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ABSTRACT

Purpose The aims of the study were: 1) to evaluate the fitting of three different aligners (Invisalign (Align Technology, Santa Clara, CA, USA), CA Clear Aligner (Scheu-Dental, Iserlohn, Germany) and F22 (Sweden&Martina, Due Carrare, Italy)) on anchorage attachments using scanning electron microscopy (SEM), and 2) to analyze the influence of 2 different types of resin used to build attachments on aligners fitting.

Methods From STL files of a patient six resin casts were obtained and rectangular attachments were bonded on them. Conventional bulk-fill resin was used to build upper attachments while a flowable resin was used to build the lower ones. Passive aligners were adapted on each cast and then sectioned buccolingually.
Microphotographs of the obtained sections were performed using a scanning electron microscope (SEM) and then micrometric measurements of aligner fitting on anchorage attachments were recorded.

Results
Analyzing the overall fitting of upper arch aligners, Invisalign provided a significant better fitting with respect to F22 (P= 0.009); differences were not significant when comparing Invisalign with CA Clear Aligner, and CA Clear Aligner with F22.
Analyzing the overall fitting of lower arch aligners, F22 provided a significant better fitting with respect to CA Clear Aligner (P= 0.008) and Invisalign (P = 0.011).
The analysis showed a significant better fitting on upper attachments, built using conventional bulk-fill resin (P = 0.034).

Conclusions Invisalign, CA Clear Aligner and F22 have comparable performance in terms of fitting on anchorage attachments. Conventional bulk-fill resin provides the best fitting on anchorage attachments.

KEYWORDS: SEM, aligner, attachment, fitting

Short title: SEM analysis of aligners fitting on attachments

INTRODUCTION

Teeth generally do not have operative points on which any appliance system can act effectively. During conventional orthodontic treatment standardized brackets are bonded on teeth and acts as purchase areas where forces are transmitted by wires.

As Angle stated in 1907: " No matter how perfect the design and construction of an appliance, if the attachments to the anchor and moving teeth be not such as to insure its stability it becomes worthless [...] Owing to the irregular and slippery surfaces of the teeth, the gaining of firm attachment to them has always been one of the problems in tooth regulation" [1].

In clear aligner therapy (CAT) the necessary purchase point are created through the formation and application on teeth surfaces of predetermined composite shapes, which are grouped under the appellation attachment [15].

In CAT orthodontic tooth movement is the result of the mechanical perturbation induced by the aligner: an intentional, predetermined "mismatch" between the aligner, teeth and attachments is programmed in each treatment stage. The aligner, which corresponds to the new desired teeth position, is fitted on the dental arch, producing in each mismatch a force system that is directly transmitted, generating the mechanical-biological chain of events that results in a new dental position. Tooth morphology is another factor to take into account when discussing about force and moments generated by aligners. As demonstrated in *in vitro* studies forces and couples delivered by aligners are determined by the shape of the crown and the type and amount of displacement of a particular tooth and therefore the contacts between the tooth crown and the inner surface of the aligner [12]. Elkholy et al. demonstrated that , the resulting collateral forces and moments delivered for the rotation of a mandibular canine depend greatly on the morphology of the tooth [6].

In a recent systematic review Rossini et al. stated that auxiliaries such as attachments, interarch elastics and IPR are needed to improve the predictability of orthodontic movement with aligners [20]. Therefore attachments can be used to modulate orthodontic movement or to manage anchorage units. Despite ranges of documented variability, the preponderance of data suggests that - regardless of force magnitude - reciprocally applied forces between anchorage and active teeth result in reciprocal displacements [17]. This is obvious in CAT too.

During last years some different attachment shapes have been designed such as CA Clear Aligner Power Grip (Scheu-Dental, Iserlohn, Germany) and Invisalign attachments (Align Technology, Santa Clara, CA, USA) to enhance anchorage management and achieve predictable tooth movements [16].

In order to improve anchorage management retentive attachments are required to overcome undesired displacements.

An in-vitro study by Dasy et al. demonstrated that attachment shape affects retention: rectangular attachments are more retentive than ellipsoid ones [5].

The use of the attachments is crucial to achieve effective treatments: Ravera et al. [18] and Garino et al. [10] demonstrated the importance of using rectangular attachments to improve the root control of distalizing molars in class II treatments. These attachments are useful not only to control tipping during molar distalization, but also to enhance posterior anchorage during anterior retraction.

In an *in vitro* study Simon et al. demonstrated that load transfer from aligners to teeth without the use of attachment is possible only to a limited extent [28].

Attachments' position and configuration are the key determinants. Despite the widespread of the technique there are no data available regarding the "play" of aligners on anchorage attachments.

Aim of this experimental study was to evaluate the fitting of three different passive aligners (Invisalign, CA Clear Aligner and F22 (Sweden&Martina, Due Carrare, Italy)) on anchorage attachments using scanning electron microscopy (SEM).

Since orthodontic tooth movement predictability strictly depends upon anchorage management this study was conducted to answer the following clinical/research questions :

1) Among the investigated systems, which one provides the best fitting of the aligner on the anchorage attachment?
2) Does the composite resin viscosity affect the fitting of the aligner on the anchorage attachment?

MATERIALS AND METHODS

A class I malocclusion patient was selected for the study. Intraoral scans of the dental arches were obtained using iTero® Element™ scanner (Align Technology, Santa Clara, CA, USA) [21,11,14]: STL (STereo Lithography interface format) files thus obtained and clinical records (digital intraoral and extraoral pictures, orthopantomography and lateral cephalometric x-ray) were sent to Align Technology, to CA Clear Aligner and to Sweden&Martina together with the relative prescription form.

An operator expert in clear aligner therapy provided the clinical prescription, that was the same for every considered system. The first aligner of every system was planned to be passive on anchorage attachments and on the other teeth.

Using the same STL files, six resin casts (methacrylic acid esters, proprietary pigment; Form2 3D printer (Formlabs Inc, Somerville, MA, USA)) were obtained with the support of a dental laboratory (Novadental, Venaria Reale, Italy).

Templates were provided by aligners' manufacturers to support the attachments realization.

As stated in the literature, the rectangular attachments showed the most retentive features [5] These attachments were selected for the further analysis. (Fig. 1).

One coat of Assure® Plus All Surface Bonding Resin (Reliance Orthodontic Products Inc., Itasca, IL, USA) was applied and then let to dry. Following the instructions provided by the manufacturer, an LED curing light Bluephase® Style (Ivoclar Vivadent AG, Liechtenstein) was then used with high intensity (1,200 mW/cm^2): it is a polywave LED with halogen-like broadband spectrum of 385 to 515 nm [9].

A conventional bulk-fill resin, Tetric EvoCeram® Bulk Fill (Ivoclar Vivadent AG, Liechtenstein) was used for the attachments on the upper casts: this is a state-of-the-art, radiopaque, nano-hybrid composite for direct restorations in posterior teeth. Tetric EvoCeram® Bulk Fill cures with light in the wavelength range of 400–500 nm (blue light) and can be applied in layers of up to 4 mm.

A flowable resin, Tetric EvoFlow® (Ivoclar Vivadent AG, Liechtenstein) was used on the lower casts; Tetric EvoFlow® is a radiopaque nano-hybrid composite for restorative dentistry. Tetric EvoFlow® cures with light in the wavelength range of 400–500 nm (blue light).

CA Clear Aligner system considers the use of different thicknesses during the different stages of the treatment. In order to perform comparable analysis for this study and considering the thickness of Invisalign aligners and F22 aligners as reference, the CA Aligner thickness of 0.5 mm was chosen [5].

In table 1 information related to the aligners considered, i.e. manufacturer, material, thickness and edge length are reported. Spacer foils were not used in the experiment (Tab.1).

Each cast was sectioned buccolingually with a cutting machine (Well Diamond Wire Saw Inc, Norcross GA, USA), a stainless steel wire with diamonds embedded into the surface.

Samples were oriented so that sectioning was perpendicular to the long axis of the teeth.

Before SEM imaging, every section was covered with golden particles (99% Au) using a specific tool (Cressington High resolution Sputter Coater 208HR, Cressington Scientific Instruments, Watford UK).

Samples were then analyzed by a scanning electron microscope (SEM), JSM-6490LA (JEOL Inc., Peabody, MA, USA) a high-performance, scanning electron microscope with an embedded energy dispersive X-ray analyzer (EDS) and a resolution of 3.0 nm: it has previously been used in micro anatomy [23] and engineering [27].

The electrons from a focused beam interact with atoms of the sample, producing signals about the inspected surface composition. By using a special detector, the secondary electrons signal was used to produce an image about the topography of the surface.

Microphotographs thus obtained were then analyzed at the Department of Nanomaterials, Center for Synaptic Neuroscience, Italian Institute of Technology, Genoa (Italy) (Fig. 2).

A total of 60 points on attachments surfaces were considered for the measurements (Fig. 3).

Ten micrometric measurements (µm) were taken for each point using ImageJ® (NIH ImageJ Software, https://imagej.nih.gov/ij/), an open source image processing program designer for scientific multidimensional images [26].

Data was expressed as mean ± standard error of the mean (SE). The normality assumption of the data was evaluated with the Shapiro-Wilk test and homogeneity of the variables with the Levene and Brown-Forsythe tests. A repeated-measures ANOVA was performed. The Akaike information criterion (AIC) and the Bayesian information criterion (BIC) to estimate autocorrelation structure were used. Significant difference was set at $P<0.05$. Tukey post-hoc analysis was used to adjust for multiple comparisons. Multiple regression analysis was performed to analyze intra- and inter-groups differences for every considered point. No stratification by point of measurements was also considered. Statistical analysis was performed using the R statistical package (version 3.0.1, R Core Team, Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Analyzing the fitting of upper arch aligners (Tab. 2) on attachments, the analysis showed a significant better fitting of CA Clear Aligner with respect to F22 aligner at the occlusal border (MD [95% CI] = -96.08 [-106.84, -85.33] µm, P = 0.004) and at the gingival border (MD [95% CI] = -75.85 [-83.61, -69.09] µm, P = 0.006) of the attachments.

A significant better fitting of Invisalign aligners with respect to F22 aligners was detected at the occlusal border (MD [95% CI] = -78.07 [-90.98, -63.33] µm, P = 0.009), at the occlusal angle (MD [95% CI] = -47.11 [-58.80, -33.12] µm, P = 0.011), at the half distance (MD [95% CI] = -76.86 [-88.11, -65.70] µm, P = 0.012) and at the gingival border (MD [95% CI] = -107.96 [-120.56, -85.55] µm, P = 0.002) of the attachments.

Analyzing the overall fitting of upper arch aligners, Invisalign provided a significant better fitting with respect to F22 aligners (MD [95% CI] = -65.38 [-83.45, -49.87] µm, P = 0.009); no differences were detected between Invisalign and CA Clear Aligner, and between CA Clear Aligner and F22 Aligner.

Analyzing the fitting of lower arch aligners on attachments (Tab. 3), the analysis showed a significant better fitting of F22 Aligner than CA Clear Aligner at the gingival border (MD [95% CI] = -69.93 [-80.62, -59.23] µm, P = 0.012), at the gingival angle (MD [95% CI] = -37.14 [-47.86, -26.43] µm, P = 0.011), at the half distance (MD [95% CI] = -104.04 [-118.75, -91.32] µm, P = 0.002), at the occlusal angle (MD [95% CI] = -148.80 [-161.80, -132.36] µm, P = 0.001) and at the occlusal border of the attachments (MD [95% CI] = -141.66 [-157.66, -129.21] µm, P = 0.001).

A significant better fitting of F22 Aligner with respect to Invisalign was shown at the gingival angle (MD [95% CI] = -72.16 [-87.98, -60.09] µm, P = 0.013), at the half distance (MD [95% CI] = -120.97 [-137.01, -103.33] µm, P = 0.001) and at the occlusal angle (MD [95% CI] = 94.07 [80.09, 111.34] µm, P = 0.007) of the attachments.

A significant better fitting of Invisalign than CA Clear Aligner was shown at the occlusal angle (MD [95% CI] = -54.73 [-64.73, -43.29] µm, P = 0.009), and at the occlusal border (MD [95% CI] = -102.60 [-112.60, -89.15] µm, P = 0.003) of the attachments.

Analyzing the overall fitting of lower arch aligners, F22 Aligner provided a significant better fitting than CA Clear Aligner (MD [95% CI] = -100.02 [-121.39, -81.68] µm, P = 0.008) and Invisalign (MD [95% CI] = -77.22 [-90.55, -59.01] µm, P = 0.011).

No significant differences between Invisalign and CA Clear Aligner were found analyzing the fitting of lower arch aligners on attachments.

Aligners fitting was improved by using conventional composite resin. Analyzing the fitting of upper and lower aligners, the analysis showed a significant better fitting on upper attachments, built using bulk-fill resin (MD [95% CI] = -66.07 [-78.06, -48.78] µm, P = 0.034).

A significant better fitting was found at the gingival border (MD [95% CI] = -78.45 [-98.56, -50.01] µm, P = 0.012), at the half distance (MD [95% CI] = -65.62 [-91.65, -40.05] µm, P = 0.023), at the occlusal angle (MD [95% CI] = -72.21 [-96.89, -55.23] µm, P = 0.019) and at the occlusal border (MD [95% CI] = -122.88 [-148.50, -103.33] µm, P = 0.001) of upper attachments (Fig. 4).

DISCUSSION

Attachments are composite geometries bonded to teeth crowns during clear align therapy in order to achieve predictable tooth movements and improve clinical efficacy of CAT [29]. Attachments are powerful tool to manage anchorage units and to provide controlled orthodontic tooth movement (OTM) [20]. No evidences regarding aligners fitting on anchorage attachments are currently available. In our knowledge this is the first study in which aligners fitting on anchorage attachments was analyzed with SEM.

Results from the present study demonstrated that all the three analyzed aligners' systems are characterized by an excellent fitting on the investigated attachments. Furthermore conventional bulk-fill composites seem to provide the best fitting.

However, F22 aligners seem to have the best values in terms of fitting on attachments: the range of values goes from 1 to 178 µm. The fitting range of Invisalign goes from 5 to 212 µm. The measured range of values for CA Clear Aligner analysis goes from 7 to 298 µm. Dasy et al. [5] demonstrated that edgeless aligners generated significantly lower forces than those with a wider edge. The increased force might be due to the enhanced stiffness caused by material shape. As a consequence the enhanced stiffness may reduce the fitting of the aligner on the attachments.

This could be the reason why CA aligners showed the worst results in term of fitting. However despite the statistical significance, measured differences might not be clinically relevant.

In CAT, orthodontic tooth movement is the result of the mechanical perturbation induced by the interaction between the aligner, the tooth and the attachment. This is the reason why, in order to overcome clear aligners limitation, the development of effective attachments, for both anchorage management and better root control, is increasing year by year.

As stated by Higley [13], anchorage indicates the resistance necessary to prevent tooth movement when not desired while permitting movement where it is desired. Anchorage control refers to restriction of unwanted tooth movement from the early stage of treatment, in the three dimensions of space: sagittal, vertical, and lateral [19]. Virtual setup softwares help the clinician to design the treatment controlling every single tooth movement required to reach the desired final tooth position, from the initial treatment stage of leveling and alignment, without aggravating the underlying malocclusion.

However when discussing about CAT, aligner alone cannot provide a proper anchorage control, especially in those situations in which tooth morphology is not favorable (i.e. small clinical crowns, reduced undercuts). This is the reason why rectangular and vertical attachments were introduced in the very early stages of aligner orthodontics and they are still used today [18].

Attachments can avoid mesial movements of posterior teeth during the treatment, asking the technician to provide a tip-back information on them. When anchorage control is required on the vertical plane, attachments can act as surfaces on which extrusive or intrusive forces can be applied in order to avoid loss of anchorage.

When anchorage control is required on the frontal plane attachments are required to avoid unwanted and periodontally dangerous movements, i.e. undesired buccal tipping [4]. Results from this study showed that fitting of every investigated aligner on anchorage attachments is excellent despite differences in aligners' thermoplastic material composition. Therefore when discussing about anchorage management in aligner orthodontics differences in thermoplastic materials seem to be not significant at least for the thickness of the materials analyzed in the present study. We did not analyze the effect of different thicknesses for the same material. Therefore the thickness and in turn the aligner stiffness might influence aligner fitting.

Attachments creation is usually made with dental composite resins, conventional or flowable, and bonded with adhesives [8].

Flowable composites are produced by reducing the filler volume. The result is an increased resin content that reduces the viscosity of the mixture. These composites are used to facilitate the restoration of cervical defects, micro-cavities and are suitable as an initial layer in large Class I and Class II cavities, because of easier adaptation [2].

This SEM study demonstrated that the three investigated systems have comparable performances on fitting on anchorage attachments. Our results showed that the use of conventional bulk-fill resins allows a higher precision of the attachments. This could be caused by the different polymerization contraction ratios. Low-viscosity resins contain from 20% to 25% less filler: since the content of monomer is higher in flowable than conventional resins, the polymerization shrinkage of flowable composites is generally higher [25,24]. Treatment duration requires that wear properties and strength of the bond to the enamel are properly considered when selecting a suitable material [3]. A previous study has shown that the shape of an attachment affects the retention force of the aligner; therefore, it can be concluded that the wear of the attachments during treatment may produce a reduced anchorage control [5].

Although wear of composites is a multifactorial process, composite hardness can be measured as a predictor of abrasive wear. Hardness is defined as the resistance to deformation by surface indentation. The Vickers hardness of Tetric

EvoFlow is 320 MPa [30], while the hardness measured for the Tetric EvoCeram is 580 MPa [22]. Therefore it can be speculated that packable composites provides better fitting and durable preservation of attachments shapes thus contributing to a better anchorage control over time.

Since the spacer foil is used as shrink-compensating for the production of moulded pieces [7], analyzing the excellent results of this study we can assume that the non-use of spacer foil can influence the thickness of aligners but might not influence the fitting of aligners on attachments.

The main limitation of the study is represented by its in vitro design. Clinical studies are required to verify the hypotheses tested in this experimental set-up. Another shortcoming is the small sample size that could not account for manufacturing tolerances, producing a limited perspective that needs to be widened in future studies. Furthermore, several elements of aligners production are patented and then could not be considered to eventually explain the observed differences.

Future similar studies should be focused on biomechanics optimized attachments in order to select the most performing designs, on the basis of the best aligner/attachment/tooth interaction.

Mechanical properties of composite resins should be considered for the creation of further dedicated attachments.

CONCLUSIONS

- The fitting of clear aligners on anchorage attachments evaluated with scanning electron microscope demonstrated excellent results for all the investigated systems (Invisalign, CA Clear Aligner and F22).
- Conventional bulk-fill composite resins seem to represent the best material for anchorage attachments creation.

REFERENCES

1. Angle EH (1907) Treatment of Malocculsion of the Teeth. SS White dental manufacturing Company,
2. Benetti AR, Havndrup-Pedersen C, Honoré D, Pedersen MK, Pallesen U (2015) Bulk-fill resin composites: polymerization contraction, depth of cure, and gap formation. Operative dentistry 40:190-200
3. Clelland NL, Pagnotto MP, Kerby RE, Seghi RR (2005) Relative wear of flowable and highly filled composite. Journal of Prosthetic Dentistry 93:153-157
4. Comba B, Parrini S, Rossini G, Castroflorio T, Deregibus A (2017) A Three-Dimensional Finite Element Analysis of Upper-Canine Distalization with Clear Aligners, Composite Attachments, and Class II Elastics. Journal of clinical orthodontics: JCO 51:24
5. Dasy H, Dasy A, Asatrian G, Rózsa N, Lee H-F, Kwak JH (2015) Effects of variable attachment shapes and aligner material on aligner retention. The Angle orthodontist 85:934-940
6. Elkholy F, Mikhaiel B, Schmidt F, Lapatki B (2017) Mechanical load exerted by PET-G aligners during mesial and distal derotation of a mandibular canineMechanische Belastung durch PET-G-Aligner bei mesialer und distaler Derotation eines mandibulären Eckzahns. Journal of Orofacial Orthopedics/Fortschritte der Kieferorthopädie 78:361-370
7. Elkholy FSF, Jäger R, Lapatki B (2017) Forces and moments applied during derotation of a maxillary central incisor with thinner aligners: An in-vitro study. American Journal of Orthodontics and Dentofacial Orthopedics
8. Feinberg KB (2015) Translucency, stain resistance and hardness of composites used for invisalign attachments. The University of Alabama at Birmingham,
9. Fornaini C, Lagori G, Merigo E, Rocca J, Chiusano M, Cucinotta A (2015) 405 nm diode laser, halogen lamp and LED device comparison in dental composites cure: an “in vitro” experimental trial. Laser therapy 24:265-274
10. Garino F, Castroflorio T, Daher S, Ravera S, Rossini G, Cugliari G, Deregibus A (2016) Effectiveness of Composite Attachments in Controlling Upper-Molar Movement with Aligners. Journal of clinical orthodontics: JCO 50:341-347
11. Garino F, Garino GB, Castroflorio T (2014) The iTero intraoral scanner in Invisalign treatment: a two-year report. J Clin Orthod 48:98-106
12. Hahn W, Zapf A, Dathe H, Fialka-Fricke J, Fricke-Zech S, Gruber R, Kubein-Meesenburg D, Sadat-Khonsari R (2010) Torquing an upper central incisor with aligners—acting forces and biomechanical principles. The European Journal of Orthodontics 32:607-613
13. Higley L (1969) Anchorage in orthodontics. American journal of orthodontics 55:791-794
14. Kaza S (2006) Scanning process and stereolithography. The Invisalign® system Surrey, UK: Quintessence Publishing:47-54
15. Kuo E, Duong T (2006) Invisalign attachments: materials. The Invisalign System Philadelphia, Pa: Quintessence 92
16. Lobiondo PE (2013) Clear-Aligner®. Ripano,
17. Meister M, Masella RS (2005) Differential moments: An anchorage system. American Journal of Orthodontics and Dentofacial Orthopedics 128:273-276
18. Ravera S, Castroflorio T, Garino F, Daher S, Cugliari G, Deregibus A (2016) Maxillary molar distalization with aligners in adult patients: a multicenter retrospective study. Progress in orthodontics 17:12
19. Roberts-Harry D, Sandy J (2004) Orthodontics. Part 9: anchorage control and distal movement. British dental journal 196:255
20. Rossini G, Parrini S, Castroflorio T, Deregibus A, Debernardi CL (2014) Efficacy of clear aligners in controlling orthodontic tooth movement: a systematic review. The Angle Orthodontist 85:881-889

21. Rossini G, Parrini S, Castroflorio T, Deregibus A, Debernardi CL (2016) Diagnostic accuracy and measurement sensitivity of digital models for orthodontic purposes: A systematic review. American journal of orthodontics and dentofacial orthopedics 149:161-170
22. Santini A, Naaman R, Aldossary M (2017) Light energy transmission and Vickers hardness ratio of bulk-fill resin based composites at different thicknesses cured by a dual-wave or a single-wave light curing unit. American journal of dentistry 30:65-70
23. Sathy BN, Mony U, Menon D, Baskaran V, Mikos AG, Nair S (2015) Bone tissue engineering with multilayered scaffolds—Part I: an approach for vascularizing engineered constructs in vivo. Tissue Engineering Part A 21:2480-2494
24. Satterthwaite JD, Maisuria A, Vogel K, Watts DC (2012) Effect of resin-composite filler particle size and shape on shrinkage-stress. Dental Materials 28:609-614
25. Satterthwaite JD, Vogel K, Watts DC (2009) Effect of resin-composite filler particle size and shape on shrinkage–strain. dental materials 25:1612-1615
26. Schneider CA, Rasband WS, Eliceiri KW (2012) NIH Image to ImageJ: 25 years of image analysis. Nature methods 9:671
27. Shafiq M, Yasin T, Saeed S (2012) Synthesis and characterization of linear low- density polyethylene/sepiolite nanocomposites. Journal of Applied Polymer Science 123:1718-1723
28. Simon M, Keilig L, Schwarze J, Jung BA, Bourauel C (2014) Forces and moments generated by removable thermoplastic aligners: incisor torque, premolar derotation, and molar distalization. American Journal of Orthodontics and Dentofacial Orthopedics 145:728-736
29. Simon M, Keilig L, Schwarze J, Jung BA, Bourauel C (2014) Treatment outcome and efficacy of an aligner technique–regarding incisor torque, premolar derotation and molar distalization. BMC Oral Health 14:68
30. Yu H, Wegehaupt FJ, Wiegand A, Roos M, Attin T, Buchalla W (2009) Erosion and abrasion of tooth-colored restorative materials and human enamel. Journal of Dentistry 37:913-922

FIGURE CAPTIONS

Fig. 1 Rectangular attachments on the surface of the resin cast

Fig. 2 SEM image: interaction between Invisalign aligner and rectangular attachment on upper first premolar (cross section, 22X magnification)

Fig. 3 Schematic presentation of five points considered for the measurements on attachments surface: 1.Gingival border, 2. Gingival angle, 3. Half distance of buccal surface, 4. Occlusal angle, 5. Occlusal border

Fig. 4 Box-plots showing the differences between upper measurements, made on attachments built using flowable resin, and lower measurements, made on attachments built using conventional bulk-fill resin. Linear regression analysis stratified by attachment point.

Table 1 Characteristics of the aligners

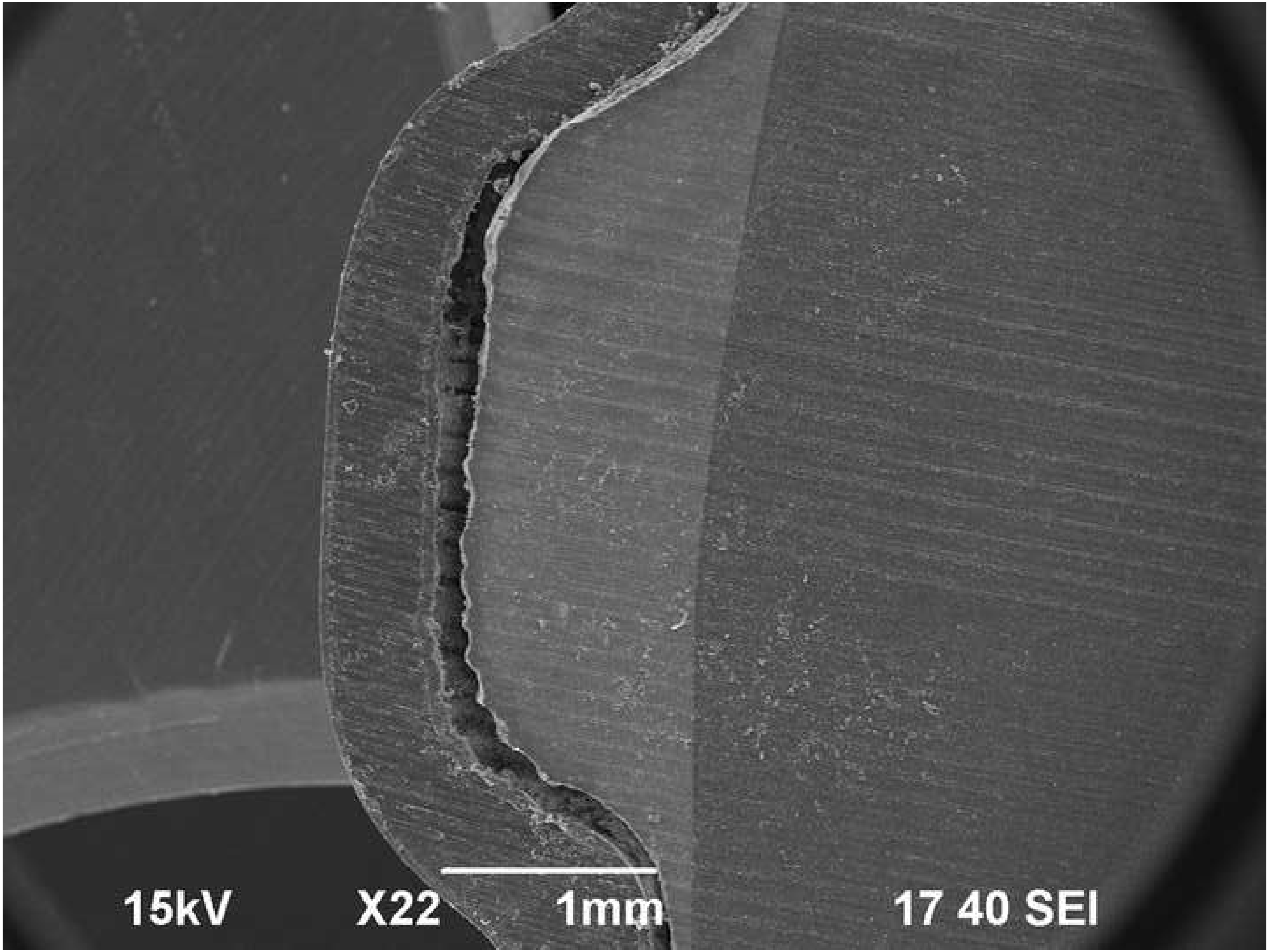
Table 2 Fitting of upper arch aligners on attachments

Table 3 Fitting of lower arch aligners on attachments

Table

Aligner	Manufacturer	Material
Invisalign	Align Technology	SmartTrack: multi-layer aromatic thermoplastic polyurethane
CA Clear Aligner	Scheu Dental	Clear Aligner soft: glycolmodified polyethylene terephthalate
F22 Aligner	Sweden&Martina	F22 Aligner polyurethane

Thickness (mm)	Edge length	Spacer foil
0.76	0 mm	none
0.5	2-3 mm	yes (Isofolan)
0.76	1 mm	none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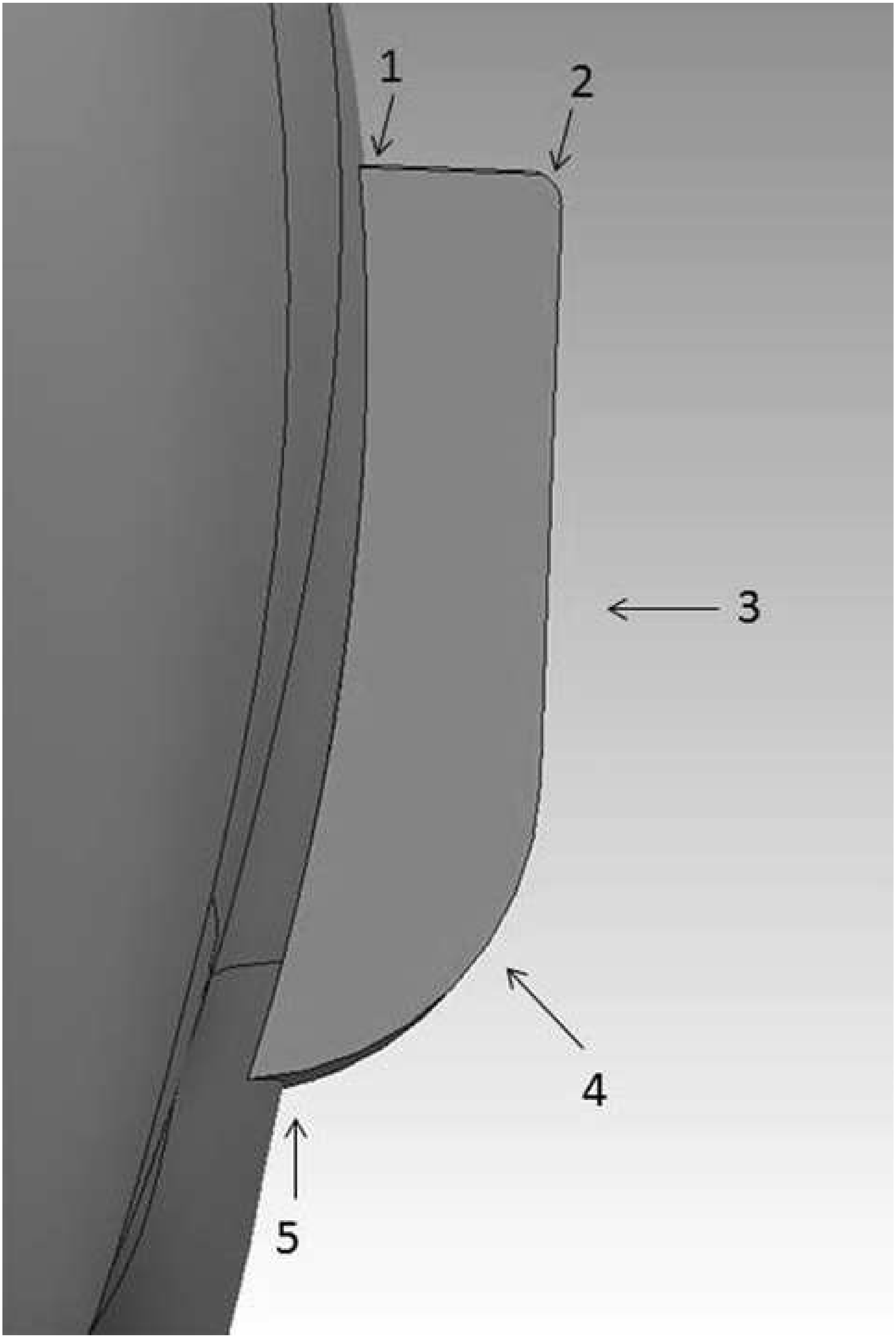
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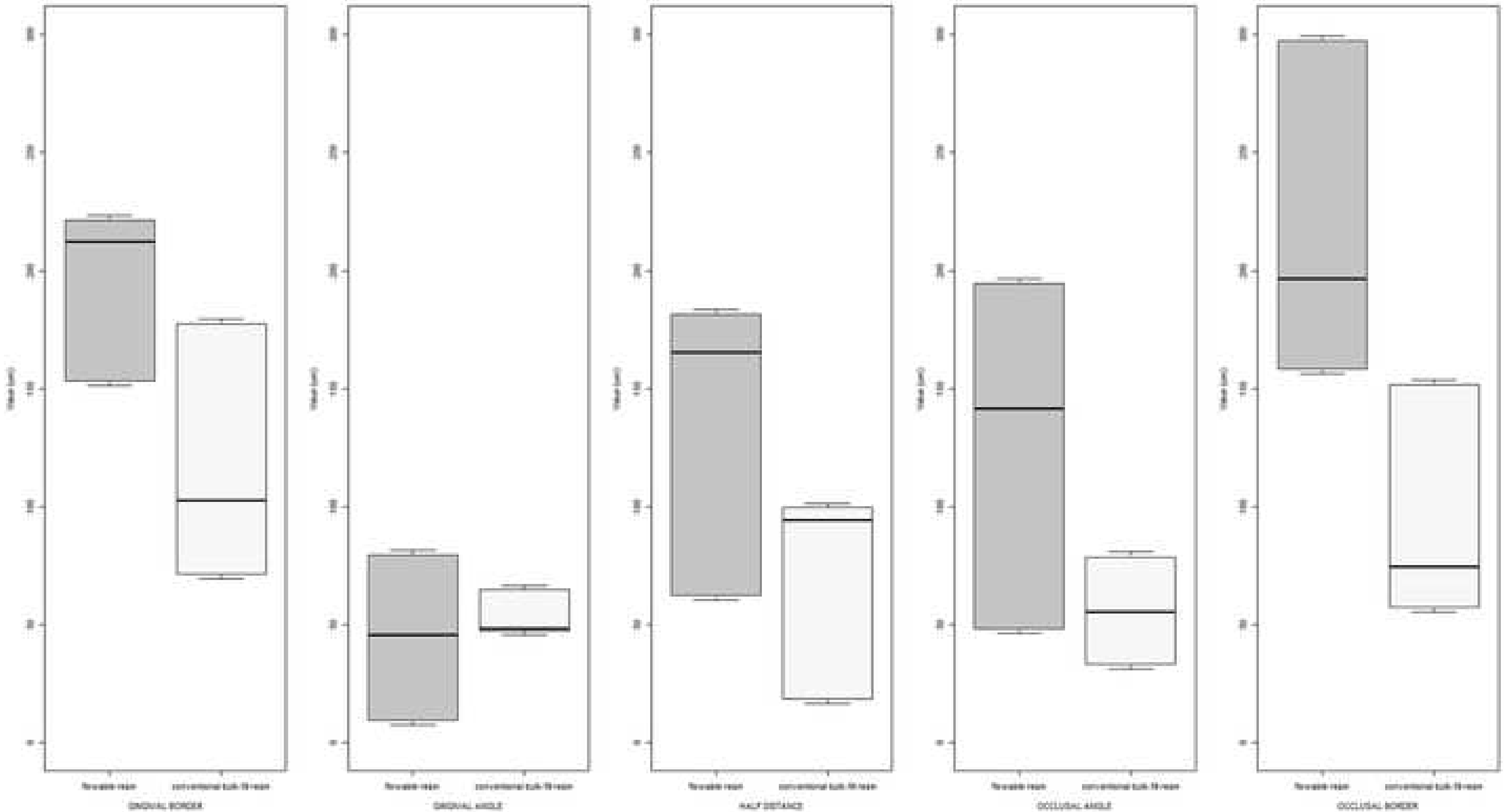

Differences between GROUP. Linear regression analysis stratified by ATTACHMENT point in UPPER mea

UPPER ATTACHMENTS	GROUP	MD (µm)	Std. Error (µm)
	Clear Aligner vs F22	-75.85	8.46
GINGIVAL BORDER	Clear Aligner vs Invisalign	-32.11	8.46
	Invisalign vs F22	-107.96	8.46
	Clear Aligner vs F22	-18.70	8.89
GINGIVAL ANGLE	Clear Aligner vs Invisalign	1.78	8.89
	Invisalign vs F22	-16.92	8.89
	Clear Aligner vs F22	6.07	8.17
HALF DISTANCE	Clear Aligner vs Invisalign	-82.93	8.17
	Invisalign vs F22	-76.86	8.17
	Clear Aligner vs F22	-24.03	8.35
OCCLUSAL ANGLE	Clear Aligner vs Invisalign	-23.08	8.35
	Invisalign vs F22	-47.11	8.35
	Clear Aligner vs F22	-96.08	8.03
OCCLUSAL BORDER	Clear Aligner vs Invisalign	18.02	8.03
	Invisalign vs F22	-78.07	8.03

MD: mean differences. Bonferroni post-hoc correction was used to control for multiple comparisons asures.

95%CI (µm)	Adjusted p-value
-83.61 | -69.09	**0.006**
-43.87 | -26.36	**0.013**
-120.56 | -85.55	**0.002**
-27.87 | 0.05	0.098
-6.08 | 10.48	0.768
-26.87 | 2.56	0.145
-5.32 | 16.81	0.345
-96.67 | -70.19	**0.008**
-88.11 | -65.70	**0.012**
-34.76 | -15.29	0.019
-13.82 | -32.35	0.023
-58.80 | -33.12	**0.011**
-106.84 | -85.33	**0.004**
7.26 | 28.77	0.087
-90.98 | -63.33	**0.009**

Differences between GROUP. Linear regression analysis stratified by ATTACHMENT point in LOWER me

LOWER ATTACHMENTS	GROUP	MD (µm)	Std. Error (µm)
GINGIVAL BORDER	F22 vs Clear Aligner	-69.93	9.36
	Invisalign vs Clear Aligner	-10.09	9.36
	F22 vs Invisalign	-59.84	9.36
GINGIVAL ANGLE	F22 vs Clear Aligner	-37.14	8.75
	Invisalign vs Clear Aligner	35.01	8.75
	F22 vs Invisalign	-72.16	8.75
HALF DISTANCE	F22 vs Clear Aligner	-104.04	8.01
	Invisalign vs Clear Aligner	16.93	8.01
	F22 vs Invisalign	-120.97	8.01
OCCLUSAL ANGLE	F22 vs Clear Aligner	-148.80	9.15
	Invisalign vs Clear Aligner	-54.73	9.15
	F22 vs Invisalign	-94.07	9.15
OCCLUSAL BORDER	F22 vs Clear Aligner	-141.66	8.87
	Invisalign vs Clear Aligner	-102.60	8.87
	F22 vs Invisalign	-39.06	8.87

MD: mean differences. Bonferroni post-hoc correction was used to control for multiple comparisons easures.

95%CI (µm)	Adjusted p-value
-80.62 | -59.23	**0.012**
-1.28 | 4.40	0.298
-71.90 | -48.11	0.024
-47.86 | -26.43	**0.011**
22.30 | 48.73	0.016
-87.98 | -60.09	**0.013**
-118.75 |-91.32	**0.002**
6.22 | 27.65	0.098
-137.01 | -103.33	**0.001**
-161.80 | -132.36	**0.001**
-64.73 | -43.29	**0.009**
-111.34 | -80.09	**0.007**
-157.66 | -129.21	**0.001**
-112.60 | -89.15	**0.003**
-50.09 | -29.98	0.021