REDEFINING ORTHODONTIC SPACE CLOSURE: SEQUENTIAL REPETITIVE LOADING OF THE PERIODONTAL LIGAMENT—A CLINICAL STUDY

Aims: To assess the rate of tooth movement, anchorage loss, root resorption, and alkaline phosphatase (ALP) activity in the gingival crevicular fluid (GCF) as a marker for bone remodeling during orthodontic space closure using two different mechanisms. Methods: Space closure was completed in 20 patients with extraction of all 4 premolars. Lateral cephalograms and radio-visiographs taken before (T1) and after (T2) space closure were assessed for anchorage loss and root resorption. Alkaline phosphatase levels were measured in 10 patients, which were divided into two groups of five each. Spaces were closed with a screw device in the first group and with active tie-backs in the second. Gingival crevicular fluid samples, collected at intervals, were assayed for alkaline phosphatase spectrophotometrically in each patient. Results: The mean rate of tooth movement was 1.32 ± 0.22 mm/month. The mean amount of anchorage loss in the maxilla and mandible was 1.23 ± 0.60 mm and 1.08 ± 0.65 mm, respectively. Sixty (25%) roots showed no root resorption, while 180 (75%) roots displayed mild to moderate blunting of their apices. Gingival crevicular fluid–alkaline phosphatase level increased significantly from day 7 to day 28 in both groups, but significantly more in the screw retraction group (P < .05). Conclusion: It is possible to infer that space closure occurs more rapidly with sequential repetitive loading of the periodontal ligament than with conventional active tie-backs. This observation is in concurrence with a significant increase in the gingival crevicular fluid–alkaline phosphatase level. World J Orthod 2010;11:221–229.

Key words: space closure, periodontal ligament, alkaline phosphatase, root resorption, anchorage loss

Orthodontic space closure is time-consuming. There is no consensus as to how to accomplish it most efficiently. While the concepts of optimal force magnitude and duration have received substantial attention,1 frequency of force application has not received due consideration. Studies on distraction osteogenesis2 show that repetitive activations result in favorable cellular responses that again lead to more rapid tooth movements. Each activation causes an upregulation of the various markers (interleukins, prostaglandins, etc) associated with remodeling processes within the periodontal ligament.3 Research has proven that changing force magnitude produces better reaction from bone and cartilage cells than a constant force.4,5
Recently, a screw-type appliance, the Hycon screw⁵,⁶ (Adenta) was proposed as a new method for space closure (Figs 1a and 1b). It allows precise activation so that force delivery can be adjusted. The first part of this study was conducted to assess the effect of sequential repetitive loading of the periodontal ligament during space closure using fixed appliances and the aforementioned screw. The aim was to assess the rate of tooth movement and the amount of anchorage loss and root resorption.

A number of gingival crevicular fluid constituents have been shown to be diagnostic markers of bone remodeling as indicated by an elevation in alkaline and acid phosphatase levels.⁷,⁸ Therefore, in the second part of this study, the alkaline phosphatase level in the GCF during space closure was evaluated.

**METHOD AND MATERIALS**

As a precursor to the clinical study, a 2D finite element model (FEM) of the canine, premolar, and molar region was constructed using Engineering Mechanical Research Corporation (EMRC) display; NISA III software (Cranes); and a periapical radiograph of the molar, premolar, and canine region as a reference. The model consisted of 2,185 nodes and 4,135 elements. To reflect normal anatomy, the teeth were connected to the surrounding alveolar bone through a virtual periodontal ligament.

The different structures (alveolar bone, teeth, and periodontal ligament) were assigned their respective material constants as determined previously by Tanne et al⁹; the experimental archwire received the mechanical properties of stainless steel. The load distribution within the periodontal ligament was then studied for one full turn (0.35 mm) of the Hycon screw (Fig 2). The model showed minimal
Fig 3a  Radiovisiograph image of canine region before activation; compare width of the tension side (arrow) with width after activation.

Fig 3b  Radiovisiograph image of canine region after activation; compare width of the tension side (arrow) with width before activation. Also note uniform compression of the distal periodontal ligament.

tipping of the teeth into the extraction site due to controlled activation and the presence of guidance by the 0.021-inch × 0.025-inch wire. The stress on the pressure side was generally low (13 cN/mm²) and uniformly distributed along the root surfaces. This was also reflected on the radiovisiographs (RVGs) before and after activation (Figs 3a and 3b). Image inversion with Dextra 3.0 software depicted any changes in the periodontal ligament more clearly.

For the clinical part of this study, 10 males and 10 females (mean age 19.9 ± 3.8 years) requiring extraction of all first premolar were randomly selected. Inclusion criteria were healthy periodontal status, healthy medical status, maximum anchorage requirements, identical ethnicity, and signed informed consent.

All patients were bonded with 0.022-inch slot brackets. Anchorage preparation included banding all second molars and placing a transpalatal and lingual arch. Leveling and aligning was initiated with 0.016-inch and completed with 0.019-inch × 0.025-inch heat-activated Ni-Ti wires. Finally, 0.021-inch × 0.025-inch stainless steel wires were placed with passive tie-backs for 4 weeks. After leveling and aligning, lateral cephalograms and RVGs of the canine and molar–premolar regions were taken.

For retraction, the Hycon screw as described by McLaughlin et al. and Kachiwala et al. was used. All patients were advised to activate this screw half a turn every 3 days until space closure was complete.
Data collection

**Rate of tooth movement.** Tooth movement was evaluated by measuring the distance between the distal wing of the canine and the mesial wing of the second premolar bracket with Vernier calipers (Dentaurum). The readings were noted every 4 weeks until space closure was completed. Figs 4 and 5 show a clinical example before and after space closure.

**Incisor retraction and anchorage loss.** Pre- (T1) and posttreatment (T2) lateral cephalograms were traced using the Panerz method. The distance from the occlusal line perpendicular to the tip of the maxillary and mandibular incisors was measured, the difference being the amount of incisor retraction.

Also, the distance from the occlusal line perpendicular to the ciasal aspect of the maxillary and mandibular molars was measured; this difference indicated the amount of anchorage loss.

**Root resorption.** The RVGs were taken with an UltraCam (Ultrak Inc.) and projected on a computer screen using Dexas 3.0 software. The canine and molar/premolar regions were scored according to the criteria given by Sharpe et al.:

0 = No apical root resorption  
1 = Slight blunting of the apex  
2 = Moderate blunting of the apex up to one fourth of the root length  
3 = Excessive blunting of the apex beyond one fourth of the root length

By adding the resorption scores for all the teeth examined, the total resorption score for each patient was determined.

**Alkaline phosphatase activity.** For the alkaline phosphatase study, six females and four males (mean age 20.6 ± 3.2 years) with the same inclusion criteria stated previously were enrolled. Leveling and aligning was performed as described earlier. In five randomly selected patients, the anterior teeth were moved with the Hycon screw; in the remaining five, active tie-backs were used.

Sampling of gingival crevicular fluid followed the protocol of Perinetti et al.  
All samples were collected from the distogingival margin of the four canines using a volumetric micropipette of 1 µl capacity. The collection took place 1 hour before and 1 hour after activation and at 7-, 14-, 21-, and 28-day intervals. The screw was activated by half turn, twice weekly, while the active tie-backs were changed every 4 weeks.
**Table 1** Total (mm), mean (mm/month) ± SD (standard deviation) and range of extraction space closure in the maxilla and mandible, including t and P value

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Mean ± SD</th>
<th>Range</th>
<th>t*</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxilla</td>
<td>4.50 ± 1.41</td>
<td>1.36 ± 0.21</td>
<td>0.87–1.77</td>
<td>1.85</td>
<td>.07</td>
</tr>
<tr>
<td>Mandible</td>
<td>4.24 ± 1.32</td>
<td>1.27 ± 0.23</td>
<td>0.50–1.70</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Unpaired t test.

**Table 2** Mean ± SD (standard deviation) and range (mm) of retraction and anchorage loss in the maxilla and mandible, including t and P value

<table>
<thead>
<tr>
<th></th>
<th>Maxilla</th>
<th>Mandible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retraction</td>
<td>Mean ± SD</td>
<td>Range</td>
</tr>
<tr>
<td></td>
<td>3.90 ± 0.82</td>
<td>3.0–5.0</td>
</tr>
<tr>
<td>Anchorage loss</td>
<td>1.23 ± 0.60</td>
<td>0.0–2.0</td>
</tr>
</tbody>
</table>

*Unpaired t test.

**STATISTICAL ANALYSIS**

For the first part of the study, descriptive data are presented as means ± SD and 95% confidence limits wherever applicable. One-way ANOVA was used for multiple group and Student t test for group-wise comparisons. Correlations between measurements were assessed by Pearson correlation coefficient. Statistical significance was set at a probability level of ≤ .05.

For the alkaline phosphatase study, means ± SD were calculated; categorical data were presented as absolute values and percentages. The increase in alkaline phosphatase level for each time interval was reflected as percentage of the baseline value (1 hour before activation). ANOVA was performed to statistically compare the measurements at intervals to the baseline values. The Mann-Whitney test was then performed to determine any significant mean differences between the groups at each site.

**RESULTS**

**Space closure**

The average space closure was 4.51 ± 1.40 mm in the maxilla and 4.23 ± 1.33 mm in the mandible. The mean space closure thus was calculated as 4.37 ± 1.37 mm. The average time to complete space closure was 3.34 ± 0.94 months.

**Rate of tooth movement**

The mean rate of tooth movement was 1.36 ± 0.21 mm/month in the maxilla and 1.27 ± 0.23 mm/month in the mandible (Table 1). The overall rate of tooth movement was thus calculated to be 1.32 ± 0.22 mm/month. Unpaired t test did not show a significant difference between tooth movements in both jaws (P > .05).

**Incisor retraction and anchorage loss**

The amount of incisor retraction was 3.90 ± 0.82 mm for maxillary incisors and 3.7 ± 0.86 mm for mandibular incisors, the difference not being significant (P > .05) (Table 2).

The average anchorage loss amounted to 1.23 ± 0.60 mm for the maxillary molars and 1.08 ± 0.65 mm for the mandibular molars; the difference was not significant (P > .05). The Pearson correlation test showed a positive, but not significant, correlation between the amount of anchorage loss and incisor retraction in the maxilla (r = 0.32, P > .05) and the mandible (r = 0.18, P > .05). Approximately 3.2 mm of maxillary and 3.4 mm of mandibular incisor retraction resulted in 1.0 mm of anchorage loss.

**Root resorption**

Of the 240 roots assessed, 60 (25%) exhibited no root resorption, 132 (55%) showed slight root resorption, and 48 (20%) had a moderate blunting of their apices. The resorption scores did not differ significantly for the individual teeth in the maxilla and mandible (P > .05) (Table 3). The ANOVA test showed that the combined resorption scores for the canines,
premolars, and molars were significantly different from one another \((P < .01)\). The unpaired \(t\) test again revealed that the molars were characterized by significantly greater root resorption than the canines \((P < .01)\) and premolars \((P < .01)\) (Table 4).

### Table 4 Statistical comparison of the resorption scores among canines, premolars, and molars

<table>
<thead>
<tr>
<th></th>
<th>(t^*)</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canines vs premolars</td>
<td>0.81</td>
<td>.43</td>
</tr>
<tr>
<td>Canines vs molars</td>
<td>3.52</td>
<td>.01</td>
</tr>
<tr>
<td>Premolars vs molars</td>
<td>2.80</td>
<td>.01</td>
</tr>
</tbody>
</table>

*Unpaired \(t\) test.

**Alkaline phosphatase activity**

Compared with the baseline measurement, the mean concentrations of alkaline phosphatase levels were significantly increased in both groups at the various time intervals (Tables 5 and 6). The one-way ANOVA showed that the values differed significantly between groups. There was an increase of about 200% in the alkaline phosphatase level between days 21 and 28 in the active tie-back group at all sites, while that in the retraction screw group was more than 260%. Also, between day 14 and 28, the difference in the alkaline phosphatase level between the two groups was significant for all four sites.

**DISCUSSION**

Despite their varying force magnitude, traditional tooth-moving devices (closing loops, elastic chains/modules, and springs) produce consistently hyalinization\(^{12}\) because their activation length is beyond the width of the periodontal space (0.25 mm).\(^{13}\) Thus, the blood supply is reduced, leading to cell-free zones.

The impact of force-application frequency with a controlled minimum activation length on a biologic system has not yet received due attention. In this study, besides classical tie-backs, the Hycon retraction screw was used for space closure. If it is activated one full turn (360 degrees), it contracts 0.350 mm.\(^{5,6}\) Because force distribution occurs reciprocally, one full turn would produce approximately 0.175 mm activation on both sides of the extraction site. This is less than the width of the periodontal ligament so blood supply can be maintained. In this study, the screw was turned only one half turn (180 degrees) twice a week. The efficient and rapid space closure observed here is an indication that the activation sequence used ensured adequate tissue response while not impeding blood supply to the periodontium. This is optimal for metabolism and subsequent osteoclast and osteoblast activity.\(^{12}\)

The force generated by a full turn activation was determined to be 410 \(\text{cN}^{\text{5}}\); it is in the 200 \(\text{cN}\) range for a 180-degree activation. This force is sufficient to overcome the friction generated between the 0.021- \(\times\) 0.025-inch stainless steel wire and the 0.022-inch bracket slot. A full-sized wire used en masse retraction of the anterior teeth will minimally deflect and thus allow a better inclination control as clinical observation also signified.

Tooth movements as high as 1.98 mm/month could be achieved, although the mean was 1.32 \(\pm\) 0.22 mm/month (95% CI = 0.88 mm to 1.98 mm/month). Ninety-five percent showed a movement of 1.5 mm/month or more, and 40% showed even more than 1.9 mm/month. Smaller movements may be attributed to the variability in bone density and trabeculation pattern. At the end of 4 months, space closure was completed in 91% of the 80 quadrants studied. In comparing the present data with those of Dixon et al,\(^{14}\)
### Table 5: Mean alkaline phosphatase values ± SD (standard deviation) (IU/L) in the gingival crevicular fluid, difference to baseline value (BL), and P value for the maxillary right and left canines in the tie-back and Hycon groups at the various time points and differences between groups

<table>
<thead>
<tr>
<th>Time</th>
<th>Maxillary right canine</th>
<th>Maxillary left canine</th>
<th>Maxillary right canine</th>
<th>Maxillary left canine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tie-back</td>
<td>Hycon</td>
<td>Tie-back</td>
<td>Hycon</td>
</tr>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Difference to BL</td>
<td>P</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>Before activation</td>
<td>58.4 ± 11.5</td>
<td>-</td>
<td>-</td>
<td>60.6 ± 2.6</td>
</tr>
<tr>
<td>After activation</td>
<td>79.0 ± 11.5</td>
<td>20.6 ± 2.4</td>
<td>&lt; .05</td>
<td>81.8 ± 1.9</td>
</tr>
<tr>
<td>Day 7</td>
<td>150.6 ± 9.4</td>
<td>92.2 ± 7.3</td>
<td>&lt; .01</td>
<td>169.4 ± 14.5</td>
</tr>
<tr>
<td>Day 14</td>
<td>164.0 ± 5.7</td>
<td>105.6 ± 6.3</td>
<td>&lt; .01</td>
<td>177.8 ± 41.3</td>
</tr>
<tr>
<td>Day 21</td>
<td>172.0 ± 11.6</td>
<td>113.2 ± 5.1</td>
<td>&lt; .01</td>
<td>229.2 ± 5.4</td>
</tr>
<tr>
<td>Day 28</td>
<td>171.6 ± 12.1</td>
<td>113.2 ± 4.4</td>
<td>&lt; .01</td>
<td>232.2 ± 4.4</td>
</tr>
<tr>
<td>ANOVA*</td>
<td>F = 115.0, P &lt; .001, LSD = 20.6</td>
<td>F = 380.2, P &lt; .001, LSD = 8.5</td>
<td>F = 301.6, P &lt; .001, LSD = 12.9</td>
<td>F = 370.8, P &lt; .001, LSD = 16.8</td>
</tr>
</tbody>
</table>

*One-way ANOVA, ** Mann-Whitney test, NS = not significant, S = significant, F = ratio of model mean square to error of mean square, LSD = least significant difference.

### Table 6: Mean alkaline phosphatase values ± SD (standard deviation) (IU/L) in the gingival crevicular fluid, difference to baseline value (BL), and P value for mandibular left and right canines in the tie-back and Hycon groups at the various time points and differences between groups

<table>
<thead>
<tr>
<th>Time</th>
<th>Mandibular right canine</th>
<th>Mandibular left canine</th>
<th>Mandibular right canine</th>
<th>Mandibular left canine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tie-back</td>
<td>Hycon</td>
<td>Tie-back</td>
<td>Hycon</td>
</tr>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Difference to BL</td>
<td>P</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>Before activation</td>
<td>63.6 ± 4.2</td>
<td>-</td>
<td>-</td>
<td>65.4 ± 8.0</td>
</tr>
<tr>
<td>After activation</td>
<td>83.2 ± 6.5</td>
<td>15.6 ± 4.4</td>
<td>&lt; .01</td>
<td>89.2 ± 4.9</td>
</tr>
<tr>
<td>Day 7</td>
<td>151.2 ± 7.9</td>
<td>87.8 ± 7.8</td>
<td>&lt; .01</td>
<td>154.0 ± 36.5</td>
</tr>
<tr>
<td>Day 14</td>
<td>165.8 ± 4.8</td>
<td>102.6 ± 4.0</td>
<td>&lt; .01</td>
<td>204.6 ± 11.3</td>
</tr>
<tr>
<td>Day 21</td>
<td>179.0 ± 5.7</td>
<td>113.4 ± 8.6</td>
<td>&lt; .01</td>
<td>234.8 ± 6.6</td>
</tr>
<tr>
<td>Day 28</td>
<td>177.6 ± 4.4</td>
<td>114.0 ± 7.4</td>
<td>&lt; .01</td>
<td>235.2 ± 2.9</td>
</tr>
<tr>
<td>ANOVA*</td>
<td>F = 388.2, P &lt; .001, LSD = 11.6</td>
<td>F = 380.2, P &lt; .001, LSD = 16.6</td>
<td>F = 366, P &lt; .001, LSD = 11.1</td>
<td>F = 353.6, P &lt; .001, LSD = 16.5</td>
</tr>
</tbody>
</table>

*One-way ANOVA, ** Mann-Whitney test, NS = not significant, S = significant, F = ratio of model mean square to error of mean square, LSD = least significant difference.
Nightingale and Jones, and Barlow, it can be inferred that the mean space closure with the Hycon screw is much faster and more efficient than traditional space-closing mechanisms. As mentioned, this may be attributed to the repetitive loading of the periodontal ligament. The upregulation of the various markers involved in the anabolic and catabolic modeling activities during tooth movement was demonstrated by Lee et al and Carano and Siciliani.

As an exudate, gingival crevicular fluid reflects metabolic changes in the periodontal tissues. The increase in alkaline phosphatase activity in the gingival crevicular fluid seems to be related to orthodontic force application because alkaline phosphatase is considered to be a marker for bone remodeling. Several studies have reported changes in alkaline phosphatase activity in osteoblasts during experimental tooth movements in both animals and humans.

In this study, gingival crevicular fluid–alkaline phosphatase activity was assayed longitudinally during tooth movement in relation to the type of force system used. Significant increases in the gingival crevicular fluid–alkaline phosphatase activity level were found over a 1-month period. The particularly significant alkaline phosphatase increase in the Hycon retraction group between days 14 and 28 as compared to the tie-back group can be explained by the fact that the elastomeric modules used in the latter sample generally lose 50% to 70% of their initial force during the first day of loading; at 3 weeks, they retain only 30% to 40% of their original force. In contrast, retraction screws do not wear out.

The mean amount of incisor retraction achieved was 3.90 ± 0.81 mm for the maxillary and 3.70 ± 0.86 mm for the mandibular incisors, and the mean anchorage loss was 1.23 ± 0.60 mm and 1.08 ± 0.65 mm for the maxillary and mandibular arches, respectively. Thus, the anchorage loss accounted for 24% to 27% of the total space closure (4.37 ± 1.37 mm), which is acceptable for maximum posterior anchorage and comparable to other methods of space closure.

Root resorption occurs when pressure on the cementum exceeds its reparative capacity. Subsequently, dentin is exposed, thereby allowing multinucleated odontoclasts to degrade the root surface. Movement of teeth typically produces some blunting of root apices independent of the type of appliance used. The relevant literature describes a prevalence ranging from 3% to 100% of the treated patients.

Of the 240 roots in this study, 85% (132) encountered a slight blunting, 20% (48) showed moderate blunting, and 25% (60) revealed no apex blunting at all.

Studies by Beck et al and McNab et al have shown that among the posterior teeth, the most frequently resorbed are the mandibular molars followed by the maxillary molars, mandibular premolars, maxillary first premolars, and maxillary second premolars. In this study, molars showed significantly greater apical root resorption than premolars and canines (P < .01), which is confirmed by the findings of Sharpe et al. There was, however, no difference of resorption between canines and premolars.

The length of treatment time and root resorption are positively correlated; increased treatment length makes roots more prone to resorption. If space closure is completed quickly in a controlled manner as in this study, treatment duration is reduced, as is the risk of root resorption.

CONCLUSION

Sequential repetitive loading of the periodontal ligament with small and controlled activations (approximately 0.175 mm) is effective for space closure as indicated by a significantly higher increase in the gingival crevicular fluid–alkaline phosphatase level if a retraction screw is used instead of active tie-backs (a superior force application); a shorter treatment length because, with traditional methods, activation intervals, force levels, and activation length vary significantly; and minimal anchorage loss and root resorption.
ACKNOWLEDGMENTS

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REFERENCES