Retention of Thermoformed Aligners with Attachments of Various Shapes and Positions

MATHEW L. JONES, DMD
JAMES MAH, DDS, MSC, DMSC
BRENDAN J. O'TOOLE, PHD

Removable clear aligners such as Invisalign,* Red, White and Blue,** and Simpli5** are increasingly being used for orthodontic tooth movement. Although each of these systems has been used successfully, a common problem is retention of the appliance on the teeth. Aligner retention can be affected by various factors, including tooth morphology and position, the degree of malocclusion, the aligner material, and wear on the appliance.

Various types of attachments have been developed to improve retention with these systems.[1,2] Custom-formed composite attachments, bonded to the teeth before placement of the aligner, can facilitate tooth movements such as intrusion and extrusion,[3] rotation, and torquing. This allows more patients to be treated with removable aligner systems, including those requiring extractions[4,5] or surgery.[6]

Our clinical experience has suggested that variations in attachment size, shape, and position can greatly influence aligner retention and efficacy. The present study was conducted to evaluate the retention provided by attachments of various shapes and positions through measurement of the aligners' resistance to vertical dislodgement.

Materials and Methods

Three different attachment shapes were evaluated in the study:
Group 1: Horizontal beveled attachments with the bevels directed occlusally.
Group 2: Horizontal beveled attachments with the bevels directed gingivally.
Group 3: Vertical rectangular attachments.

Each of these groups was divided into three subgroups according to the occlusogingival position of the attachment on the tooth:
Position A: 2mm from the gingival margin.
Position B: Centered.
Position C: 2mm from the occlusal surface.

The same maxillary typodont*** was used to create impressions with 10 different maxillary right first premolars, including one tooth without an attachment that served as a control. Using all possible combinations of attachment shapes and

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***Part No. D85SDP-200, Kilgore International, Inc., 36 W. Pearl St., Coldwater, MI 49036; www.kilgoreinternational.com.

Dr. Jones is in the private practice of orthodontics at 814 W. Gore Blvd., Lawton, OK 73501; e-mail: mattljones@gmail.com. Dr. Mah is a Contributing Editor of the *Journal of Clinical Orthodontics,* an Associate Clinical Professor and Director, Craniofacial Virtual Reality Laboratory, University of Southern California, Los Angeles, and an Associate Clinical Professor, Advanced Education in Orthodontics and Dentofacial Orthopedics, University of Nevada, Las Vegas, NV. Dr. O'Toole is an Associate Professor of Mechanical Engineering and Director, Center for Materials and Structures, University of Nevada, Las Vegas.


Dr. Jones


Dr. Mah


Dr. O'Toole

TABLE 1
AVERAGE MAXIMUM DISPLACEMENT FORCE (NEWTONS ± S.D.)

	Position A	Position B	Position C	Control
				1.40 ± 0.59
Group 1	12.95 ± 6.84	12.00 ± 4.96	2.56 ± 0.94	
Group 2	9.60 ± 2.77	11.11 ± 3.60	4.10 ± 1.51	
Group 3	17.08 ± 6.90	13.66 ± 3.41	2.88 ± 1.17	

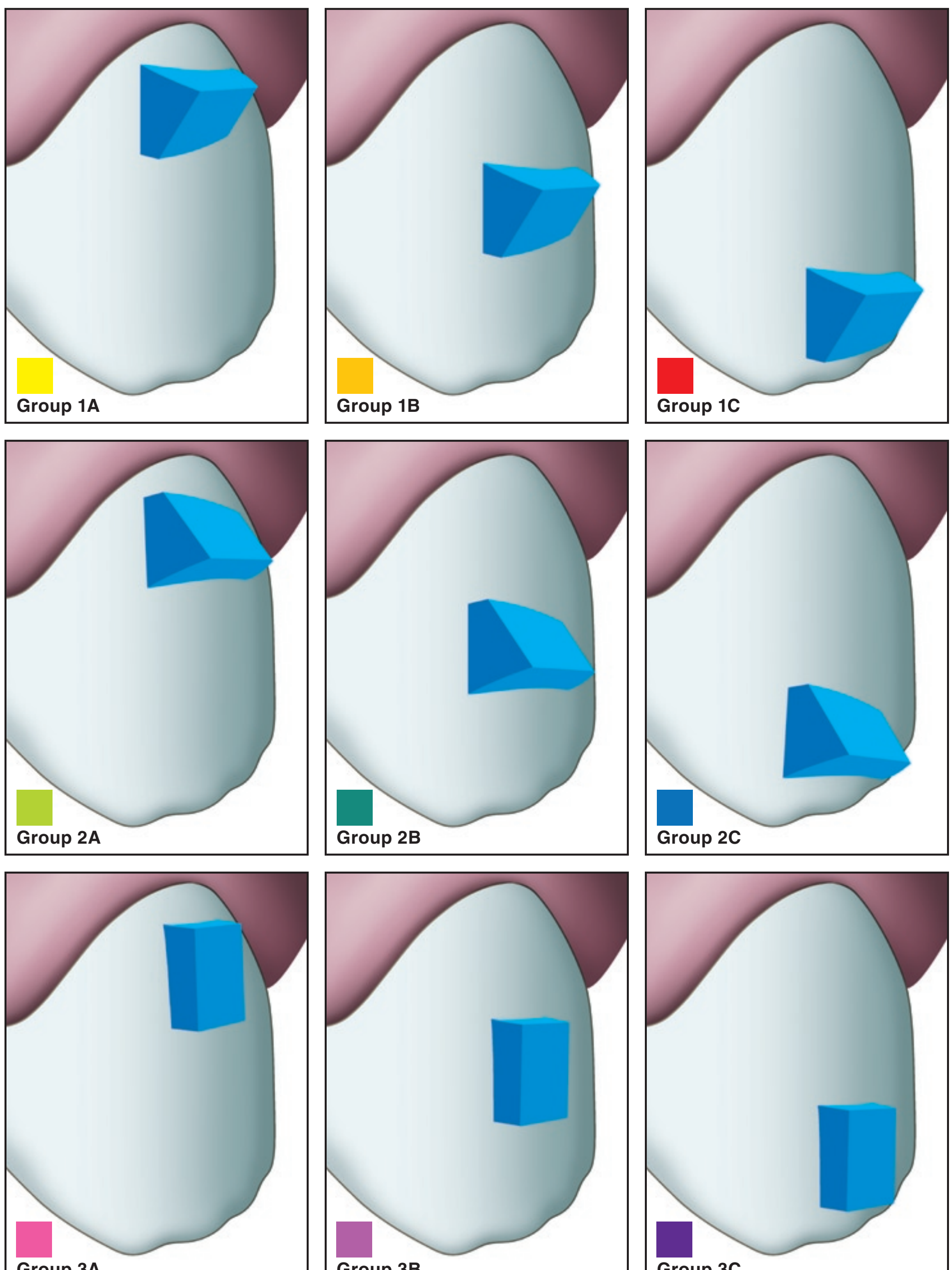

Fig. 1 Nine combinations of attachment design and position.

positions, the nine experimental teeth were set up as follows (Fig. 1):
Group 1A: Horizontal beveled attachment with the bevel directed occlusally, positioned 2mm from the gingival margin.
Group 1B: Horizontal beveled attachment with the bevel directed occlusally, centered occlusogingivally.
Group 1C: Horizontal beveled attachment with the bevel directed occlusally, positioned 2mm from the occlusal surface.
Group 2A: Horizontal beveled attachment with the bevel directed gingivally, positioned 2mm from the gingival margin.
Group 2B: Horizontal beveled attachment with the bevel directed gingivally, centered occlusogingivally.
Group 2C: Horizontal beveled attachment with the bevel directed gingivally, positioned 2mm from the occlusal surface.
Group 3A: Vertical rectangular attachment positioned 2mm from the gingival margin.
Group 3B: Vertical rectangular attachment centered occlusogingivally.

Fig. 2 Maxillary right first premolar and corresponding aligner secured to testing machine, and vertical force applied to dislodge aligner from tooth.

Group 3C: Vertical rectangular attachment positioned 2mm from the occlusal surface.

A polyvinyl siloxane impression was taken of the typodont with each of the 10 different maxillary right first premolars in place, and the 10 impressions were sent to a laboratory** for fabrication of the aligners. The laboratory used Excalibur stone† to create casts from the impressions and a Ministar‡ pressure-molding machine to mold Forestadent Track A††† aligner material to the stone casts. At least two Simpli5 aligners were made for each of the casts and trimmed to the gingival margin of the typodont.

The 10 sets of aligners were tested as follows: The maxillary right first premolar and the corresponding aligner were secured to a United testing machine‡‡ (Fig. 2). Vertical displacement forces were applied perpendicular to the occlusal plane at a rate of .04"/minute. Tensile forces were recorded on a continuous analog scale.

This procedure was repeated six times, for a total of seven displacements for each of the aligners, and the average maximum displacement force for each aligner group was calculated. Statistical analysis was performed to determine whether there were significant differences among the groups, with the level of significance set at $p < .05$.

Results

The greatest average maximum displacement force (Table 1) was recorded for Group 3A (vertical rectangular attachment positioned 2mm from the gingival margin), followed by Group 3B (vertical rectangular attachment centered occlusogingivally) and Group 1A (horizontal beveled attachment with bevel directed occlusally, positioned

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†Garreco, Inc., P.O. Box 1258, Heber Springs, AR 72543; www.garreco.com.

‡Scheu Dental Technology, Am Burgberg 20, 58642 Iserlohn, Germany; www.scheu-dental.com.

†††Registered trademark of Forestadent, Westliche Karl-Friedrich-Str. 151, 75172 Pforzheim, Germany; www.forestadent.com.

‡‡United Calibration Corp., 5802 Engineer Drive, Huntington Beach, CA 92649; www.tensiletest.com.

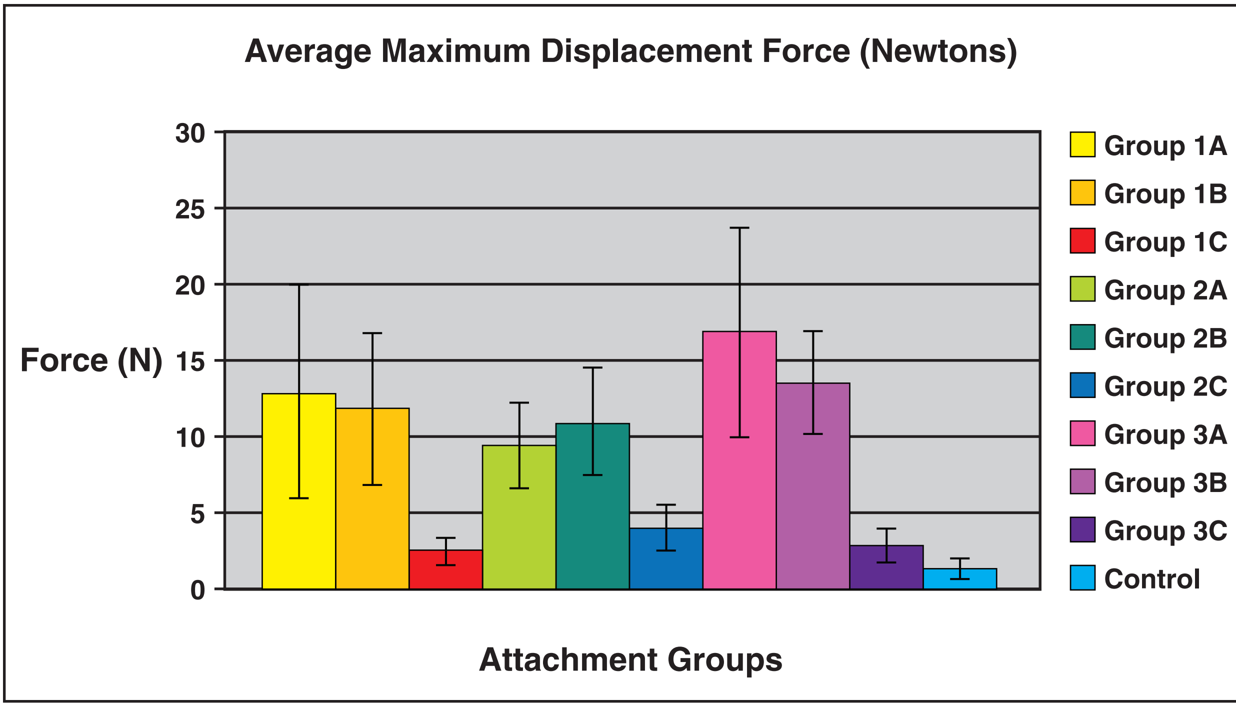

Fig. 3 Average maximum displacement force by attachment type.

2mm from the gingival margin).

Overall, the vertical rectangular attachment (Group 3) showed the greatest average maximum displacement force (Fig. 3), followed by the horizontal beveled attachment with the bevel directed occlusally (Group 1). For all attachment designs except the horizontal beveled attachment with the bevel directed gingivally, the most retentive position was 2mm from the gingival margin (Position A), followed by the centered position (Position B) and 2mm from the occlusal surface (Position C). These differences were all statistically significant ($p < .05$). For the horizontal beveled attachment with the bevel directed gingivally, the centered position (Position B) was most retentive, followed by 2mm from the gingival margin (Position A) and 2mm from the occlusal surface (Position C). All of the attachment types showed much greater resistance to displacement than the control group.

Discussion

Conventional wisdom has suggested that horizontal attachments positioned closer to the occlusal surfaces will be more retentive because the aligners are less flexible in this region.[2] As the thermoforming process drapes the material over the dental model and draws it over the sides, the material thins in the gingival regions, resulting in less stiffness in these areas. Our results suggest, however, that this phenomenon does not significantly affect appliance retention. In fact, aligner retention improved with more gingival placement of the attachments, probably due to the increased degree of undercut on the gingival aspect of the attachment as it follows the curvature of the tooth surface (Fig. 4).

Further clinical research is required to determine the acceptable range of force for various types of tooth movement with removable aligners, as well as to determine the best range of force values to optimize both appliance retention and ease of insertion and removal. If all the tested configurations turn out to be adequate for these purposes, other variables such as esthetics, ease of attachment

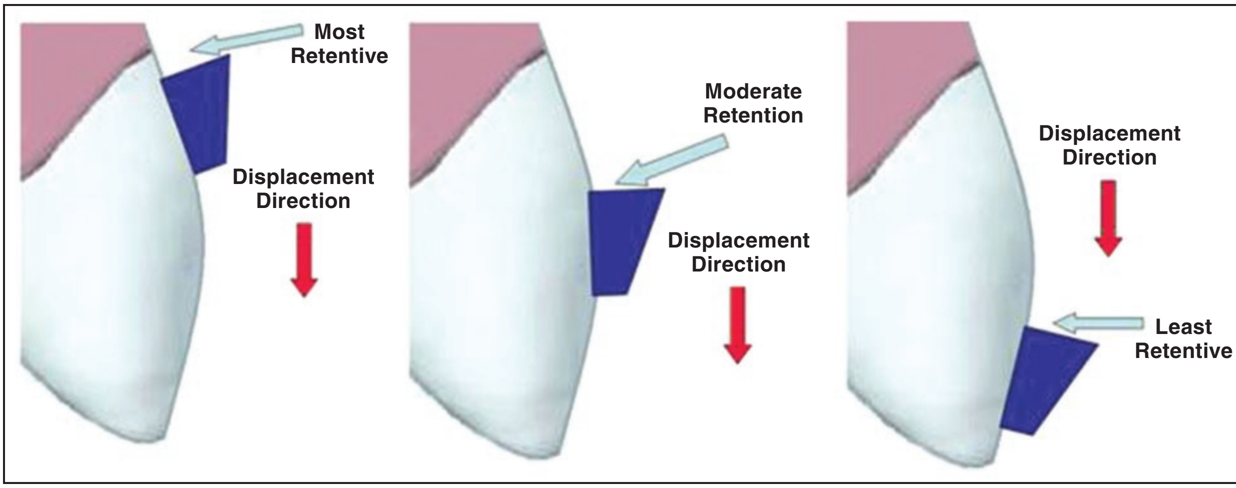

Fig. 4 Maximum retention provided by positioning attachments more gingivally.

placement, and accessibility for oral hygiene may become more important factors in attachment design and placement. In addition, clinical studies are needed to improve our understanding of retentive forces with respect to appliance efficacy, various types of tooth movement, and patient comfort during placement and removal. Durability of the attachments was not addressed in this study, but may have clinical significance, since aligners are inserted and removed frequently. In addition, other forces not measured, such as torsional forces, may be involved in aligner retention.

Conclusion

A thorough understanding of the retentive properties of various types of attachments is essential when planning tooth movement using removable aligners. For certain tooth movements such as extrusion, maximal retentive force is needed. According to the results of our study, this can be achieved by placing the attachment more gingivally, by choosing an attachment that does not have a gingivally directed bevel, or both. In cases where maximal retention is not needed, other types of attachments may be used to facilitate appliance removal.

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REFERENCES

1. Kravitz, N.D.; Kusnoto, B.; Agran, B.; and Viana, G.: Influence of attachments and interproximal reduction on the accuracy of canine rotation with Invisalign: A prospective clinical study, Angle Orthod. 78:682-687, 2008.
2. Colville, C.D.; Fischer, K.; and Paquette, D.E.: A snap fit: Using attachments to improve clear aligner therapy, Orthod. Prod., September 2006.
3. Turatti, G.; Womack, R.; and Bracco, P.: Incisor intrusion with Invisalign treatment of an adult periodontal patient, J. Clin. Orthod. 40:171-174, 2006.
4. Womack, W.R.: Four-premolar extraction treatment with Invisalign, J. Clin. Orthod. 40:493-500, 2006.
5. Hönn, M. and Göz, G.: A premolar extraction case using the Invisalign system, J. Orofac. Orthop. 67:385-394, 2006.
6. Boyd, R.L.: Surgical-orthodontic treatment of two skeletal Class III patients with Invisalign and fixed appliances, J. Clin. Orthod. 39:245-258, 2005.