middle stages of treatment.[8, 9]

Waters[1] mentioned that looped arches could offer enough stiffness for the stabilizing sections of the arch and also offer flexibility where it is required.

Considerations on the design of the experiment

In general, there are many methods of testing the elasticity of orthodontic wire materials. When an orthodontic wire is exposed to a bending or torsional force, the inner fiber of the wire is compressed and the outer fiber elongated.[10] Because it is difficult to understand the inherent properties of the material with the bending or torsional test, the tension test along the neutral axis is preferred in quantifying the mechanical properties of the wire. In the tensile test, all fibers of the wire are under the condition of the same direction and stress. For this reason, the American Society for Testing and Materials (ASTM) prescribes the standard tensile test as 0.5 inches in diameter and 2 inches in focal distance. However, the value of the results from this type of test is too large for the orthodontist to easily understand and apply to clinical practice. And in orthodontic practice, there are few situations for the wire to be activated in the direction of the long axis (compression and tension). Consequently, the American Dental Association (ADA) specifications prescribe that the mechanical properties of orthodontic wires should be presented by the cantilever bending tests (ADA specification No. 32).[11] However, because the cantilever action of orthodontic wire is also very rare in practice, many orthodontic studies dealt with a 3-point bending test or its modifications.[1,12,13] In this study, a modified cantilever test was used, in which the supporting end was fixed by the bracket and the loading end was also engaged by the bracket moving upward. This type of method is different from a simple cantilever test, because there is an extra bending effect in the loading end and friction between the bracket and wire. However, this type of testing method can simulate more closely the situation of uprighting posterior teeth and changes in the cant of occlusal plane (Figure 4).

For all of those, this type of testing methods was accepted. For the same reasons, the closing direction of the loop was determined as the direction of activation.

In fact, the LDR could not fully explain the force system of MEAW. Moments are generated at individual brackets, and the LDR related to the horizontal force as well as the LDR related to the vertical force should be accounted for. Therefore, this study may be a partial description of the mechanical property of MEAW. However, because of the following reasons, this study was limited to LDR related to the vertical force. The first reason and the main effect of MEAW is second-order control of posterior teeth. So the major role of L-loop is to provide vertical control of tooth movement. The second reason is that a specific property of MEAW is that it permits posterior teeth to move individually. In order to certify this fact, it is necessary to measure the LDR at the interbracket span.

The regional LDR of MEAW

A low LDR is not necessarily advantageous for tooth movement in every instance. Whereas NiTi wires of low stiffness are recommended for severely malpositioned teeth in the early stages of treatment, TMA wires of moderate stiffness and capacity for plastic deformity are better in the middle stages. Stainless steel of high stiffness is most useful in the final stages. Furthermore, wires with different LDRs for the regional needs facilitate precise tooth movements and are most useful, eg, a lower LDR for the segment of active tooth movement and a higher LDR for the anchoring parts. For that matter, the effectiveness of the MEAW mechanism for the correction of the sagittal and the vertical dysplasias in the finishing stage has been confirmed by numerous studies.[3,4,14,15] These unique effects have been attributed to L-loops, which lessen the LDR, act as stress breakers, and provide the horizontal and vertical control of tooth movements.

As shown in Figures 5 and 6, L-loops of a MEAW have different LDRs regionally—a high value for the anterior segment and a low value for the posterior segments because of the length of horizontal loops. For the maxillary wires, the LDR for the L-loop is lower than that of other wires except for the LDR of NiTi between the lateral incisor and the canine. Table 5 shows that the ratios of the LDR for the L-loop to those of NiTi, TMA, and plain stainless steel are on the average 1:1.74, 1:2.74, and 1:7.61, respectively. For the mandibular wires, although the LDR of a MEAW and a stainless steel wire between the central and the lateral incisors was higher than those of the other materials, it was lower in every other region, with the ratios on the average 1:1.77, 1:2.69, and 1:7.46, respectively. In addition, it can be stated that although the difference between the LDR of the L-loop and that of NiTi in a long interbracket span was small, the difference was more significant in a short interbracket span (Tables 5 and 6).

Lee and Chang[3] have measured the entire arch LDR of the MEAW and compared it with that of wires of different materials. An upper MEAW's LDR ratio is 1:2.52 of a plain stainless steel, 1:0.49 of a National, and 1:0.80 of a TMA. In other words, LDR of the entire arch of a MEAW is somewhat stiffer than a TMA and twice as stiff as a Nitinol wire, but a MEAW with its regionally various LDR has a unique mechanism and mechanical properties. Chun and Nahm,[4] who used the finite element analysis on the LDR of various wires, obtained results similar to those of Lee and Chang. This study, however, showed that MEAW in the posterior interbracket area has an even bigger LDR ratio of approximately 1:7.5 when compared to a plain stainless steel wire. This finding seems to correspond to Kim's[5] estimate.

The differences between the whole arch LDR and the regional LDR could be explained by 2 factors. First, in the stress strain curves of shape memory wires, such as NiTi wire, the slopes (ie, stiffness) change according to the amount of elastic deflection. The stiffness is relatively high at the beginning of deflection but is significantly reduced with increased deflection. In other words, the stiffness, or the LDR, of NiTi measures differently according to the amount of deflection (Figure 7). Lee and Chang,[3] in their examination of the entire arch LDR, deflected the posterior end of MEAW by 15 mm in order to simulate an actual clinical application of the MEAW. In the finishing stage of the treatment, however, the deflection range in the interbracket span would not exceed 1.0 mm because a greater deflection would cause plastic deformation of stainless steel wires. A 1.0-mm deflection, therefore, was adequate for the purpose of this study. As the results of this study showed, NiTi and TMA have higher LDR than L-loops in the interbracket span. Second, although the wire segments engaged in the brackets do not contribute to lowering the stiffness of the entire arch, the horizontal part of the L- loops can affect vertical elastic deflection and thereby reduce stiffness.

As shown in Figure 8, the average length of the wire between the distal of lateral incisor bracket and the second molar tube is 43 mm for the NiTi and 120 mm for the MEAW. The length of a 5 twin bracket in that range adds up to 18.5 mm. The ratio of the length of the bracket to the length of the entire arch, which determines the LDR of vertical direction, is 15.49% for MEAW and 43% for NiTi, indicating a marked increment of the LDR for NiTi.

It can be summarized that although the entire arch of the MEAW is stiffer than that of the other memory wires, it is less stiff in the interbracket regions where the loops are incorporated. As demonstrated earlier, the LDR of the MEAW differs from region to region. It has also been shown that it is possible to obtain wire stiffness value by eliminating the interbracket span factor, as shown in Table 7.[7]

In the case of the MEAW, the relative difference in the stiffness of an individual interbracket span can be calculated by fixing its entire arch stiffness at the value 1.0, as shown in Figure 9. For instance, the anterior region without the loop has a high stiffness, making it possible for incisors to be adjusted as a unit. The first loop to which intermaxillary elastics are usually engaged is twice as stiff as other posterior loops in the maxilla and 1.5 times stiffer in the mandibular arch. This prevents the orthodontic force generated by the elastics from concentrating in the region of the first loop and distributes the force to other regions.

Low stiffness at the interbracket region also makes it possible to apply a low and constant force allowing the teeth to move toward the directions as applied by the MEAW. On the other hand, the high wire stiffness of the entire arch wire makes it possible to transmit orthodontic force effectively from the anterior to the posterior segments. Because there is no regional difference in the wire stiffness, the LDR of NiTi and TMA, in contrast, is determined by interbracket distance alone. In this instance, because the wire stiffness in the interbracket span is higher than that of the entire arch in NiTi, individual tooth movements are difficult, and the transmission of the force is ineffective.

The mechanism of action of the MEAW has been examined in a photoelasticity study by Lee and Kim[14] and in a holographic study by Jin and Yang.[15] According to their observations, the MEAW was seen to transmit force generated by intermaxillary elastics throughout the entire arch. The results of our study confirmed their findings.

CONCLUSION Return to TOC

In order to quantify the unique mechanical properties of the MEAW, the LDR of the MEAW and those of various arch wires in individual interbracket span were measured and compared. The L-loops of 4 different sizes were made out of .016 × .022–inch Permachrome stainless steel wire. Five samples of each loop size were prepared and compared with plain stainless steel, NiTi, and TMA wires of the same dimension.

The LDR in interbracket span was measured with the Instron, and the regional wire stiffness was calculated with the following results.

1. The LDR of the L-loop of the MEAW at an individual interbracket span was rated on the average 1:7.54 of plain stainless steel wire, 1:1.76 of NiTi wire, and 1:2.72 of TMA wire.
2. The MEAW at an individual interbracket span had lower wire stiffness than the entire arch wire, and its value differed regionally.

The results of this study suggested that MEAW had a unique mechanical property that could allow the individual teeth movement and transmit the elastic force effectively through the entire arch wire.

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TABLES Return to TOC

TABLE 1. Materials Used in This Study

	Manufacturer	Commercial Name	Size of Cross-section, mm[a]
L-loop[b]	Unitek	Standard rectangle wire	0.406 × 0.556
Stainless steel wire	Unitek	Standard rectangle wire	0.406 × 0.559
β-Titanium wire	Ormco	TMA	0.420 × 0.558
Nickel titanium wire	Ormco	NiTi	0.401 × 0.542

[a] The size of wires was measured with a micrometer (Mitutoyo Co; scale, 0–25 mm).
[b] The specimens were thermally treated and electrically polished.

TABLE 2. Interbracket Span (mm)

	Tooth No.					
Region	1–2	2–3	3–4	4–5	5–6	6–7
Maxilla	7.0	6.5	5.0	5.0	7.0	7.0
Mandible	5.0	5.0	5.0	5.0	7.0	9.0

TABLE 3. The Load Deflection Rate of Various Wires at Each Max~ illary Interbracket Span (g/mm)[a]

	Tooth No.					
Region	1–2	2–3	3–4	4–5	5–6	6–7
L-loop	936.4[b]	320	2.28.4	228.4	108.0	108.0
NiTi	200.0	268.0	280.0	480.0	200.0	200.0
TMA	338.1	436.2	699.9	699.9	338.1	338.1
Stainless steel	936.4	1206	1939.1	1939.1	936.4	936.4

[a] NiTi indicates nickel-titanium.
[b] Because the L-loop is not used in the region between the central incisor and the lateral incisor, the value of the L-loop is the same as that of a plain stainless steel wire.

TABLE 4. The Load Deflection Rate of Various Wires at Each Man~ dibular Interbracket Span (g/mm)[a]

	Tooth No.					
Region	1–2	2–3	3–4	4–5	5–6	6–7
L-loop[b]	1939.1	351.8	228.4	228.4	108.0	90.0
NiTi	480.0	480.0	480.0	480.0	200.0	130.0
TMA	699.9	699.9	699.9	699.9	338.1	144.4
Stainless steel	1939.1	1939.1	1939.1	1939.1	936.4	554.4

[a] NiTi indicates nickel-titanium.
[b] Because the L-loop is not used in the region between the central incisor and the lateral incisor, the value of the L-loop is the same as that of a plain stainless steel wire.

TABLE 5. The Ratio of Regional Load Deflection Rate of NiTi, TMA, and Stainless Steel as Compared With L-Loop (Maxilla)[a]

Region (Tooth No.)	L-Loop	NiTi	TMA	Plain Stainless Steel
1–2	1.00[b]	0.21	0.36	1.00
2–3	1.00	0.84	1.36	3.77
3–4	1.00	2.10	3.06	8.49
4–5	1.00	2.10	3.06	8.49
5–6	1.00	1.85	3.13	8.67
6–7	1.00	1.85	3.13	8.67
Average[c]	1.00	1.74	2.74	7.61

[a] NiTi indicates nickel-titanium.

[b] Because the L-loop is not used in the region between the central incisor and the lateral incisor, the value of the L-loop is the same as that of a plain stainless steel wise.

[c] Average was calculated excluding the first region, because the L-loop is not used in this region.

TABLE 6. The Ratio of Regional Load Deflection Rate of NiTi, TMA, and Stainless Steel as Compared With L-Loop (Mandible)[a]

Region (Tooth No.)	L-Loop	NiTi	TMA	Plain Stainless Steel
1–2	1.00[b]	0.24	0.36	1.00
2–3	1.00	1.36	1.99	5.51
3–4	1.00	2.10	3.06	8.49
4–5	1.00	2.10	3.06	8.49
5–6	1.00	1.85	3.13	8.67
6–7	1.00	1.44	2.22	6.16
Average[c]	1.00	1.77	2.69	7.46

[a] NiTi indicates nickel-titanium.

[b] Because the L-loop is not used in the region between the central incisor and the lateral incisor, the value of the L-loop is the same as that of a plain stainless steel wire.

[c] Average was calculated excluding the first region, because the L-loop is not used in this region.

TABLE 7. Load Deflection Rate—Wire Stiffness Conversion

$LDR = WS/L^3$

LDR = load deflection rate

WS = wire stiffness

L = length

$WS = LDR \times L^3$

FIGURES Return to TOC

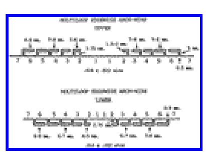

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FIGURE 1. The diagram of the multiloop edgewise arch wire

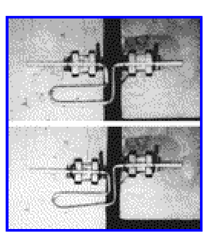

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FIGURE 2. The load deflection rate of an L-loop is being tested: top, passive state; bottom, loop in activation

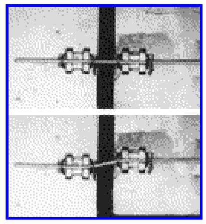

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FIGURE 3. The load deflection rate of a plain wire is being tested: top, passive state; bottom, wire in activation

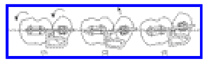

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FIGURE 4. The situation of uprighting the posterior teeth and changing the inclination of occlusal plane with multiloop edgewise arch wire mechanics

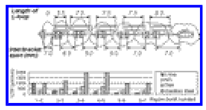

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FIGURE 5. The load deflection rate in each interbracket span (maxilla)

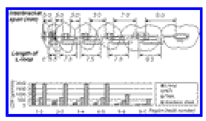

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FIGURE 6. The load deflection rate in each interbracket span (mandible)

Click on thumbnail for full-sized image.

FIGURE 7. Load-deflection curve of stainless steel and nickel-titanium wires

Click on thumbnail for full-sized image.

FIGURE 8. Ratio between the sum of bracket and wire length

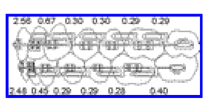

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FIGURE 9. Wire stiffness of the multiloop edgewise arch wire in each interbracket span in contrast to that of the entire arch (=1.0)

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