Mini-implant anchorage for en-masse retraction of maxillary anterior teeth: A clinical cephalometric study

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Introduction: This study was conducted to determine the efficiency of mini-implants as intraoral anchorage units for en-masse retraction of the 6 maxillary anterior teeth when the first premolars are extracted compared with conventional methods of anchorage reinforcement. Methods: Thirty patients requiring high anchorage after extraction of the maxillary first premolars were selected for this study. They were divided into 2 groups of 15 each. In the first group (G1), mini-implants were used for en-masse retraction; in the second group (G2), conventional methods of anchorage preservation were followed. Horizontal, vertical, and angular positions of the maxillary first molar and central incisor were evaluated cephalometrically before and after orthodontic retraction. Results: The maxillary first molars in the G1 patients showed net distal movement of 0.55 mm, and mesial movement of 1.95 mm was found in G2. The differences were statistically significant. Distal tipping of the first molar of $-0.13^\circ \pm 3.63^\circ$ was seen in G1, and mesial tipping of $3.7^\circ \pm 3.9^\circ$ was observed in G2. No significant differences were found in the rates of incisor retraction between the 2 groups. However, G1 showed more than 2 mm of incisor intrusion; this was statistically significant. Conclusions: Mini-implants are efficient for intraoral anchorage reinforcement for en-masse retraction and intrusion of maxillary anterior teeth. No anchorage loss was seen in either the horizontal or the vertical direction in G1 when compared with G2. However, a statistically significant decrease in intermolar width was noted in G1.


Anchorage control plays a pivotal role in the effective management of orthodontic patients for obtaining both structural and facial esthetics. Anchorage is defined as the resistance to unwanted tooth movement or as the desired reaction of posterior teeth to space closure mechanotherapy. Depending on the requirement, it can be classified as minimum, medium, or maximum anchorage. Maximum anchorage is needed when the treatment objectives require that no or very little anchorage can be lost.

Obtaining maximum or absolute anchorage has always been an arduous goal for the practicing orthodontist, often resulting in a condition, dreaded by most, called anchorage loss. Anchorage loss is the reciprocal reaction of the anchor unit that can obstruct the success of orthodontic treatment by complicating anteroposterior correction. To address this problem, many appliances and techniques have been devised; Nance holding arch, transpalatal bars, extraoral traction, multiple teeth at the anchorage segment, and differential moments are some commonly used ones. However, all these methods have a few inherent disadvantages—complicated designs, need for exceptional patient cooperation, elaborate wire bending, and so on.

In recent years, titanium screws have gained enormous popularity in the orthodontic community and are being considered as absolute sources of orthodontic anchorage. Their primary advantages are easy placement and removal, immediate loading, placement at various anatomic locations including the alveolar bone between the roots of teeth, and low cost. These screws have spawned many clinical applications, such as en-masse retraction of anterior teeth.

However, the treatment effects of skeletal anchorage for en-masse retraction are largely unsubstantiated, except for a few case reports. Do mini-implants perform significantly better than conventional anchor-
age reinforcements? Do the posterior teeth or the anchorage units that we are trying to protect, especially in patients with en-masse retraction, show any movement? This study was therefore undertaken to investigate the efficiency of titanium-based mini-implants as intraoral anchorage for en-masse retraction of maxillary anterior teeth and compare them with conventional methods of anchorage reinforcements. Additionally, the treatment effects on the molars and incisors were also quantified.

MATERIAL AND METHODS

In the initial selection of patients, no plan for unbiased allocation by randomization was followed because all patients were selected on the basis of anchorage needs. The study sample consisted of 30 subjects (21 female, 9 male) from the Department of Orthodontics of KLES Academy of Higher Education and Research in Belgaum, India. These patients had the following characteristics: (1) age between 14 years 5 months and 22 years 3 months (at selection) with a mean pretreatment age of 17 years 2 months; (2) 17 patients had Angle Class I malocclusion with bialveolar dental protrusion and 13 had Angle Class II Division I malocclusion with severe overjet; (3) on the basis of these diagnoses, extraction of 2 maxillary first premolars and maximum anchorage was indicated in all subjects (with or without extractions in the mandibular arch), and maximum anchorage was indicated to restrict mesial movement of the maxillary first molars until overjet or bimaxillary protrusion was resolved and desired esthetics achieved; (4) the subjects had full permanent dentition (with or without the third molars), and those with severe crowding were excluded; (5) treatment was done with fixed mechanotherapy by using preadjusted edgewise appliances, .022-in Roth prescription brackets (GAC International, Bohemia, NY); and (6) maximum retraction of the anterior teeth was desired.

All patients or guardians were advised of the purpose of the study and signed a consent form. No patient who was approached for the study refused to participate. Then the subjects were randomly divided into 2 groups before treatment.

Group 1 (G1) included 15 subjects (10 female, 5 male) who received anchorage for en-masse retraction of the 6 maxillary anterior teeth with mini-implants.

Group 2 (G2) included 15 subjects (11 female, 4 male) who received the conventional method of anchorage reinforcement that best suited their needs. Nance holding arch, extraoral traction, banding of the second molars, and differential moments were some methods used.

The mini-implants were custom made at our institute by modifying conventional surgical screws, measuring 1.3 mm in diameter and 8 mm in length. For en-masse retraction of the maxillary anterior teeth, the most suitable site for placement of implants was selected as the alveolar bone (or interdental space) between the maxillary second premolar and first molar, preferably between the attached and movable mucosae (mucogingival junction). Intraoral periapical radiographs were taken with an acrylic guide bar in place to identify the precise location for implant placement to avoid contact with dental roots (Fig 1). After initial leveling and aligning, the implants were placed under local anesthesia. They were checked for primary stability (mechanical retention) and immediately loaded. Strict instructions were given to the patient regarding oral hygiene.

In the G1 patients, only the maxillary first molars were banded, and all remaining teeth in the maxillary arch mesial to the first molars were bonded. After initial leveling and aligning, a 0.017 × 0.025-in stainless steel archwire with anterior hooks (crimpable hooks) placed distal to the lateral incisors was placed in the maxilla, and 150 g of force was applied on each side with a nickel-titanium coil spring (closed) extending from the implant to the crimpable hook to retract the maxillary anterior teeth en masse (Fig 2).

Lateral cephalometric radiographs were taken of all patients at 2 times: T1, before retraction or placement of the implant; and T2, after closure of the extraction spaces.

The dental linear and angular measurements are shown in Figures 3 and 4.

When there was a double image, the midpoint between the 2 points was traced. Centroid points were determined for the crowns of the maxillary first molars at the midpoint between the greatest mesial and distal convexity of the crowns as seen on the cephalometric radiographs. The long axis of the maxillary molar was obtained by drawing a line through the centroid perpendicular to the line connecting the most convex points on the crown.
Fig 2. Clinical setup for en-masse retraction.

Fig 3. Cephalometric points and planes used in this study. Cephalometric points: S, geometric center of the pituitary fossa; N, the most anterior point on the frontonasal suture on the midsagittal plane; ANS, the anterior tip of the sharp bony process of the maxilla at the lower margin of the anterior nasal opening; PNS, the posterior spine of the palatine bone constituting the hard palate; U6M, the most anterior point on the mesial outline of the crown of the maxillary first molar; U6D, the most posterior point on the distal outline of the crown of the maxillary first molar; Ia, the root apex of the maxillary central incisor; Io, the most incisal point on the crown of the maxillary central incisor; L, centroid of the maxillary first molar crown (midpoint between U6M and U6D). Cephalometric planes: PP, palatal plane—line joining ANS to PNS; SN, anterior cranial base—line joining S to N; SV, perpendicular to SN plane through S.

Fig 4. Maxillary dentoalveolar measurements. Maxillary first molar measurements: 1, U6M-SV—distance from the greatest mesial convexity on the first molar to SV; 2, U6D-SV—distance from the greatest distal convexity on the first molar to SV; 3, U6M-PP—distance from the greatest mesial convexity on the first molar to the PP; 4, U6D-PP—distance from the greatest distal convexity on the first molar to the PP; 5, U6 angle—angle formed by the longitudinal axis of the maxillary first molar and the SV. Maxillary central incisor measurements: 6, Io-SV—distance between the incisal edge of the maxillary central incisors and the SV; 7, Ia-SV—distance between the apical tip of the root of the maxillary central incisors and the SV; 8, Io-PP—distance between the incisal edge of the maxillary central incisors and the PP; 9, Ia-PP—distance between the apical tip of the root of the maxillary central incisors and the PP; 10, I angle—angle between the longitudinal axis of the maxillary central incisor and the SN plane.
The horizontal (anteroposterior) movement of the molars and incisors was calculated by measuring along a line (SV) perpendicular to the anterior cranial base at sella. The vertical movement of the maxillary molars and incisors was determined by measuring the distance to the palatal plane (PP). Angular changes were assessed in the relationship of the long axis of the teeth to the anterior cranial base (SN plane).

To determine and quantify the movements of the central incisors, the quotient of the moved distance of the most apical point (Ia) and the moved distance of the most occlusal point (Io) were calculated. If the apical point moved in the opposite direction to the coronal point or vice versa, the amount received a negative sign. Tooth movements were classified on the basis of the quotient obtained (Ia/Io):

- 0, uncontrolled tipping;
- 0, controlled tipping;
- 0, controlled tipping and bodily movement;
- 1, bodily movement; and
- 1, root movement.

Intermolar and intercanine widths were calculated on the dental casts of the G1 patients before and after retraction of the 6 maxillary anterior teeth to quantify the transverse changes on the maxillary arch.

### Statistical analysis

All statistical analyses were performed by using the SPSS software package (SPSS for Windows 98, version 10.0, SPSS, Chicago, Ill). For each variable measured on the lateral cephalograms and the dental casts, the mean and standard deviation were calculated. Independent-samples t tests were used for comparison between the 2 groups to determine the significance (P < 0.05) of the changes between the paired cephalometric variables at T1 and T2. A paired-samples t test was used to evaluate the treatment changes in G1. Differences with probabilities less than 5% (P < 0.05) were considered statistically significant.

### RESULTS

The average times required for space closure were 9.2 months in G1 and 10.6 months in G2. In 3 patients, complete space closure by anterior retraction was not done, because treatment needs required protraction of the posterior teeth after some incisor retraction. In these patients, the T2 records were taken before starting protraction.

The data in this study were evaluated and comparisons were made between the molar and incisor positions in G1 and G2 (Tables I-IV). All variables were differences obtained by subtraction of the T2 values from the T1 values. A positive value indicates a larger posttreatment value. Negative values indicated intrusion, distal movement, or crown posterior and root anterior angular changes; positive values indicated extrusion, mesial movement, or crown anterior and root posterior angular changes. The results are as follows.

### Cephalometric findings

1. Maxillary first molar (horizontal movements). The changes in molar position during the retraction phase obtained from the cephalometric radiographs

### Table I. Dental linear and angular changes (T2-T1) measured on the cephalometric radiographs

<table>
<thead>
<tr>
<th>Measurement</th>
<th>G1</th>
<th>G2</th>
<th>P value</th>
<th>Significance</th>
</tr>
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<tbody>
<tr>
<td>U6M-SV (mm)</td>
<td>15</td>
<td>0.83</td>
<td>1.4</td>
<td>0.83</td>
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<tr>
<td>U6D-SV (mm)</td>
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<td>0.27</td>
<td>0.98</td>
<td>0.27</td>
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<td>U6M-PP (mm)</td>
<td>15</td>
<td>0.23</td>
<td>0.73</td>
<td>0.23</td>
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<td>U6D-PP (mm)</td>
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<td>0.3</td>
<td>0.65</td>
<td>0.3</td>
</tr>
<tr>
<td>U6 angle (°)</td>
<td>15</td>
<td>0.13</td>
<td>3.63</td>
<td>0.13</td>
</tr>
<tr>
<td>Ia-SV (mm)</td>
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<td>0.9</td>
<td>1.33</td>
<td>0.9</td>
</tr>
<tr>
<td>Io-SV (mm)</td>
<td>15</td>
<td>6.23</td>
<td>2.65</td>
<td>6.23</td>
</tr>
<tr>
<td>Ia-PP (mm)</td>
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<td>2.13</td>
<td>1.58</td>
<td>2.13</td>
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<td>Io-PP (mm)</td>
<td>15</td>
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<td>1.31</td>
<td>2.2</td>
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<td>I angle (°)</td>
<td>15</td>
<td>−11.27</td>
<td>4.88</td>
<td>−11.27</td>
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</table>

NS, Not significant; *P < 0.01; †P < 0.001.
Table II. Comparison of cephalometric variables in G1

<table>
<thead>
<tr>
<th>Measurement</th>
<th>T1</th>
<th>T2</th>
<th>P value</th>
<th>Significance</th>
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<tr>
<td></td>
<td>n</td>
<td>Mean SD</td>
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<td></td>
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<td>U6M-SV (mm)</td>
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<td>41.93 5.72</td>
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<td>U6D-SV (mm)</td>
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<td>28.1 5.35</td>
<td>27.63 5.63</td>
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<td>U6M-PP (mm)</td>
<td>15</td>
<td>21.7 1.49</td>
<td>21.47 1.51</td>
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<td>U6D-PP (mm)</td>
<td>15</td>
<td>20.2 2.08</td>
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<td>0.05</td>
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<td>U6 angle (°)</td>
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<td>–8.9 5.37</td>
<td>0.41</td>
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<td>Ia-SV (mm)</td>
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<td>60.5 6.11</td>
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<td>Ia-PP (mm)</td>
<td>15</td>
<td>7.13 2.83</td>
<td>4.83 3.05</td>
<td>0.13</td>
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<td>I angle (°)</td>
<td>15</td>
<td>109.93 4.87</td>
<td>63.67 6.91</td>
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NS, Not significant; *P < 0.05; †P < 0.001.

Table III. Quantification of incisor movement in the sagittal plane

<table>
<thead>
<tr>
<th>Measurement</th>
<th>G1 Mean SD</th>
<th>G2 Mean SD</th>
<th>P value</th>
<th>Significance</th>
</tr>
</thead>
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<tr>
<td>Incisors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ia/Io</td>
<td>0.2 0.33</td>
<td>–0.15 0.56</td>
<td>0.05</td>
<td>*</td>
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</table>

*P ≤0.05.

were −0.83 ± 1.4 mm (U6M-SV) and −0.55 ± 0.98 mm (U6D-SV) for G1, and 2.07 ± 0.68 mm (U6M-SV) and 1.83 ± 1.19 mm (U6D-SV) for G2. There were a net distal movement of the molar in G1 and a net mesial movement in G2. The differences were highly significant (P <0.001) (Table I). However, the differences in G1 were not significant (P >0.05) (Table II).

2. Maxillary first molar (vertical movements). Vertical changes in first molar position were −0.23 ± 0.73 mm (U6M-PP) and −0.30 ± 0.65 mm (U6D-PP) for G1, and 0.73 ± 0.60 mm (U6M-PP) and 0.65 ± 0.53 mm (U6D-PP) for G2. Although with mini-implants a net intrusive effect on the molars was recorded, it was not statistically significant (P >0.05) (Tables I and II).

3. Maxillary first molar (angular movements of U6). A distal crown tip was noted of −0.13° ± 3.63° in G1, with a mesial crown tip of 3.7° ± 3.9° in G2. The restrictive effect on mesial tipping of the molar in G1 when compared with G2 was clinically significant (P <0.01) (Table I), but the readings within G1 were not statistically significant.

4. Maxillary central incisor (horizontal movements). Changes in incisor position in G1 showed root movement of −0.90 ± 1.33 mm (Ia-SV) and crown movement of −6.23 ± 2.65 mm (Io-SV); in G2, the mean changes were 0.37 ± 2.57 mm (Ia-SV) and −5.72 ± 2.37 mm (Io-SV). No statistically significant differences were found in the amount of incisor retraction between the 2 groups (P >0.05) (Table I).

5. Maxillary central incisor (vertical movements). Changes in vertical position of the incisors in G1 were −2.13 ± 1.58 mm (Ia-PP) and −2.20 ± 1.31 mm (Io-PP). G2 showed mean values of −0.2 ± 1.19 mm (Ia-PP) and 0.4 ± 1.14 mm (Io-PP). Statistically significant amounts of intrusion of the maxillary central incisor was recorded in G1 (P <0.001) (Tables I and II).

6. Maxillary central incisor (angular movements). Tipping amounts of the incisors were −11.27° ± 4.88° in G1 and −10.83° ± 5.61° in G2. The differences were not statistically significant (P >0.05) (Table I).

The maxillary central incisors in G1 were retracted primarily by controlled tipping and partly by translation (Ia/Io = 0.20 ± 0.33). Incisor retraction in G2 also showed significant amounts of controlled tipping, but some uncontrolled tipping was also noted (Ia/Io = −0.15 ± 0.56). The differences were statistically significant (P ≤0.05) (Table III).

On the dental casts, G1 showed no significant differences in maxillary intercanine width before and after retraction (−0.27 ± 1.13 mm). However, the decrease in intermolar width (−1.83 ± 1.29 mm) was clinically significant (P <0.05) (Table IV).

DISCUSSION

A primary concern in orthodontics has been the development of techniques to adequately preserve anchorage. With preadjusted edgewise appliance systems, sliding mechanics has become a commonly practiced technique. Although it has compounded the concern for preserving anchorage, it has also caused orthodontists to look for appliances that can provide better biomechanical control of the posterior teeth for anchorage preservation during space closure.
Recently, anchorage control with self-tapping screws or mini-implants (also called miniscrews, microscrews, and microimplants) has gained enormous credibility in the clinical management of space closure.

Our success rate with mini-implants was about 87% because we lost 4 implants (of 30) in the initial stages of our study. The mini-implants were replaced after 6 weeks. All implants showed primary stability at placement and were loaded immediately. Inflammation was minimal and did not interfere with the retraction of the anterior teeth. Contrary to a few reports, treatment times were not significantly shorter in patients with implants. A possible explanation could be that, with implants, closure of extraction spaces was completely done by distalization of anterior teeth, whereas in G2 there was simultaneous movement of the anterior and posterior teeth into the extraction spaces.

**Anchorage preservation**

The maxillary first molar remained stable and upright through the retraction phase. Net distal movement of 0.55 mm and distal tipping of 0.13° were noted, but they were statistically insignificant. Similar results of maxillary molar distalization were reported recently. In stark contrast, the molars in G2 showed net mesial movement of 1.95 mm accompanied by mesial crown tipping of 3.7°; these were clinically significant when compared with G1. Distalization of the molar usually tends to open the mandibular plane because of a wedging effect caused by extrusion of the molars. But, in this study, retraction with mini-implants had an intrusive effect on the maxillary molars. Intrusive mechanics can be highly beneficial in maintaining the vertical dimension of the face, especially in patients with high angles. However, the intrusion was not statistically significant.

Previous reports noted 1.6 to 4 mm of mesial movement of molars while retracting only the canines with traditional mechanics. With adjuncts for anchor preservation, up to 2.4 mm of anchor loss was observed. Headgear, banding of second molars and second premolars, transpalatal arches, and Nance appliances have routinely been used as adjuncts to enhance the anchorage of the first molars. Headgear has been the most preferred appliance in this regard. However, its effect depends mainly on patient cooperation. Also, headgear is usually worn less than 12 hours a day, whereas most orthodontic forces are continuous. Risk of injury and esthetic concern are other factors that affect the use of headgear. Although some studies showed that a transpalatal arch can enhance anchorage, Bobak et al reported that a transpalatal arch did not significantly modify the orthodontic anchorage. Also, many consider palatal bars just a secondary method of anchorage support. Significant levels of anchorage loss have also been reported with the Nance appliance along with reduced hygiene under the acrylic resin button; this in turn is frequently associated with inflammation of soft tissue in that area. Application of differential moments has been an effective way of maintaining anchorage, but the rotation of canine and premolars has always been a matter of concern, resulting in increased treatment time.

**Incisor retraction and intrusion**

The amount of incisor retraction in the 2 groups was comparable with no statistical significance. However, retraction with implants was primarily achieved by controlled tipping and partly by translation (Ia/Io = 0.20) because the forces applied were closer to the center of resistance of the maxillary anterior teeth. According to one report, in which implants were used similar to our study, up to 7 mm of bodily retraction of the incisors was achieved. However, we achieved only about 1.0 mm (mean) of bodily retraction, with a maximum of 3 mm in 1 subject. According to Horiuchi et al, palatal cortical bone and width of alveolar bone could be limiting factors in orthodontic retraction. Edwards found that the bone at the midroot level and the alveolar margins, but not at higher levels, was remodeled with tooth movement; he postulated that an anatomic barrier for retraction of teeth was higher at the anteropalatal curvature. Additionally, a stainless steel wire in a .022-in slot has about 15° of play; this makes torque control even more difficult over the incisors. We could have supplemented the

<table>
<thead>
<tr>
<th>Measurement</th>
<th>T1 Mode</th>
<th>SD</th>
<th>T2 Mode</th>
<th>SD</th>
<th>T2-T1 Mode</th>
<th>SD</th>
<th>P value</th>
<th>Significance</th>
</tr>
</thead>
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<tr>
<td>Intermolar width</td>
<td>52.43</td>
<td>2.22</td>
<td>50.53</td>
<td>2.45</td>
<td>-1.83</td>
<td>1.29</td>
<td>0.03</td>
<td>*</td>
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<tr>
<td>Intercanine width</td>
<td>36.53</td>
<td>2</td>
<td>36.27</td>
<td>2.14</td>
<td>-0.27</td>
<td>1.13</td>
<td>0.38</td>
<td>NS</td>
</tr>
</tbody>
</table>

NS, Not significant; *P ≤0.05.
retraction unit with a torquing auxiliary for augmenting bodily retraction, but that might have had an effect on the anchorage value of the maxillary first molar. Clinically significant levels of intrusion were noted in G1. The root and incisor tips showed significant correlation in their apical movement ($r = 0.87$), indicating true bodily intrusion. The occlusogingival position of the mini-implant plays a defining role in directing the forces of retraction and intrusion through the anterior teeth. However, availability of bone stock, thick mucosa, and proximity to dental roots sometimes do not allow altering the vertical position of the implant. Another factor that can change the force direction is the vertical height of the crimpable hook or power arm. By reducing the height of the power arm, greater intrusion can be achieved.

Excessive forces during treatment can cause external apical root resorption, particularly when heavy continuous forces are used.$^{39}$ However, the forces exerted with implants for en-masse retraction were extremely physiologic (150-200 g), because precalibrated nickel-titanium coil springs were used. Also, due to the group movement of the teeth, forces were equally distributed along the root surface area and thus did not concentrate at 1 point.

**Effect on the maxillary arch as a unit**

The force exerted by the nickel-titanium coil springs (bilaterally) had 2 distinct components: a larger retraction force and a smaller intrusive force causing en-masse retraction and some intrusion of the maxillary anterior teeth (Fig 5). After space closure, contact between the canine and the second premolar was established. At this point, any further continuation of the retractive force resulted in its transmission to the posterior segment through the interdental contacts. The coil springs in most patients were left in place for at least several months after space closure to obtain a tight overjet. This might have caused some distalization of the molars, as observed cephalometrically. However, an interesting finding was that, in spite of the distalization force, the molars did not extrude but, on the contrary, showed a slight intrusive movement. Similar results were obtained in a recent study involving en-masse distalization of the dentition with microscrew anchorage.$^{40}$ It could be that the intrusive component of the force caused binding of the stainless steel archwire to the brackets, resulting in transmission of the force to the entire arch. Because of a relatively small sample size, we could not achieve statistical significance in some measurements. Further investigation, perhaps with a larger sample size, is needed.

The retraction of the 6 maxillary anterior teeth in G1 was done in 1 step, instead of the traditional 2-step retraction of the canine and incisors. Individual canine retraction often results in rotations and mesiodistal tipping of the canine. However, with en-masse retraction, no such problems were encountered. Intercanine width did not change significantly through the study in G1, although a statistically significant decrease in intermolar width was noted. This movement can be attributed to the deformation in the rectangular archwire because of the distal pull of the coil springs. A thicker archwire or a transpalatal arch might prove useful.

En-masse retraction with mini-implants not only eases the biomechanics involved but also causes an early change in the facial profile. This, together with the fact that spaces distal to the lateral incisors that are evident after individual canine retraction never appear with en-masse retraction, greatly enhances patient cooperation and motivation.

**CONCLUSIONS**

The mini-implants placed in the interdental bone between the maxillary first molar and second premolar proved to be efficient for intraoral anchorage reinforcements for en-masse retraction and intrusion of the maxillary anterior teeth. There was no anchorage loss with mini-implants in either horizontal (anteroposterior) or vertical direction compared with conventional methods of anchorage reinforcements. However, a decrease in intermolar width was noted. No significant differences were found in the rates of retraction between the 2 groups. It is hoped that more investigations with larger samples will be forthcoming to further evaluate this approach of treatment.

**REFERENCES**


![Fig 5. Force system involved: $F$, total force; $i$, intrusive force, $r$, retractive force ($r$ is much greater than $i$).](image)