Optically transparent aligners with cellulose coating and naturally derived plasticizers for orthodontic treatments

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ABSTRACT

The effectiveness of optically transparent aligners for orthodontic treatments depends on the locally generated forces and the anchoring of each tooth. Contrary to roots, the crowns' positions and orientations are optically detectable with intraoral scanners. We demonstrate that the aligner-induced therapy progress can be quantified on the basis of three intraoral scans, performed before therapy start, at about half the treatment time, and at the end of the therapy. We report a case study of four comparable patients comparing aligners from 0.75 mm-thick polyethylene terephthalate glycol-modified (PET-G) films with 25 µm-thin cellulose-coated 0.5 and 0.7 mm-thick PET-G films. The aligners applied result in crown movements of up to 1 mm during the therapy. Even better detectable are the intrusion and extrusion of the crowns, respectively. The data of the three translational and three rotational degrees of freedom of each crown together with the planning data are listed and form a basis for future quantitative studies on aligner-induced therapies.

Keywords: Clear aligner therapy, intraoral scanning, polyethylene terephthalate glycol-modified (PET-G) films, avoidance of non absorbable microplastics, three-dimensional registration, case study with four patients, quantification of aligner-induced crown movements, gauging extrusion and intrusion of individual crowns

1. INTRODUCTION

Polymeric films have been successfully employed for orthodontic treatments for more than two decades.[1,2] The polyethylene terephthalate glycol-modified (PET-G) aligners are especially popular because of their optical transparency, their mechanical properties and their processibility by thermoforming. PET-G is generally accepted to be chemically stable and biocompatible within the oral cavity. Changes triggered during laser cutting and mechanical treatments could alter the properties with influences on cellular responses, but no clear evidence has been identified.[3] The PET-G aligners, however, give rise to microplastics and additives that are detected within the patient's blood.[4,5] These particles are a result of biting and grinding. They reach the blood through the gastrointestinal tract without digestion. So far, we hardly know what harmful side effects these microparticles may cause in our body. It is, therefore, reasonable to search for suitable aligner materials, which prevent the occurrence of microplastics within the patient's body.

One alternative is the cellulose coating of PET-G films and the use of naturally derived plasticizers, which reduce or even fully avoid the unwanted phenomenon of not absorbable microparticles.[6] The orthodontic therapy using such sandwich structures provides a reasonable fit to the crowns[7] and is currently offered by the company

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Bussmann Orthodontie-Labor AG, Lucerne, Switzerland. A direct quantitative comparison of the cellulose-coated with the bare films for patient treatment is missing.

The digital workflow based on intraoral scanners has substantially facilitated aligner fabrication.[8] The performance of aligner therapy is continuously improving but only recently quantified.[6,9]

The tooth movement in orthodontics was described on the microscopic level.[10] One can also use oral scans to assess the movements of the crowns because intraoral scanners are accessible to many clinics and avoid the X ray use. A recent study,[6] proposed a procedure for the quantification of the position changes in the individual crowns in the upper and lower jaws induced by aligner therapy. This procedure is also a basis for the present study with four patients by means of intraoral scans at three time points, i.e. therapy start, therapy middle point, and therapy end point. The case study should encourage systematic clinical trials to quantify the performance of aligner therapy in the view of materials selection.

2. MATERIALS AND METHODS

2.1 Fabrication of aligners

The aligner pairs were fabricated by the company Bottmedical AG in Basel, Switzerland, according to their standard procedure. Planar PET-G films with nominal thicknesses of 750 , 700 , and 500 µm served as basis. The two thinner films were coated by means of 25 µm cellulose on both sides. Therefore, the related aligners were denoted as PET-G.750, NA.750, and NA.550. Based on the intraoral scans, see below, and the related planning, 3D-printed models were produced. The films heated to a temperature of 190 °C were pressed with a pressure of 4.8 bar against these models for thermoforming using the device Biostar® (SCHEU-DENTAL GmbH, Iserlohn, Germany). The obtained average aligner thicknesses were 60 % of the planar ones.[7] After the separation of the aligners from the models, they were trimmed for a proper gingival interface and packed for shipping according to the standards.

2.2 Case study with four patients

The experienced cranio-maxillofacial surgeon J.v.J. used the intraoral scanner Medit i700 (Medit Corp., Seongbuk-gu, Republic of Korea) to record the clinical situation of the oral cavity from the four patients before the therapy start, in the middle, and at the end of the treatment. These time points are denoted as StartScan, MidScan, and EndScan and the corresponding therapy plans as StartPlan, MidPlan, and EndPlan. The patients signed the informed consent forms before therapy start.

The four patients are comparable with respect to age, number of teeth, and planned treatment duration, see Table 1. The actual orthodontic treatment, however, was longer than originally planned, see Table 1, and based on a biweekly to monthly supply of aligner pairs according to the therapy plan.

Table 1: The four patients are comparable with respect to age, number of teeth, and planned treatment duration. The actual orthodontic treatment, however, was often longer than originally planned. The table also contains the information of the polymeric aligner films employed.

Patient	Sex	Age [Years]	#Teeth in upper/lower jaw		Film	#Aligners in upper/lower jaw		Plan [Weeks]	Duration [Weeks]
1	male	30.3	14	14	PET-G.750	10	7	22	36
2	female	31.1	14	14	NA.550	8	7	17	35
3	male	31.6	15	16	NA.750	5	6	22	33
4	male	36.3	14	14	NA.750	4	9	22	23

The patients were advised to wear the aligners for a duration of at least 22 hours per day. For eating and teeth brushing, the aligners should be carefully removed. The patients were instructed to gently clean the aligners with a tooth brush twice per day.

Figure 1 shows the intraoral scan data at the therapy end for Patients 1 and 2. Anatomical landmarks on the second molars and labels between central incisors were manually selected, see black dots, to establish a global coordinate system,[11] defining the global left (black arrows) and extrusion directions (magenta arrows).

The global anterior direction is orthogonal to these axes. Each crown also has its coordinate system. Extrusion (magenta) aligns with the global system, mesial (orange) points to the neighboring crown, and buccal (blue) is orthogonal to the other two.

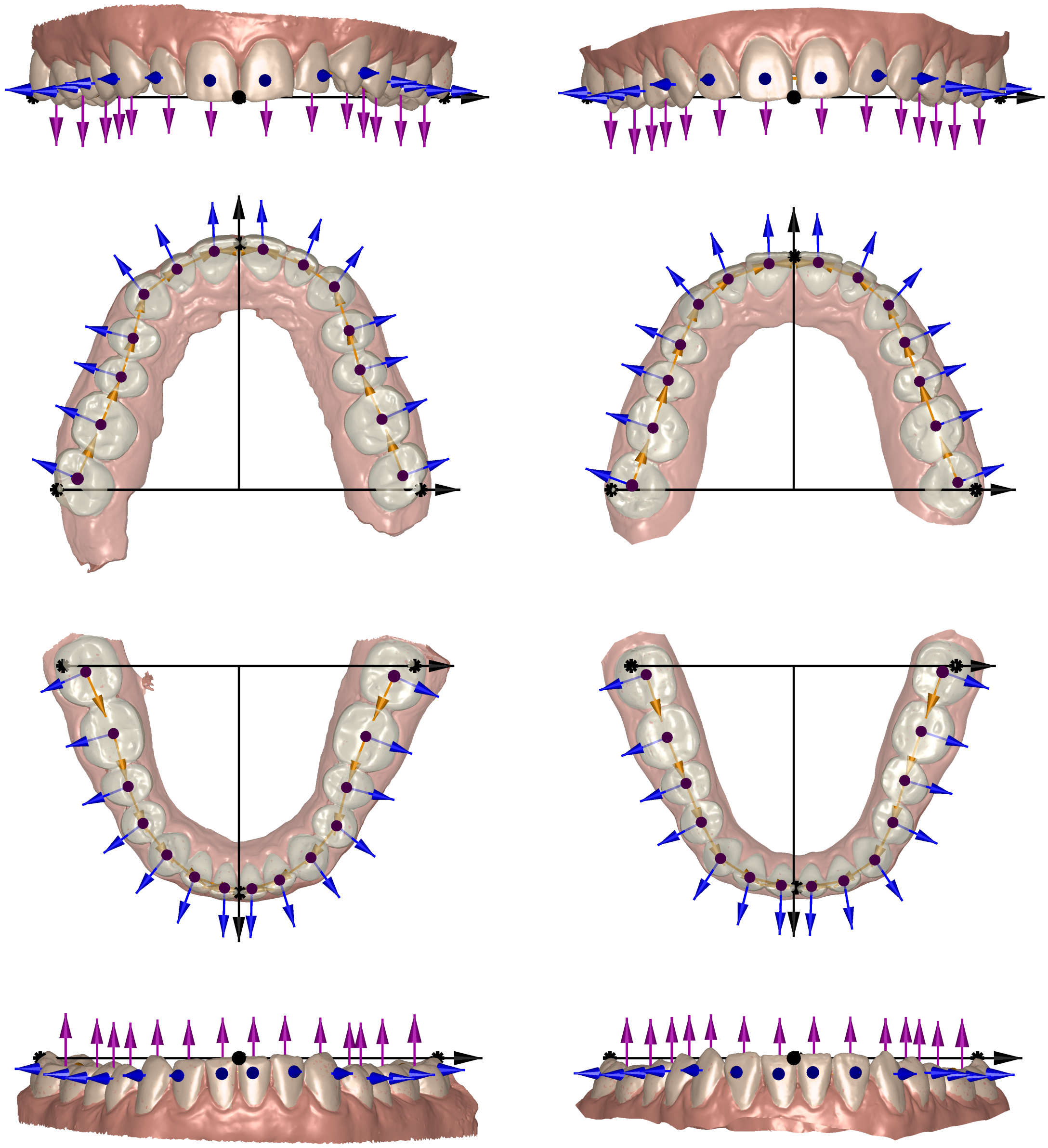


Figure 1: The global and local coordinate systems were defined using the scans of the therapy end points, exemplarily represented for Patient 1 on the left side and Patient 2 on the right part of the figure. The black dots are manually selected landmarks to define the global coordinate system indicated by the black arrows. The coordinate systems of the individual crowns in mesial, extrusion and buccal directions are displayed by the orange-, magenta- and blue-colored arrows, respectively.

2.3 Data evaluation

The individual crowns were semiautomatically segmented from the intraoral EndScans by the experienced dentist I.F. using the tool OnyxCeph3™ (Image Instruments GmbH, Chemnitz, Germany) in less than 25 minutes per jaw. Then, the jaw surfaces were trimmed using the software FreeCAD (version 0.19) to align with the mucogingival junction. Segmented crowns were fused into a single surface mesh and rigidly registered to the trimmed jaw surfaces using MATLAB's `pcregistericp` function. Thereafter, non-rigid registration, based on MATLAB's `nricp` function,[12] was employed to define the orthodontic crown motion. The crown segmentations from the EndScan were propagated to the StartScan and to the MidScan data based on the closest points after the non-rigid registration. The crowns' translation and rotation were calculated by fitting a rigid transformation to the non-rigid motion field, setting the center of rotation at the crown's center of mass. This fitting used the Kabsch algorithm[13] to minimize root-mean-square distance, utilizing the MATLAB software from fileexchange `25746-kabsch-algorithm`. Comparisons between the actual crown positions and rotations to the therapy plans were similarly determined by rigid and non-rigid registrations.

3. RESULTS

3.1 Qualitative evaluation of the aligner-based orthodontic therapy

Figure 2 displays the renderings obtained from intraoral scans before the therapy start for the four selected patients of this study, see first column. The teeth of the upper and lower jaws have to be re-positioned to close larger gaps and to line-up overlapping front teeth. The four patients obtained a treatment plan using sets of optically transparent aligners. The second column shows the therapy success at about half time. One can clearly recognize the progress especially for the front teeth. The envisioned success, however, was not reached yet. Therefore, the treatment had been continued for about another 20 weeks with the results shown by the renderings of the intraoral scans represented in the third column of Figure 2.

The three intraoral scans per patient support the qualitative evaluation of the aligner-based therapy. Therapy progress can be visually inspected by compring the scans or, even better, by watching Video 1. For example, the gaps between the crowns of the upper jaw of Patient 2 became closed indicating the desired therapy success. For Patients 3 and 4, the alignment of the incisors is obviously improved and the tooth misalignment corrected.

3.2 Qualitative evaluation of the aligner-based orthodontic therapy

The re-positioning of the crowns is quantitatively displayed by means of the color-coded surface renderings in Figure 3. The images in each column depict the data from one of the four patients. The related aligner films used are given in the text above each column. The images in the upper part represent the crown movement during the initial treatment steps. The images in the lower part of Figure 3 characterize the achieved therapy success in a quantitative manner. Crowns given in dark blue were not re-positioned. The turquoise color makes visible displacements by about 0.5 mm. The largest displacements observed have a magnitude of about 1 mm and are represented in yellow.

In a similar fashion, one can color-label extrusion and intrusion, see Figure 4. Whereas the mint color shows the extrusion, the reddish color is related to intrusion, see the color bar in Figure 4. Comparing the related images of the crowns in Figures 3 and 4, their repositioning pattern is clearer from the extrusion/intrusion representation.

3.3 Comparison between aligner shape and achieved repositioning

In order to generate force and torque on the crowns to be re-positioned, a difference between aligner shape and the situation in the oral cavity must be present. Figure 5 shows the magnitude differences for each crown, ranging from dark blue for no difference to red for a difference of 1 mm. The extrusion/intrusion differences are uncovered by the images in Figure 6, using the same color-code as in Figure 4.

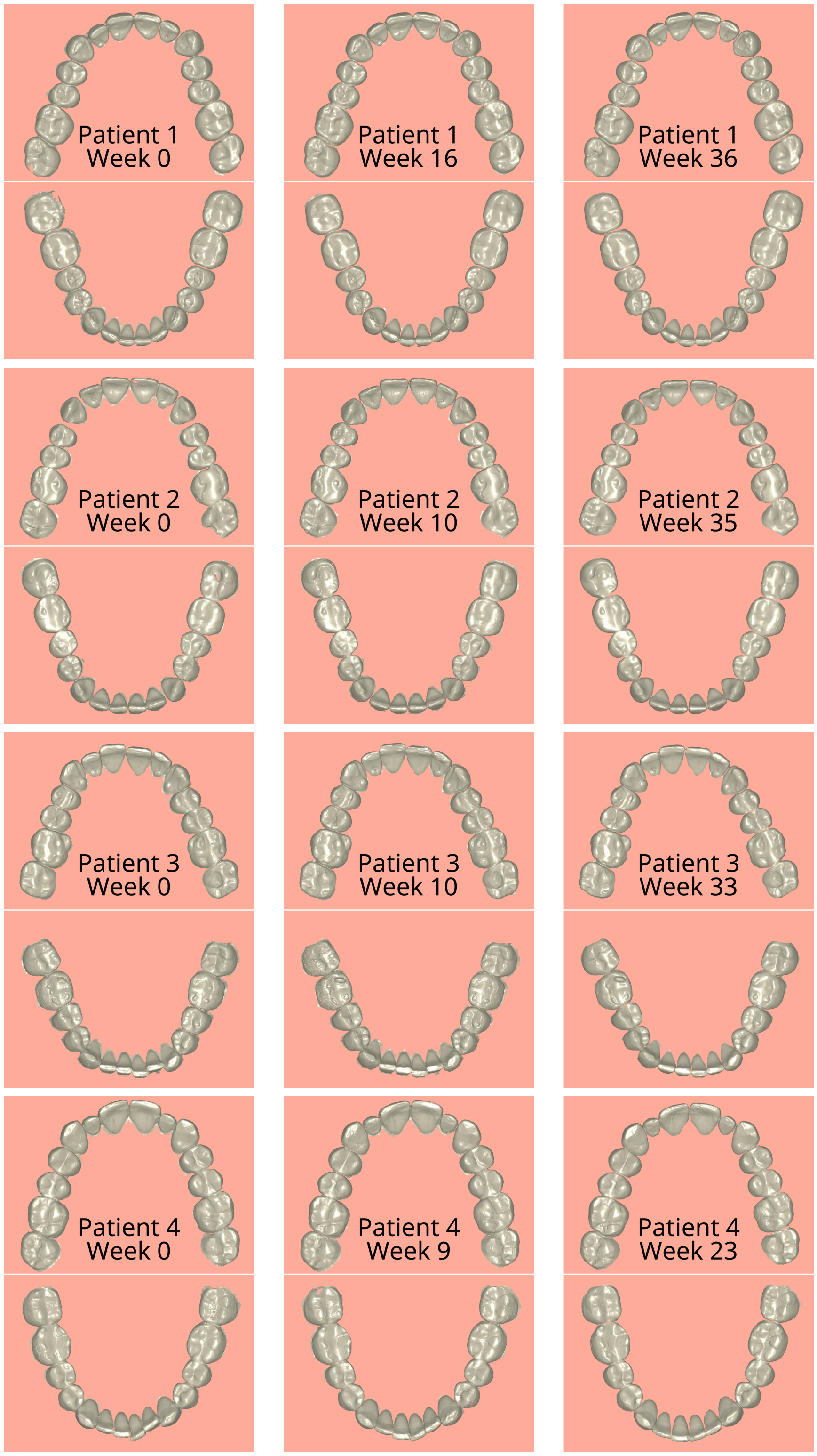
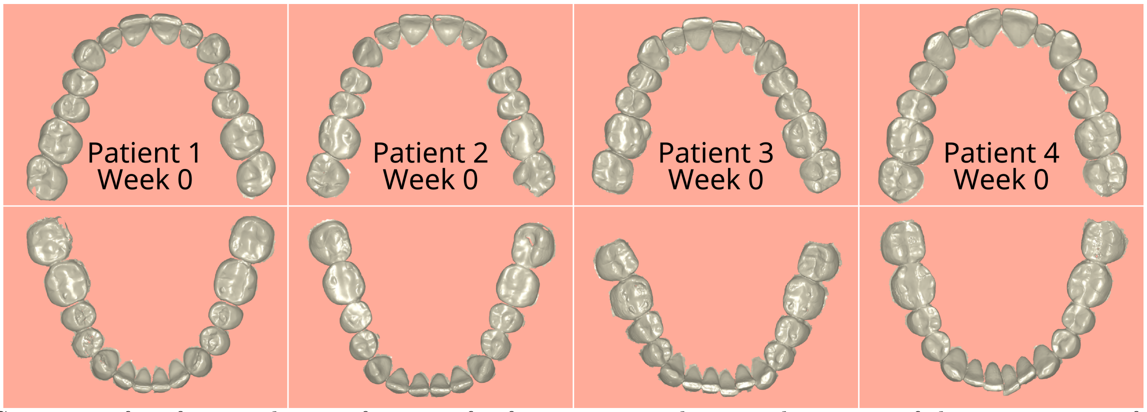


Figure 2: The surface rendering of crowns shows the therapy progress. Each column corresponds to a time point, i.e. the left column - therapy start, central column - therapy middle point, and right column - therapy end point. The rows relate to the four patients of this case study. Video 1 gives an even better impression on the therapy progress.



Video 1. Sequence of surface rendering of crowns for four patients, showing the course of therapy progress from the start via the middle to the end: http://dx.doi.org/10.1117/12.3089195.1.

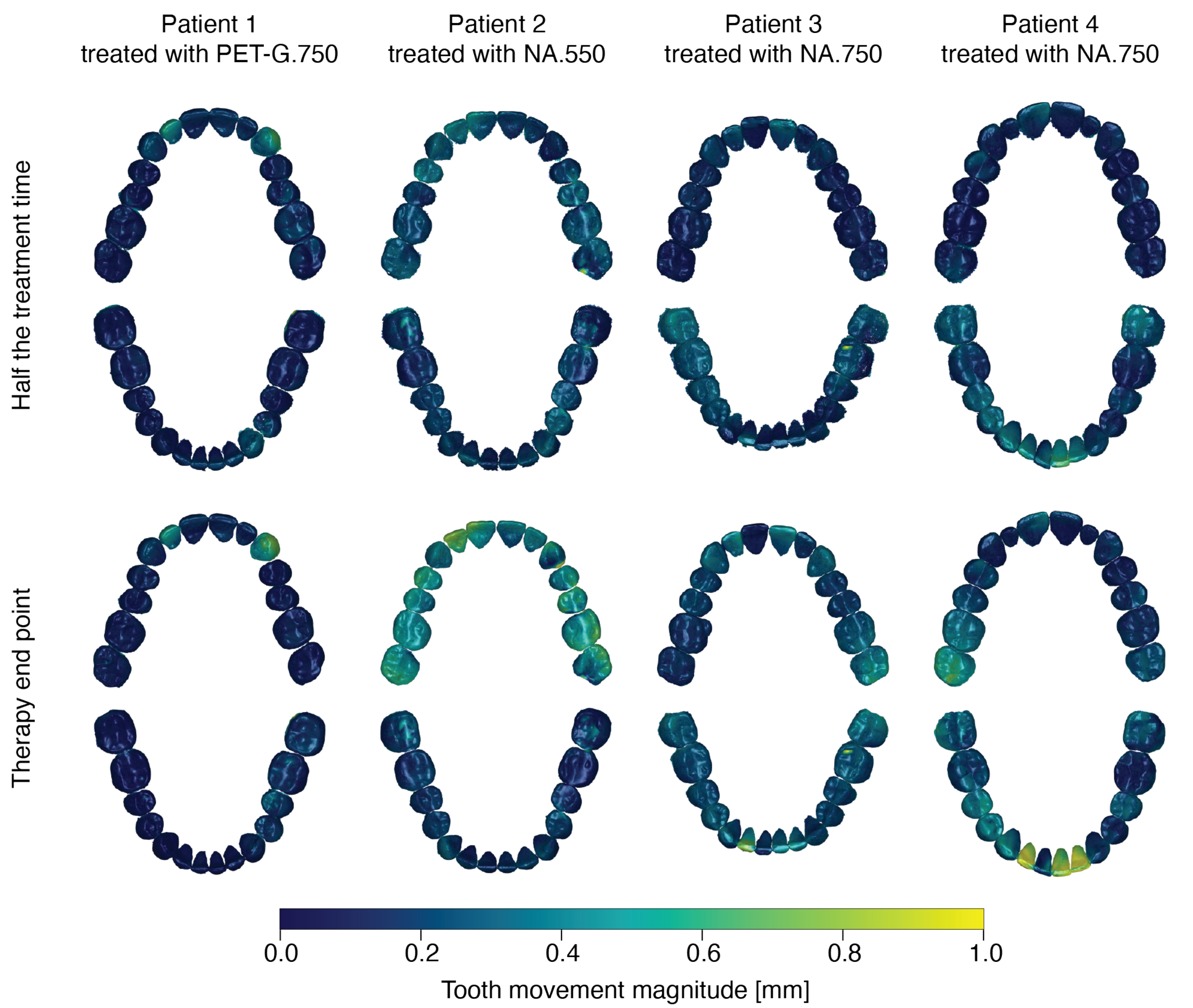


Figure 3: The color-coded surface rendering of crowns depicts the magnitude of aligner-induced crown movements. Each column corresponds to one of the four patients. The used aligner films are indicated. In the upper part, the crown movement during the first treatment steps are represented, whereas in the lower part of the figure, the achieved therapy success is quantitatively visualized.

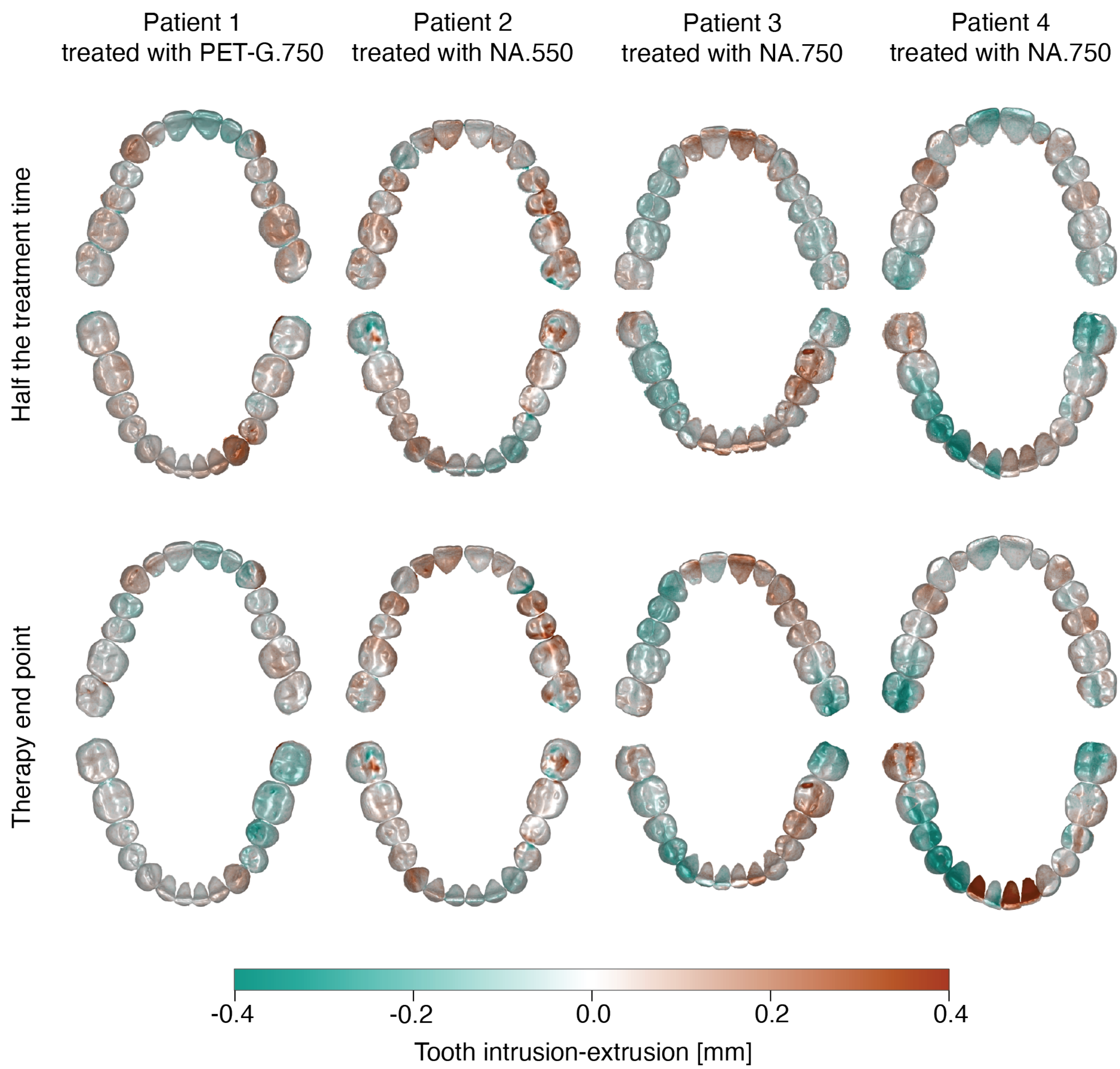


Figure 4: The surface rendering of crowns is color-labeled from mint to a reddish with the aim to quantitatively display the extrusion and intrusion directions of the individual crowns. Each column corresponds to one of the four patients with the employed aligner films. In the upper part, the changes during the first treatment steps are represented, whereas in the lower part of the figure, the achieved therapy success is quantitatively visualized.

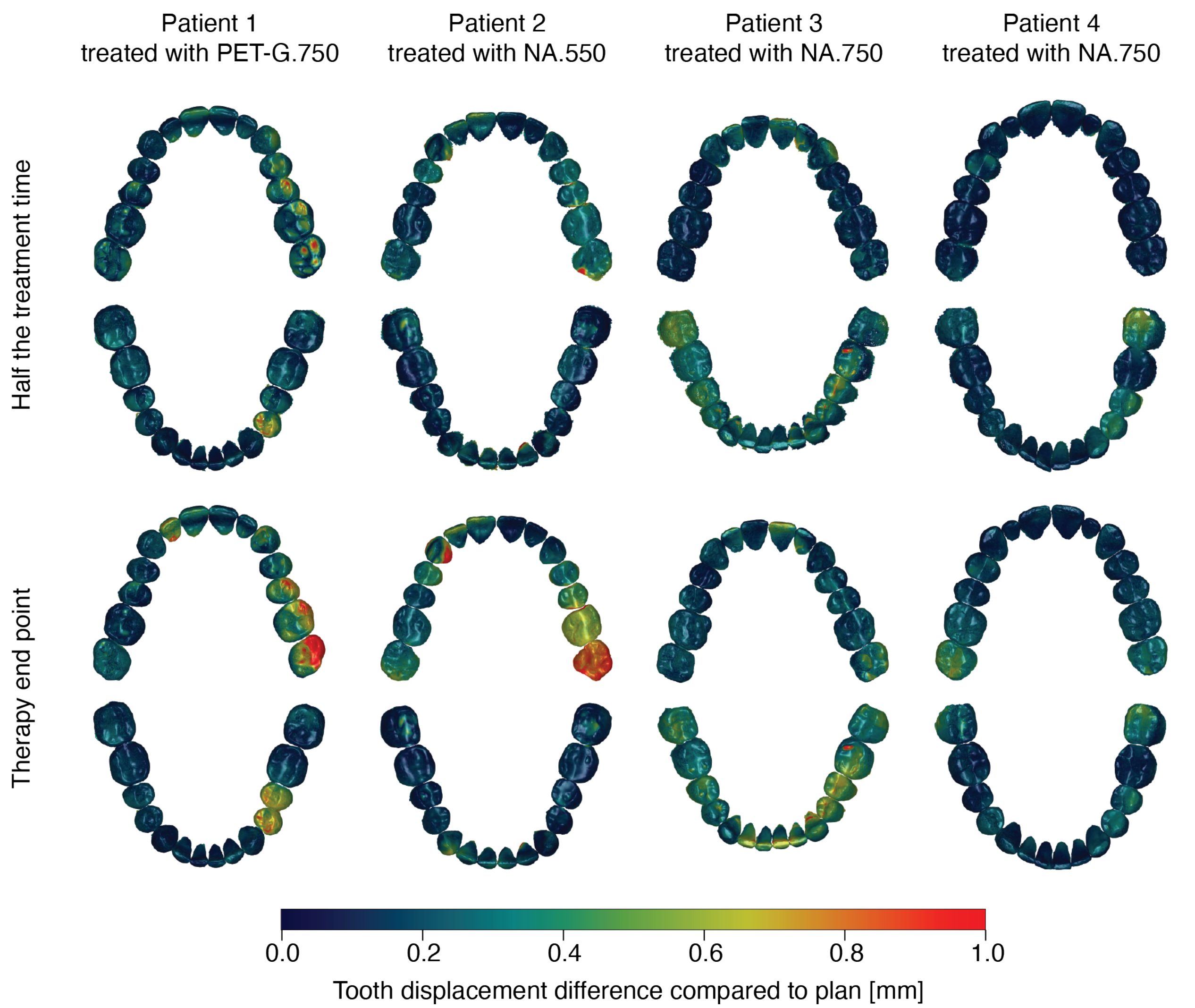


Figure 5: The color-coded surface rendering of crowns depicts the displacement differences between the crowns and the plan, i.e. the shape of the aligner applied during the related treatment step. Each column corresponds to one of the four patients treated with the aligner films indicated. In the upper part, the differences during the first treatment steps are represented, whereas in the lower part of the figure, the differences at the end of the therapy are quantitatively visualized.

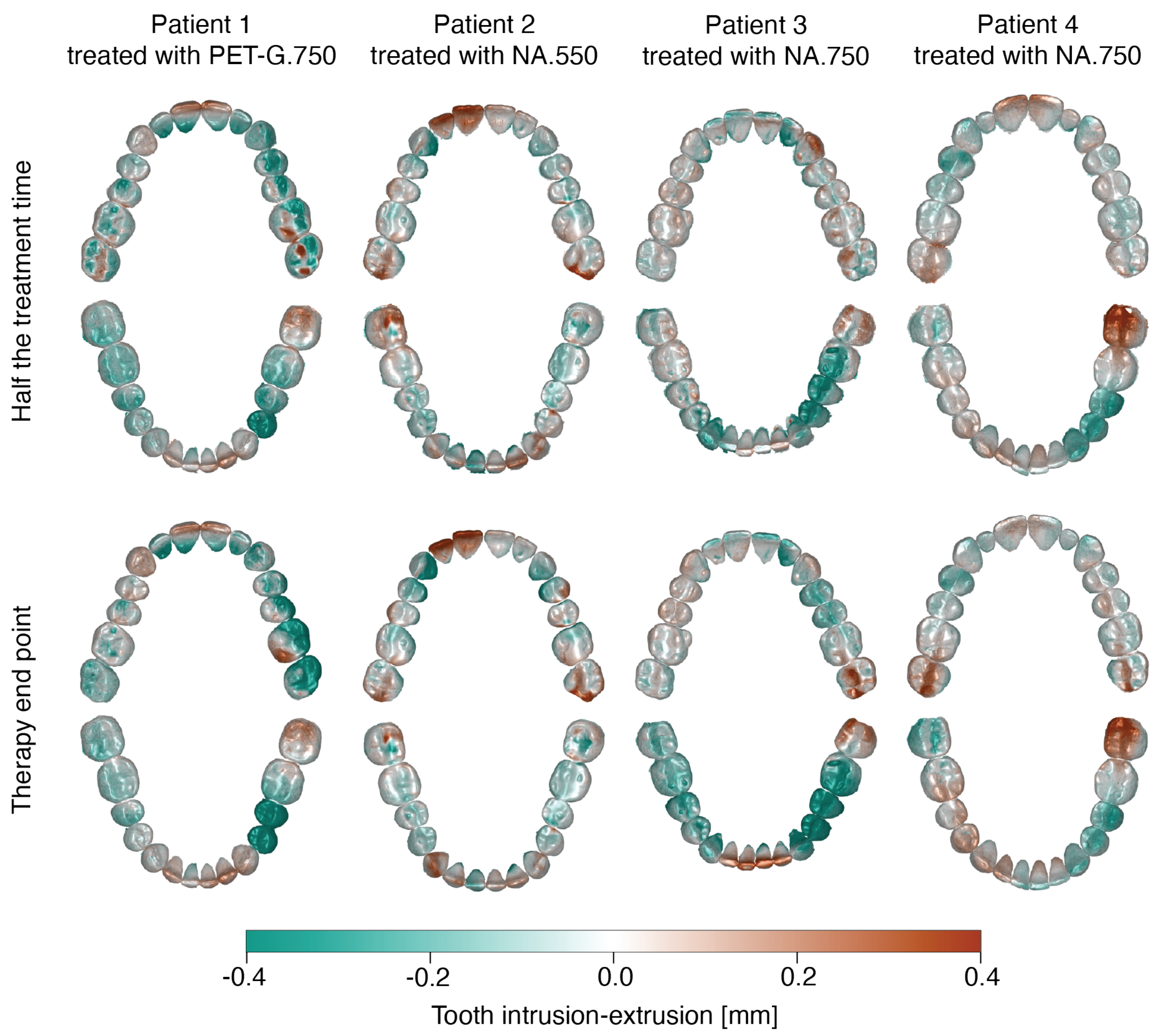


Figure 6: The surface rendering of crowns is color-labeled from mint to a reddish to quantitatively display the extrusion and intrusion differences to the plan, i.e. the differences between the individual crowns and the shape of the aligner applied during the related treatment step. Each column corresponds to one of the four patients. In the upper part, the differences during the first treatment steps are represented, whereas in the lower part of the figure, the differences at the end of the therapy are quantitatively visualized.

3.4 Detailed quantification of the rotation and translation of the individual crowns due to aligner therapy

Each crown can be considered as a solid state, because it hardly changes its shape within the therapy period. The dislocation of a solid state in the three-dimensional space is described by three translational and three rotational degrees of freedom. These six degrees of freedom are tabulated in Tables 2 to 5 to make the data available for more detailed interpretation and possible integration into statistically relevant studies on aligner therapies.

4. DISCUSSION

4.1 Limitations of aligner-based orthodontic therapies

In orthodontics, optically transparent aligners have been employed for more than two decades. Their success is limited, as indicated in literature reviews.[14–16] In general, longer clinical phases than planned are required for successful treatments.[17] Original work also shows the limitation of polymeric aligner-based therapy.[18] Therefore, many orthodontists and patients have doubts about the success of aligner therapies. The forces of aligners from PET-G and polyurethane are low compared to conventional braces. Nevertheless, the forces can be adapted by the aligner thickness.[19] For the effective bodily tooth movement, the rather thick and single-layered rigid polymers are selected.[19] Multi-layered aligners generally exert lower forces compared to their single-layered counterparts.[19] Therefore, one expects less successful treatments using the cellulose-based films. Even less successful are fully biodegradable aligners films, because they usually absorb more than 1% water resulting in swelling and softening.[20] In general, the forces applied to the crowns are below 1 N. For the tooth translation and the application of torque, forces between 0.5 to 1.0 N are foreseen. For tipping and rotation, the forces correspond to values between 0.3 and 0.6 N. For intrusion, the necessary forces can be as low as 0.1 N.[21–23] This behavior, one can recognize by comparing the color-coded images in Figures 2 and 3, where we detect intrusion/extrusion for many crowns, but often aligner-induced crown movements below 0.1 mm.

4.2 Challenges in recruiting patients for clinical studies on aligner-based orthodontic therapy

At a first glance, it seems to be rather simple to identify and convince potential patients to participate at a clinical trial to compare the performance of aligners. There are, however, many drawbacks. First, the exclusion criteria are a strong restriction. The patients should have reached an age of 18 years. Pregnant individuals are excluded due to the known influence of hormones on gingival inflammation, salivary composition, and oral flora, which can affect the assessment of aligner material performance. While aligner materials are designed to be biocompatible and stable under typical intraoral conditions, the impact of pregnancy-associated physiological changes on their behavior compromises the validity of such a clinical trial. It is also challenging to hide the information on the used aligner material to both patient and treating orthodontist for unbiased study design. As a consequence, the literature contains many case studies.

4.3 Frequency of intraoral scans to quantify the therapy success

First, we like to emphasize that the intraoral scans only capture the crowns of the upper and lower jaws. The related roots and the bone coverage, however, are important for the therapy plan and its validation,[24] but require X-ray doses, which should be avoided, although a recent study has shown the benefits of using cone-beam computed tomography in comparing clear aligners to conventional brace treatments.[25] The restriction to the crown imaging is a clear limitation of this study. In principle, intraoral scans can be acquired every week in order to get a clear basis for the aligner-induced changes, because contrary to the X-ray-based methods no harmful radiation is applied. The effort for weekly appointments, however, is inadequate. Therefore, the current case study relies on intraoral scans performed before therapy start, at about half the treatment time, and at the end of the therapy. Refinement scans, as included in other studies,[26] are skipped. Although automatic approaches for segmenting the individual crowns from intraoral scans are more and more common, manual adjustments are generally required for clinical usage.[27] In the current study, we employed a software that can be used for automatic crown segmentation, but we have trimmed the cast bases to get a reasonable result. Each crown was separated from the patient's intraoral scan. It should be highlighted that the points for the definition of the crown boundaries were manually selected. Depending on crown size and shape, the number of points selected ranged from ten to 15.

Table 2: Results for **upper jaw** listing planned (P) and achieved (A) rotation and translation components from Start to **Mid** treatment state per patient (N) and tooth (T).

		Rotation [°] around axis						Translation [mm] in direction					
		buccal		intrusion		mesial		buccal		intrusion		mesial	
N	T	P	A	P	A	P	A	P	A	P	A	P	A
1 (PET-G.750)	17	0.39	0.18	0.28	-0.03	0.62	0.15	-0.15	0.01	-0.04	0.01	0.05	0.02
1	16	0.28	-0.11	0.21	-0.05	0.39	0.22	-0.07	0.00	-0.01	0.03	0.06	0.03
1	15	1.37	-0.11	-0.67	-0.21	0.23	0.84	-0.05	-0.01	-0.05	0.03	0.08	0.01
1	14	0.27	-0.09	-1.00	-0.39	-0.10	0.74	0.03	-0.00	-0.06	0.01	0.15	0.06
1	13	-0.04	0.47	0.66	0.63	0.64	0.97	0.24	0.09	0.16	0.15	-0.00	0.02
1	12	0.32	1.08	-0.83	-0.45	4.74	2.00	0.39	0.38	-0.07	0.06	-0.05	-0.02
1	11	0.75	1.01	-0.85	-0.76	5.48	1.51	0.19	0.08	-0.06	-0.06	-0.09	-0.02
1	21	-0.52	0.01	0.49	0.28	3.77	0.80	0.05	0.00	-0.11	-0.14	0.02	-0.02
1	22	0.15	0.76	0.12	0.14	3.20	1.95	0.04	-0.01	-0.29	-0.11	0.01	-0.02
1	23	0.37	0.77	-0.53	-0.32	0.85	0.75	-0.14	-0.35	-0.14	0.02	0.12	0.22
1	24	-0.41	-0.55	0.26	-0.36	-1.23	0.62	-0.07	0.04	-0.17	0.04	0.09	-0.04
1	25	1.56	0.52	-1.17	-0.43	-2.12	0.03	-0.18	0.07	-0.12	0.05	0.02	-0.03
1	26	0.92	0.11	0.26	-0.01	-1.98	-0.19	-0.09	0.02	-0.04	0.08	-0.03	-0.03
1	27	0.02	-0.34	-0.05	-0.04	-1.00	-0.47	-0.11	0.05	-0.03	0.05	-0.02	-0.01
2 (NA.550)	17	0.69	-0.43	0.28	-0.12	0.35	0.04	0.00	0.21	0.07	0.02	0.32	0.21
2	16	0.30	-0.15	0.18	-0.32	0.45	0.00	-0.07	0.02	0.04	0.10	0.27	0.21
2	15	0.41	-0.30	-0.88	-0.85	0.44	-0.16	-0.12	-0.05	0.05	0.06	0.31	0.21
2	14	2.17	1.10	0.61	-0.66	-0.25	-0.77	-0.19	-0.10	-0.04	0.08	0.68	0.39
2	13	0.89	-0.21	-0.74	-0.22	3.81	-0.56	-0.37	-0.26	-0.22	-0.06	-0.00	-0.05
2	12	0.05	-0.46	1.00	0.30	0.89	-1.04	-0.53	-0.31	0.17	0.06	-0.11	-0.13
2	11	0.43	-0.31	2.59	1.37	-0.83	-1.15	-0.30	-0.26	0.28	0.11	-0.03	-0.09
2	21	-0.88	0.01	-0.02	-0.16	-0.21	-0.35	-0.15	-0.12	0.05	0.01	0.09	0.12
2	22	-0.66	-0.07	0.18	-0.58	0.05	-0.64	-0.21	-0.13	0.02	0.04	-0.06	0.05
2	23	-0.72	-0.31	0.09	-0.27	0.78	-0.37	-0.28	-0.08	-0.08	0.01	-0.10	-0.05
2	24	1.07	0.25	-0.76	-0.33	1.07	0.59	-0.01	0.13	-0.01	0.03	0.37	0.07
2	25	0.48	0.52	0.41	1.14	-0.46	0.59	0.05	0.16	0.06	0.12	0.41	0.15
2	26	0.84	-0.12	0.38	-0.03	0.12	1.13	-0.02	0.09	-0.00	0.05	0.42	0.15
2	27	0.38	-0.85	1.15	0.05	-0.15	0.77	-0.13	0.05	0.07	0.03	0.38	0.16
3 (NA.750)	17	0.05	0.35	-0.01	0.06	-0.09	0.21	-0.05	-0.04	-0.01	0.03	0.03	-0.04
3	16	0.27	0.32	-0.24	-0.03	0.16	0.06	-0.10	-0.03	-0.03	-0.04	-0.00	-0.08
3	15	0.32	0.19	0.19	0.09	0.06	-0.25	-0.12	-0.03	-0.06	-0.08	-0.04	-0.09
3	14	-0.00	-0.05	-1.03	-0.60	-0.09	0.06	0.07	0.05	-0.07	-0.06	-0.11	-0.08
3	13	0.03	-0.28	0.09	0.05	0.83	-0.06	-0.42	-0.18	-0.08	-0.02	0.04	0.02
3	12	-0.69	-0.48	1.67	0.53	-1.08	0.30	0.47	0.15	0.03	0.09	-0.11	0.00
3	11	-0.46	0.15	-0.75	-0.35	-0.21	0.43	0.17	0.05	-0.02	0.04	-0.14	-0.01
3	21	-0.41	0.11	0.68	-0.13	0.06	0.39	0.56	0.18	0.10	0.13	0.00	-0.00
3	22	0.70	-0.40	1.42	0.75	1.76	-0.32	-0.07	0.03	-0.03	0.08	0.20	0.07
3	23	0.05	-0.26	0.45	0.00	0.42	-0.46	-0.39	-0.13	0.08	0.04	0.12	0.02
3	24	-0.35	-0.68	-1.29	-0.59	0.39	0.25	0.02	0.05	-0.04	0.02	-0.07	-0.06
3	25	-0.37	-0.34	-0.79	0.14	0.56	0.27	0.00	0.01	-0.04	-0.02	-0.12	-0.05
3	26	-0.26	-0.04	-0.20	0.06	-0.17	0.17	0.03	0.02	-0.04	-0.04	-0.09	-0.02
3	27	-0.46	0.23	0.04	0.25	-0.31	0.52	-0.01	-0.09	-0.04	-0.00	-0.10	-0.02
4 (NA.750)	17	-0.04	-0.37	-0.06	-0.50	0.00	0.47	0.02	0.06	-0.02	-0.07	-0.00	-0.04
4	16	-0.02	-0.62	0.04	-0.10	0.05	0.43	0.02	-0.01	-0.01	-0.00	-0.00	-0.02
4	15	0.13	0.13	0.04	0.13	-0.07	0.25	0.02	-0.02	-0.02	0.05	-0.01	-0.02
4	14	0.02	-0.05	1.69	0.66	-0.26	-0.07	0.03	0.01	-0.02	0.10	-0.01	-0.06
4	13	0.99	0.13	0.24	0.10	-0.03	0.03	-0.08	-0.10	-0.04	0.01	0.02	-0.07
4	12	0.36	0.45	0.08	-0.14	-0.03	0.02	0.03	-0.00	-0.04	0.01	-0.02	-0.13
4	11	0.28	0.23	-0.23	-0.52	0.28	-0.77	-0.15	-0.10	-0.05	-0.08	-0.00	-0.03
4	21	-0.30	0.00	0.11	-0.23	0.03	-0.54	-0.06	0.02	-0.02	-0.03	0.02	-0.04
4	22	0.17	0.41	-0.30	-0.66	0.36	-0.32	0.01	0.07	-0.03	-0.01	-0.01	-0.05
4	23	1.01	-0.06	0.14	-0.36	-0.20	-0.34	0.05	0.10	0.00	0.02	0.02	-0.05
4	24	0.04	0.26	0.19	0.28	0.12	-0.13	-0.00	0.02	-0.03	-0.01	0.03	0.03
4	25	0.13	0.17	0.13	0.31	-0.00	0.10	-0.02	-0.03	0.06	0.05	0.04	0.04
4	26	0.03	-0.04	0.02	0.09	0.01	0.28	-0.02	-0.07	-0.03	0.01	0.04	0.02
4	27	0.11	-0.15	0.11	0.02	0.01	0.14	-0.01	-0.04	-0.04	-0.04	0.02	0.00

Table 3: Results for **lower jaw** listing planned (P) and achieved (A) rotation and translation components from Start to **Mid** treatment state for patient (N) and tooth (T).

		Rotation [°] around axis						Translation [mm] in direction					
		buccal		intrusion		mesial		buccal		intrusion		mesial	
N	T	P	A	P	A	P	A	P	A	P	A	P	A
1 (PET-G.750)	37	0.58	-0.38	-0.13	-0.06	-1.23	-0.55	0.06	0.02	0.08	0.01	0.01	-0.02
1	36	1.09	-0.04	-0.31	-0.22	-0.52	-0.81	0.01	0.01	-0.04	0.07	0.02	-0.03
1	35	0.74	-0.49	-0.03	-0.17	1.00	0.15	0.05	-0.01	-0.22	-0.00	-0.02	-0.08
1	34	-0.22	-1.50	-0.79	1.03	0.22	-0.23	0.09	0.04	-0.36	0.11	-0.13	-0.12
1	33	-0.58	0.53	-1.31	-0.28	0.27	0.44	0.08	-0.04	0.22	0.22	-0.18	-0.12
1	32	0.49	0.65	-0.63	-0.03	1.27	-0.11	-0.06	-0.07	0.22	0.12	-0.11	-0.07
1	31	1.36	0.64	-0.51	-0.19	0.97	-0.59	-0.15	-0.12	0.10	0.06	-0.03	-0.04
1	41	-0.93	-0.24	0.37	-0.08	2.07	-0.50	-0.18	-0.12	-0.00	0.01	0.02	0.03
1	42	0.33	0.25	-1.10	-0.94	-0.06	-0.44	-0.10	-0.07	0.09	0.04	0.03	-0.02
1	43	-1.29	-0.41	-0.94	-0.15	-0.03	-0.27	-0.04	-0.05	-0.03	0.02	-0.03	-0.03
1	44	-0.85	-0.19	-0.46	-0.24	-0.74	-0.45	0.12	-0.02	-0.08	0.03	-0.08	-0.04
1	45	1.27	-0.06	-0.09	-0.10	-0.84	-0.11	0.07	-0.03	-0.11	0.03	0.01	-0.03
1	46	0.02	-0.16	0.00	-0.00	-0.57	-0.03	0.03	-0.02	-0.07	0.05	-0.00	-0.03
1	47	-0.07	-0.57	-0.03	-0.06	-0.39	-0.05	-0.01	-0.00	-0.09	0.02	-0.02	-0.03
2 (NA.550)	37	0.15	-0.11	-0.01	-0.01	-0.16	-0.55	-0.02	-0.03	0.02	0.08	0.03	0.05
2	36	0.23	0.16	0.16	0.46	0.16	-1.04	-0.02	-0.10	-0.02	0.07	0.05	0.09
2	35	-0.19	0.17	-0.39	0.06	0.26	-0.91	-0.13	-0.18	-0.03	0.03	-0.01	0.03
2	34	0.20	0.03	0.02	0.17	0.28	-1.02	-0.23	-0.24	-0.03	-0.03	-0.03	0.02
2	33	-0.31	-0.46	-1.50	-0.30	0.48	-0.91	-0.14	-0.17	-0.06	-0.10	0.02	0.03
2	32	1.36	-0.29	1.87	-0.03	1.37	-0.82	-0.12	-0.13	0.01	-0.06	0.21	0.12
2	31	0.56	-0.73	2.48	0.68	-1.05	-0.50	0.21	0.03	-0.08	-0.03	0.13	0.12
2	41	-0.61	0.44	2.52	0.84	-0.39	-0.67	-0.01	-0.06	-0.20	0.03	-0.18	-0.10
2	42	-0.85	0.13	1.50	0.79	-0.24	-0.95	-0.33	-0.17	0.03	0.09	-0.13	-0.09
2	43	-0.95	-0.08	-2.65	-0.37	-0.50	-0.97	-0.18	-0.08	0.07	0.10	0.07	0.06
2	44	-0.49	0.06	-0.25	0.34	-0.34	-0.26	-0.14	-0.12	-0.04	0.11	0.06	0.12
2	45	-0.07	-0.01	-0.07	0.05	-0.24	-0.14	-0.09	-0.11	-0.02	0.07	0.11	0.15
2	46	0.19	-0.16	-0.09	0.28	-0.11	0.31	0.04	-0.02	0.02	0.04	0.06	0.10
2	47	0.05	0.00	0.08	0.24	-0.78	0.53	0.08	0.04	0.01	-0.07	0.10	0.15
3 (NA.750)	37	-0.10	-0.97	-0.47	-1.20	0.40	-0.40	-0.04	0.17	0.02	-0.08	-0.05	-0.08
3	36	0.21	-0.79	-0.55	-0.87	0.59	-0.65	-0.07	0.07	-0.05	0.08	-0.05	-0.12
3	35	0.49	0.02	-0.33	0.06	0.30	-0.31	-0.14	0.06	-0.15	0.11	-0.09	-0.12
3	34	-0.46	-0.07	-0.10	0.10	0.16	-0.49	-0.00	0.02	-0.26	0.04	-0.15	-0.11
3	33	0.35	-0.27	1.96	0.72	1.44	-0.30	0.13	0.03	-0.08	0.04	-0.18	-0.15
3	32	-0.02	-0.47	1.61	0.99	1.73	0.06	0.11	-0.07	0.10	0.12	-0.18	-0.13
3	31	0.17	-0.45	0.77	0.80	3.08	1.17	0.14	0.00	0.05	0.13	-0.12	-0.08
3	41	-0.05	0.60	-1.26	-1.58	2.11	0.99	0.14	-0.02	0.06	0.10	0.03	0.04
3	42	-1.37	0.21	1.53	-0.79	0.93	1.77	0.39	0.16	-0.05	0.15	-0.06	0.00
3	43	-0.41	-0.25	2.50	-0.09	0.70	0.85	-0.08	-0.07	-0.26	0.03	-0.18	-0.10
3	44	0.00	-0.20	0.37	-0.49	0.23	0.37	-0.24	0.05	-0.25	-0.09	-0.27	-0.20
3	45	-0.18	0.18	-0.37	-0.25	0.03	0.47	-0.23	0.11	-0.20	-0.13	-0.33	-0.18
3	46	0.32	0.02	-0.30	-0.58	-0.00	0.37	-0.06	0.18	-0.14	-0.13	-0.33	-0.14
3	47	0.14	1.09	-0.33	-0.26	0.04	0.93	-0.12	0.30	-0.04	0.01	-0.31	-0.16
4 (NA.750)	37	0.13	-0.78	-0.02	0.43	-0.09	1.08	-0.01	-0.22	0.10	-0.17	-0.11	-0.06
4	36	0.58	-0.44	0.12	0.25	0.02	0.39	-0.02	-0.11	-0.01	0.00	-0.12	-0.06
4	35	0.35	-0.06	0.28	0.72	-0.67	0.91	0.28	0.11	-0.24	0.04	-0.26	-0.08
4	34	-0.49	-0.48	-0.45	0.37	0.44	-0.01	-0.07	0.06	-0.18	0.06	-0.29	-0.11
4	33	-0.53	-0.10	1.03	0.97	0.25	0.13	0.10	0.14	-0.09	0.06	-0.22	-0.16
4	32	-0.12	-0.27	2.67	1.96	0.23	0.82	0.45	0.34	0.06	0.13	-0.24	-0.25
4	31	1.18	0.73	-2.14	-0.88	-1.49	1.27	0.60	0.39	0.05	0.17	-0.33	-0.34
4	41	0.11	0.63	-0.13	-1.08	-0.20	0.59	0.10	0.03	-0.16	-0.03	0.10	0.18
4	42	0.49	0.21	0.21	-0.08	-0.47	0.63	0.41	0.36	0.01	0.00	-0.10	-0.06
4	43	-0.88	-0.05	-0.46	0.13	1.12	0.55	-0.15	-0.10	-0.17	-0.18	-0.22	-0.11
4	44	-0.76	-0.12	-1.37	-0.89	0.90	1.10	-0.11	-0.03	-0.16	-0.19	-0.29	-0.15
4	45	0.34	0.63	-0.19	0.07	-0.32	0.54	0.24	0.14	-0.19	-0.15	-0.27	-0.17
4	46	0.67	1.08	0.21	0.53	0.04	0.07	-0.04	-0.12	-0.02	0.01	-0.11	-0.09
4	47	0.03	-0.00	-0.40	0.05	-0.19	0.11	-0.06	-0.24	0.07	0.12	-0.10	-0.05

Table 4: Results for **upper jaw** listing planned (P) and achieved (A) rotation and translation components from Start to **End** treatment state for patient (N) and tooth (T).

		Rotation [°] around axis						Translation [mm] in direction					
		buccal		intrusion		mesial		buccal		intrusion		mesial	
N	T	P	A	P	A	P	A	P	A	P	A	P	A
1 (PET-G.750)	17	-0.11	-0.17	0.01	-0.23	0.01	0.34	-0.27	-0.09	-0.12	0.01	0.12	0.07
1	16	0.02	0.18	0.31	0.08	0.50	0.36	-0.12	-0.06	-0.03	0.00	0.14	0.07
1	15	1.17	0.20	-1.07	0.00	0.33	0.90	-0.08	-0.06	-0.07	-0.02	0.17	0.05
1	14	0.35	-0.06	-0.99	-0.24	0.07	0.63	0.02	-0.04	-0.05	-0.05	0.20	0.05
1	13	-0.15	0.22	0.65	0.42	0.41	0.89	0.27	0.09	0.18	0.11	0.03	0.03
1	12	0.11	0.72	-1.11	0.17	7.02	1.98	0.71	0.39	-0.18	0.06	-0.12	-0.03
1	11	0.64	0.59	-0.47	-0.07	5.56	1.45	0.17	0.08	-0.01	-0.00	-0.05	-0.03
1	21	0.01	-0.00	0.02	0.04	4.04	0.95	-0.03	-0.00	-0.09	-0.09	-0.01	-0.00
1	22	0.86	0.55	0.59	0.39	3.81	1.54	0.06	0.03	-0.22	-0.07	-0.01	0.01
1	23	1.24	0.80	-0.89	0.16	0.23	0.34	-0.67	-0.44	-0.13	0.00	0.48	0.34
1	24	-0.13	-0.38	0.22	0.04	-2.47	0.31	-0.09	0.02	-0.19	0.01	0.07	-0.04
1	25	2.89	0.13	-2.01	-0.04	-4.67	0.03	-0.31	0.04	-0.26	0.01	0.00	-0.04
1	26	2.09	0.26	0.08	0.19	-5.67	-0.11	-0.26	-0.08	-0.27	0.05	-0.14	-0.02
1	27	1.38	-0.23	0.20	0.07	-6.93	0.10	-0.22	-0.05	-0.63	0.02	-0.16	0.02
2 (NA.550)	17	0.76	-0.66	0.20	-0.98	0.15	-0.02	0.14	0.40	0.06	0.03	0.48	0.28
2	16	0.34	-1.14	-0.08	-0.77	0.32	-0.51	-0.00	0.16	0.04	0.10	0.51	0.39
2	15	0.97	-0.24	-1.55	-1.56	0.98	-0.49	-0.11	0.01	0.04	0.07	0.56	0.42
2	14	1.18	-0.17	-0.44	-1.33	1.02	-0.64	-0.18	-0.06	-0.02	0.15	0.85	0.51
2	13	2.50	-0.45	-0.98	-0.39	6.75	-0.81	-0.61	-0.37	-0.32	0.04	0.06	-0.03
2	12	0.55	0.32	3.35	0.53	0.81	-1.84	-0.75	-0.54	0.32	0.14	-0.42	-0.38
2	11	0.61	-0.16	2.86	1.24	-1.09	-1.31	-0.50	-0.49	0.29	0.10	-0.13	-0.14
2	21	-0.47	-0.19	0.54	0.42	-0.42	-0.72	-0.37	-0.35	0.01	0.01	0.15	0.14
2	22	-0.47	-0.30	-0.25	-0.20	-0.34	-1.23	-0.44	-0.42	0.01	0.04	-0.08	0.00
2	23	-2.75	-2.33	-2.27	-2.93	1.75	-0.17	-0.36	-0.19	-0.16	-0.06	-0.01	0.01
2	24	4.24	0.65	-3.01	-2.13	3.29	0.06	-0.15	0.05	0.04	0.15	0.73	0.40
2	25	3.70	2.02	1.28	1.42	-0.42	0.16	-0.02	0.29	0.15	0.17	0.70	0.37
2	26	1.11	-1.13	0.19	-0.72	0.52	0.96	-0.09	0.36	0.05	0.13	0.66	0.30
2	27	0.43	-0.96	1.15	-0.22	-0.06	0.24	-0.35	0.37	0.14	0.07	0.61	0.22
3 (NA.750)	17	0.25	0.24	-0.06	0.04	-0.10	-0.15	-0.06	0.08	-0.02	0.03	0.04	-0.08
3	16	0.22	0.45	-0.16	-0.16	0.08	-0.15	-0.13	0.04	-0.05	-0.04	-0.01	-0.11
3	15	0.23	0.16	-0.21	-0.19	0.31	-0.28	-0.19	-0.04	-0.08	-0.12	-0.04	-0.12
3	14	0.13	0.10	-0.71	-0.45	-0.20	-0.36	0.03	0.03	-0.12	-0.15	-0.13	-0.13
3	13	-0.12	-0.43	0.28	0.08	0.71	-0.43	-0.46	-0.22	-0.13	-0.12	0.01	-0.03
3	12	-0.54	-0.39	2.19	0.90	-0.89	0.52	0.62	0.34	-0.00	0.06	-0.16	-0.06
3	11	-0.26	0.24	-0.83	-0.58	-0.26	0.47	0.11	0.03	-0.05	-0.01	-0.13	-0.03
3	21	-0.30	0.22	0.90	-0.01	0.62	0.86	0.70	0.30	0.08	0.18	-0.00	0.00
3	22	0.24	-0.84	0.74	0.59	2.02	-0.33	-0.10	0.01	-0.04	0.10	0.20	0.11
3	23	-0.15	-0.24	0.33	0.30	0.30	-0.51	-0.43	-0.27	0.10	0.13	0.10	0.05
3	24	-0.27	-0.85	-1.89	-1.16	0.83	0.46	0.04	-0.00	-0.05	0.12	-0.14	-0.13
3	25	-0.67	-0.68	-1.44	-0.45	1.05	-0.12	0.02	0.07	-0.04	0.08	-0.22	-0.14
3	26	-0.33	-0.70	-0.18	-0.47	-0.04	0.02	0.08	0.24	-0.05	0.00	-0.20	-0.13
3	27	-0.19	-1.02	-0.11	-0.53	0.03	0.40	0.05	0.34	-0.02	-0.13	-0.19	-0.16
4 (NA.750)	17	-0.07	-0.75	-0.09	-0.52	-0.09	-0.09	0.11	0.49	-0.02	-0.13	0.04	0.03
4	16	-0.10	-0.64	0.05	-0.30	-0.14	-0.36	0.09	0.32	-0.00	-0.01	0.06	0.14
4	15	0.01	-0.11	-0.29	-0.62	-0.11	-0.28	0.09	0.21	-0.01	0.03	0.03	0.05
4	14	0.18	-0.16	2.39	1.13	-0.60	-0.43	0.07	0.15	-0.04	0.10	0.03	-0.01
4	13	1.04	0.03	0.30	-0.32	-0.21	-0.32	-0.07	-0.09	-0.04	-0.01	0.05	-0.05
4	12	0.03	0.38	-0.15	-0.97	-0.39	0.01	0.05	-0.00	-0.05	0.03	-0.01	-0.08
4	11	0.20	0.30	-0.30	-1.03	0.01	-0.32	-0.15	-0.23	-0.04	-0.07	0.02	0.00
4	21	-0.43	-0.07	0.08	-0.36	0.03	-0.23	-0.06	-0.13	-0.01	-0.01	0.03	0.01
4	22	0.03	0.22	0.31	0.02	-0.02	-0.33	0.00	-0.06	-0.05	0.00	-0.01	-0.06
4	23	1.26	0.41	0.28	-0.60	-0.38	-0.17	0.02	0.04	0.02	0.05	-0.00	-0.08
4	24	0.14	0.26	0.12	-0.27	0.12	-0.13	-0.03	0.06	-0.02	0.01	0.02	0.01
4	25	0.28	0.52	0.11	-0.12	-0.33	-0.18	-0.04	0.11	0.09	0.09	0.01	0.02
4	26	0.04	-0.18	0.05	-0.12	0.14	-0.12	-0.06	0.15	-0.02	0.01	0.02	-0.00
4	27	0.34	-0.43	0.22	-0.14	0.21	0.12	-0.05	0.23	-0.01	-0.03	0.01	-0.02

Table 5: Results for **lower jaw** listing planned (P) and achieved (A) rotation and translation components from Start to **End** treatment state for patient (N) and tooth (T).

		Rotation [°] around axis						Translation [mm] in direction					
		buccal		intrusion		mesial		buccal		intrusion		mesial	
N	T	P	A	P	A	P	A	P	A	P	A	P	A
1 (PET-G.750)	37	1.49	0.64	-0.27	0.00	-1.14	-0.46	0.07	0.01	-0.01	-0.08	0.02	0.02
1	36	1.61	0.21	-0.40	-0.46	-0.33	-0.55	0.01	0.00	-0.15	-0.06	0.04	0.01
1	35	1.17	-0.61	-0.18	0.07	1.83	0.77	0.14	0.01	-0.70	-0.16	0.03	-0.02
1	34	-0.13	-0.83	-0.84	0.88	-0.06	-0.42	0.13	0.12	-0.67	-0.09	-0.11	-0.09
1	33	-0.97	0.00	-0.73	-0.19	0.19	0.44	0.10	0.01	0.13	0.09	-0.12	-0.05
1	32	0.18	0.12	-0.44	-0.06	1.03	0.27	-0.01	0.00	0.16	0.04	-0.04	0.01
1	31	0.75	0.28	-0.02	0.07	0.97	0.10	-0.10	-0.04	0.09	0.01	0.03	0.01
1	41	-0.69	-0.02	0.21	0.12	2.01	0.07	-0.12	-0.07	-0.01	0.00	-0.03	-0.00
1	42	0.52	0.19	-0.89	-0.73	-0.07	0.14	-0.05	-0.03	0.10	0.01	0.03	-0.03
1	43	-0.77	-0.21	-0.91	-0.07	-0.06	0.12	-0.01	-0.01	-0.01	-0.00	-0.03	-0.04
1	44	-0.87	-0.26	-0.64	-0.25	-0.72	-0.12	0.17	0.00	-0.05	-0.02	-0.08	-0.06
1	45	1.13	-0.23	-0.35	-0.00	-0.68	0.05	0.13	-0.00	-0.12	-0.01	0.03	-0.04
1	46	0.07	-0.23	-0.01	-0.12	-0.64	0.00	0.06	0.02	-0.08	-0.01	-0.00	-0.03
1	47	0.23	-0.22	-0.02	0.03	-0.45	0.09	-0.01	0.02	-0.09	0.00	-0.02	-0.04
2 (NA.550)	37	0.18	-0.09	0.02	0.15	0.18	0.04	0.00	0.09	-0.00	0.03	0.03	0.03
2	36	0.39	0.42	-0.12	-0.09	0.43	-0.44	0.01	0.01	-0.05	0.05	0.03	0.07
2	35	-0.08	-0.24	-0.28	-0.16	0.10	-0.31	-0.09	-0.11	-0.04	0.04	-0.03	-0.01
2	34	0.24	0.19	0.16	0.45	1.00	-0.24	-0.19	-0.19	-0.03	0.02	-0.04	-0.00
2	33	0.33	0.07	-1.33	-0.21	0.53	-0.48	-0.12	-0.15	-0.06	-0.06	-0.00	-0.01
2	32	1.02	-0.03	1.01	0.15	1.75	-0.49	-0.08	-0.16	-0.02	-0.04	0.12	0.09
2	31	0.54	-0.19	2.57	1.11	-0.50	-0.10	0.22	-0.01	-0.02	-0.03	0.08	0.14
2	41	-1.31	0.06	3.08	0.46	0.26	-0.09	0.02	-0.07	-0.21	-0.03	-0.12	-0.06
2	42	-1.37	-0.30	2.30	1.15	0.10	0.02	-0.34	-0.09	0.09	0.05	-0.07	-0.11
2	43	-0.90	0.14	-2.67	-0.60	-0.70	-0.32	-0.36	-0.11	0.28	0.13	0.13	0.11
2	44	0.11	-0.22	0.14	0.19	-0.20	-0.16	-0.15	-0.07	-0.07	0.04	0.07	0.15
2	45	0.24	0.01	-0.06	0.20	-0.19	-0.24	-0.09	-0.07	-0.04	0.03	0.12	0.13
2	46	0.41	-0.20	0.39	0.32	-0.26	-0.07	0.06	0.07	-0.01	0.03	0.10	0.13
2	47	0.41	0.42	0.37	0.65	-0.64	0.19	0.10	0.10	0.01	0.01	0.12	0.17
3 (NA.750)	37	0.21	-1.09	-0.74	-0.87	-0.09	0.39	-0.04	0.27	-0.05	-0.15	-0.10	-0.14
3	36	0.50	-0.65	-0.59	-0.40	-0.01	0.19	-0.11	0.12	-0.18	0.13	-0.11	-0.20
3	35	-0.34	-0.46	-0.28	0.32	0.01	0.19	-0.17	0.07	-0.30	0.14	-0.17	-0.16
3	34	-0.44	-0.23	-0.24	-0.02	0.20	-0.05	-0.02	0.01	-0.43	0.09	-0.22	-0.20
3	33	-0.15	-0.16	3.03	0.81	2.09	-0.46	0.21	0.06	-0.22	0.04	-0.18	-0.22
3	32	-1.10	-0.17	2.54	2.28	3.28	0.30	0.43	0.20	0.24	0.16	-0.46	-0.29
3	31	0.16	0.06	0.36	0.41	5.55	0.78	0.53	0.29	0.20	0.09	-0.32	-0.22
3	41	0.30	0.31	-0.85	-1.52	2.99	0.47	0.22	-0.00	0.10	-0.05	0.11	0.11
3	42	-2.07	-0.40	2.38	0.89	1.79	1.05	1.06	0.62	0.08	0.03	-0.10	-0.02
3	43	-0.59	-0.44	2.21	0.28	1.16	-0.14	-0.08	-0.07	-0.34	-0.16	-0.14	-0.07
3	44	-0.37	0.20	0.38	-0.04	0.99	-0.08	-0.25	-0.02	-0.36	-0.18	-0.31	-0.20
3	45	-0.57	0.54	-0.59	0.21	0.16	0.01	-0.26	0.01	-0.32	-0.08	-0.36	-0.21
3	46	0.24	-0.10	-0.65	-0.39	0.10	-0.15	-0.07	0.10	-0.26	-0.06	-0.31	-0.19
3	47	-0.11	0.16	-0.44	-0.28	0.22	0.26	-0.16	0.17	-0.12	0.03	-0.31	-0.21
4 (NA.750)	37	0.16	-0.96	-0.24	0.26	-0.37	1.17	0.01	-0.14	0.08	-0.13	-0.10	-0.07
4	36	0.23	-0.47	-0.11	0.18	0.05	0.77	-0.00	-0.08	0.00	0.03	-0.09	-0.07
4	35	-0.05	-0.00	0.13	0.02	-0.73	0.90	0.26	0.21	-0.22	0.01	-0.23	-0.13
4	34	-0.76	-0.42	-0.69	-0.35	0.54	0.15	-0.08	0.05	-0.11	0.03	-0.24	-0.12
4	33	-0.62	-0.41	0.45	0.65	-0.26	-0.16	0.09	0.15	-0.04	0.05	-0.15	-0.12
4	32	-0.65	-0.92	1.52	1.03	-2.47	-0.85	0.96	0.83	0.21	0.26	-0.21	-0.22
4	31	1.17	0.80	-3.42	-2.28	-2.60	-0.30	0.78	0.68	0.17	0.27	-0.30	-0.34
4	41	0.83	0.73	-1.76	-1.34	-0.10	0.00	-0.01	0.01	-0.11	-0.00	0.09	0.13
4	42	1.08	0.46	0.69	0.66	-2.35	-1.17	0.92	0.81	0.18	0.12	-0.19	-0.17
4	43	-0.17	-0.01	0.53	0.58	0.78	0.25	-0.19	-0.11	-0.15	-0.18	-0.27	-0.17
4	44	-0.21	0.44	-0.57	-0.52	0.37	0.89	-0.17	-0.01	-0.16	-0.23	-0.34	-0.23
4	45	-0.08	0.68	-0.43	0.00	0.14	1.20	0.18	0.20	-0.17	-0.19	-0.26	-0.21
4	46	0.23	0.98	-0.11	0.29	0.19	0.76	-0.07	-0.14	-0.05	-0.05	-0.11	-0.10
4	47	-0.10	0.60	-0.25	0.30	0.11	1.17	-0.06	-0.24	0.01	0.13	-0.09	-0.07

5. CONCLUSIONS AND OUTLOOK

intraoral scans allow for the quantification of aligner-based orthodontic treatments. Obviously, intraoral scans performed before therapy start, at about half the treatment time, and at the end of the therapy are sufficient for a quantitative evaluation of the therapy success. They are even the basis for improving future treatments, because the position and the orientation of the crowns with respect to the aligner shape used are assessable and listed in tables. The detailed quantitative evaluation of the polymeric films (thickness, sandwich-structure, material) used to fabricate aligners requires rather large cohorts, since the wide variety of clinical cases has to be considered. The commonly applied numerous exclusion criteria for the related clinical trials make such studies challenging. The current case study, however, is valuable, because the experimental data of the four patients are comprehensively listed in tables and might be integrated into future cohort studies. Further data from other case studies could contribute to obtain a more and more detailed overview on the aligner performance in orthodontic therapies.

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REFERENCES

[1] Ke, Y., Zhu, Y., and Zhu, M., "A comparison of treatment effectiveness between clear aligner and fixed appliance therapies," *BMC Oral Health* **19**(1), 24 (2019).

[2] Papageorgiou, S. N., Koletsi, D., Iliadi, A., Peltomaki, T., and Eliades, T., "Treatment outcome with orthodontic aligners and fixed appliances: a systematic review with meta-analyses," *Eur. J. Orthodontics* **42**(3), 331–343 (2020).

[3] Barbaro, K., Ciurli, G., Candida, E., Silvestrini-Biavati, F., Lanteri, V., Ghisellini, P., Rando, C., Eggenhöffner, R., and Ugolini, A., "Molecular biocompatibility assessment of PETG aligners after processing by laser or milling," *Materials* **18**(20), 4793 (2025).

[4] Gopinath, P. M., Parvathi, V. D., Yoghalakshmi, N., Kumar, S. M., Athulya, P. A., Mukherjee, A., and Chandrasekaran, N., "Plastic particles in medicine: A systematic review of exposure and effects to human health," *Chemosphere* **303**, 135227 (2022).

[5] Quinzi, V., Orilisi, G., Vitiello, F., Notarstefano, V., Marzo, G., and Orsini, G., "A spectroscopic study on orthodontic aligners: First evidence of secondary microplastic detachment after seven days of artificial saliva exposure," *Sci. Total Environ.* **866**, 161356 (2023).

[6] Filippon, I., Tanner, C., von Jackowski, J. A., Schulz, G., Töpper, T., and Müller, B., "Determining aligner-induced tooth movements in three dimensions using clinical data of two patients," *Oral* **4**(4), 487–504 (2024).

[7] Ammann, R., Tanner, C., Schulz, G., Osmani, B., Nalabothu, P., Töpper, T., and Müller, B., "Three-dimensional analysis of aligner gaps and thickness distributions, using hard X-ray tomography with micrometer resolution," *J. Med. Imaging* **9**(3), 031509 (2022).

[8] Revilla-León, M., Raney, L., Piedra-Cascón, W., Barrington, J., Zandinejad, A., and Özcan, M., "Digital workflow for an esthetic rehabilitation using a facial and intraoral scanner and an additive manufactured silicone index: A dental technique," *J. Prosthet. Dent.* **123**(4), 564–570 (2020).

[9] Kau, C. H., Soh, J., Christou, T., and Mangal, A., "Orthodontic aligners: Current perspectives for the modern orthodontic office," *Medicina* **59**(10), 1773 (2023).

[10] Asiry, M. A., "Biological aspects of orthodontic tooth movement: A review of literature," *Saudi J Biol. Sci.* **25**(6), 1027–1032 (2018).

[11] Ali, D., Mohammed, H., Koo, S.-H., Kang, K.-H., and Kim, S.-C., "Three-dimensional evaluation of tooth movement in Class II malocclusions treated without extraction by orthodontic mini-implant anchorage," *Korean J Orthod.* **46**(5), 280–289 (2016).

[12] Amberg, B., Romdhani, S., and Vetter, T., "Optimal step nonrigid ICP algorithms for surface registration," in [*2007 IEEE Conference on Computer Vision and Pattern Recognition*], 1–8, IEEE (2007).

[13] Kabsch, W., "A solution for the best rotation to relate two sets of vectors," *Acta Crystallogr. Sect. A* **32**(5), 922–923 (1976).

[14] Gonçalves, A., Collard, A., Monteiro, F., Matos, D., Carvalho, Ó., Azevedo, R., Silva, F. S., and Pinho, T., "Accuracy of invisalign® on upper incisors: A systematic review," *Turk. J Orthod.* **36**(2), 126 (2023).

[15] Inchingolo, A. M., Inchingolo, A. D., Carpentiere, V., Del Vecchio, G., Ferrante, L., Di Noia, A., Palermo, A., Di Venere, D., Dipalma, G., and Inchingolo, F., "Predictability of dental distalization with clear aligners: A systematic review," *Bioengineering* **10**(12), 1390 (2023).

[16] AlMogbel, A., "Clear aligner therapy: Up to date review article," *J Orthod. Sci.* **12**(1), 37 (2023).

[17] Galluccio, G., De Stefano, A. A., Horodynski, M., Impellizzeri, A., Guarnieri, R., Barbato, E., Di Carlo, S., and De Angelis, F., "Efficacy and accuracy of maxillary arch expansion with clear aligner treatment," *Int. J. Environ. Res. Public Health* **20**(5), 4634 (2023).

[18] Chamberland, S. and Nataf, N., "Noninvasive conservative management of anterior open bite treated with TADs versus clear aligner therapy," *Clin. Oral Investig.* **28**(4), 236 (2024).

[19] Elshazly, T. M., Bourauel, C., Ismail, A., Ghoraba, O., Aldesoki, M., Salvatori, D., Elattar, H., Alhotan, A., and Alkabani, Y., "Effect of material composition and thickness of orthodontic aligners on the transmission and distribution of forces: An in vitro study," *Clin. Oral Investig.* **28**(5), 258 (2024).

[20] Li, X., Ren, C., Wang, Z., Zhao, P., Wang, H., and Bai, Y., "Changes in force associated with the amount of aligner activation and lingual bodily movement of the maxillary central incisor," *Korean J Orthod.* **46**(2), 65–72 (2016).

[21] Theodorou, C. I., Kuijpers-Jagtman, A. M., Bronkhorst, E. M., and Wagener, F. A., "Optimal force magnitude for bodily orthodontic tooth movement with fixed appliances: A systematic review," *Am J Orthod Dentofacial Orthop* **156**(5), 582–592 (2019).

[22] Moga, R.-A., Buru, S. M., and Chiorean, C. G., "Overall stress in periodontal ligament under orthodontic movement during a periodontal breakdown," *Am J Orthod Dentofacial Orthop* **161**(2), e127–e135 (2022).

[23] Gao, L. and Wichelhaus, A., "Forces and moments delivered by the PET-G aligner to a maxillary central incisor for palatal tipping and intrusion," *Angle Orthodontist* **87**(4), 534–541 (2017).

[24] Tüfekçi, E., Carrico, C. K., Gordon, C. B., and Lindauer, S. J., "Does crown, root, and bone visualization in a clear aligner virtual setup impact treatment decisions?," *Am. J Orthod. Dentofacial Orthop.* **165**(6), 671–679 (2024).

[25] Al-Worafi, N. A., Zheng, B., Al-Warafi, L. A., Alyafrusee, E. S., Alsomairi, M. A. A., and Liu, Y., "Impact of molar teeth distalization by clear aligners on maxillary alveolar bone thickness and root resorption: A three-dimensional study," *BMC Oral Health* **24**(1), 237 (2024).

[26] Meade, M. J., Weir, T., Seehra, J., and Fleming, P. S., "Clear aligner therapy practice among orthodontists in the United Kingdom and the Republic of Ireland: A cross-sectional survey of the British Orthodontic Society membership," *J. Orthod.* **51**(2), 120–129 (2024).

[27] Woo, H., Jha, N., Kim, Y.-J., and Sung, S.-J., "Evaluating the accuracy of automated orthodontic digital setup models," in [*Semin. Orthod.*], **29**(1), 60–67, Elsevier (2023).