Forces and moments generated by removable thermoplastic aligners: Incisor torque, premolar derotation, and molar distalization

Mareike Simon,[a] Ludger Keilig,[b] Jörg Schwarze,[c] Britta A. Jung,[d] and Christoph Bourauel[e]
Freiburg, Bonn, and Cologne, Germany

Introduction: The exact force systems as well as their progressions generated by removable thermoplastic appliances have not been investigated. Thus, the purposes of this experimental study were to quantify the forces and moments delivered by a single aligner and a series of aligners (Invisalign; Align Technology, Santa Clara, Calif) and to investigate the influence of attachments and power ridges on the force transfer. **Methods:** We studied 970 aligners of the Invisalign system (60 series of aligners). The aligners came from 30 consecutive patients, of which 3 tooth movements (incisor torque, premolar derotation, molar distalization) with 20 movements each were analyzed. The 3 movement groups were subdivided so that 10 movements were supported with an attachment and 10 were not. The patients' ClinCheck (Align Technology, Santa Clara, Calif) was planned so that the movements to be investigated were performed in isolation in the respective quadrant. Resin replicas of the patients' intraoral situation before the start of the investigated movement were taken and mounted in a biomechanical measurement system. An aligner was put on the model, the force systems were measured, and the calculated movements were experimentally performed until no further forces or moments were generated. Subsequently, the next aligners were installed, and the measurements were repeated. **Results:** The initial mean moments were about 7.3 N·mm for maxillary incisor torque and about 1.0 N for distalization. Significant differences in the generated moments were measured in the premolar derotation group, whether they were supported with an attachment (8.8 N·mm) or not (1.2 N·mm). All measurements showed an exponential force change. **Conclusions:** Apart from a few maximal initial force systems, the forces and moments generated by aligners of the Invisalign system are within the range of orthodontic forces. The force change is exponential while a patient is wearing removable thermoplastic appliances. (Am J Orthod Dentofacial Orthop 2014;145:728-36)

The Invisalign system, introduced by Align Technology (Santa Clara, Calif) in 1999, combines the basic principles of Kesling's,[1] Ponitz's,[2] McNamara's,[3] and Sheridan's[4] orthodontic treatment with removable thermoplastic appliances (RTAs; appliances made from transparent plastic material such as polyurethane) with modern CAD-CAM stereolithography and tooth movement simulation software. Since it is a relatively new method, some aspects are still insufficiently investigated. Most previous studies on RTAs are case reports and system descriptions.[5,6] Furthermore, material science studies have evaluated the changes in force delivery properties of RTAs after thermocycling, as well as the chemical and morphologic changes after usage.[7-9]

Forces and moments generated by RTAs have barely been investigated.

In 3 follow-up in-vitro studies, Hahn et al[10-12] quantified the forces for 3 tooth movements (rotation, tipping, and torque of a maxillary central incisor) generated by 3 thermoplastic materials (Ideal Clear [Dentsply GAC, Gräfelfing, Germany], Erkodur [Erkodent Erich Kopp GmbH, Pfalzgrafenweiler, Germany], and Biolon [Dreve Dentamid GmbH, Unna, Germany]). They all had a thickness of 1.0 mm but differed in the thermoforming process. Regarding their results, it seems that pressure-formed appliances exert greater force systems at higher rates of activation compared with

[a]Orthodontist, Department of Orthodontics, University Hospital of Freiburg, Freiburg, Germany; doctoral candidate, Department of Oral Technology, School of Dentistry, University of Bonn, Bonn, Germany.
[b]Senior scientist, Department of Oral Technology, School of Dentistry, University of Bonn, Bonn, Germany.
[c]Private practice, Cologne, Germany.
[d]Professor and head of clinic, Department of Orthodontics, University Hospital of Freiburg, Freiburg, Germany.
[e]Professor and head, Orthodontics Department, School of Dentistry, University of Bonn, Bonn, Germany.
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Address correspondence to: Mareike Simon, Hugstetter Str 55, 79106 Freiburg, Germany; e-mail, mareike.simon@uniklinik-freiburg.de.
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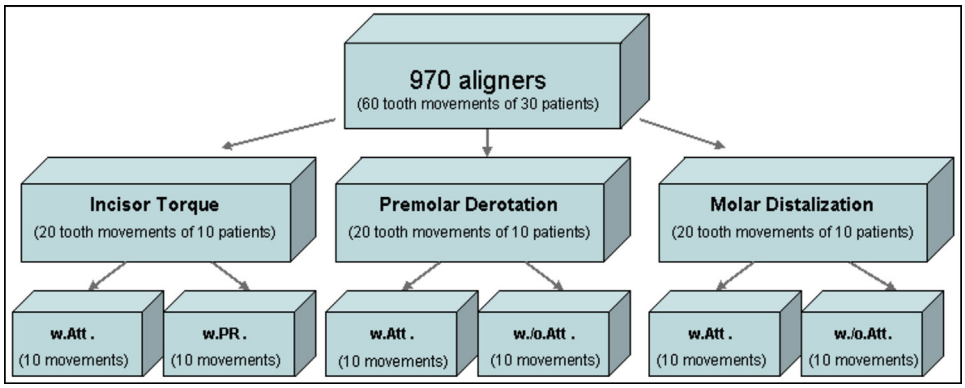

Fig 1. On the basis of the tooth movement to be analyzed, participating patients were divided in 3 main groups (incisor torque, premolar derotation, molar distalization). To determine the influence of auxiliaries to the force transfer, 2 subgroups were made in each main group: in 1 subgroup the movement was performed with an attachment (*w.Att.*), and in the other subgroup no attachment was used (*w./o.Att.*), except incisor torque, where power ridges were used (*w.PR.*). The attachments used in each group were "horizontal ellipsoid attachment" for maxillary incisor torque (group 1), "optimized rotation attachment" for premolar derotation (group 2), and "horizontal beveled gingival attachment" for molar distalization (group 3).

thermoplastic vacuum-formed appliances. However, the results were statistically significant only in some cases.

In an in-vivo study, Barbagallo et al[13] investigated the force transmitted by aligners (synonym for RTAs) of the ClearSmile system (Clear Smile appliance, Woollongong, Australia) using Pressurex films (Fuji Photo Film Co, Ltd, Tokyo, Japan). The films, placed under the aligners, recorded the overall mean forces. The measurements were performed on the first day and after 2 weeks—the last day of wearing the aligner. They found a high initial mean force on the first day and a low final force, and concluded that the force curve is not linear but, rather, exponential. Their results agree with the findings of Vardimon et al,[14] who indirectly evaluated the generated forces of aligners of the Invisalign system. Assuming that forces generated by aligners behave like the von Mises strains developed in an aligner, they bonded strain gauge rosettes on aligner surfaces and measured in-vivo strains during Invisalign treatment. Their results showed a peak strain on the first day followed by a plateau phase at a lower force level between days 2 and 15.

The main disadvantages of these in-vivo studies are that the data only show an overall mean force on a specific position on the crown at a certain time. The exact force systems in all 3 planes of space, as well as the exact distribution of the forces and moments, have not been detected so far, but they are important to know when planning orthodontic treatment with an aligner system.

Thus, the aims of this experimental study were (1) to quantify the exact initial force systems that are delivered by an individual aligner, (2) to measure the force systems generated by a series of aligners, and (3) to investigate the influence of auxiliaries (attachments, power ridges) on the force transfer.

These aims were achieved by aligners of the Invisalign system for 3 predefined tooth movements, since these are the movements described as impossible or difficult to perform with RTAs: incisor torque, premolar derotation, and molar distalization.[15-17]

MATERIAL AND METHODS

In this study, we investigated the initial force systems delivered by 970 individual aligners and 60 series of aligners (mean aligners per series, 16.7; SD, 5.0). These aligners came from 30 consecutive patients (11 male, 19 female; ages, 13-72 years; mean age, 32.9 years; SD, 16.3 years) who underwent orthodontic treatment in 2011 and 2012 in a private orthodontic practice in Cologne, Germany. Our inclusion criteria for the patients were orthodontic treatment with Invisalign aligners and a need for 1 of these 3 movements: incisor torque, premolar derotation, or molar distalization. Exclusion criteria were cleft lip and palate or any other syndrome-associated orofacial malformation.

According to the investigated tooth movement, the 30 patients were divided into 3 main movement categories with 10 patients in each group. In each movement category, 20 tooth movements (2 per patient) were determined. To investigate the influence of auxiliaries such as attachments (temporarily bonded composite buttons) and power ridges (pressure lines close to the gingival margin), the 3 main movement categories were split into 2 subgroups using a split-mouth design (Fig 1).