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Controlled Space Closure with a Statically Determinate Retraction System

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ABSTRACT

We designed a variant of a cantilever spring, the statically determinate retraction system, and studied its mechanical characteristics. This novel system consisted of a single-force cantilever arm made of 0.017 × 0.025–inch titanium molybdenum alloy wire for active retraction and a passive rigid stabilizing unit. Since the active component for space closure is a cantilever, it is simple to measure the force system of the spring with a force gauge (ie, the system is a statically determinate system). A torque tester apparatus was used to examine the property of this retraction spring with a helix at the posterior and a simple bend at the anterior. Both a standard shape and modified shapes of the spring were studied. At full activation, the standard spring delivered 163 g with a load-deflection rate of six g/mm. When the magnitude of the anterior bend of the spring was increased, the horizontal component of the force increased more than the vertical component. In contrast, when the posterior bend of the spring increased, the vertical component of the force increased more than the horizontal component. A clinical case presented here clearly demonstrates the versatility and applicability of the spring.

KEY WORDS: Cantilever, Orthodontic appliance, Statically determinate retraction system.

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INTRODUCTION Return to TOC

Both friction (sliding) and frictionless (loop) mechanics are used for space closure in extraction therapy. In sliding mechanics, the wire and position of the bracket give control of tooth movement, whereas in a loop-spring system, control is built into the spring. Either method has its own advantages, and the methods complement each other. One of the major advantages of frictionless mechanics is that a known force system is delivered to teeth because there is no dissipation of force by friction. However, it may be difficult to measure the exact force system clinically produced by a loop-spring appliance because when both ends of a loop spring are engaged in brackets, a moment and a force are generated concomitantly, and it is difficult to measure both a moment and a force simultaneously. This results in a statically indeterminate system.

The force system of loop-springs of an appropriate shape can be tested in the laboratory, and the clinician can then fabricate the spring in accordance with the shape already tested. However, even a spring accurately precalibrated in the laboratory[1–3] is still not immune to clinical problems because its exact force system will vary depending on the angulation of brackets, various interbracket distances, and errors during fabrication. The response of the tooth to a given force system apparently also varies depending on individual differences in bone density, tooth shapes, and periodontal conditions that require frequent monitoring of the patient. Therefore, any spring that allows a modification of the force system during the course of treatment would be greatly advantageous as long as clinicians can properly control its structural mechanics and spring geometry.[4,5]

The complexity in controlling the properties of a loop-spring can be greatly reduced when a loop-spring becomes a cantilever with a single-force direction and a point-of-force application. The force system of a cantilever spring can be estimated by a simple measurement of the force with a force gauge and a ruler. A single-force spring design is statically determinate, whereas a retraction loop-spring to which forces and moments are applied at each end is complex. Rigid, apically placed lever arms have been developed by Fontanelle[6] and Kucher[7] with coil springs that produce single forces on the lingual surface. Melsen and Fiorelli[8] have also applied a statically determinate system to different types of tooth movement. However, it would be difficult to apply these large systems to the buccal side because of anatomic limitations.

The retraction system introduced here is a flexible, buccally placed cantilever that can be maintained at a low height and that therefore does not interfere with anatomic structures. Specifically, the system is a statically determinate retraction system (SDRS) in which only a single force needs to be measured. An SDRS was designed to meet the following criteria: (1) the total force system of the appliance is statically determinate so that clinicians can identify the magnitude of force and calculate the equivalent moment (M)/force (F) ratios at the bracket of the anterior and posterior units; (2) the load-deflection rate is low so that force can be relatively light and constant; (3) the M/F ratio is maintained relatively constant during deactivation of the spring, regardless of the amount of activation and tooth movement and keeping the axis of rotation of the tooth constant so that unnecessary tooth movement can be minimized; and (4) the force system of the appliance is easily modifiable at a clinician's need. We performed a series of in vitro tests to study the properties of this novel retraction cantilever spring.

MATERIALS AND METHODS Return to TOC

Figure 1 demonstrates the components of the SDRS. The system consists of passive rigid stabilizing units and active retraction springs. Rigid stainless steel wire is used for the buccal stabilizing units and an anterior stabilizing unit. The buccal stabilizing units are connected with a transpalatal arch to the contralateral side.[1] The anterior stabilizing arch has a distal extension with a hook about six mm superior to the canine bracket slot. The SDRS spring is made with 0.017 × 0.025–inch titanium molybdenum alloy wire. A turn of helix is placed in front of the auxiliary tube for the molar and ended with a hook at the anterior end. A 90° bend is placed in the middle of the spring. The spring is activated 90° at the helix as well. The hook from the SDRS spring and the extension hook of the anterior segment are connected with a ligature.

To study the mechanical characteristics of the SDRS, a standard spring made of 0.017 × 0.025–inch titanium molybdenum alloy with a 90° bend at the posterior and anterior was first mounted on a custom made torque tester (Figure 2). To test the spring in a typical clinical condition, the anterior hook was assumed to be six mm superior and two mm distal to the canine bracket with a 20-mm interbracket distance. Figure 3 shows a schematic drawing of the apparatus and spring after activation. The spring was activated to place the anterior hook at the x and y target points (−18, 6) with respect to the posterior tube at (0, 0). The moment (M) at the posterior end and the angle of deflection (θ) at the anterior free-end were measured with a torque gauge (651X-3M , Data Instruments Inc, Wayland, MA). The line of force was kept perpendicular to the anterior end of the spring, which passed through the point (−18, 6). Since the length of the moment arm (L) can be measured, the force (F) at the anterior free-end was calculated from the torque measurement (F = M/L). The horizontal component of the given force parallel to the occlusal plane, F(h), and its vertical counterpart, F(v), were calculated. To calculate the load-deflection rate of the standard spring, angle P was increased from 0° (full activation) to 25°.

Next, to study shape characteristics of the SDRS, the magnitude of the anterior bend (angle A) and the posterior bend (angle B) were altered (Figure 4). Angle A was decreased stepwise from 90° to 40° in 10° steps while angle B was maintained at 90°. Angle B was decreased from 90° to 30° in 10° steps while angle A was maintained at 90°. The effect on the force system under the varied conditions was evaluated at a full activation. For all experimental designs, five springs were tested, and the measurements were averaged.

RESULTS Return to TOC

The force system of the standard spring

At full activation, 160 g was delivered by the SDRS spring (Table 1). Over the 8.2-mm activation range, the load-deflection rate averaged 1.9 g per degree or 5.9 g/mm. The angle of the force (θ) varied from 42.4° to 38.7° and was relatively constant over the 25° deactivation range.

Effects of altering the anterior bend

Angle A was decreased from 90° to 40° in 10° steps while angle B was maintained at 90°. Table 2 shows the average values of actual measurements including the moment, force, and ratio between horizontal (distal) and vertical (intrusive) components of the force obtained from the five springs. Figure 5A depicts how the horizontal and vertical components of the force changed. The horizontal component of the force increased steeply while the vertical component of the force remained relatively constant. Thus, the ratio between the horizontal and vertical components increased as the anterior bend increased (Figure 5B).

Effects of altering the posterior bend

The posterior bend (angle B) was decreased from 90° to 30° gradually while the anterior bend (angle A) was maintained at 90°. Table 2 shows that the vertical component of the force increased more steeply than the horizontal component (Figure 6A). Thus, the ratio between the horizontal and vertical components of the force decreased (Figure 6B).

Clinical application of the SDRS

A 43-year-old woman with severe protrusion of the upper anterior teeth, a large overjet, and overbite was treated with an SDRS (Figure 7). A Class II molar relationship and a severe curve of Spee in the lower arch were evident. The treatment objectives were reduction of lip fullness by a controlled retraction of the upper anterior teeth and intrusion of the lower anterior teeth while maintaining the vertical dimension. Figure 8 depicts the lateral and occlusal views of the treatment objectives.

Before initial leveling, selective intrusion of the upper incisors along the long axis was performed. Premolars that were to be extracted afterwards were used for anchorage, and therefore all adverse effects were confined to those teeth. Note that the upper (right) first premolar was rotated clockwise to some degree and extruded after intrusion of the anterior segment (Figure 9).

After initial alignment, the buccal and anterior segments were stabilized with rigid wire. Buccal segments were transversely connected with a rigid transpalatal arch.

The SDRS was inserted and activated. The line of force was adjusted to pass near or above the center of resistance of the upper first molar and six mm above the upper canine bracket slot (Figures 10A,B, and C).[9,10] The lower anterior segment was intruded before leveling (Figures 10C,D). After controlled retraction of the anterior segment, the elastics from the hook of the anterior segment and the hook at the molar tube were added to promote root movement of the anterior segment (Figure 10D). After root movement was completed, full arch alignment was performed in the usual manner (Figures 10E,F). The treatment objectives were accomplished as planned (Figure 11).

DISCUSSION Return to TOC

An M/F ratio at the bracket of 5–7 for the anterior segment and 8–12 for the posterior segment may be appropriate to achieve controlled tipping of the anterior segment and translation of the posterior segment.[11] The M/F ratio at a bracket is simply the distance from the bracket to the line of action of a substituted equivalent single force. Thus, the single force with its line of action passing 5–7 mm above the anterior brackets and 8–12 mm above the posterior brackets is equivalent to these M/F ratios at the bracket. A mentally visualized line of action of single force identifies a required M/F ratio.

The vertical height of the anterior hook determines the equivalent anterior M/F ratio at the bracket. This height was arbitrarily set at six mm in our experiment, but it can always be modified to the clinician's needs. Posteriorly, the line of action passes above the center of resistance of the posterior teeth (Figure 1). When the line of action is moved apically to achieve the necessary M/F ratio, anatomic structures such as a shallow mucobuccal fold or a buccal frenum could interfere with the actions of the SDRS. Moving the point of application of force along the line of action anteriorly can reduce the height of the SDRS assembly. Figure 1B shows that by placing the hooks anteriorly, the height of the spring can be kept low while still maintaining an M/F ratio of greater than 10 for the posterior segment (Figure 1B).

Table 1 shows that angle θ was kept relatively constant, which means that the initially predetermined M/F ratio was maintained unaltered. Figures 1A and B show the deactivated and activated shapes of the SDRS spring. Although the path of activation is not exactly linear, its line of action does not change during its range of action. This indicates that the M/F ratio is relatively constant throughout space closure as well. Therefore, the axis of rotation of the teeth can remain constant, and unnecessary tooth movement and jiggling can be minimized.

In the SDRS, the load-deflection rate is reduced and the range of action is increased when compared with the rate and range of other loop-springs (with both ends restrained) of the same dimension. Since the average SDRS spring delivers 160 g of force at activation, the load-deflection rate is about six g/mm and, consequently, reactivation is usually unnecessary during space closure.

Once the shape of any loop-spring has been modified for a different force system, its force system will change substantially at a minor change of the shape of the spring, and therefore, the effect of the change can be unpredictable.[4] Therefore, the clinician cannot easily modify the shape of a loop to produce accurately the desired force system. In contrast, with the SDRS, the horizontal component of the force can be adjusted by the anterior bend. Decreasing the anterior bend can reduce the horizontal force, effectively keeping the vertical force constant.

The vertical component of the force is adjustable at the posterior bend. Modifying the anterior bend alters the ratio between the horizontal and vertical forces, whereas altering the posterior bend influences the effective overall magnitude of force. The effect from the change of shape can be visualized easily by looking at the angular change of the line of action. Since the line of action can be easily visualized, its relation to the center of resistance of anterior and posterior teeth can be easily monitored. In a statically indeterminate loop, changes in the force system can be monitored only after teeth have been moved. After initial space closure, the line of action can be reversed easily as necessary for later root movement by using an elastic chain from the hook on the molar band to the hook of the posterior assembly via the hook of anterior stabilizing unit, as shown in Figure 10C.

All measurements presented in the current study were obtained in vitro. Therefore, they may not reflect clinical conditions exactly. For instance, the line of force may not always be perpendicular to the anterior end of the spring. The direction of the ligature tie between the canine and spring hooks determines the direction of the force. This study measured the force at 90° to the wire. However, the direction of the tie can differ from situation to situation. Clinically, the force at full activation can be measured with a force gauge. Care must be taken to ensure that the direction of pull with the gauge is on a line connecting the two hooks in the activated position of the spring.

CONCLUSIONS Return to TOC

The SDRS provides a measurable known force system that leads to space closure in cases in which differential moments and an anterior intrusive force are required. The advantages of the SDRS are the following:

1. SDRS uses frictionless mechanics, and its statically determinate force delivery system (ie, magnitude, direction, and point of force application) can be easily established by a single force measurement.
2. The cantilever spring has a low load-deflection rate; thus, the force produced is relatively constant, and reactivation is often not required.
3. The force direction changes minimally and remains during space closure, as does the axis of rotation. Therefore, unnecessary jiggling of teeth can be minimized.
4. Its force system can easily be visualized, and modification of the system is relatively easy for both initial and subsequent activation.

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TABLES Return to TOC

TABLE 1. Standard Spring Geometry and Force System

Deactivation Angle (P), degrees	Arc Length,[a] mm	Moment, gmm	Angle θ, degrees	Force (F), g	Length (L), mm
0	0.00	3100	38.7	160.1	19.4
5	1.68	2800	39.4	145.4	19.3
10	3.34	2600	39.9	135.5	19.2
15	5.00	2500	40.4	130.8	19.1
20	6.62	2300	41.4	121.2	19.0
25	8.21	2100	42.4	111.6	18.8

[a] Arc length = L × P × π/180. Arc length indicates the actual length that the free end of the spring moves.

TABLE 2. Measurements of the Forces and Moments of Varied Spring Shapes at Full Activation

Angle A, degrees	Angle θ, degrees	Moment, g/mm	F (Resultant), g	F (Horizontal), g	F (Vertical), g	Ratio F (Horizontal)/ F (Vertical)
90[a]	39.0[a]	3150[a]	163.1[a]	102.6[a]	126.7[a]	0.81[a]
80	36.6	3030	154.3	92.0	123.9	0.74
70	33.9	2920	146.4	81.6	121.5	0.67
60	30.2	2830	139.4	70.1	120.5	0.58
50	27.4	2730	133.1	61.2	118.1	0.52
40	24.2	2640	127.5	52.3	116.3	0.45
90[a]	37.8[a]	3150[a]	161.7[a]	99.1[a]	127.8[a]	0.78[a]
80	38.8	3000	155.1	97.2	120.9	0.80
70	39.7	2850	148.3	94.7	114.1	0.83
60	40.5	2600	136.1	88.4	103.5	0.85
50	41.8	2270	120.1	80.0	89.5	0.89
40	42.5	1880	100.0	67.6	73.7	0.92
30	43.2	1600	85.6	58.6	62.4	0.94

[a] Measurements for the standard spring.

FIGURES Return to TOC

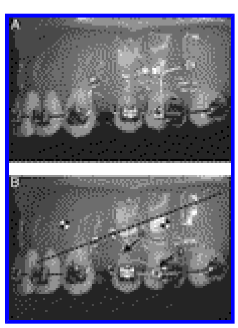

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FIGURE 1. (A) The statically determinate retraction system (SDRS) before activation. (B) Activated shape of the SDRS. Note the indicated locations of the center of resistance for the anterior and posterior segments and the line of action (dotted line)

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FIGURE 2. The torque gauge measurement system used in the study

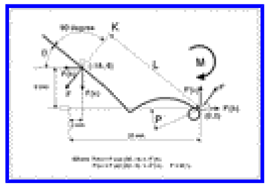

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FIGURE 3. An activated, standard statically determinate retraction system and its force system in equilibrium. The anterior hook was assumed to be six mm superior and two mm posterior to the canine bracket. To calculate the load-deflection rate, angle P was altered. K indicates direction of force; L, length of the spring; M, moment applied; F(h), horizontal component of the force; and F(v), vertical component of the force. The deactivation force system on the tooth should be reversed

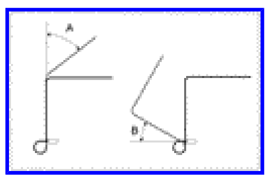

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FIGURE 4. Angle A indicates the magnitude of anterior bend, and angle B indicates the magnitude of posterior bend. Angles A and B were varied to test the properties of the statically determinate retraction system

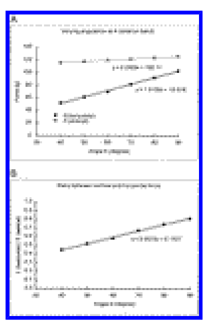

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FIGURE 5. Results from altering angle A. (A) The horizontal force increased more steeply than the vertical force. (B) Therefore, the ratio between the horizontal and vertical forces increased as the anterior bend increased

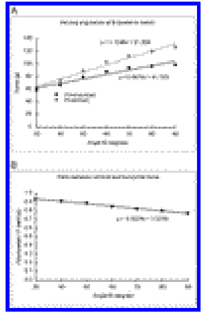

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FIGURE 6. Results from altering angle B. (A) The vertical force increased more steeply than the horizontal force. (B) Therefore, the ratio between the horizontal and vertical forces decreased as the posterior bend increased

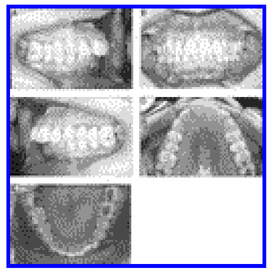

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FIGURE 7. Pretreatment state of occlusion. The patient had procumbent anterior teeth and Class II molars with a severe curve of Spee

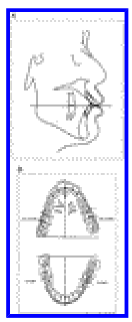

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FIGURE 8. Treatment objectives. A significant retraction of the upper anterior segment and an intrusion of the lower incisors were planned after two upper first bicuspid extractions

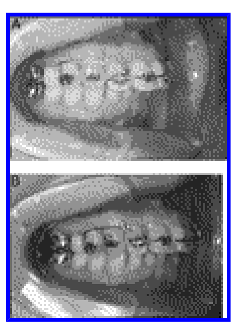

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FIGURE 9. (A) Before intrusion. (B) After intrusion. Intrusion was performed along the long axis of the anterior teeth to the same level of the canine. Upper first premolars were used for anchorage, and adverse effects were concentrated on these teeth, which were to be extracted later

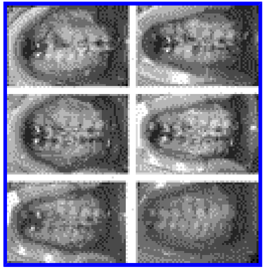

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FIGURE 10. Retraction of the anterior teeth with the statically determinate retraction system. (A–C) Note the controlled tipping of the anterior segment and translation of the posterior segment. (C and D) The lower anterior segment was intruded with a three-piece intrusion arch. (D) The root movement of the upper anterior segment. (E) The finishing arches. (F) The final result

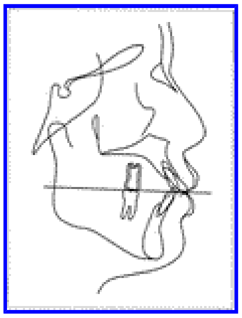

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FIGURE 11. Superimposition of the pretreatment and posttreatment tracings. Planned treatment objectives were accomplished with the statically determinate retraction system

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