Original Article

Initial forces experienced by the anterior and posterior teeth during dental-anchored or skeletal-anchored en masse retraction in vitro

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ABSTRACT

Objective: To investigate initial forces acting on teeth around the arch during en masse retraction using an in vitro Orthodontic SIMulator (OSIM).

Materials and Methods: The OSIM was used to represent the full maxillary arch in a case wherein both first premolars had been extracted. Dental and skeletal anchorage to a posted archwire and skeletal anchorage to a 10-mm power arm were all simulated. A 0.019×0.025-inch stainless steel archwire was used in all cases, and 15-mm light nickel-titanium springs were activated to approximately 150 g on both sides of the arch. A sample size of $n = 40$ springs were tested for each of the three groups. Multivariate analysis of variance ($\alpha = 0.05$) was used to determine differences between treatment groups.

Results: In the anterior segment, it was found that skeletal anchorage with power arms generated the largest retraction force ($P < .001$). The largest vertical forces on the unit were generated using skeletal anchorage, followed by skeletal anchorage with power arms, and finally dental anchorage. Power arms were found to generate larger intrusive forces on the lateral incisors and extrusive forces on the canines than on other groups. For the posterior anchorage unit, dental anchorage generated the largest protraction and palatal forces. Negligible forces were measured for both skeletal anchorage groups. Vertical forces on the posterior unit were minimal in all cases (<0.1 N).

Conclusions: All retraction methods produced sufficient forces to retract the anterior teeth during en masse retraction. Skeletal anchorage reduced forces on the posterior teeth but introduced greater vertical forces on the anterior teeth. (*Angle Orthod.* 2017;87:549–555)

KEY WORDS: En masse retraction; Dental anchorage; Skeletal anchorage; Orthodontic biomechanics; Force analysis; Orthodontic simulator

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INTRODUCTION

Closure of extraction spaces is often required in orthodontic treatment to eliminate spacing in the dental arches and improve occlusal interrelationships. First premolars are often targeted for extraction, leaving one segment comprised of the six anterior teeth, and two posterior segments comprised of the second premolar and the erupted molars. Traditionally, retraction of the anterior segment is anchored by the two posterior segments. This procedure is often referred to as *en masse retraction*.

Conventionally, en masse retraction utilizes forces from elastomeric chains, looped archwires, or retraction springs from the posterior dentition to a post on the archwire. Resulting protraction forces on the posterior segment may produce an undesirable side effect on the treatment outcome if mesialization of the posterior teeth is considered unfavorable.[1] Therefore, management of the posterior anchorage is crucial to orthodontic treatment.[2] With the introduction of skeletal-based anchorage via orthodontic temporary screws, there is the potential to prevent these unwanted side effects on the anchorage unit during en masse retraction. Although theoretically this makes sense, some studies have shown mesialization of the anchorage unit.[3,4] In contrast, other studies have suggested distalization of the posterior anchorage unit, which may or may not be favorable.[5,6] Lastly, intrusion of the anterior segment often occurs during retraction with skeletal-based anchorage.[7]

The inability to control anchorage during orthodontic space closure can compromise treatment results. Additional methods such as extraoral anchorage or skeletal anchorage could be used to restore anchorage, but increased treatment time may result. Also, poor anchorage control often results in tooth crowns tipping into the extraction space, which increases treatment time because roots need to be uprighted after space closure.[8] Long-term stability is believed to rely on root parallelism in that orthodontic relapse and periodontal damage are associated with a poorly aligned dentition.[9] Vertical control of both the anterior and posterior segments is also important in the management of overbite, occlusal plane, and skeletal pattern.

En masse retraction studies have traditionally evaluated rates of tooth movement in vivo, relying on cephalometric measurements[10,11] and dental cast measurements[12,13] with applied forces being measured via force gauges.[14] Due to the inherent difficulty in accurate force measurements in vivo, studies using in vitro or numerical methods are considered. Two techniques often employed are force load cells[15,16] and finite element analysis.[17–19] The limitations of previous force load cell studies used to investigate retraction mechanics are that they have looked at only single- or two-tooth systems.[15,16,20] The purpose of this study was to investigate the initial three-dimensional forces and moments applied to a representative 14-tooth maxillary dentition during en masse retraction for dental- and skeletal-anchorage methods.

MATERIALS AND METHODS

Force and moment measurements were carried out using an Orthodontic SIMulator (OSIM) device,[21–23] shown in Figure 1. The stainless steel (SS) posts representing individual teeth were connected to load cells using custom adapters. Six-axis Nano17 load cells (ATI Industrial Automation, Apex, NC) measured the forces and moments acting on each tooth in three dimensions. All force and moment measurements were recorded at the load cell, which had a different coordinate system than did the tooth. To determine the forces and moments acting at the bracket, a FARO Arm (FARO, Lake Mary, Fla) was used to measure the bracket location relative to the load cell for each tooth. A Jacobian transformation was used to transform the forces and moments measured at the load cell to the bracket center.

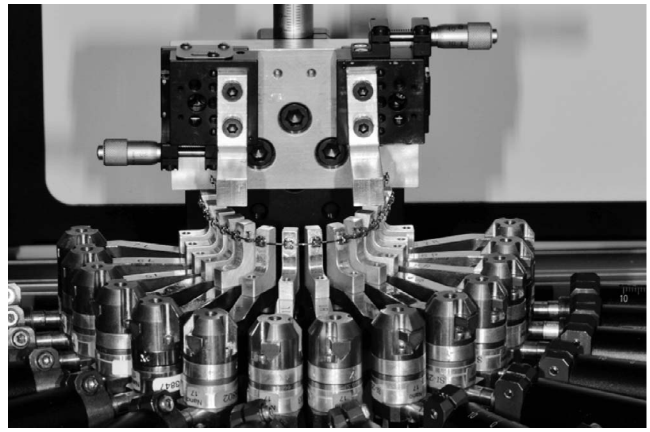

Figure 1. Orthodontic SIMulator (OSIM) with the skeletal anchorage adapter.

A custom platform was created for OSIM to provide a skeletal miniscrew attachment point, as illustrated in Figure 1. The maxillary translation stage allowed attachments to be moved in posterior and anterior directions to achieve the ideal position between the second premolar and the first molar. Using a vertically oriented translation stage, attachment points were positioned 8 mm above the archwire. With the custom arms in the desired position, hooks were secured using epoxy resin to create an attachment point for the retraction springs.

A set of 14 maxillary Damon Q (Ormco Corp, Orange, Calif) orthodontic brackets were used. Each bracket was positioned using a mounting jig and bonded to individual posts using epoxy resin. All experiments were conducted using a 0.019×0.025-inch SS archwire. Archwire posts were presoldered by the manufacturer, whereas power arms were crimped onto the archwire. Retraction forces were generated using 15-mm light NiTi springs (Ormco) on both sides.

All tests were carried out in a temperature-controlled chamber set to 37°C to represent the approximate oral cavity temperature. A neutral archwire position was found via locating of the posts such that all forces acting on each tooth around the arch were less than 0.1 N. Load cells were then biased prior to attaching springs.

The three treatment groups compared in this study were subjected to dentally anchored retraction using a posted archwire (group 1), skeletally anchored retraction using a posted archwire (group 2), and skeletally anchored retraction using archwire power arms (group 3). In group 1, retraction springs were connected from a hook on the first molar bracket to the archwire post. In group 2, retraction springs were connected from the

Figure 2. Representation of treatment groups 1 (left), 2 (middle), and 3 (right) on OSIM.

simulated skeletal miniscrew to the archwire post. In group 3, archwire power arms (American Orthodontics, Sheboygan, Wisc) were crimped onto a 0.019 × 0.025-inch SS archwire in the same position as the previous archwire posts. The 10-mm power arm height-attachment point was used as it best approximated the center of resistance of the anterior tooth segment. A representation of all three groups on OSIM is presented in Figure 2.

In all tests, an extraction was simulated by removing both first premolars from the arch. The remaining teeth were grouped into two segments: (1) the anterior tooth segment, represented by the six anterior teeth (1.3–2.3); (2) the posterior anchor segment, represented bilaterally by the posterior teeth (1.7–1.5 and 2.5–2.7). A pilot study determined that a sample size of $n = 40$ per group was sufficient to detect differences of 0.2 N at a significance level of $\alpha = 0.05$. Force and moment measurements were acquired along three (x-, y-, and z-) axes, represented by F_x, F_y, and F_z for forces and M_x, M_y, and M_z for moments. The x-axis represents the mesiodistal direction; the y-axis the buccolingual direction; and the z-axis, the occlusogingival direction. Before connecting the springs, 50 force/moment data readings over approximately 1 s were recorded from the load cells and averaged. The springs were then engaged according to a randomized test order for groups 1 and 2, and again sampled 50 times and averaged. Group 3 tests were not randomized due to the need to switch archwires but otherwise followed the same procedure. Forces and moments were taken to be the difference between baseline measurements and those once the springs were attached.

Because the directions of the x- and y-axes vary by tooth along the arch, multiple teeth could not be directly compared. That is, for example, the labial direction of a canine does not align with the labial direction of an incisor. Thus, a single anteroposterior axis was chosen to reflect that of the dental arch. Protraction forces for the posterior segment were also summed and compared. Because the z-axis did not change throughout the arch, no further calculations were required. To determine an overall retraction force for the anterior segment, the component of force from each tooth in that segment was calculated along the single anteroposterior axis. The resultant anteroposterior force from each tooth was given the term Fd, with their sum denoted as FdSUM as shown in Figure 3.

A statistical significance level of $\alpha = 0.05$ was chosen for all testing. Multivariate analysis of variance was used to determine differences between treatment groups separately on the anterior and posterior tooth segment. Assumption testing was carried out using box plots for normality, matrix scatter plots for relationship between dependent variables, and Box's test for equality of covariance matrices. Greenhouse-Geisser correction was used for multivariate hypothesis testing. A Tamhane correction was used when applicable during post hoc testing.

RESULTS

Box plots illustrating results for the anterior segment are provided in Figure 4, and those for the posterior segments are shown in Figure 5.

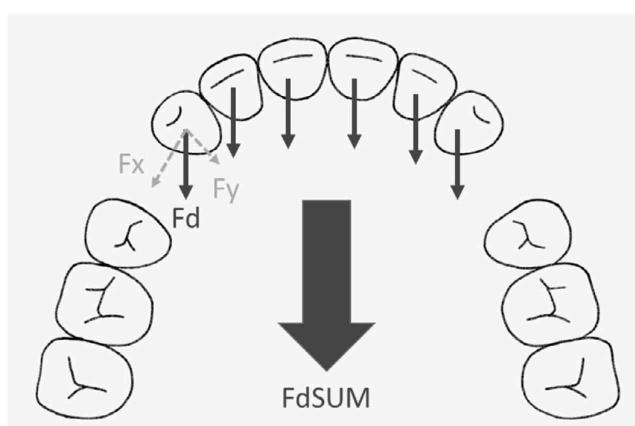

Figure 3. Schematic representation of Fd and FdSUM for the anterior segment.

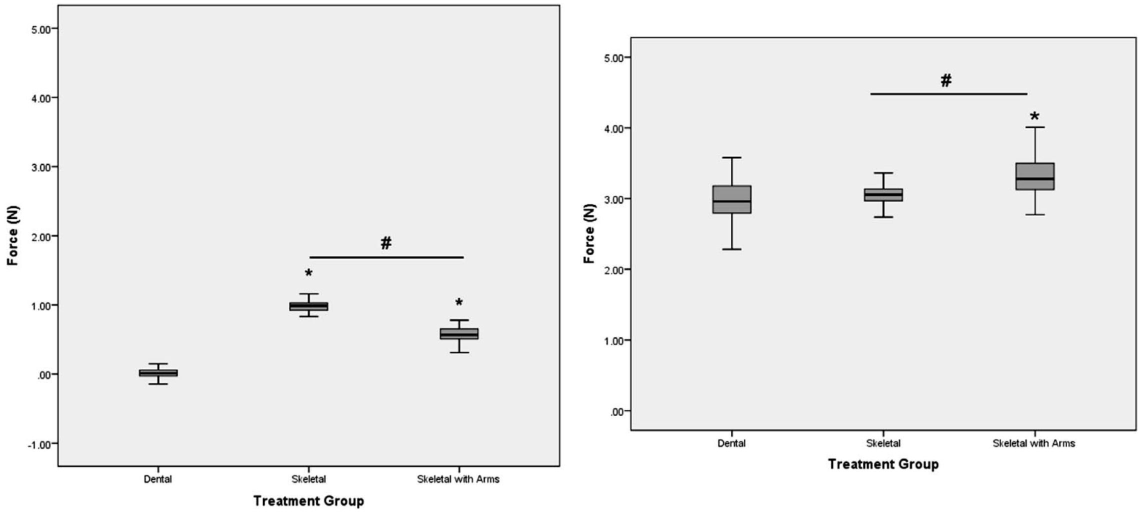

Figure 4. Vertical (left) and retraction (right) forces acting on the anterior segment for all three treatment groups (* statistically significant differences; $P < .05$).

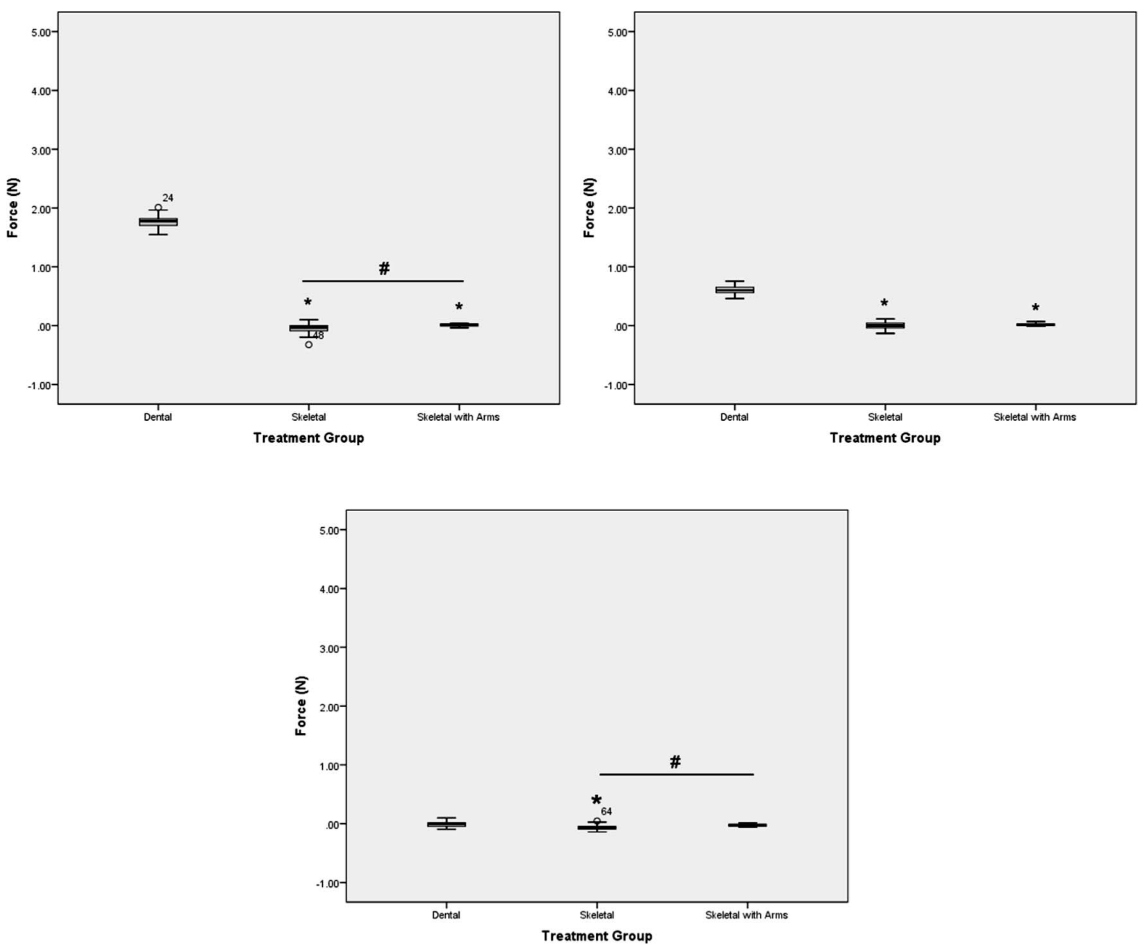

Figure 5. Protraction (top left), palatal (top right), and vertical (bottom) forces acting on the posterior segment for all three treatment groups (* statistically significant differences; $P < .05$).

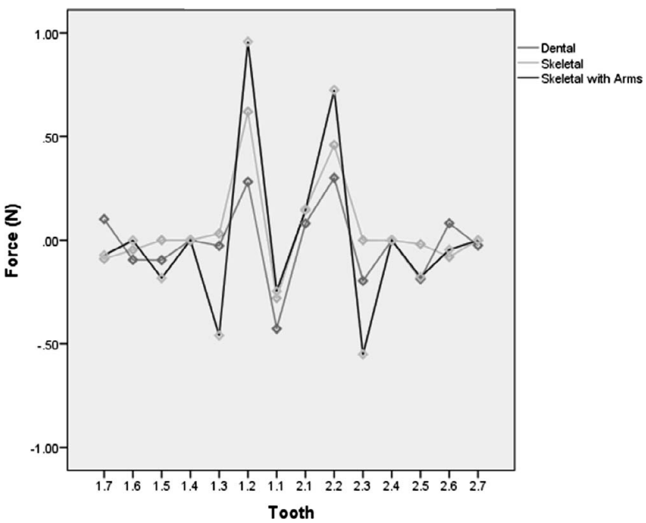

Figure 6. Vertical force profile at each tooth for all three treatment groups.

In group 1, retraction springs generated an average retraction force of 2.99 ± 0.27 N. Group 2 was subjected to a force of 3.05 ± 0.14 N, which was not significantly different from that of group 1 ($P = .49$). Adding power arms to the skeletal anchorage, group 3, significantly increased retraction forces to 3.30 ± 0.30 N over those of groups 2 ($P < .001$) and 1 ($P < .001$).

Regarding vertical forces acting on the anterior segment, group 1 was exposed to an average of 0.01 ± 0.07 N, which was significantly less than those for group 2 at 0.98 ± 0.70 N ($P < .001$). The vertical forces on group 3 were significantly reduced to 0.57 ± 0.11 N over group 2 ($P < .001$), but were significantly larger than those on group 1 ($P < .001$).

To compare forces on the posterior anchorage unit, the sum of forces acting on the right and left units were averaged to give a single value. Group 1 experienced the largest protraction force of 1.77 ± 0.10 N per side. Using skeletal anchorage in groups 2 and 3 produced negligible forces in both cases, which were significantly less than the forces on group 1 ($P < .001$).

Group 1 experienced minimal extrusive forces on the posterior segment of –0.01 ± 0.05 N per side. Group 2 saw increased extrusive forces to –0.06 ± 0.04 N ($P <$ .001). Adding power arms in group 3 decreased vertical forces acting on the posterior segment to –0.02 ± 0.02 N per side ($P < .001$) compared with those on group 2.

The overall vertical force profile around the arch is provided in Figure 6. In all three groups, the greatest vertical forces were exerted on the lateral incisors, with the largest occurring in group 3 with power arms. A reciprocal intrusive force was also measured in the canines for group 3, but was negligible or absent in groups 1 and 2.

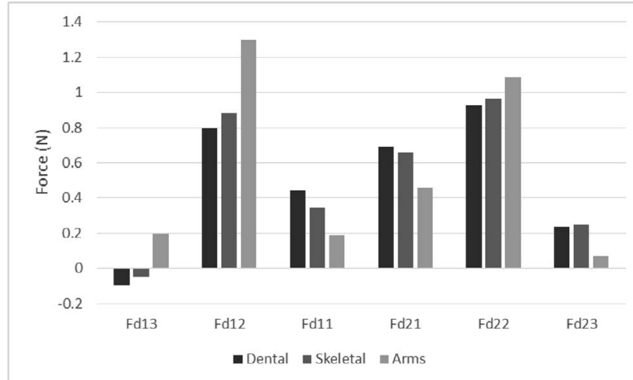

Figure 7. Retraction forces applied to individual teeth in the anterior segment.

DISCUSSION

The lateral incisors experienced the greatest forces, both horizontal and vertical. This was due to the proximity of those teeth to the archwire post or power arm. While also close to the point of force application, the canines experienced less forces than did the lateral incisors. This is likely a result of the orientation of the canine bracket. With the lateral incisor bracket being more perpendicular to the applied retraction force than was the canine, it is expected that more of this force would be transferred to it. Vertical forces acting on the lateral incisors were the highest, particularly for skeletal anchorage. The larger vertical forces on the canines during application of skeletal anchorage is due to the force vector being oriented more in the vertical direction when springs are connected to skeletal—as opposed to dental—anchors.

Vertical forces acting on the anterior retraction unit were reduced when power arms were used compared with conventional skeletal anchorage, supporting their use when reduced vertical forces are desirable. However, the intrusive vertical forces acting on the lateral incisors were increased compared with conventional skeletal anchorage . Furthermore, the canines experienced an extrusive force that was not as pronounced in other groups. The explanation for these findings is that the power arm acts as a moment arm at the level of the archwire. Therefore, when transferring this load from its point of application away from the archwire, a moment of force results. These findings suggest that in cases in which canine extrusion or lateral incisor intrusion is unfavorable, power arms should be used with caution.

Both horizontal and vertical forces were maximal near the archwire posts and their adjacent brackets; these forces then quickly decayed along the archwire. This is illustrated in Figure 7. Similarly, although vertical forces were generated in skeletally anchored groups, they were detected primarily in the anterior segment, with minimal vertical forces being measured on posterior teeth. This again suggests that the initial forces act primarily on teeth adjacent to archwire posts.

Precise control of forces applied to teeth during retraction is important to the clinician in managing tooth movement. Forces in the range of 0.35–0.60 N have been reported to produce dental tipping and extrusion, whereas forces in the range of 0.70–1.20 N have been reported to produce bodily movement.[2] In the present study, all retraction groups generated sufficient force to retract the anterior teeth by producing approximately 0.5 N per tooth, implying mainly tipping forces. Compared with dental anchorage, skeletal anchorage increased the retraction force per tooth by 0.05 N, to approximately 0.55 N. This increase was found to be statistically significant, but is unlikely to have a clinical impact.

Skeletal anchorage, both with and without power arms, significantly reduced protractive forces when compared with traditional dental anchorage. By connecting the retraction springs to the fixed skeletal anchorage instead of directly onto the maxillary molars, forces in all three dimensions were reduced. Additionally, forces exerted by the archwire on the posterior unit were minimal. Slight differences between total force on the anterior vs posterior units is likely a result of force transmission loss along the archwire in the anterior unit.

In addition to retraction of the anterior unit, there was also a tendency of the unit to rotate as a result of the spring forces. Yoshida et al.[24] reported center of resistance values for a six-tooth anterior unit during en masse retraction to be 10.5–13.7 mm superiorly from the incisal edge. With bracket slots placed approximately 4–5 mm from the incisal edge on these teeth, this creates a moment arm between 5.5–9.7 mm. Using FdSUM values from this study, a moment in the range of approximately 16–32 Nmm would be generated on the anterior unit. The sense of this moment would cause rotation of the central incisors toward the occlusal plane—a result commonly noted in en masse retraction.

While the work presented here provides valuable information in the field of orthodontics, it does have limitations. Only the initial forces and moments were considered. During en masse retraction, teeth in the anterior and posterior segments undergo some combination of tipping and bodily movement that alters the forces acting on those teeth. In addition, interproximal tooth contact was not considered due to equipment limitations. Inclusion of such contact could be expected to increase force transmission between teeth. Certain conditions of the oral environment such as periodontal ligament reaction, effect of saliva, and forces from cheek muscles were not replicated and may have had some effect on measurements. Finally, this study considered only one type of bracket, archwire, and spring for a well-aligned dentition. It is unknown how changing the materials used or introducing tooth misalignments could impact results.

CONCLUSIONS

- All retraction methods produced sufficient forces to retract the anterior teeth during en masse retraction.
- Skeletal anchorage reduced forces on posterior teeth and introduced greater vertical forces on anterior teeth.
- The addition of power arms during application of skeletal anchorage reduced vertical forces on anterior teeth, but created a localized moment in the archwire, generating canine extrusive forces and increased lateral incisor intrusive forces.

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