Original Article

Influence of Attachments and Interproximal Reduction on the Accuracy of Canine Rotation with Invisalign

A Prospective Clinical Study

Neal D. Kravitz[a]; Budi Kusnoto[b]; Brent Agran[c]; Grace Viana[d]

ABSTRACT

Objective: To evaluate the influence of attachments and interproximal reduction on canines undergoing rotational movement with Invisalign.

Materials and Methods: In this prospective clinical study, 53 canines (33 maxillary and 20 mandibular) were measured from the virtual TREAT models of 31 participants treated with anterior Invisalign. The pretreatment virtual model of the predicted final tooth position was superimposed on the posttreatment virtual model using ToothMeasure, Invisalign's proprietary measurement software. A one-way analysis of variance (ANOVA) ($P < .05$) compared three treatment modalities: attachments only (AO), interproximal reduction only (IO), and neither attachments nor interproximal reduction (N). Student's *t*-tests ($P < .05$) compared the mean accuracy of canine rotation between arches.

Results: The mean accuracy of canine rotation with Invisalign was 35.8% (SD = 26.3). Statistical analyses indicated that there was no significant difference in accuracy between groups AO, IO, and N ($P = .343$). There was no statistically significant difference ($P = .888$) in rotational accuracy for maxillary and mandibular canines for any of the treatment groups. The most commonly prescribed attachment shape was the vertical-ellipsoid (70.5%).

Conclusions: Vertical-ellipsoid attachments and interproximal reduction do not significantly improve the accuracy of canine rotation with the Invisalign system.

KEY WORDS: Invisalign; Accuracy; Superimposition; Attachments; Interproximal reduction

INTRODUCTION

Since its advent nearly a decade ago, Invisalign has grown rapidly in worldwide consumer demand and professional use leading to a paradigm shift in patient marketing and orthodontic treatment. Despite its growing popularity, questions remain regarding the limitations and proper use of this system. In particular, many clinicians have reported difficulty correcting rotations with Invisalign, especially canines and premolars. A randomized survey study by Sheridan[1] reported that ''uncorrected rotations'' was one of the most prevalent problems encountered by orthodontists using Invisalign, often resulting in the need for refinement impressions or conversion to fixed appliances.

The derotation of cylindrical teeth presents a biomechanical challenge due to the lack of interproximal undercuts causing the aligner to slip as it attempts to rotate the tooth.[2] Align Technology Inc recommends the use of resin attachments, interproximal reduction, thermopliers, overcorrection or auxiliaries to aid rotational movement.[3] However, it remains the responsibility of the clinician to accurately diagnose difficult movement and prescribe treatment within the limitations of the aligner material.

An internal study by Nguyen and Cheng[2] first evaluated the performance of aligners for canine and premolar rotations by superimposing virtual models with ToothMeasure, Align's propriety superimposition software. The results of their study revealed that the overall accuracy of canine and premolar rotation was only

[a] Private practice in orthodontics, Chantilly, Va.

[b] Assistant Professor and Clinical Chair, Department of Orthodontics, University of Illinois at Chicago, Chicago, Ill.

[c] Research Assistant, Department of Orthodontics, School of Dentistry, University of Illinois at Chicago, Chicago, Ill.

[d] Statistician, Department of Orthodontics, University of Illinois at Chicago, Chicago, Ill.

Corresponding author: Dr Neal D. Kravitz, Department of Orthodontics, University of Illinois at Chicago, 801 S Paulina Street, MC 841, Chicago, IL 60612
(e-mail: nealkravitz@gmail.com)

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39%. The researchers concluded that derotated canines and premolars are unlikely to achieve their treatment goal with the initial series of aligners alone.

To date, published data on Invisalign have primarily consisted of case reports, technical articles, and material studies,[4] none of which provide scientific evidence regarding the efficacy of rotation with Invisalign. In turn, much of what we know about the treatment effects and proper application of the Invisalign system for rotating teeth is largely anecdotal.

Boyd and Vlaskalic,[5] Boyd,[6] and Kuo and Duong[7] suggested the use of labial and lingual attachments to aid rotational movement with Invisalign. Chenin et al[8] presented two case reports with successful canine rotation using a combination of labial attachments and interproximal reduction. Boyd[6] advocated 10% overcorrection (which he refers to as the "11/10 rule") whereas Kuo[2] suggested 5° of rotation beyond ideal position and use of thermopliers when needed. Joffe[9] cautioned clinicians attempting rotations greater than 20°, and Boyd and Vlaskalic[5] suggested the adjunctive use of fixed appliances for rotations greater than 45°. Still others advocate slowing down the speed of movement to 0.1 mm of rotational movement per aligner.

In a retrospective cohort study, Djeu et al[10] assessed treatment outcomes of Invisalign compared with conventional fixed appliances, using the American Board of Orthodontics objective grading system (OGS). The study reported no statistical difference in tooth alignment ($P = .149$), including rotation. The author commented that rotation of premolars was particularly successful in those teeth with resin attachments, "confirming" the influence of attachments on rotational movement. However, the OGS measures marginal ridge alignment, not rotation specifically. Furthermore, no information was provided regarding the number of teeth undergoing rotation that had attachments or whether any of those teeth received interproximal reduction.

The purpose of this prospective clinical study was to assess the influence of attachments and interproximal reduction on canines undergoing rotational movement with Invisalign. The amount of rotation predicted by ClinCheck was compared with the amount of rotation actually achieved after Invisalign treatment. A better understanding of the Invisalign system may help guide clinicians in establishing a protocol for correction of malrotated teeth.

MATERIALS AND METHODS

The patients examined were part of a prospective clinical study of adult patients (18 years and older) who underwent anterior Invisalign treatment at the Department of Orthodontics, University of Illinois–Chicago. A focus of that study was to evaluate the efficacy of anterior tooth movement with Invisalign. This study compared the accuracy of canine rotation for three treatment groups: canines with attachments only (AO), interproximal reduction only (IO), and neither attachments nor interproximal reduction (N).

Patient recruitment was performed at the Department of Orthodontics, University of Illinois–Chicago. Thirty-eight consecutively treated patients were enrolled into the clinical study. Clinicians were prohibited from altering the sequence or speed of tooth movement, using auxiliaries (ie, buttons, elastics) other than Invisalign attachments, or altering the aligners with scissors or thermopliers. Clinicians were allowed to request or refuse interproximal reduction, proclination, attachments, and overcorrections on ClinCheck at their discretion. Patients were instructed to wear each aligner 22 hours a day, 7 days a week for 2–3 weeks, and complete a daily compliance log during treatment recording the number of hours the aligners were worn each day.

After completing the initial series of aligners, posttreatment polyvinyl siloxane (PVS) impressions were mailed to Align Technology Inc. Two Align Technology Inc technicians assigned to the research study e-mailed the pretreatment and posttreatment virtual TREAT models back to the University where they were de-identified and stored. Pretreatment models were evaluated for presence, location, and shape of attachments or interproximal reduction on the maxillary and mandibular canine. The amount of interproximal reduction (as prescribed on ClinCheck) on the mesial and distal surfaces of the canine was recorded, but not evaluated during this study.

The pretreatment and posttreatment virtual models were then transferred into ToothMeasure for model superimposition. ToothMeasure is a software application developed by Align Technology Inc and is used internally to provide measurements on scanned computer models. Furthermore, it enables a single operator to reproducibly superimpose two digital models on user-selected reference points, such as untreated teeth, palatal rugae, and dental implants within 0.2 mm and 1.0° of accuracy.[2,11]

The final-stage of the projected pretreatment model was superimposed on the zero-stage of the posttreatment model, using the untreated posterior teeth as a reference (Figures 1 and 2). ToothMeasure provided a matching results report on the matching accuracy of the pretreatment and posttreatment virtual models. If there was poor tooth matching for a posterior tooth, that tooth was not selected as a reference for superimposition. After model superimposition, ToothMeasure performed an efficacy analysis report, which provided the predicted and achieved values for maxillary and mandibular canine rotation.

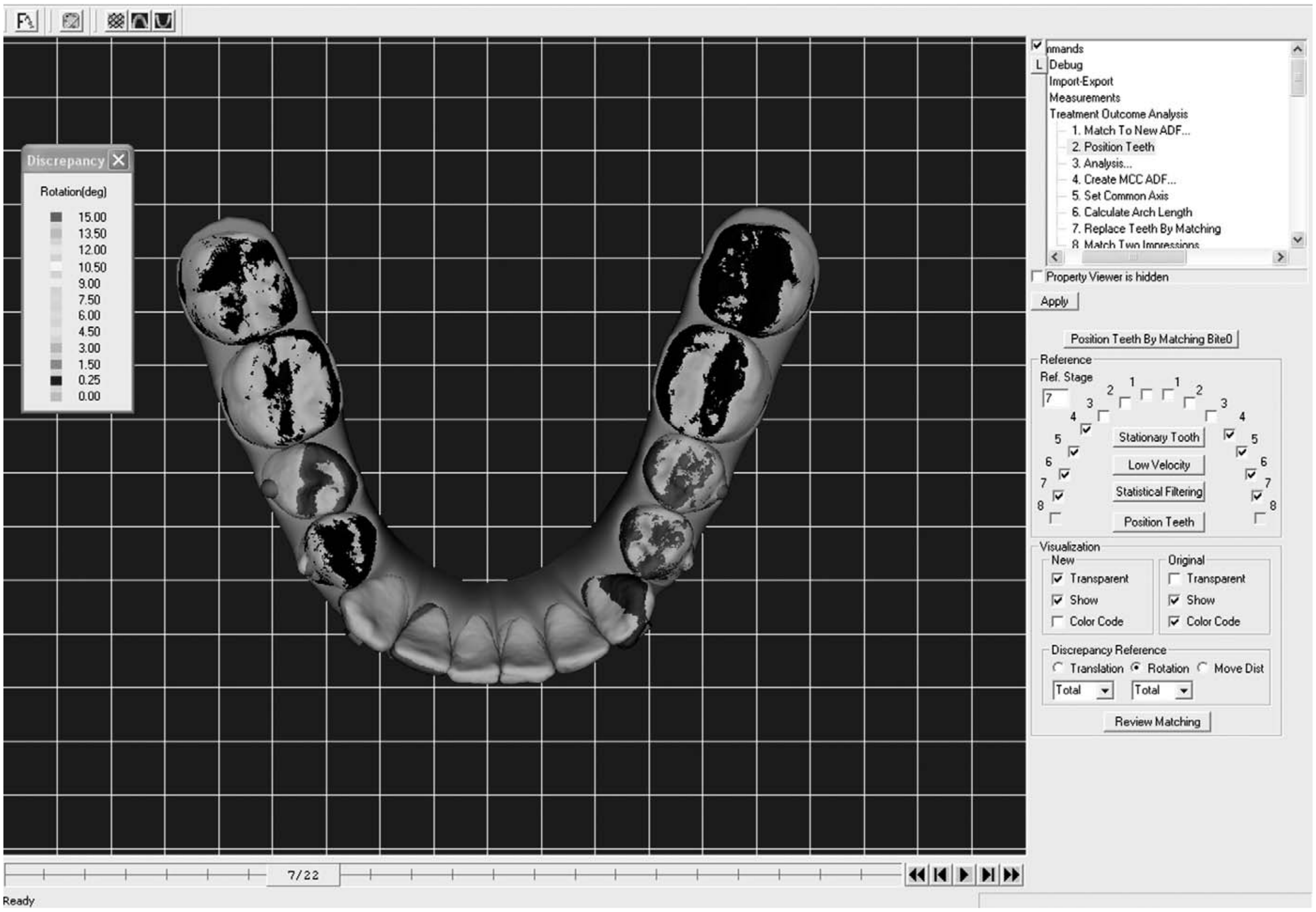

Figure 1. Superimposition of the predicted Treat model over the achieved Treat model in ToothMeasure. The two models are superimposed over the stationary posterior teeth within 0.2 mm of accuracy. Note the stability of the posterior teeth and the deviation between predicted vs achieved values for the lower left canine.

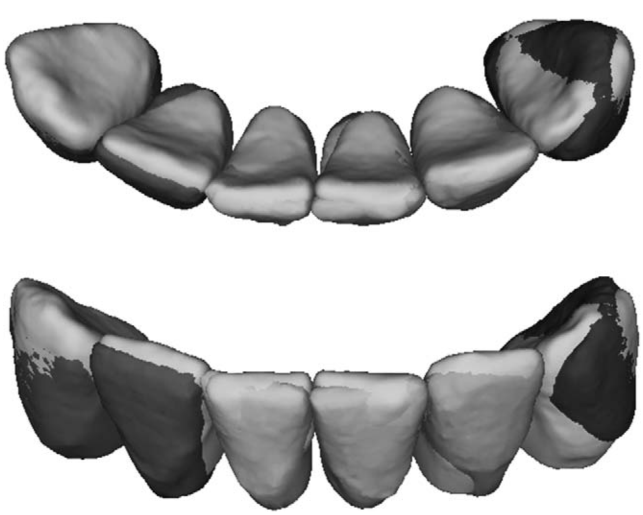

Figure 2. Deviation in the predicted (grey) and achieved (color) anterior tooth positions. Red-color indicates greater than 15° of deviation.

All predicted rotational movements ≤1.0° were eliminated from the data sample to account for the error in model superimposition. The remaining sample was categorized into three treatment groups (AO, IO, and N) and teeth were randomly selected into groups of equal size. At the end of random selection, the sample comprised 53 canines (33 maxillary, 20 mandibular) from 31 patients (13 male, 18 female). Of these patients, 28 received dual-arch treatment and three received single-arch treatment only.

A one-way analysis of variance (ANOVA) test ($P < .05$) was used to determine the significance of differences in rotational accuracy between the AO, IO, and N groups. Student's *t*-tests ($P < .05$) compared the mean accuracy of canine rotation between arches. All statistical analyses were performed with SPSS statistical software (SPSS Inc, Chicago, Ill).

RESULTS

The last data collection was performed in December 2006. Patient compliance forms were collected at the

Table 1. Sample Demographics

Category	N
Male	13 (41.9%)
Female	18 (58.1%)
White	19 (61.3%)
Hispanic	8 (25.8%)
Asian/Indian/Middle Eastern	3 (9.7%)
African-American	1 (3.2%)
Mean age	29.4 years

Table 2. Treatment Demographics

Category	N
Mean treatment duration, months	7
Mean number of upper aligners	10
Mean number of lower aligners	11
Both upper and lower arch treatment	28
Upper arch treatment only	2
Lower arch treatment only	1
Ellipsoid attachment	16
Rectangular attachment	1
Ellipsoid and vertical attachment	12
Ellipsoid and horizontal attachment	4
Rectangular and horizontal attachment	1

Table 3. Mean Accuracy of Canine Rotation

Category[a]	Mean Accuracy	N	SD
Maxillary (AO)	34.9	15	29.0
Maxillary (IO)	40.3	9	26.2
Maxillary (N)	34.2	9	23.9
Mandibular (AO)	21.0	2	29.7
Mandibular (IO)	45.9	9	19.6
Mandibular (N)	27.5	9	31.3

[a] AO indicates attachments only; IO, interproximal reduction only; N, neither attachments nor interproximal reduction.

end of treatment and all patients claimed to have worn their aligners for 21–23 hours/day. The AO, IO, and N groups had similar distribution in gender, age, ethnicity, and number of treatment aligners.

The sample revealed a mean age of 29.4 years (male = 27.9, female = 30.4) with 58.1% of canines from female participants (Table 1). The mean number of upper aligners and lower aligners was 10 and 11, respectively, with the average treatment lasting 7.2 months (Table 2). The mean amount of predicted rotation for the entire sample was 11.8°.

The mean accuracy of canine rotation for all three groups was 35.8% (SD = 26.3) (Tables 3 and 4). The highest mean accuracy was achieved by the IO group (43.1%), with 12 of 18 canines attempting rotations greater than 5° (range 8.7° to 33.9°). The next highest mean accuracy was achieved by the AO group (33.3%), with 15 of 17 canines attempting rotations greater than 5° (range 6.9° to 31.1°). The N group had the lowest mean accuracy (30.8%); in this group only

Table 4. Mean Accuracy of Canine Rotation as a Function of Treatment Modality

Treatment Group[a]	Mean Accuracy	N	SD
Attachment only (AO)	33.3	17	28.6
IPR only (IO)	43.1	18	22.6
Neither (N)	30.8	18	27.3
Total	35.8	53	26.3

[a] AO indicates attachments only; IO, interproximal reduction only; N, neither attachments nor interproximal reduction.

Table 5. One-Way Analysis of Variance (ANOVA) Summary Table Comparing Treatment Modalities

Category	SS	df	MS	F	*P*
Between groups	1505.388	2	752.7	1.1	.34
Within groups	34378.254	50	687.57	—	—
Total	35883.642	52	—	—	—

$P < .05$. SS indicates sum of squares; MS, mean square difference.

Table 6. Student's *t*-Test Comparing Mean Accuracy of Canine Rotation

Category	Mean Accuracy, %	N	SD	*t*	df	*P*
Maxillary	36.2	33	26.3	0.14	51	.89
Mandibular	35.0	22	26.9			

$P < .05$.

2 of 18 canines attempted rotations greater than 5°. This rotation was 16.4° in one patient and 36.8° in the other patient. For the majority of patients in this study, the discrepancy between final tooth position and aligner was clinically discernable.

No statistically significant differences ($P = .343$) in rotational accuracy were found between the AO, IO, and N groups (Table 5). Furthermore, there was no statistically significant difference ($P = .888$) in accuracy of rotation for maxillary and mandibular canines for any of the treatment groups (Table 6).

The most commonly prescribed attachment shape was Invisalign's standard dimension (0.75 mm thick), vertical ellipsoid (70.5%). All attachments were labially placed and centrally located.

DISCUSSION

Many orthodontists consider canine rotation with Invisalign a challenging and unpredictable movement. Currently, clinicians employ varying combinations of auxiliaries, overcorrection, attachments, and interproximal reduction as they attempt to achieve more predictable results. The purpose of this prospective clinical trial was to evaluate the efficacy of attachments and interproximal reduction, and take the first steps

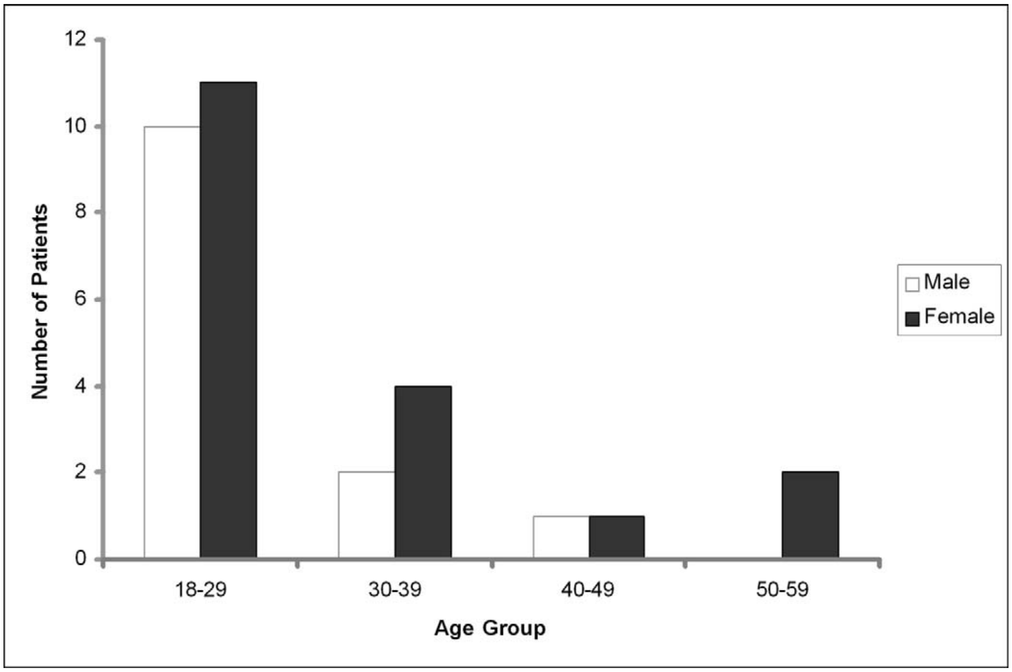

Figure 3. Number of male and female patients by age group.

toward determining a systemic approach for addressing malrotations with the Invisalign system.

The sample for our study consisted primarily of white female patients with a mean sample age of 29.4 years. Meier et al[12] surveyed patients who were interested in Invisalign treatment and reported that the characteristic profile of patients interested in Invisalign was women (72%) between 20 and 29 years of age. In the same study, the age group with the largest sample of male patients interested in Invisalign treatment was 30–39 years of age. In our study, the age group with the greatest number of participants was between 18–29 years of age, with nearly an equal distribution of men and women (Figure 3). Overall, the male participants comprised a significantly higher percentage (41%) of the sample, with a younger mean age (27.9 years).

The most significant finding in the study was that the mean accuracy of canine rotation for the entire sample was 35.8%. Only 15 of the 53 canines achieved rotational accuracy greater than 50%. These results are consistent with the internal findings of Nguyen and Cheng,[2] and verify the difficulty of derotating canines with the Invisalign system. Therefore, clinicians attempting derotations with aligners alone may consider addressing malrotations at the end-stages of treatment after completing the more predictable movements. Additionally, clinicians may consider prescribing far greater overcorrection than previously suggested by Boyd[6] and Kuo[13]. However, the clinician should consider that at some time of derotation the aligner will likely stop to perform, and any further overcorrection would not improve rotational accuracy.

There was no statistical difference in rotational accuracy among the attachments only, interproximal reduction only, and neither attachments nor interproximal reduction groups. Canines that received interproximal reduction reported the highest mean rotational accuracy and lowest standard deviation. These results were unexpected because interproximal reduction is both technique- and time-sensitive (in terms of appropriate stage of treatment).

These results are of particular interest because there has been a recent movement among Invisalign providers to limit the use of interproximal reduction in an effort to decrease valuable chair time and maximize patient comfort. However, the primary advantage of interproximal reduction is that teeth require less movement for alignment. Round-tripping with aligners will likely require a greater number of stages of treatment, and aligners may not properly adapt to the teeth at later stages resulting in a decrease in the accuracy of tooth movement.

The relatively low accuracy of rotation for the AO group was not expected. The addition of attachments increases a tooth's geometric mass and enhances the undercuts along a horizontal plane, which should aid rotational movement.[2] However, the results of this study indicated that labially placed, centrally located, vertical ellipsoid attachments offer only modest improvements in rotational accuracy in comparison to those teeth that had no attachments at all. This finding may be attributed to a combination of the shape and placement of the attachment, as well as the greater number of canines in the AO group that underwent rotational movement greater than 5°. Current recommendations from Align Technology Inc are to place attachments in the incisal one-third of the tooth to maximize aligner retention. This may be an option for maxillary teeth, whereas for mandibular teeth, incisal attachments might cause unwanted prematurities. Further studies are needed to determine the influence of alternative shapes and locations of both template-formed resin attachments and preformed composite attachments on rotational movement.

With regard to treatment between arches, there was no statistical difference in accuracy of maxillary and mandibular canines for any of the treatment groups. Boyd[6] has suggested greater difficulty derotating mandibular canines due to their smaller, more rounded clinical crown. In our study, maxillary canines in the N group achieved only slightly higher rotational accuracy than mandibular canines in the N group. Furthermore, the highest mean rotational accuracy and lowest standard deviation was achieved by mandibular canines in the IO group (mean accuracy = 45.9%, mean SD = 19.6).

There were three significant limitations to this study: (1) an acceptable sample size was not obtained for canines with both attachments and interproximal reduction; (2) the amount of interproximal reduction was not evaluated. The amount of reproximation was prescribed between the canine and its adjacent teeth, and there was no reliable method implemented to measure the amount of enamel reduction on the canine alone. Future studies are needed to determine the influence of various amounts of interproximal reduction at different stages of treatment. And (3) overcorrections were not accounted for, as the final projected tooth position was the measurement used. Therefore, some teeth that reported a low accuracy of rotation might have actually achieved their desired tooth position.

Clinically tested protocols regarding the placement and shape of Invisalign attachments, staging and amount of interproximal reduction, the amount of overcorrection, and the speed of tooth movement are needed to improve the accuracy of rotating teeth with aligners alone. Until then, correction of malrotated canines with Invisalign remains challenging and unpredictable.

CONCLUSIONS

- The mean accuracy of canine rotation for the AO, IO, and N groups was 35.8%.
- There was no significant difference in accuracy of rotation between canines with attachments only, interproximal reduction only, or neither attachments nor interproximal reduction.
- The highest accuracy was achieved by the IO group, indicating that the presence of interproximal contact may be a critical factor in the success of canine rotation.
- Labially placed, centrally located, vertical-ellipsoid attachments were the most commonly prescribed attachment shapes for correcting malrotations. These attachments offered little clinical improvement over using no attachments at all.

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REFERENCES

1. Sheridan JJ. The Readers' Corner. 2. What percentage of your patients are being treated with Invisalign appliances? *J Clin Orthod.* 2004;38:544–545.
2. Nguyen CV, Chen J. In: Tuncay OC ed. *The Invisalign System.* New Malden, UK: Quintessence Publishing Co, Ltd; 2006:121–132.
3. Align Technology Inc. *The Invisalign Reference Guide.* Santa Clara, Calif: Invisalign; 2002.
4. Turpin DL. Clinical trials needed to answer questions about Invisalign. *Am J Orthod Dentofacial Orthop.* 2005;127:157–158.
5. Boyd RL, Vlaskalic V. Three-dimensional diagnosis and orthodontic treatment of complex malocclusion with the Invisalign appliance. *Semin Orthod.* 2001;7:274–293.
6. Boyd RL. Predictability of successful orthodontic treatment using Invisalign. The Greater Philadelphia Society of Orthodontists page. Available at: http://www.gpso.org/events/2003_outline.pdf. Accessed September 1, 2007.
7. Kuo E, Duong T. In: Tuncay OC ed. *The Invisalign System.* New Malden, UK: Quintessence Publishing Co, Ltd; 2006: 91–98.
8. Chenin DA, Trosien AH, Fong PF, Miller RA, Lee RS. Orthodontic treatment with a series of removable appliances. *J Am Dent Assoc.* 2003;134:1232–1239.
9. Joffe L. Invisalign: early experiences. *J Orthod.* 2003;30: 348–352.
10. 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.
11. Miller RJ, Kuo E, Choi W. Validation of Align Technology's Treat III digital model superimposition tool and its case application. *Orthod Craniofac Res.* 2003;6(suppl 1):143–149.
12. Meier B, Wiemer KB, Miethke RR. Invisalign—patient profiling. Analysis of a prospective survey. *J Orofac Orthop.* 2003;64:352–358.
13. Kuo E. In: Tuncay OC ed. *The Invisalign System.* New Malden, UK: Quintessence Publishing Co, Ltd; 2006:115–120.