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An in Vitro Study on Aligner Rotational "Lag" With In-Office Clear Aligner Therapy

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Introduction: The purpose of this study was to investigate the amount of rotational "lag" in Clear Aligner Therapy (CAT) in reference to maxillary anterior teeth. **Methods:** A 3D digital model with ideal alignment of maxillary teeth #2-15 with cutouts at teeth #6, 8, and 10 was fabricated. Plastic teeth were set in areas of cutouts in ideal alignment using a stent and then cutouts were filled with wax. A CAT series was created to rotate the plastic teeth from ideal to 9° of rotation in 6 aligners (1.5° between each aligner) using a hot water bath. Initial and final digital scans were compared via superimposition to calculate the amount of rotation. "Lag" was calculated by subtracting the amount of achieved rotation from 9°. **Results:** There were significant differences in rotational "lag" among tooth shapes ($F(2, 105) = 13.14$, $p < .0001$). Tooth #8 lag (Mean = 3.12, SD = 1.76) was significantly smaller than tooth #6 (Mean = 5.46, SD = 2.23)($p < .0001$) and tooth #10 (Mean = 4.95, SD = 2.08) ($p = 0.0007$). No significant difference was found between tooth #6 and #10 ($p = 0.55$). **Conclusions:** The CAT series was significantly more efficient in rotating max central incisors than lateral incisors and canines. None of the teeth tested completed the full 9° of rotation.

An in Vitro Study on Aligner Rotational "Lag" With In-Office Clear Aligner Therapy

Introduction and Literature Review

The technological advances witnessed in the past few decades have been extraordinary. It is only natural that these advances have permeated into the dental field. Diagnostic and treatment planning abilities have been enhanced by three-dimensional imaging. Intraoral scanners provide an alternative to traditional impressions, and digital models can replace plaster models for diagnosis, treatment planning, and appliance fabrication.[1] Combined with the increasing patient demand for esthetic options and personalized treatment, these advances have given rise to numerous clear aligner systems as alternatives to fixed appliances.[1,2] Though these clear aligner systems are relatively new to the dental field, the idea of removable, flexible appliances made from an idealized setup originated in 1944 with Kesling's Tooth Positioner.[2-6]

Essentially, Clear Aligner Therapy (CAT) sequentially moves teeth with removable clear aligners based on a series of computerized models which can be implemented by orthodontists and general practitioners.[7,8] There are few published studies that focus on the predictability of orthodontic tooth movement with CAT and most studies relied on weaker forms of published evidence like case reports, expert opinions and low-level poorly designed studies.

There are several advantages with CAT. One of which is not impeding oral hygiene procedures. Therefore, decreasing the risk of decalcifications, caries, gingivitis, and periodontal disease[3]. Another advantage is that CAT is more esthetic, hence, higher patient acceptance. Eating restrictions are decreased and there are fewer clinical emergencies.[2,9]

Limitations of CAT include the reliance on patient compliance for success. An inability to alter the course of treatment once aligners are fabricated. There is limited control of root movement and intermaxillary correction.[10] Predictability decreases when extruding anterior teeth and improving anterior buccolingual inclination, and rotation of rounded teeth is problematic.[10,11] Consequently, case selection is of the utmost importance when using CAT.[7,12-14]

Rotation is an orthodontic movement that has been reported as difficult to achieve with CAT. Previous studies showed that without attachments, rotations of teeth were generally incomplete, especially teeth with rounded crowns. [1,4,6,11,15,16]

In regard to rotations, one of the significant mechanical deficiencies in straight-wire appliances is the slot play or deviation angle between the arch wire and the bracket slot. Rotational "play" depends on the rotational lever arm and the quality of the ligation technique used to keep the arch wire seated in the bottom of the slot.[17] Rotational "play" is minimized by using brackets with adequate rotational lever arm lengths and ligating with sufficient force to keep the arch wire seated in the bottom of the slot.[17] There are a number of techniques to derotate teeth with fixed appliances.[18-20]

Similar to "slot play" with fixed appliances there exists an aligner "lag" based on the material properties with CAT.[21] Space closure, rotations, intrusion, extrusion, torque, tip, buccal and lingual tooth movements have been shown to require finishing after CAT.[22] Different methods have been used to finish CAT cases: manual addition of stages after the last aligner, new set-ups from final impressions, and overcorrection programmed to occur at the end of treatment. [21] If the accuracy percentage of a specific tooth is known, overcorrecting it by the appropriate amount may result in the desired outcome.[11]

The aim of this in vitro study was to determine the accuracy of rotational movements with in-office aligners to identify the amount of aligner "lag" in an effort to possibly plan overcorrection more precisely. The null hypothesis was that there would be no differences in "lag" between the groups based on the tooth type.

In addition, differences of 2° in rotation were considered clinically relevant. This threshold value was chosen in reference to the American Board of Orthodontics (ABO) model grading system for case evaluation. According to the model grading system criteria, discrepancies of 0.5 mm or greater in the alignment of contact points and marginal ridges will result in the deduction of points. A marginal ridge discrepancy of 0.5 mm equates to a crown-tip deviation of 2° for an average-sized molar. Therefore, differences of 0.5 mm or more in the mesial-distal, facial-lingual and occlusal-gingival direction and differences of 2° or more in tip, torque, and rotation were considered clinically relevant.[1]

Materials and Methods

This study is a laboratory based in vitro study carried out by the Orthodontic Department at the United States Air Force Postgraduate Dental School, Joint Base Lackland, San Antonio, TX with association to the Uniformed Services University, Bethesda, MD.

A digital scan was taken with the 3Shape R700 (Great Lakes Orthodontics, Tonawanda, NY) of the maxilla of a wax dentoform (Dentaurum USA, Langhorne, PA) with plastic teeth #2-15 (Dentaurum USA, Langhorne, PA) in ideal occlusion. A 3D digital model was made from Verodent MED670 polyjet material (Stratasys Inc., Eden Prairie, MN) and printed by Stratasys Objet Eden260V 3D printer (Stratasys Inc., Eden Praire, MN) of the ideal occlusion wax model.

On the digital model of the ideal occlusion, vertical cutouts at the area of #6,8,10 were removed and the 3D model was printed (see figure 1). The same wax from the original wax dentoform and the corresponding plastic teeth were then placed into the sectioned model. Teeth placement and orientation were completed using a transfer stent (Reprosil, Dentsply, Milford, DE) transfer stent as shown in figures 2 and 3. Melted wax was then poured around the test teeth in and allowed to cool (see figure 4). Any excess wax was removed from model.

Using the 3 Shape Ortho Planner software, teeth #6, 8, 10 were mesiolingually rotated by 1.5° increments until 9° of rotation was achieved on software (6 increments).[6] These degrees of rotations were chosen based on previous studies stating that results show that the accuracy was significantly reduced for predicted rotations greater than 15° as well as for rotations with a planned staging greater than 1.5° per aligner.[23] After each 1.5° increment, a 3D model was printed and a thermoplastic aligner was fabricated (Essix Ace .030 thick, 125mm round plastic, Dentsply Sirona Orthodontics, York, PA) using a Biostar thermoplastic former (Great Lakes Technologies, Tonawanda, NY). These 6 thermoplastic aligners comprised the clear aligner therapy series [Aligner A(1.5°), B(3°), C(4.5°), D(6°), E(7.5°), F(9°)].

Aligner A was placed on the 3D model with the waxed in, ideally aligned plastic teeth and then placed in a water bath (Polyscience, Niles, IL) at 115°F for 5 minutes. This step was repeated with Aligners B-F, with a 5-minute ice bath in between each aligner to allow for complete cooling of the wax.

Once Aligner F was completed, a digital scan was taken of the model with the achieved rotation. Initial and final digital scans were imported into GeoMagic Studio 2014 (3D Systems, Rock Hill, SC). The final digital scan was superimposed over the initial digital scan with regional superimpositions on the non-moving posterior teeth (see figure 5). Points were then placed on the mesial and distal of incisal edges of the incisors (#8,10) and the most mesial and distal points of the canine (#6) for the initial and final scan (see figure 6 and 7). The mesiodistal rotations were measured by connecting the two points on the incisal edges of the incisors and the most mesial and distal points of the canine.

A plane was then created using the mesiolingual cusp tips of the second molars (#2,15) and the middle of the incisal edge of #9, which were all non-moving teeth (see figure 8). The plane was then offset occlusally 10mm from the digital model. The points of the initial and final scans were then projected to this plane (see figure 9). This essentially converted the points from a 3D space with plotted points to a 2D plane with plotted points. The distance between the two points on one tooth from the initial scan and the same tooth from the final scan determined the length of two intersecting vectors. This in turn allowed for the calculation of a degree of rotation. The formula for calculating the angle is:

$$A = (x_1 – x_2), (y_1 – y_2)$$
$$B = (x_1 – x_2), (y_1 – y_2)$$

$$\cos \Theta = \frac{(A * B)}{||A|| * ||B||}$$

The data was then exported to an Excel (Microsoft, Redmond, WA) file. The final formula was done in Excel to calculate the inverse cosign to arrive at an angle of rotation. This value that was calculated was the amount of degrees that the tooth was rotated by the CAT series. The rotational "lag" was then calculated by subtracting the degrees of rotation achieved from the ideal 9°. All three teeth (#6,8,10) were analyzed at the same time. This was repeated for each initial and final scan superimposition (36 times).

The outcome variable, the amount of aligner "lag" measured by absolute difference in degree from the ideal 9°, was normally distributed according to Shapiro-Wilk Test ($p = 0.21$); therefore, the outcome data was presented as mean and standard deviation. A repeated-measures analysis of variance (ANOVA) was performed to determine significant differences in the outcome among different tooth shapes (i.e., Tooth Number) as the outcomes were measured from the same sample (alpha = 0.05). Statistical analyses were performed with SAS version 9.4 (Statistical Analysis Software, Cary, NC).

Results

A repeated-measures ANOVA result indicated that there were significant differences in lag among tooth shapes ($F(2, 105) = 13.14$, $p < .0001$). The Tukey's post hoc test result indicated that the lag with Tooth #8 (Mean = 3.12, SD = 1.76) was smaller than Tooth #6 (Mean = 5.46, SD = 2.23)($p < .0001$) and Tooth #10 (Mean = 4.95, SD = 2.08) ($p = 0.0007$). No significant difference in lag was found between Tooth #6 and Tooth #10 ($p = 0.55$).

Discussion

The null hypothesis was rejected because there was a significant difference between the groups. There was a statistically significant difference between the central incisor and the lateral incisor and between the central incisor and the canine. There was no significant difference between the lateral incisor and the canine.

The results of the current study resemble those of others that found derotations of canines to have relatively poor accuracy. [6,15,23] The literature describes derotations of cylindrical teeth as one of the most difficult movements to perform with aligners. Thermoplastic appliances tend to lose anchorage and slip off due to the absence of undercuts and a round tooth shape. Attachments would be needed on the tooth's surface so that counter-moments can occur, leading to tooth movement in the opposite direction.[6,16,24] According to Kravitz et al., the use of interproximal reduction (IPR) can also positively influence the correction of derotations.[15]

The highest accuracy of rotation, or least amount of lag, was achieved by the maxillary central incisor. These results are similar to those of Kravitz et al. and Nguyen and Cheng who reported that incisors achieved the highest accuracy of rotation and canines and premolars the lowest accuracy of rotation.[15,25]

The lateral incisor on the other hand, did not respond as per previous studies. In Kravitz et al.'s study, there were no statistically significant differences in rotations among incisors, which lead us to believe that shape may have a greater influence than size in reference to derotations with Invisalign.[15] In this instance, inability of the clear aligner to derotate the lateral may have been more an aspect of the study limitations.

There were limitations to this study whose purpose was to investigate the rotational lag and provide a baseline for what may be achieved with CAT alone, using 0.30mm Essix material without auxiliaries in an in vitro setting. First, the lateral incisor tended to intrude into the wax more often than the canine and the central incisor. The intrusion was a variable observed while completing the study; however, it was not measured. Intrusion of the lateral incisor would mean that it was not fully seated in the aligner, which would account for the incomplete rotation.

Additionally, a limitation of the water bath was that the water temperature fluctuated in the range of 112°F to 119°F. An effort was made to soften the wax to allow for tooth movement, but not soften it to the point that the teeth intruded into the wax and out of the aligner.

The initial position of the plastic teeth may have been affected when placing the melted wax into the stent. A more rigid stent that held the crowns of the plastic teeth more securely while melted wax was poured to hold them in place, would have helped with this aspect of the study. The occlusal force that is provided by aligner tray seaters (chewies), or even an opposing aligner to continuously seat the aligner was also absent from this study since there were no forces on the aligners while they were in the water bath.

Many of the retrospective studies that compared the movements of teeth before and after CAT had difficulty with superimposition because most of the teeth were moving at the same time and in multiple directions.[11,15] The intention of this in vitro study was to investigate one specific movement, rotation, of the teeth in question, #6,8,10. Superimpositions were more accurate because regional superimpositions on non-moving posterior teeth were used and not just a few points.

All achieved rotations were smaller than the predicted 9° by different amounts. However, none of the teeth studied were within 2° of the ideal 9° making the study clinically relevant, in that rotations remained that would have points deducted in the ABO Cast-Radiograph Evaluation. Given that this was an in vitro study where plastic teeth and wax were used, more complete expression of the CAT was expected than was achieved for all teeth in question. It is apparent that an aligner rotational "lag" exists, but further studies need to be completed in vivo in order to extrapolate data and apply in a clinical setting.

Conclusions

Within the limitations of this study, it was concluded that CAT was more effective in rotating central incisors than lateral incisors and canines. However, none of the teeth in question achieved rotations within 2° of the expected 9°, that may have made it more clinically relevant.

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References

1. Grunheid T, Loh C, Larson BE. How accurate is Invisalign in nonextraction cases? Are predicted tooth positions achieved? Angle Orthod 2017;87:809-815.
2. Weir T. Clear aligners in orthodontic treatment. Aust Dent J 2017;62 Suppl 1:58-62.
3. Bollen AM, Huang G, King G, Hujoel P, Ma T. Activation time and material stiffness of sequential removable orthodontic appliances. Part 1: Ability to complete treatment. Am J Orthod Dentofacial Orthop 2003;124:496-501.
4. Frongia G, Castroflorio T. Correction of severe tooth rotations using clear aligners: a case report. Aust Orthod J 2012;28:245-249.
5. Kesling HD. Coordinating the predetermined pattern and tooth positioner with conventional treatment. Am J Orthod Oral Surg 1946;32:285-293.
6. Rossini G, Parrini S, Castroflorio T, Deregibus A, Debernardi CL. Efficacy of clear aligners in controlling orthodontic tooth movement: a systematic review. Angle Orthod 2015;85:881-889.
7. Best AD, Shroff B, Carrico CK, Lindauer SJ. Treatment management between orthodontists and general practitioners performing clear aligner therapy. Angle Orthod 2017;87:432-439.
8. Vicens J, Russo A. Comparative use of Invisalign by orthodontists and general practitioners. Angle Orthod 2010;80:425-434.
9. Zheng M, Liu R, Ni Z, Yu Z. Efficiency, effectiveness and treatment stability of clear aligners: A systematic review and meta-analysis. Orthod Craniofac Res 2017;20:127-133.
10. Grunheid T, Gaalaas S, Hamdan H, Larson BE. Effect of clear aligner therapy on the buccolingual inclination of mandibular canines and the intercanine distance. Angle Orthod 2016;86:10-16.
11. Charalampakis O, Iliadi A, Ueno H, Oliver DR, Kim KB. Accuracy of clear aligners: A retrospective study of patients who needed refinement. Am J Orthod Dentofacial Orthop 2018;154:47-54.
12. Boyd RL. Esthetic orthodontic treatment using the invisalign appliance for moderate to complex malocclusions. J Dent Educ 2008;72:948-967.
13. Djeu G, Shelton C, Maganzini A. Outcome assessment of Invisalign and traditional orthodontic treatment compared with the American Board of Orthodontics objective grading system. Am J Orthod Dentofacial Orthop 2005;128:292-298; discussion 298.
14. Gu J, Tang JS, Skulski B, Fields HW, Jr., Beck FM, Firestone AR et al. Evaluation of Invisalign treatment effectiveness and efficiency compared with conventional fixed appliances using the Peer Assessment Rating index. Am J Orthod Dentofacial Orthop 2017;151:259-266.
15. Kravitz ND, Kusnoto B, BeGole E, Obrez A, Agran B. How well does Invisalign work? A prospective clinical study evaluating the efficacy of tooth movement with Invisalign. Am J Orthod Dentofacial Orthop 2009;135:27-35.
16. Papadimitriou A, Mousoulea S, Gkantidis N, Kloukos D. Clinical effectiveness of Invisalign(R) orthodontic treatment: a systematic review. Prog Orthod 2018;19:37.
17. Creekmore TD, Kunik RL. Straight wire: the next generation. Am J Orthod Dentofacial Orthop 1993;104:8-20.
18. Gyawali R. An Effective Technique for Minor Rotation Correction. Int J Orthod Milwaukee 2016;27:21-22.
19. Knight JM, Tuncay OC. Composite hooks enhance rotational control. Clin Orthod Res 1998;1:68-70.
20. Zachrisson BU. JCO/interviews Dr. Bjorn U. Zachrisson on excellence in finishing. Part 2. J Clin Orthod 1986;20:536-556.
21. Duong T, Kuo E. Finishing with invisalign. Prog Orthod 2006;7:44-55.
22. Vlaskalic V, Boyd RL. Clinical evolution of the Invisalign appliance. J Calif Dent Assoc 2002;30:769-776.

23. Simon M, Keilig L, Schwarze J, Jung BA, Bourauel C. Treatment outcome and efficacy of an aligner technique--regarding incisor torque, premolar derotation and molar distalization. BMC Oral Health 2014;14:68.
24. Simon M, Keilig L, Schwarze J, Jung BA, Bourauel C. Forces and moments generated by removable thermoplastic aligners: incisor torque, premolar derotation, and molar distalization. Am J Orthod Dentofacial Orthop 2014;145:728-736.
25. Nguyen CV, Cheng J. Three-Dimensional Superimposition. In: Tuncay OC, editor. The Invisalign System. New Malden, United Kingdom: Quintessence Publishing Company, Ltd.; 2006. p. 121-132.

Figure 1: 3D digital model of the ideal occlusion with vertical cutouts at #6, 8, and 10.

Figure 2: Plastic test teeth (#6,8,10) placed in the transfer stent.

Figure 3: 3D digital model of ideal occlusion with vertical cutouts placed into the transfer stent.

Figure 4: 3D digital model of ideal occlusion with plastic test teeth in place.

Figure 5: Digital superimposition of initial and final digital scan with regional superimposition on non-moving posterior teeth.

Figure 6: Digital model of initial scan with points placed on mesial and distal of incisal edges of #8 and 10 and the most mesial and distal points of the canine (#6).

Figure 7: Digital model of final scan with points placed on mesial and distal of incisal edges of #8 and 10 and the most mesial and distal points of the canine (#6).

Figure 8: Plane created using the mesiolingual cusp tips of the second molars (#2,15) and the middle of the incisal edge of #9.

Figure 9: All points from initial and final scan were then projected to the plane.