JOURNAL OF ALIGNER ORTHODONTICS

Official publication of:
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Editor-in-Chief:
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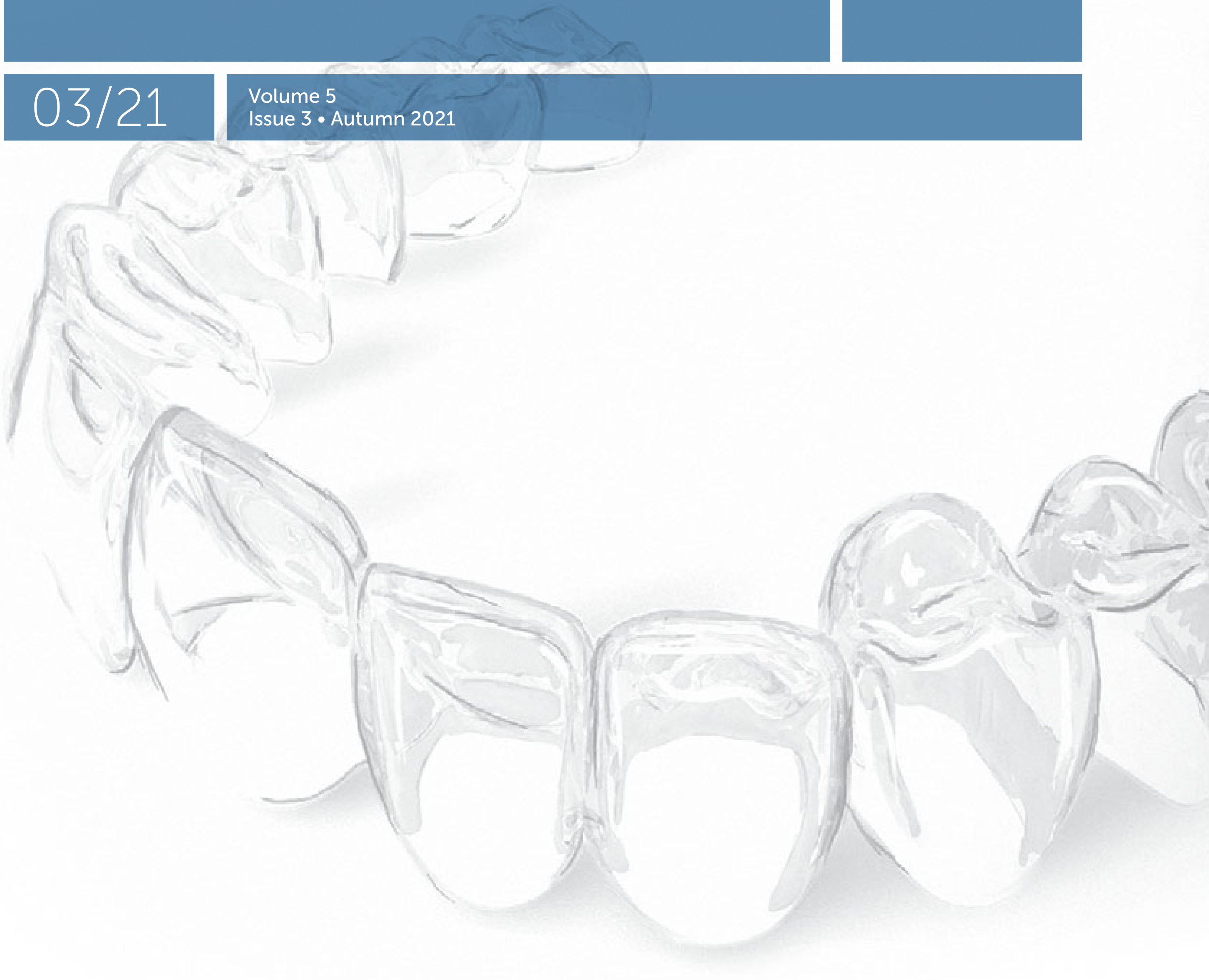
03/21

Volume 5
Issue 3 • Autumn 2021



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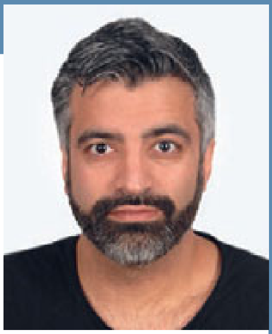
EDITORIAL

Even in aligner orthodontics, the only constant in life is change


Sachin Chhatwani

To quote Heraclitus, “the only constant in life is change”. There have been huge changes in society, from those of the industrial era to the digital revolution in a now globalized world. Above all, change in industrial society is always marked by innovation, such as the development of the steam engine and the invention of the computer. This is followed by further innovations and continuous further development. It is not only the industrialized world that continues to evolve, but every aspect of human life.

Currently, orthodontics is experiencing its digital revolution, even though digital setups are nothing new in aligner therapy. Impressions were already digitized towards the end of the 1990s, when the simulated result was presented to the patient.

For a long time, there were few players on the world market in aligner therapy. But here, too, a change is taking place. Well-known companies that were not previously active in the field of aligner therapy are now fully committed to this treatment method. Some of them see no future at all in classic fixed orthodontics and are abandoning this business field altogether. Disruptive start-ups sell aligner therapies online, in their own stores or with selected dental practitioners. An orthodontist may no longer even be needed.

As orthodontists, we can counteract and offer the production of in-house aligners and thus offer competitive price structures. In addition, appointment intervals can be shortened by using state-of-the-art telemonitoring technologies. Still, these are all areas where a disruptive start-up with its financial resources will outpace us in the long run. Aligner companies will find better algorithms and use artificial intelligence to improve patient care.

There is a progressive change in our profession and concerns amongst orthodontists are on the rise. But how is this development possible at all?

We orthodontists have laid the foundation ourselves, with dental clinics that advertise pure non-extraction therapies, and research showing that the temporomandibular joint plays no role in the field of orthodontics – but is that so? Is it even anatomically possible, that there is no connection between the temporomandibular joint and teeth? Do teeth and surrounding structures really have no influence on other structures? Is it simply enough to expand any crowding and simply to procline teeth as much as needed? Are there no recessions or long-term consequences? In orthodontic literature it is difficult to find an answer to all these questions. As a simplified example, one study showed an apical migration of the gingival zenith of mandibular incisors when teeth were proclined to a certain degree, whereas another study could not find any correlation between gingival recessions and mandibular incisor proclina-

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tion.[1,2] We have tools to assess the quality of studies and to judge accordingly, but both studies missed the influence of the gingival biotype.

Very recently, Mheissen et al[3] showed that in most longitudinal orthodontic trials optimal statistical analyses were not utilized and that the interpretation of the results might be compromised. It is important in our field to ask ourselves the right research questions and to see if they were answered with correctly performed studies.

Orthodontics is not just about straightening teeth and being profit-oriented, regardless of whether you are a dental practitioner or a disruptive start-up company. It is about respecting the biological limits and not disregarding the musculature and the joints. The influence of tooth position on surrounding structures and vice versa should be the focus not only of research but also in the clinical setting. To ignore these factors takes away the complexity of our profession.

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ALIGNER ORTHODONTICS

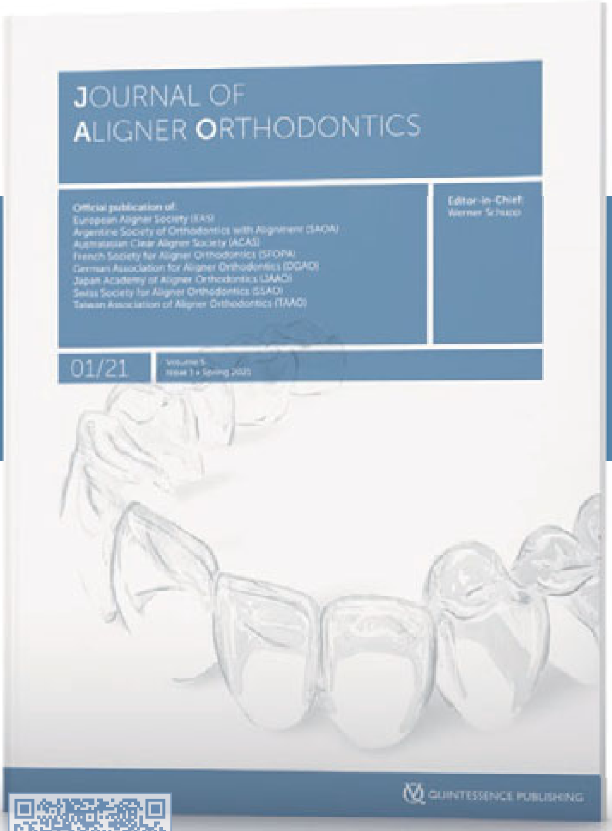
03/21

Volume 5
Issue 3 • Autumn 2021

EDITORIAL

ORIGINAL SCIENTIFIC ARTICLES

CASE REPORTS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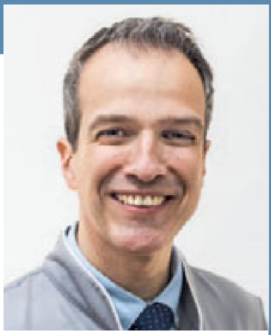
ORIGINAL SCIENTIFIC ARTICLE


Gabriel Schmidt Dolci

Gabriel Schmidt Dolci, Donald Ferguson, Nikhilesh R Vaid, James Mah, Stefan Cardon

Hybrid mechanics for early interceptive treatment of anterior crossbite

KEY WORDS *anterior crossbite, Class III treatment, clear aligners, extraoral traction appliance, growing patient, in-office aligners, interceptive orthodontics, maxillary arch expansion, removable orthodontic appliances*

Early interception of anterior crossbite has functional, structural and aesthetic benefits that have been widely enumerated in the literature. The goal of early interception usually involves proclination of the maxillary incisors, thus eliminating mandibular anterior shift; maxillary disjunction and protraction to correct transverse and sagittal deficiencies, respectively; and maintenance or improvement of mandibular compensation, thus creating as much horizontal overlap as possible. The present study illustrates a case treated for 24 months with a modified Catalan appliance incorporated into in-office aligners. The treatment results highlighted the efficacy of hybrid mechanics for mandibular compensation and protraction of the maxillary dentition. The 5-year follow-up demonstrated relative stability of the final outcome.

Introduction

Skeletal Class III malocclusion represents a major clinical concern even among experienced orthodontists, and the benefits of its early treatment have long been debated[1-5]. The literature indicates that cases of anterior crossbite (ACB) associated with true or pseudo-Class III malocclusion should be treated as soon as the malocclusion is diagnosed[4-6].

Moreover, ACB can represent the phenotype of a complex skeletal Class III malocclusion, or can simply be associated with forward mandibular displacement to achieve maximum intercuspation, known as functional ACB or pseudo-Class III. The differential diagnosis between skeletal and pseudo-Class III is crucial and can be established following a detailed anamnesis and clinical and cephalometric examination[7]. Careful application of the Lin 3-Ring method can indicate the prognosis for the correction of ACB through nonsurgical treatment[8].

The present case report illustrates a peculiar clinical condition in which a functional forward mandibular shift occurred in association with a Class III pattern, leading to ACB. Hybrid mechanics involving in-office aligners and fixed

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Journal of Aligner Orthodontics 2021;5(3):175–183

Figs 1a-f Pretreatment facial and intraoral photographs taken with the mandible in maximal intercuspation.

appliances were devised to intercept the malocclusion at an early stage, thus re-establishing the normal development of the dentition.

Case presentation

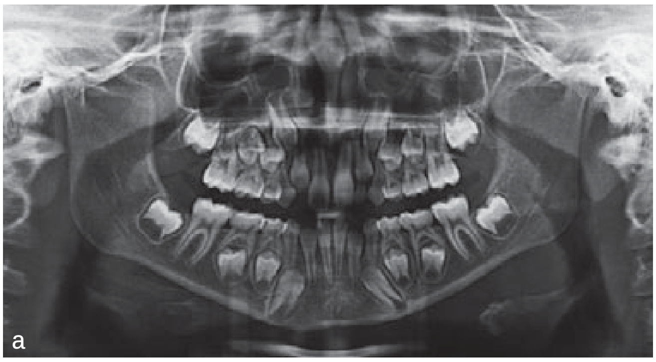
Diagnosis and treatment plan

An 8-year-old girl attended an orthodontic consultation at a private practice (SC) with the chief complaint of ACB associated with functional issues during mastication. She was in the first stage of mixed dentition, and the anamnesis indicated a family history of skeletal Class III malocclusion, nocturnal snoring and predominant mouth breathing.

The clinical examination revealed a long lower facial height, midface deficiency, straight facial profile, reduced nasolabial angle, retrusive upper lip and large buccal corridor (Fig 1). In maximum intercuspation, the patient presented with the distal surfaces of the second molars in a mesial step, ACB with a negative horizontal overlap of 2.0 mm, a 4.0-mm vertical overlap, and the upper and lower midlines coinciding with the facial midline; however, when the mandible was guided into centric relation, a premature occlusal contact was observed between the maxillary and mandibular central incisors (Fig 2). Consequently, it was supposed that ACB was mainly related to forward mandibular displacement during closure to maximum intercuspation. As such, further radiographic examinations were performed to define the differential diagnosis between skeletal and pseudo-Class III. Oral hygiene and periodontal status were verified. The clinical examination also indicated that the patient exhibited mixed breathing, and an otolaryngologist had already been consulted.

A panoramic radiograph showed the presence of all the permanent teeth except the third molars. The eruption sequence also appeared to be adequate (Fig 3). Cephalometric analysis[9,10] revealed a Class III skeletal pattern with a sagittal maxillary deficiency and clockwise rotation of the

Figs 2a-c The mandible was manipulated into centric relation; note the premature contact between the maxillary and mandibular central incisors.



Figs 3a-b Pretreatment panoramic and lateral cephalometric radiographs taken with the mandible in edge-to-edge relation and maximal intercuspation, respectively, suggesting normal development of the dentition and retroclination of the maxillary and mandibular incisors.

Table 1 Cephalometric analysis. Initial data indicated a discrepancy between maxillary and mandibular lengths (Co-A and Co-Gn)

Variable	Ideal	Pre-treatment	Post-treatment
SNA, degrees	82	78.3	80.0
SNB, degrees	80	77.3	77.0
ANB, degrees	2	1.0	3.0
SN-GoGn, degrees	32	39.5	43.3
Y-axis, degrees	59	61.2	63.1
NAPog, degrees	0	−4.4	5.2
1-NA, mm	5	1.8	3.0
1.NA, degrees	22	13.7	16.9
1-NB, mm	5	2.1	3.0
1.NB, degrees	25	16.8	19.3
A-NPerp, mm	0–1	1.0	2.9
Pog-NPerp, mm	6–8	9.4	2.3
Co-A, mm	75	75.2	88.0
Co-Gn, mm	92	101.1	118.2
ANS-Me, mm	54	53.5	68.0
Upper pharynx, mm	17.4	3.3	8.8
Lower pharynx, mm	10–12	11.5	12.3
FMA, degrees	25	23.6	28.0
IMPA, degrees	90	80.0	83.1

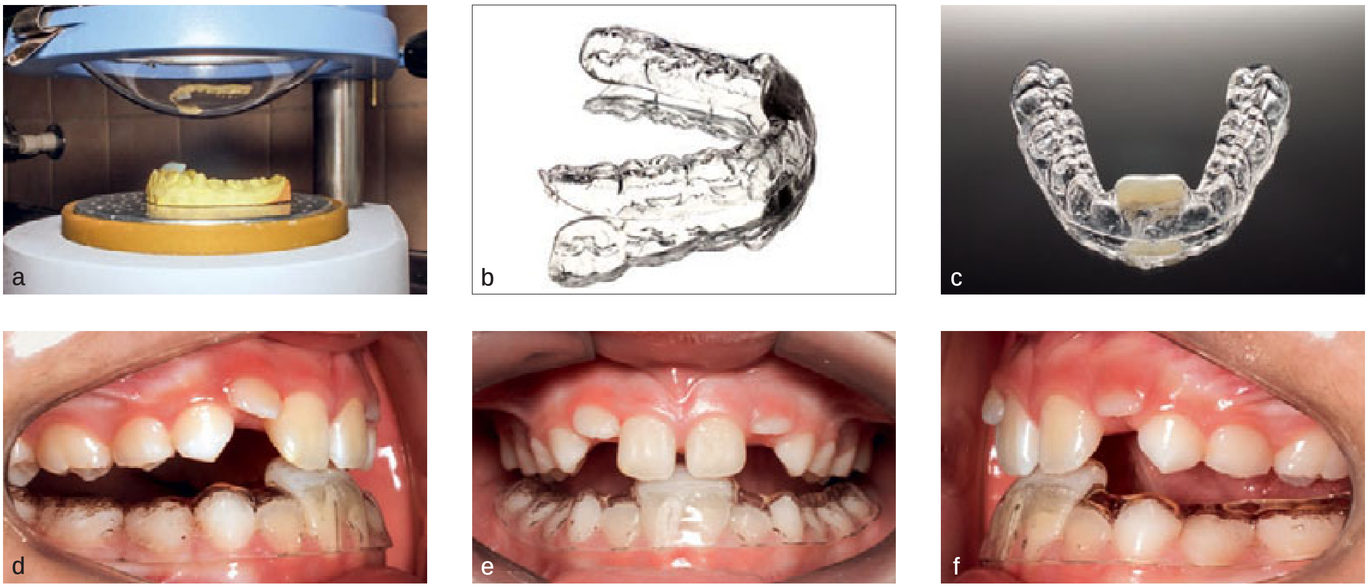
mandible, determining a slight vertical growth pattern. The maxillary and mandibular incisors were retroclined, and significant nasopharyngeal obstruction was observed (Fig 3 and Table 1).

The treatment objectives were as follows:

- to procline the maxillary incisors, thus eliminating mandibular anterior shift;
- to perform maxillary disjunction and protraction with the intention of correcting transverse and sagittal deficiencies, respectively;
- to maintain or even improve mandibular compensation, thus creating as much horizontal overlap as possible;
- to improve the nasal airway capacity;
- to allow normal development of the dentition.

Treatment progress

First, an aesthetic removable inclined plane (modified Catalan appliance) was used to promote premature contact in the palatally displaced maxillary incisors[11,12], thus moving



Figs 4a-f **(a to c)** A polyethylene terephthalate glycol (PET-G) foil (1 mm) was thermoformed to construct an aesthetic removable bite plane. **(d to f)** Intraoral aspects at placement of the appliance.

Figs 5a-c Facial and intraoral photographs taken with the mandible in centric occlusion 1 month after placement of the aesthetic removable bite plane.

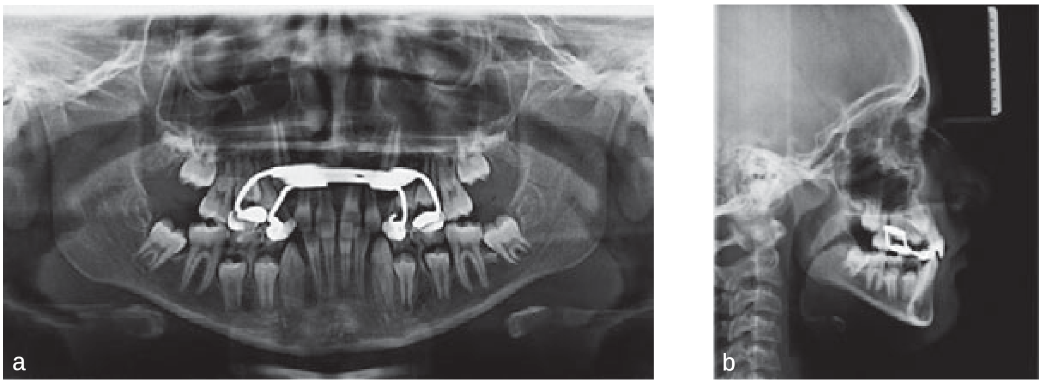
these teeth buccally and correcting the functional ACB (Fig 4). The patient was instructed to wear the appliance on a full-time basis, removing it only during meals and oral hygiene procedures. After 1 month, the ACB was corrected (Fig 5), then the second phase of interceptive treatment began.

Aiming to increase the maxillary dimensions (transverse and sagittal), a modified Hygienic Rapid Palatal Expander[13] was used to widen the maxilla (Fig 6) and the screw was activated twice a day, with one quarter turn made every 12 hours for 14 days[14]. Maxillary protraction was then carried out using a Petit face mask (Morelli, São Paulo, Brazil)[15]. The patient was instructed to wear the appliance for 14 hours each day (day and night) and the magnitude of the force was increased gradually, reaching 400 gf on each side after 1 month of appliance wear.

To improve the horizontal overlap, mass retraction of the mandible was planned concomitant to maxillary protraction. A removable aesthetic appliance with ceramic buttons bonded in the canine region was devised to support the mechanics of Class III elastics. To avoid appliance instability when the patient was wearing elastics, physical retentions were made from composite resin and placed in the cervical region of the posterior teeth (Fig 6). The use of an aesthetic aligner in the mandible had a positive impact on patient compliance, because such appliances have better psychological effects when compared to buccal/lingual braces[16]. The patient was instructed to wear the appliance with bilateral Class III elastics (3/16-inch) daily and nightly during this phase, which lasted 13 months and resulted in the achievement of a Class II molar relationship (Fig 6).

Figs 6a-i **(a and b)** Facial and intraoral aspects upon delivery of the face mask. **(c to e)** After 3 weeks, a removable lower splint was devised (PET-G foil, 1 mm) to support Class III elastics. **(f to h)** After 13 months, overcorrection of the molar relationship was observed, thus achieving an Angle Class II relationship. **(i)** The red arrows indicate composite resin retentions made in the cervical region of the posterior teeth.

The overall treatment time was 24 months. After this, no retainers were used in the maxilla or mandible (Figs 7 and 8). The development of the dentition was controlled periodically, twice a year, until the establishment of the permanent dentition, which occurred when the patient was 13 years old (Fig 9).



Figs 7a-b Posttreatment panoramic and lateral cephalometric radiographs.

[redacted] [redacted] [redacted]

Figs 8a-f Posttreatment facial and intraoral photographs.

Figs 9a-h Postretention facial and intraoral photographs taken at the 5-year follow-up.

Treatment results and follow-up

All the treatment goals were achieved during this early orthodontic intervention: the maxillary incisors were flared, the maxillary bone was widened and anteriorly displaced and the mandibular incisors were maintained retroclined. Major clearing of the upper airways and clockwise mandibular rotation also occurred, and the latter had direct repercussions on the lower facial height (Table 1 and Fig 7).

After treatment, a facial clinical examination demonstrated improved smile aesthetics. The buccal corridor and profile were significantly modified, primarily as a result of maxillary expansion and protraction. The interarch relationship improved considerably, as shown by the bilateral Class I canine intercuspation (Fig 8).

After 5 years of follow-up, all these outcomes appeared to be stable. Although the treatment presented some dental limitations (crowding, aligning and levelling, rotations, angulations and inclinations), as shown in Fig 9, the patient was pleased with the outcome and did not wish to undergo further corrective orthodontic treatment.

Discussion

One of the main steps in early Class III treatment is a precise diagnosis to define the aetiology and complexity of the malocclusion. After clinical examination and cephalometric analysis, two diagnostic points were fundamental to devising the treatment plan for the patient: there was a functional ACB in association with retroclined maxillary incisors and the patient presented with a skeletal Class III tendency with a sagittal and transverse maxillary deficiency. Although the literature has reported mandibular shift as a clinical characteristic of pseudo-Class III[17], it should be underlined that even skeletal Class III can present this condition, especially if the maxillary incisors are retroclined, thus causing a premature contact during mandibular closure. For instance, even considering the skeletal Class III aetiology, an excellent prognosis for ACB was recognised when the patient presented an acceptable facial profile in centric relation, when the canines and molars were in or near a Class I relationship, and when the mandibular functional shift had been corrected[7].

It is important to highlight the clear benefits of early correction of functional crossbite. According to Bock et al[18], 50% of functional crossbite treatments that started in the late mixed dentition failed, compared to 15% in treatments started in the early mixed dentition. Thus, the first orthodontic strategy employed by the present authors was to use an aesthetic removable bite plane[11] that employs differential anchorage, promoting maxillary incisor proclination and distributing the reaction forces through the entire mandible (Fig 4). Furthermore, this appliance generates a premature contact in the incisor region, thus opening the bite and consequently facilitating ACB correction. As shown in Fig 5, the crossbite was corrected rapidly (1 month); however, the removable bite plane failed to establish an adequate horizontal and vertical overlap.

Sagittal and transverse maxillary deficiency were confirmed through cephalometric analysis[9] and a facial clinical examination. According to McNamara Jr[9], at 6 years of age, the mean midfacial (Co-A) and mandibular lengths (Co-Gn) should be 80 mm and 98 mm, respectively. As shown in Table 1, the patient seemed to present a real maxillary deficiency and mandibular prognathism. Thus, with the intention of intercepting skeletal Class III malocclusion, maxillary disjunction and protraction were planned. Studies have suggested that early intervention for skeletal Class III is related to major orthopaedic effects and a reduced amount of dental compensation[1-3]. In the same way, Mandall et al[4] indicated that face mask use has the positive effect of reducing the requirement for future orthognathic surgery, finding that two-thirds of patients submitted to this treatment protocol did not need surgery and 68% presented positive horizontal overlap at 15 years of age. On the other hand, just one-third of control group patients (no treatment) did not need surgery[4].

As can be seen in Fig 8, immediately after face mask removal, the patient presented a major midfacial improvement, especially with regard to the facial profile and buccal corridor. Although the treatment time of 24 months could be considered long, Class III overcorrection offers advantages in this first phase of orthodontic interception and seems to contribute towards long-term stability. Even after 5 years of follow-up, clinical examination noted the maintenance of a sagittal and transverse balance between the maxilla and mandible (Fig 9). Thus, the clinical and cephalometric observations described in Table 1 agree that Class III intervention in the early mixed dentition is apparently able to increase sagittal growth of the maxilla and therefore induce major favourable craniofacial changes, as previously described in the literature[19].

Another interesting strategy used in the treatment of this patient was the employment of a removable mandibular splint with bonded buttons in the canine regions, devised to support Class III elastics. This device acted as an adjuvant to face mask use, encouraging excellent patient acceptance and compliance. In other words, a protocol involving concomitant use of a face mask and Class III elastics (daily and nightly) was established. The goals of these mechanics were to achieve overall mandibular retraction and assist maxillary protraction (Fig 6). Successful use of mandibular splints with Class III elastics has already been reported in early dentition (4 to 5 years of age) in patients with a normal or low-angle vertical relationship[20]. The primary drawback of these mechanics was arguably the instability of the splint when using elastics. To overcome this issue, composite resin retentions were made in the cervical region of the posterior teeth to avoid displacement of the appliance (Fig 6).

Conclusions

The present study describes the early treatment of a functional ACB associated with skeletal Class III. The chosen clinical strategy involved use of an orthopaedic device associated with in-office aesthetic appliances. The treatment results highlighted the efficacy of these hybrid mechanics to compensate the mandible and protract the maxilla, and the 5-year follow-up seemed to demonstrate relative stability of the final outcome.

Declaration

The authors declare these are no conflicts of interest relating to this study.

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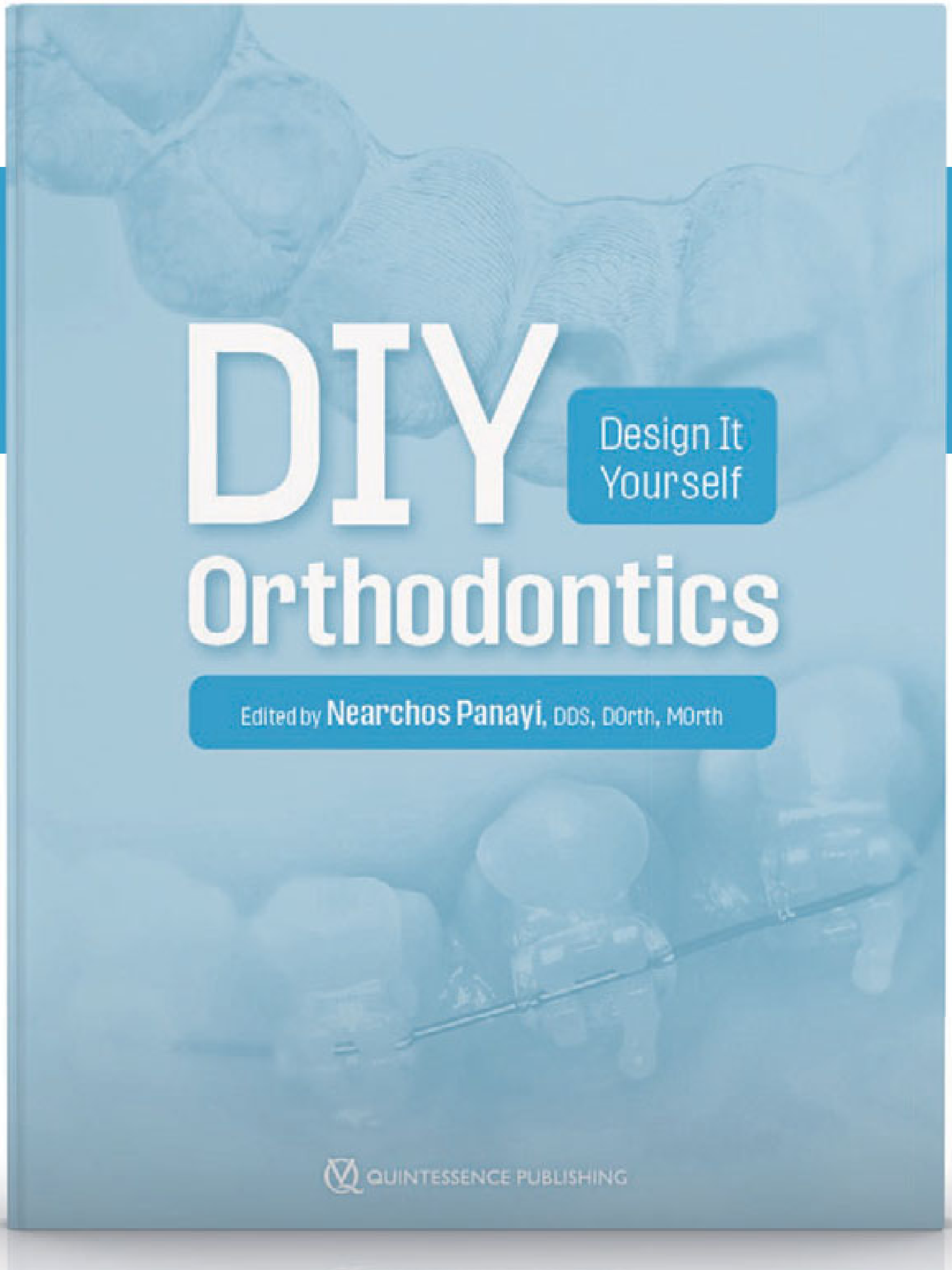
NEW

TAILOR-MADE DIGITAL ORTHODONTICS



Nearchos Panayi (Editor)

DIY Orthodontics

Design It Yourself

232 pages, 534 illus.
ISBN 978-1-64724-051-6
€138

This book describes the digital technology currently used in orthodontics, including volume and surface scanning, CAD software, 3D printing, and artificial intelligence. The text guides the reader through the application of this technology for all aspects of orthodontic treatment in an informative ‘design it yourself’ section. All the necessary technological ingredients needed for a self-sufficient digital orthodontic clinic are described, with a focus on the in-house design and production of tailor-made appliances achieved by digitally diagnosing and evaluating the virtual patient and then creating an individualized treatment plan. Now you can design your own expanders, retainers, clear aligners, brackets, indirect bonding trays, and even wires with a wire-bending robot! The technology is incredible, what we need is the courage to learn and experiment with it for the benefit of our patients. Are you ready for the challenge?

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ORIGINAL SCIENTIFIC ARTICLE

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Effects of Class II maxillomandibular elastics on Invisalign aligners: An in vitro study

Fabrício Sanches Fernandes

KEY WORDS *aesthetic aligners, Invisalign, orthodontics*

Objective: *To evaluate the effects of Class II maxillomandibular elastics on Invisalign aligners (Align Technology, San Jose, CA, USA) and assess whether the type of fitting or immersion in a medium simulating the oral environment influence possible dimensional changes.*

Materials and methods: *Twenty new pairs of Invisalign aligners were tested. Ten pairs had inserts for maxillomandibular elastics made by the manufacturer (precision cuts) and ten had cutouts. Epoxy resin casts were created for aligners, and were later mounted on articulators. Class II maxillomandibular elastics were attached to the fittings with a force of approximately 130 gf. The width and anteroposterior distance were measured at predetermined points prior to the use of elastics and 24 hours, 7 days and 14 days after force application began. Ten sets of models, each with a pair of aligners, were immersed in artificial saliva at 37°C over the experimental period, and the other 10 were kept in a dry environment.*

Results: *Statistically significant changes were observed mainly in the first 24 hours. In the dry environment, the aligners with precision cuts suffered the most considerable deformations. Dimensional changes increased in both groups when they were maintained in a simulated oral environment. The highest values of changes were observed closer to the site where the elastics were fitted.*

Conclusion: *Class II maxillomandibular elastics cause dimensional deformations of Invisalign aligners. The changes recorded in maxillary intercanine distance and the distance between mandibular first molars in the immersed aligners with both types of fitting were considered statistically and clinically significant.*

Introduction

The idea of making removable and flexible devices to move teeth dates back many years. In 1945, Kesling[1] introduced the tooth positioner as a method of reducing the spaces left after removal of the orthodontic appliance. He realised that several minor tooth movements could be incorporated into the positioner, and that important tooth movements could be performed using a series of positioners manufactured from sequential setups as treatment progressed[1,2]; however, the main limitation of this method is the difficulty of manually dividing a larger general tooth movement into small, precise stages[3].

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Developments in materials and manufacturing technology have facilitated the manufacture of aesthetic positioners for orthodontic treatment. The use of these positioners in orthodontics, later called aligners, has spread rapidly, with an increasing number of patients seeking an aesthetic and comfortable alternative to fixed braces[4].

The Invisalign system (Align Technology, San Jose, CA, USA) was introduced in 1998, and was the first orthodontic treatment method based solely on digital 3D technology[3]. From a single impression of the patient's teeth, it is possible to produce a final projection, plan the stages of tooth movement from the initial to the final state and create a series of aligners that are capable of moving the teeth according to the treatment plan[5]. The system generally requires patients to wear their aligners for a minimum of 20 hours a day and to remove them only when eating, drinking, brushing their teeth or flossing[3].

Prior to September 2001, Invisalign aligners were made from a material called Proceed30 (PC30), a mixture of polymers that did not meet all physicochemical and clinical requirements for orthodontic movement[5]. Many disadvantages were reported, which in some cases limited the use of these aligners[6,7]. PC30 was later replaced by the polymeric material Exceed30 (EX30), which exhibited 1.5 times more elasticity and improved aligner adaptation by four times[8]. In 2013, EX30 was replaced by Smart Track (LD30), a multilayer aromatic thermoplastic polyurethane/copolyester that displays greater consistency in the application of orthodontic forces, better elasticity and improved chemical stability[8].

Maxillomandibular elastics can be combined with aligners to correct sagittal discrepancies between dental arches or control anchorage. These elastics can be supported by buttons bonded to the teeth or incorporated into the appliance using cutouts made by the orthodontist or requested during the ClinCheck (Align Technology) phase. In the latter case, they are called precision cuts[9]. Align Technology recommends a force of 128 gf for the elastics but warns that they can compromise the strength and durability of the aligner, and thus advises that only one precision cut be made per quadrant. Making precision cuts on teeth with conventional attachments can also affect the performance of both accessories[10].

Thermoplastic polymers used to manufacture aligners have some limitations. They absorb water, which can cause expansion and changes in their mechanical properties[11]. It has been demonstrated that, in intraorally aged Invisalign aligners, the indentation modulus[12] and Martens hardness[13] decrease during use, weakening the force delivery capacity and leaving the aligner less resistant to wear. The increase in the elastic index also contributes to its weakening[13]. Despite these limitations, the influence of maxillomandibular elastics on the dimensional stability of aligners remains unknown.

The present study aimed to verify the effects of Class II maxillomandibular elastics on Invisalign aligners and assess whether the type of fitting or immersion in a medium simulating the oral environment influence possible dimensional changes.

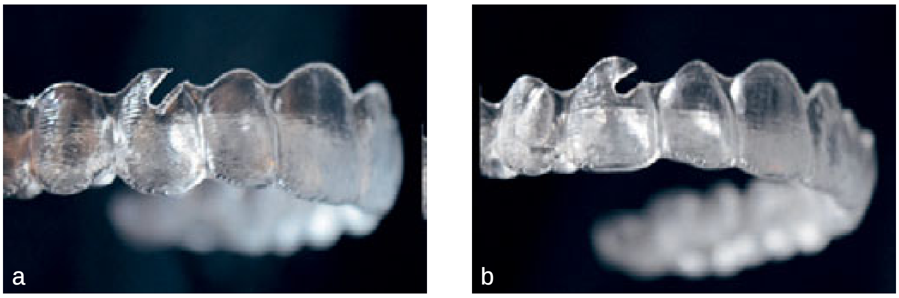
Materials and methods

Twenty new pairs of Invisalign aligners made from Smart Track material were used. The aligners had been made for orthodontic patients but, due to changes in treatment plans, they became redundant and were donated to be used in the present study. Each pair consisted of two aligners from the same individual, one for the maxillary teeth and one for the mandibular teeth.

The aligners were filled with epoxy resin (Redelease, São Paulo, Brazil) and their bases were constructed using the same material. Epoxy resin was chosen because it offers excellent reproduction of detail and stability[14,15] and can be submerged without any change to its properties[16]. The casts were then mounted in articulators (Inova Pro, São Paulo, Brazil) that simulated the patients' occlusion.

Ten pairs of aligners were kept immersed in a laboratory water bath (model 100, Fanem, São Paulo, Brazil) filled with artificial saliva (Farmácia Formulando, Niterói, Brazil) at a constant temperature of 37°C for the entire experimental period. They were removed from the machine only to perform measurements and change the elastics. The remaining 10 pairs of aligners were tested in a dry environment.

For both the immersed and non-immersed groups, cutouts for five pairs of aligners for maxillomandibular elastics were made by Align Technology (precision cuts), while cuts for the other five pairs were performed manually in a laboratory by one of the researchers (FSF). A hole was created using a 1.5-mm diamond bur (KG Sorensen, Cotia, Brazil)



Figs 1a-b **(a)** Precision cut and **(b)** manual fitting.

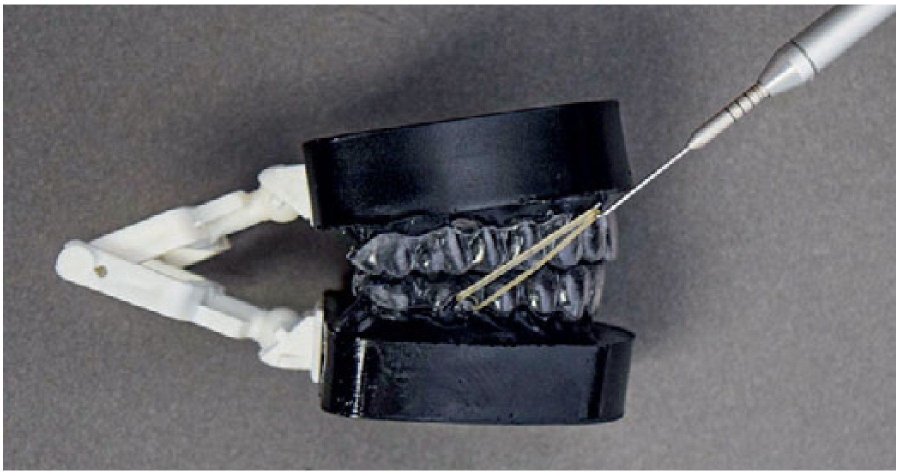


Fig 2 Measurement of force produced by maxillomandibular elastics using a tensiometer.

and finished with an orthodontic ligature cutter (#020-A, Orthopli, Philadelphia, PA, USA) to obtain a similar shape to that of the precision cut. The fittings were located in the canine site for the aligners for the maxillary teeth and in the first molar site for those for the mandibular teeth, to enable the placement of Class II elastics (Fig 1).

The 5/16 diameter maxillomandibular elastics (Morelli, São Paulo, Brazil) were inserted into the grooves using a tensiometer (SDS Ormco, Orange, CA, USA) and tensioned until they reached approximately 130 gf (Fig 2). They were changed every 24 hours and their thickness varied between light, medium and heavy so that the desired strength was achieved.

Marks were made using a permanent marker with a 0.1-mm line width (Pilot, Tokyo, Japan) at the highest point of the buccal surface of the right and left canines (intercanine), the right and left first premolars (1PM), the right and left second premolars (2PM) and the right and left first molars (1M). Marks were also made at the most anterior point, located in the uppermost part at the point of contact between the central incisors, and at the most posterior right (AP right) and left (AP left) points, at the most distal points of the most posterior tooth of the aligner on each side (Fig 3). Linear distance measurements were taken using a digital caliper (Starrett, São Paulo, Brazil) just before and 24 hours, 7 days and 14 days after placement of the elastics.

Statistical analysis

An intraclass correlation coefficient (ICC) was used to assess operator calibration by comparing repeated measures. For this purpose, 24 measurements obtained from five pairs of aligners were repeated after 15 days.

Normality was confirmed using a Shapiro-Wilk test. A repeated-measures analysis of variance (ANOVA) was used to assess the differences between time points in each group. ANOVA and a Tukey post hoc test were used to evaluate the differences between the groups. The results are presented in Tables 1 to 4. The level of significance was set at 5% ($P < 0.05$) for all analyses. Differences greater than 0.5 mm for each side of the dental arch were considered clinically significant. The data were analysed using SPSS software (version 20.0, IBM, Chicago, IL, USA).

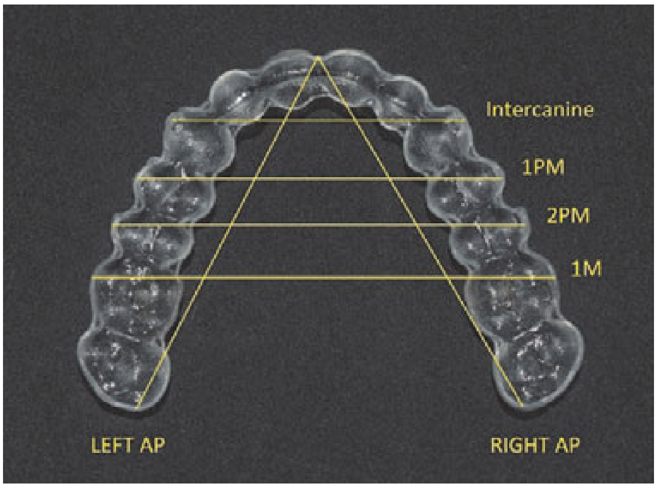


Fig 3 The evaluated linear distances.

A power analysis was performed for the intercanine distance, which was the primary outcome, considering α = 0.05, a minimum detectable difference of 0.6 mm and a mean standard deviation (SD) of 0.2 mm, achieving a power of 80%.

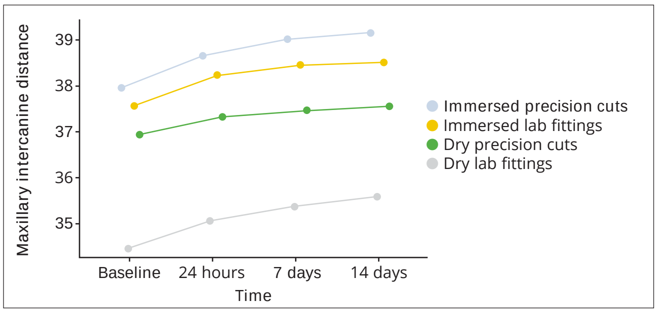


Fig 4 Intercanine distances in the different groups.

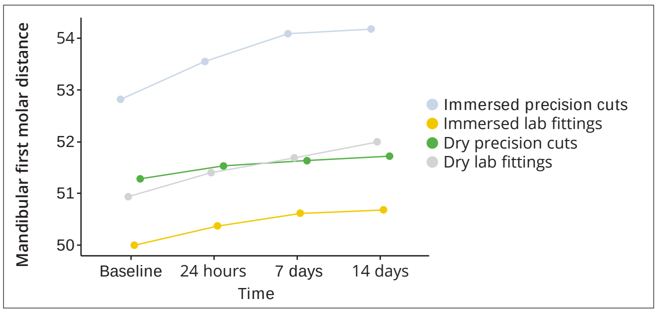


Fig 5 Intermolar distances in the different groups.

Results

The ICC for intrarater agreement was 0.996 for intercanine distance, 0.991 for 1PM distance, 0.994 for 2PM distance, 0.974 for 1M distance, 0.905 for AP right distance and 0.824 for AP left distance; thus, the reproducibility of all variables studied was considered excellent.

Table 1 presents the means and SDs of the maxillary measurements for each group at each time point. In the immersed aligners group, a statistically and clinically significant difference ($P < 0.05$) was observed only for the intercanine distance in the precision cuts and fittings made in the laboratory after 7 and 14 days, respectively. A statistically significant increase ($P < 0.05$) was also recorded in many of the distances evaluated for the immersed aligners, especially in the first 7 days. Figure 4 illustrates the maxillary intercanine distances in the different groups.

Table 2 presents the means and SDs of the mandibular measurements for each group at each time point. For the immersed aligners, there was a statistically and clinically significant difference ($P < 0.05$) for the 1M distance only. In the precision cut group, this difference ($P < 0.05$) emerged in the first 7 days, whereas in the laboratory fitting group, it was verified after 14 days. The non-immersed aligners with precision cuts showed statistically significant differences ($P < 0.05$) for all distances, except for the AP right and left distances, at different time points. The 1M distances in the different groups are shown in Fig 5.

The means and SDs of differences in the maxillary measurements between the groups for each time interval are shown in Table 3. The differences were calculated for each individual at each interval, then the means for each group and interval were calculated. In the first 24 hours, the immersed aligners with precision cuts showed significantly greater dimensional changes ($P < 0.05$) in transversal 1PM and 1M distances than all other groups. The immersed aligners with manual fittings presented statistically greater dimensional changes ($P < 0.05$) than all other groups in the 1M and AP right distances between 7 and 14 days.

The means and SDs of differences in the mandibular measurements between the groups for each time interval are shown in Table 4. The differences were calculated for each individual at each interval, then the means of each group and interval were calculated. Although the immersed

Table 1 Mean ± standard deviation (SD) and statistical significance for variables evaluated in the maxilla. Different superscript letters in the same row indicate a statistically significant difference between the respective time points

Measurement		Mean ± SD, mm			
		Baseline	24 hours	7 days	14 days
Intercanine distance	Dry lab fitting	36.95 ± 1.78^{a}	37.33 ± 1.50^{a}	37.47 ± 1.53^{a}	37.57 ± 1.52^{a}
	Immersed lab fitting	34.47 ± 1.70^{a}	35.07 ± 1.63^{b}	35.38 ± 1.60^{c}	35.60 ± 1.76^{c}
	Dry precision cut	37.58 ± 0.22^{a}	38.23 ± 0.31^{b}	38.49 ± 0.35^{b}	38.54 ± 0.37^{b}
	Immersed precision cut	37.96 ± 2.39^{a}	38.67 ± 2.16^{ab}	39.03 ± 2.16^{bc}	39.18 ± 2.22^{c}
1PM distance	Dry lab fitting	43.94 ± 1.05^{a}	44.09 ± 0.98^{a}	44.27 ± 1.07^{a}	44.28 ± 1.07^{a}
	Immersed lab fitting	42.76 ± 2.89^{a}	43.00 ± 2.81^{b}	43.17 ± 2.81^{c}	43.31 ± 2.81^{bc}
	Dry precision cut	45.10 ± 0.20^{a}	45.19 ± 0.26^{a}	45.23 ± 0.32^{a}	45.23 ± 0.30^{a}
	Immersed precision cut	45.60 ± 3.28^{a}	46.35 ± 3.31^{b}	46.57 ± 3.30^{b}	46.59 ± 3.29^{b}
2PM distance	Dry lab fitting	48.71 ± 1.16^{a}	48.79 ± 1.09^{a}	48.81 ± 1.09^{a}	48.80 ± 1.10^{a}
	Immersed lab fitting	48.65 ± 2.51^{a}	48.82 ± 2.52^{b}	48.93 ± 2.55^{c}	48.98 ± 2.55^{c}
	Dry precision cut	49.79 ± 0.30^{a}	49.78 ± 0.27^{a}	49.78 ± 0.27^{a}	49.78 ± 0.27^{a}
	Immersed precision cut	50.75 ± 4.31^{a}	51.07 ± 4.19^{ab}	51.22 ± 4.30^{b}	51.23 ± 4.30^{b}
1M distance	Dry lab fitting	53.72 ± 1.34^{a}	53.86 ± 1.07^{a}	53.88 ± 0.98^{a}	53.86 ± 0.98^{a}
	Immersed lab fitting	52.76 ± 1.38^{a}	52.89 ± 1.38^{b}	52.99 ± 1.38^{c}	53.04 ± 1.40^{c}
	Dry precision cut	55.34 ± 0.40^{a}	55.31 ± 0.39^{a}	55.33 ± 0.38^{a}	55.33 ± 0.38^{a}
	Immersed precision cut	55.97 ± 4.57^{a}	56.46 ± 4.55^{ab}	56.56 ± 4.58^{b}	56.56 ± 4.56^{b}
AP right distance	Dry lab fitting	53.03 ± 3.08^{a}	53.06 ± 3.03^{a}	53.04 ± 3.02^{a}	53.02 ± 3.04^{a}
	Immersed lab fitting	46.67 ± 4.29^{a}	46.78 ± 4.26^{a}	46.83 ± 4.28^{ab}	46.88 ± 4.29^{b}
	Dry precision cut	53.71 ± 0.30^{a}	53.68 ± 0.30^{b}	53.69 ± 0.31^{ab}	53.69 ± 0.32^{ab}
	Immersed precision cut	54.04 ± 1.97^{a}	54.07 ± 1.98^{ab}	54.13 ± 1.98^{b}	54.12 ± 1.98^{b}
AP left distance	Dry lab fitting	53.14 ± 2.38^{a}	53.16 ± 2.35^{a}	53.16 ± 2.29^{a}	53.15 ± 2.34^{a}
	Immersed lab fitting	48.74 ± 2.78^{a}	48.85 ± 2.77^{b}	48.93 ± 2.74^{bc}	48.97 ± 2.73^{c}
	Dry precision cut	51.11 ± 0.87^{a}	51.09 ± 0.86^{a}	51.10 ± 0.86^{a}	51.10 ± 0.87^{a}
	Immersed precision cut	51.70 ± 3.32^{a}	51.77 ± 3.31^{a}	51.87 ± 3.33^{a}	51.89 ± 3.35^{a}

aligners with precision cuts showed the greatest dimensional change for the 1M distance at 24 hours, the difference in dimensional change between the immersed aligners with precision cuts and the other groups was not statistically significant. In contrast, between 24 hours and 7 days, this group showed more statistically significant dimensional changes ($P < 0.05$) for the 2PM distance than all other groups. The immersed aligners with fittings made in the laboratory showed statistically greater dimensional changes ($P < 0.05$) for the 1PM, 1M and AP linear distances than all other groups between 7 and 14 days.

Table 2 Mean ± SD and statistical significance for variables evaluated in the mandible. Different superscript letters in the same row indicate a statistical difference between the respective time points

Measurement		Mean ± SD, mm			
		Baseline	24 hours	7 days	14 days
Intercanine distance	Dry lab fitting	29.23 ± 1.44^{a}	29.23 ± 1.43^{a}	29.19 ± 1.36^{a}	29.17 ± 1.37^{a}
	Immersed lab fitting	28.23 ± 0.56^{a}	28.36 ± 0.56^{b}	28.45 ± 0.56^{c}	28.50 ± 0.58^{c}
	Dry precision cut	28.25 ± 0.18^{ab}	28.23 ± 0.19^{ab}	28.26 ± 0.18^{a}	28.23 ± 0.18^{b}
	Immersed precision cut	29.21 ± 1.55^{ab}	29.59 ± 1.37^{a}	29.67 ± 1.38^{b}	29.68 ± 1.39^{b}
1PM distance	Dry lab fitting	38.97 ± 0.90^{a}	39.03 ± 0.89^{a}	39.05 ± 0.87^{a}	39.04 ± 0.87^{a}
	Immersed lab fitting	37.48 ± 1.09^{a}	37.65 ± 1.04^{a}	37.75 ± 1.02^{b}	37.84 ± 1.05^{b}
	Dry precision cut	36.35 ± 0.33^{ab}	36.34 ± 0.35^{a}	36.37 ± 0.35^{b}	36.37 ± 0.34^{ab}
	Immersed precision cut	38.15 ± 2.89^{a}	38.43 ± 2.79^{a}	38.60 ± 2.81^{b}	38.61 ± 2.81^{b}
2PM distance	Dry lab fitting	44.98 ± 1.61^{a}	45.02 ± 1.61^{a}	45.10 ± 1.62^{a}	45.10 ± 1.61^{a}
	Immersed lab fitting	44.54 ± 1.80^{a}	44.79 ± 1.81^{b}	44.92 ± 1.82^{c}	45.05 ± 1.82^{c}
	Dry precision cut	43.24 ± 0.45^{a}	43.27 ± 0.44^{ab}	43.30 ± 0.45^{c}	43.33 ± 0.46^{bc}
	Immersed precision cut	45.36 ± 3.98^{a}	45.68 ± 3.78^{a}	46.16 ± 3.87^{b}	46.22 ± 3.83^{b}
1M distance	Dry lab fitting	51.28 ± 2.33^{ab}	51.52 ± 2.09^{a}	51.63 ± 2.02^{ab}	51.72 ± 2.09^{b}
	Immersed lab fitting	50.94 ± 0.70^{a}	51.39 ± 0.72^{b}	51.68 ± 0.80^{b}	51.99 ± 0.73^{c}
	Dry precision cut	50.00 ± 0.54^{a}	50.36 ± 0.68^{b}	50.61 ± 0.83^{ab}	50.67 ± 0.84^{ab}
	Immersed precision cut	52.83 ± 4.71^{a}	53.55 ± 4.37^{ab}	54.09 ± 4.38^{c}	54.18 ± 4.43^{bc}
AP right distance	Dry lab fitting	49.82 ± 3.53^{a}	49.80 ± 3.55^{a}	49.77 ± 3.52^{a}	49.77 ± 3.53^{a}
	Immersed lab fitting	47.68 ± 3.38^{a}	47.76 ± 3.39^{b}	47.82 ± 3.42^{bc}	47.88 ± 3.43^{c}
	Dry precision cut	49.12 ± 0.18^{a}	49.08 ± 0.18^{a}	49.12 ± 0.18^{a}	49.11 ± 0.17^{a}
	Immersed precision cut	50.14 ± 2.73^{a}	50.19 ± 2.71^{a}	50.23 ± 2.74^{a}	50.25 ± 2.74^{a}
AP left distance	Dry lab fitting	50.27 ± 2.96^{a}	50.21 ± 2.95^{a}	50.01 ± 2.85^{a}	50.00 ± 2.85^{a}
	Immersed lab fitting	48.57 ± 2.49^{a}	48.67 ± 2.48^{a}	48.75 ± 2.49^{b}	48.80 ± 2.50^{c}
	Dry precision cut	50.43 ± 0.32^{a}	50.37 ± 0.30^{a}	50.40 ± 0.31^{a}	50.39 ± 0.32^{a}
	Immersed precision cut	50.11 ± 3.44^{a}	50.19 ± 3.43^{a}	50.24 ± 3.45^{a}	50.26 ± 3.46^{a}

Table 3 Mean ± SD and statistical significance for differences in the maxillary measurements between the groups for each time interval. Different superscript letters in the same column indicate a statistically significant difference between groups

Measurement		Mean ± SD, mm			
		Baseline–24 hours	24 hours–7 days	7–14 days	Baseline–14 days
Intercanine distance	Dry lab fitting	0.38 ± 0.36^{a}	0.14 ± 0.10^{a}	0.10 ± 0.09^{a}	0.62 ± 0.39^{a}
	Immersed lab fitting	0.60 ± 0.19^{a}	0.26 ± 0.17^{a}	0.21 ± 0.18^{a}	1.12 ± 0.15^{ab}
	Dry precision cut	0.65 ± 0.23^{a}	0.30 ± 0.05^{a}	0.04 ± 0.03^{a}	0.95 ± 0.31^{ab}
	Immersed precision cut	0.71 ± 0.45^{a}	0.35 ± 0.20^{a}	0.15 ± 0.11^{a}	1.21 ± 0.26^{b}
1PM distance	Dry lab fitting	0.14 ± 0.15^{a}	0.18 ± 0.17^{a}	0.01 ± 0.03^{a}	0.34 ± 0.24^{ab}
	Immersed lab fitting	0.24 ± 0.11^{a}	0.17 ± 0.02^{a}	0.13 ± 0.11^{b}	0.55 ± 0.13^{b}
	Dry precision cut	0.09 ± 0.07^{a}	0.03 ± 0.07^{a}	0.00 ± 0.04^{a}	0.12 ± 0.12^{a}
	Immersed precision cut	0.75 ± 0.21^{b}	0.21 ± 0.12^{a}	0.02 ± 0.03^{ab}	0.99 ± 0.19^{c}
2PM distance	Dry lab fitting	0.07 ± 0.09^{a}	0.02 ± 0.04^{ab}	−0.01 ± 0.02^{a}	0.09 ± 0.08^{a}
	Immersed lab fitting	0.17 ± 0.05^{ab}	0.10 ± 0.03^{ab}	0.04 ± 0.02^{b}	0.32 ± 0.07^{b}
	Dry precision cut	−0.01 ± 0.03^{a}	0.00 ± 0.02^{a}	0.00 ± 0.02^{a}	0.00 ± 0.04^{a}
	Immersed precision cut	0.32 ± 0.16^{b}	0.14 ± 0.12^{b}	0.01 ± 0.00^{ab}	0.47 ± 0.11^{c}
1M distance	Dry lab fitting	0.13 ± 0.27^{a}	0.02 ± 0.10^{a}	−0.01 ± 0.02^{a}	0.13 ± 0.37^{a}
	Immersed lab fitting	0.12 ± 0.03^{a}	0.10 ± 0.03^{a}	0.05 ± 0.02^{b}	0.27 ± 0.07^{ab}
	Dry precision cut	−0.03 ± 0.02^{a}	0.01 ± 0.02^{a}	0.00 ± 0.01^{a}	−0.01 ± 0.02^{a}
	Immersed precision cut	0.49 ± 0.23^{b}	0.09 ± 0.05^{a}	0.00 ± 0.02^{a}	0.59 ± 0.25^{b}
AP right distance	Dry lab fitting	0.03 ± 0.11^{ab}	−0.02 ± 0.02^{a}	−0.02 ± 0.01^{a}	−0.01 ± 0.13^{a}
	Immersed lab fitting	0.11 ± 0.06^{b}	0.05 ± 0.03^{b}	0.04 ± 0.03^{b}	0.21 ± 0.06^{b}
	Dry precision cut	−0.03 ± 0.01^{a}	0.01 ± 0.03^{ab}	0.00 ± 0.00^{a}	−0.01 ± 0.04^{a}
	Immersed precision cut	0.02 ± 0.04^{ab}	0.06 ± 0.05^{b}	0.00 ± 0.01^{a}	0.08 ± 0.02^{ab}
AP left distance	Dry lab fitting	0.02 ± 0.06^{ab}	0.00 ± 0.14^{a}	−0.01 ± 0.05^{a}	0.01 ± 0.21^{ab}
	Immersed lab fitting	0.11 ± 0.03^{b}	0.08 ± 0.03^{a}	0.04 ± 0.02^{a}	0.23 ± 0.05^{b}
	Dry precision cut	−0.01 ± 0.02^{a}	0.00 ± 0.01^{a}	0.00 ± 0.02^{a}	−0.01 ± 0.03^{a}
	Immersed precision cut	0.07 ± 0.11^{ab}	0.09 ± 0.05^{a}	0.02 ± 0.02^{a}	0.19 ± 0.13^{ab}

Table 4 Mean ± SD and statistical significance for differences in the mandibular measurements between the groups for each time interval. Different superscript letters in the same column indicate a statistically significant difference between groups

Measurement		Mean ± SD, mm			
		Baseline–24 hours	24 hours–7 days	7–14 days	Baseline–14 days
Intercanine distance	Dry lab fitting	0.00 ± 0.01^{ab}	−0.04 ± 0.08^{a}	−0.02 ± 0.02^{a}	−0.06 ± 0.07^{a}
	Immersed lab fitting	0.13 ± 0.03^{ab}	0.09 ± 0.03^{b}	0.05 ± 0.03^{b}	0.27 ± 0.08^{ab}
	Dry precision cut	−0.02 ± 0.01^{a}	0.02 ± 0.01^{ab}	−0.02 ± 0.00^{a}	−0.01 ± 0.01^{a}
	Immersed precision cut	0.37 ± 0.42^{b}	0.08 ± 0.03^{b}	0.01 ± 0.02^{ab}	0.47 ± 0.41^{b}
1PM distance	Dry lab fitting	0.06 ± 0.09^{ab}	0.02 ± 0.09^{a}	−0.01 ± 0.01^{a}	0.07 ± 0.10^{a}
	Immersed lab fitting	0.16 ± 0.08^{bc}	0.10 ± 0.02^{ab}	0.08 ± 0.04^{b}	0.35 ± 0.10^{b}
	Dry precision cut	−0.01 ± 0.01^{a}	0.02 ± 0.00^{a}	0.00 ± 0.02^{a}	0.01 ± 0.03^{a}
	Immersed precision cut	0.28 ± 0.14^{c}	0.16 ± 0.05^{b}	0.00 ± 0.01^{a}	0.46 ± 0.16^{b}
2PM distance	Dry lab fitting	0.03 ± 0.02^{a}	0.07 ± 0.07^{a}	0.00 ± 0.02^{a}	0.12 ± 0.07^{a}
	Immersed lab fitting	0.25 ± 0.08^{ab}	0.13 ± 0.04^{a}	0.13 ± 0.06^{b}	0.51 ± 0.15^{b}
	Dry precision cut	0.02 ± 0.01^{a}	0.03 ± 0.01^{a}	0.02 ± 0.03^{a}	0.08 ± 0.02^{a}
	Immersed precision cut	0.31 ± 0.27^{b}	0.48 ± 0.10^{b}	0.05 ± 0.08^{ab}	0.85 ± 0.30^{c}
1M distance	Dry lab fitting	0.24 ± 0.29^{a}	0.11 ± 0.09^{a}	0.08 ± 0.07^{a}	0.43 ± 0.34^{a}
	Immersed lab fitting	0.45 ± 0.17^{a}	0.28 ± 0.19^{ab}	0.31 ± 0.12^{b}	1.05 ± 0.09^{bc}
	Dry precision cut	0.36 ± 0.15^{a}	0.24 ± 0.15^{ab}	0.06 ± 0.05^{a}	0.67 ± 0.33^{ab}
	Immersed precision cut	0.72 ± 0.59^{a}	0.53 ± 0.23^{b}	0.09 ± 0.07^{a}	1.35 ± 0.42^{c}
AP right distance	Dry lab fitting	−0.01 ± 0.01^{ab}	−0.03 ± 0.05^{a}	0.00 ± 0.02^{a}	−0.04 ± 0.03^{a}
	Immersed lab fitting	0.08 ± 0.02^{c}	0.05 ± 0.04^{b}	0.06 ± 0.03^{b}	0.20 ± 0.06^{b}
	Dry precision cut	−0.04 ± 0.02^{a}	0.04 ± 0.02^{b}	−0.01 ± 0.01^{a}	−0.01 ± 0.03^{a}
	Immersed precision cut	0.05 ± 0.10^{bc}	0.04 ± 0.04^{b}	0.01 ± 0.01^{a}	0.11 ± 0.08^{b}
AP left distance	Dry lab fitting	−0.05 ± 0.08^{a}	−0.20 ± 0.35^{a}	0.00 ± 0.03^{a}	−0.26 ± 0.41^{a}
	Immersed lab fitting	0.10 ± 0.05^{b}	0.07 ± 0.03^{a}	0.04 ± 0.01^{b}	0.22 ± 0.02^{b}
	Dry precision cut	−0.05 ± 0.02^{a}	0.03 ± 0.02^{a}	−0.01 ± 0.02^{a}	−0.03 ± 0.04^{ab}
	Immersed precision cut	0.08 ± 0.11^{ab}	0.04 ± 0.03^{a}	0.02 ± 0.01^{ab}	0.15 ± 0.12^{b}

Discussion

The sequential use of aligners that gradually move teeth into the desired position forms the basis of orthodontic treatment performed with removable thermoformed devices. The optimal adaptability of the aligners is critical to the success of this type of treatment.

The Invisalign system permits the placement of maxillomandibular elastics in precision cuts. Cuts can also be performed chairside, for example using pliers (e.g., IX890, Ixion Tear Drop Aligner Pliers, DB Orthodontics, Silsden, UK or OLS-1502 Clear Aligner Punch drop shape, Carl Martin, Solingen, Germany). Elastics are indicated for anchorage control when treating sagittal discrepancies between the dental arches, such as Class II malocclusions (according to the Angle classification). Although it is possible to simulate the result of use of these elastics virtually[17], it is still unclear whether they influence the dimensional stability of aligners.

Thermoplastic polymers used to fabricate aligners absorb water[11]. This absorption reduces moduli and the main glass transition temperature increases fracture strain and impact strength (softening or plasticising effect)[18]. Furthermore, changes to the dimensions of the appliance caused by hygroscopic expansion can affect its adjustment to the teeth and consequently modify the orthodontic forces[13]. The present study compared aligners submerged in artificial saliva (water bath maintained at 37°C, simulating the oral environment) with aligners kept in a dry environment to determine whether use of maxillomandibular elastics increases the dimensional changes caused by water absorption. The investigation was conducted over a 2-week period.

Galan-Lopez et al[19] recommend a customised aligner change frequency depending on the complexity of the case and the degree of movement desired. Despite the lack of consensus regarding the aligner change frequency, Bollen et al[2] found that changing aligners every 2 weeks produces more efficient tooth movement when compared to changing them weekly.

In the dry environment, the placement of maxillomandibular elastics changed the dimensions of the aligners, specifically in the places where the fittings were located; thus, the closer the placement of maxillomandibular elastics to the fitting, the more significant the dimensional change. These changes may have occurred due to the force released by the elastics on the aligners being located in the fittings rather than being globally distributed. The aligners with precision cuts presented statistically significant changes in nine sites (considering both maxillary and mandibular sites), whereas those with fittings made in the laboratory showed significant changes only for the mandibular 1M distance. These findings suggest that the use of maxillomandibular elastics can produce dimensional changes in aligners, and that fittings made by an orthodontist are preferable to precision cuts, at least with regard to the prevention of possible deformations.

When the maxillomandibular elastics were placed in conditions simulating the oral environment, a significant change was noted in most of the measured sites, with the exception of the AP left distance for the maxillary precision cuts and the AP left and right distances for the mandibular precision cuts. The immersed aligners with precision cuts displayed more significant changes in cross-sectional measurements, whereas those with manual fittings showed more significant changes in anteroposterior distances. These findings may be attributed to differences in how the fittings were produced, i.e., whether they were made by Align Technology or by the orthodontist. The manual fittings may have been located in a region closer to the centre of the aligner, which was more stable and less flexible, meaning that the strength of the elastics acted mainly in an anteroposterior direction. As the peripheral region is more flexible, the strength of the elastics could generate greater deformation in a transverse direction than in an anteroposterior direction. The immersion process increased the dimensional changes of the aligners.

For the immersed aligners, the most significant variation was observed in the intercanine distance in the maxilla after 14 days. An increase of 1.13 mm was noted for the aligners with fittings made in the laboratory and 1.22 mm for those with precision cuts. The greater height of the anterior teeth could explain the reduced resistance of the material in the most peripheral part of the aligner, thereby influencing the result. There were also significant variations in the distance between the first molars in the immersed aligners for the mandibular teeth 14 days after the start of the experiment. For the aligners with fittings made in the laboratory, a 1.05-mm increase was observed, and for those with precision cuts, the increase was 1.35 mm. Again, more significant changes were observed closer to the fittings. The use of buttons attached to the maxillary canines and mandibular molars might reduce the deformation in this region of the aligners.

The Invisalign system performs simultaneous tooth movements, and each tooth is moved by a maximum of 0.25 mm per stage[17]. The alterations in the maxillary intercanine distance observed in the first 24 hours were greater than this value and increased over time in the immersed groups. For the laboratory fitting group in the dry environment, the changes exceeded 0.25 mm from day 7. Changes of this magnitude were also noted from day 7 in the mandibular intermolar distance for the immersed group. The movements predicted for these teeth would not be achieved under these circumstances. Furthermore, the aligners that suffered these dimensional changes have the potential to move teeth (e.g., maxillary canines and mandibular first molars) to a non-planned position. The present authors therefore agree with the criteria adopted by the American Board of Orthodontics[20] that state that differences greater than 0.50 mm for linear measurements in the mesiodistal, faciolingual and occlusogingival directions can be considered clinically relevant.

In general, torque movement is not planned in the locations of fittings for maxillomandibular elastics. Thus, if fittings for elastics are made during treatment, the orthodontist should verify which movements are programmed for the teeth near to the site where the cut will be made.

The orthodontic forces exerted by aligners are partly determined by the thickness and stiffness of the material used for their manufacture. When materials with a higher elastic modulus are employed, it is possible to reduce the thickness to achieve the desired forces[13]. In addition, these forces are less affected by the frequency of aligner removal during treatment[21]. According to Cowley[22], one of the most significant flaws in removable thermoformed appliances is the excessive flexibility of the material close to the gingival margins. Invisalign aligners have a higher elastic index than other aligners made from thermoplastic polyethylene terephthalate glycol (PETG) materials[13]. Thus, the Invisalign system is hypothetically more susceptible to dimensional changes when acted upon by other forces, such as those exerted by maxillomandibular elastics, although further studies are required to confirm this.

In a study conducted in 2009, Kravitz et al[23] concluded that the mean accuracy of tooth movement with the Invisalign system was 41.0%. In 2017, this had risen to 87.7%[24]. According to Houle et al[24], this increase is due to a new version of the ClinCheck software, changes in the algorithm and improvements to the technique. The dimensional changes produced by maxillomandibular elastics can decrease the accuracy of the system, making it difficult for the expected result to be achieved. It may be necessary to make adjustments during treatment, generate new scans and make revisions that are time-consuming for the orthodontist, and increase costs and treatment time. Then, when the orthodontist intends to include Class II maxillomandibular elastics in orthodontic mechanics, these dimensional changes must be considered during the planning process.

Oral environment conditions are challenging to reproduce in vitro. The present authors were unable to reproduce tooth movement, occlusal contacts and exposure to microbial species; thus, the use of elastics over 24 hours was not in accordance with what is expected in real treatment scenarios.

Data regarding the effects of maxillomandibular elastics on aligners can improve aesthetic aligner treatment. Overcorrection during virtual planning can be necessary to achieve the desired position clinically, but the aforementioned data would help to achieve clinical outcomes closer to the predicted results, saving time and resources.

Conclusions

Invisalign aligners undergo dimensional deformation when Class II maxillomandibular elastics are placed. When immersed, the deformations suffered by the aligners with fittings made in the laboratory and with precision cuts increased. Changes observed in the maxillary intercanine distance and the distance between mandibular first molars with immersed aligners with both types of fitting were considered statistically and clinically significant. When Class II elastics are planned to be attached directly onto the aligners, these dimensional changes must be considered during the planning process.

Declaration

The authors declare there are no conflicts of interest relating to this study.

Acknowledgements

The authors thank the National Council for Scientific and Technological Development (CNPq) for the Master scholarship during the development of the present study. They also thank Dr Eduardo Kant Colunga Rothier for his generous donation of the aligners that composed the research sample.

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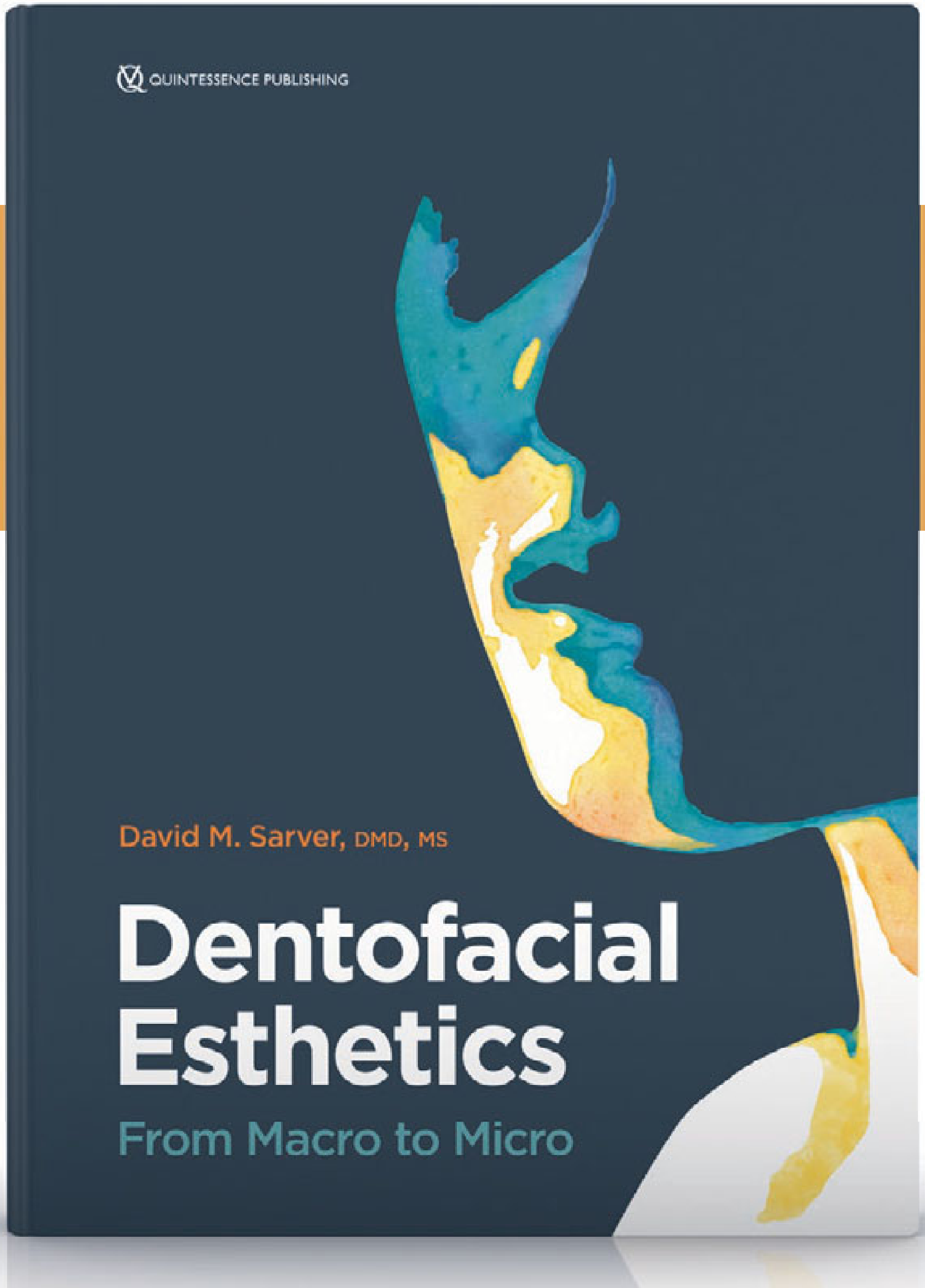
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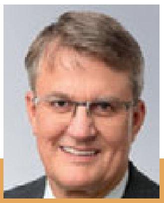

ORIGINAL SCIENTIFIC ARTICLE

Claudia Spanier, Anja Ratzmann, Karl-Friedrich Krey

Influence of print layer height and printing material on model accuracy and precision: A 3D surface comparison of models printed using fused filament fabrication

Claudia Spanier

KEY WORDS *3D printing, 3D superimposition, digital light processing, fused filament fabrication, orthodontic models*

Objectives: *To investigate the effect of layer height on the accuracy of orthodontic models utilising fused filament fabrication, particularly with regard to optimising in-office aligner manufacture. The suitability of fused filament fabrication was assessed by comparing the results to a high precision digital light processing control group.*

Materials and methods: *Based on a digital sectioned maxillary model, 18 physical models were printed using fused filament fabrication technology at different layer heights (50.0 µm, 80.9 µm, 100.0 µm, 150.0 µm, 160.8 µm, 200.0 µm, 250.0 µm, 300.0 µm and 332.6 µm) using two different materials (polylactide PLA NX2 and lignin-based polymer Green-TEC PRO [Extrudr, Lauterach, Austria]). Two DLP models with a layer height of 20.0 µm were produced, representing the control group. Subsequently, all physical models were digitally scanned and compared via 3D superimposition using GOM Inspect software (GOM, Braunschweig, Germany).*

Results: *The Dahlberg analysis and intraobserver intraclass correlation proved the accuracy of the 3D superimposition measurement to be excellent and repeatable. Models printed using fused filament fabrication technology from lignin-based polymer within the range of 100.0 to 332.6 µm decreased in precision as layer height increased. Furthermore, the analysis recorded declining precision of fused filament fabrication models below 100.0 µm. Models printed using lignin-based polymer were superior in precision compared to those made from polylactide.*

Conclusions: *The accuracy and precision of fused filament fabrication models can be regulated by altering layer height; however, other parameters such as optimised printing material and print settings are necessary for consistent high quality. As such, fused filament fabrication printing is an accurate, cost-effective and sustainable technology to create aligner models in orthodontic practice.*

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Introduction

As a result of the rapid technological advances that have taken place over recent decades, 3D printing is now a viable option in orthodontic practice. The symbiosis of intraoral scanning, virtual planning and appliance manufacturing offered by this technology allows for a complete digital in-office workflow.

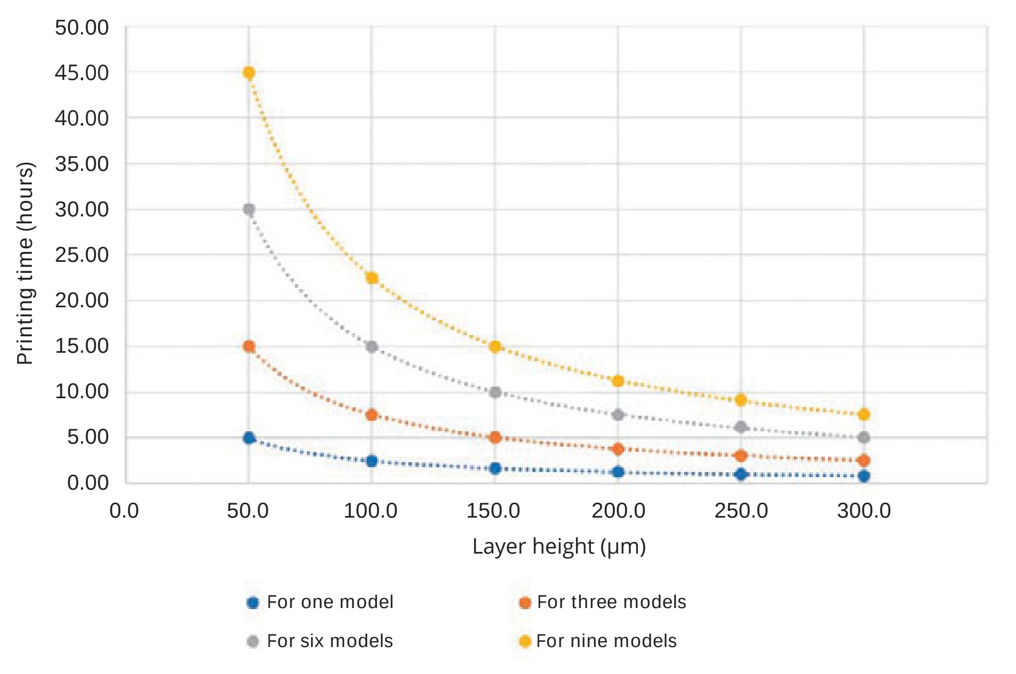

Fig 1 Printing time according to layer height.

Table 1 Simulation of printing times in relation to Z-resolution for the TEVO Tornado FFF printer

Layer height (µm)	Printing time for one model	Printing time for nine models
50.0	4 h 55 min	44 h 58 min
100.0	2 h 27 min	22 h 28 min
150.0	1 h 38 min	14 h 58 min
200.0	1 h 14 min	11 h 14 min
250.0	1 h 0 min	9 h 10 min
300.0	49 min	7 h 31 min

The origins of rapid prototyping date back to 1981 when the Japanese automobile designer Hideo Kodama invented an additive technology using ultraviolet light to cure polymers layer by layer. In 1986, Charles Hull established the first 3D printer utilising stereolithography (SLA). This was followed by the development of digital light processing (DLP) by Larry Hornbeck in 1987, fused filament fabrication (FFF) by Scott Crump in 1988, and the concept of inkjet-based 3D printing, also known as PolyJet photopolymer printing (PPP), in 1998[1].

SLA, DLP, PPP and FFF play a key role in the creation of orthodontic dental models. They mainly differ in terms of print resolution, printing speed, and the cost of the technology itself and its associated materials. Other factors include print volume, printing orientation, carbon footprint and post-processing procedures. Print resolution, which can be adjusted by altering the layer height, has been found to have a particular impact on the accuracy of dental casts[2]. Previous studies found a higher Z-resolution, which equates to a reduced layer height, to be correlated with higher accuracy of the printed object[2,3]. Interestingly, decreasing layer height leads to a higher amount of material to be printed and exponentially higher printing times (Fig 1, Table 1), resulting in higher overall modelling costs[4].

Consequently, FFF printing with as low a Z-resolution as is clinically possible is of crucial importance to enable cost-efficient in-office aligner production.

Taking into account the economic advantages and simplicity of use of FFF printers, it is surprising that numerous studies have examined the accuracy of dental models printed using SLA, DLP and PPP technology[3,5-9], whereas there is little research on FFF technology[2,4,10]. Concerning FFF printing, Kamio et al[4] utilised whole mandibles with layer heights from 200 to 500 µm, Lee et al[10] used single replica teeth with a layer height of 330 µm, and Pérez et al[2] focused on various printing parameters, working with cylindrical samples and layer heights of 150 and 250 µm.

The aims of the present study were twofold. First, the effect of Z-resolution on the accuracy of orthodontic models printed using FFF technology was examined utilising a sectioned maxillary model with layer heights ranging from 50.0 to 332.6 µm. Second, the clinical suitability of FFF printing was evaluated by comparing their accuracy to a high precision DLP control group with a layer height of 20 µm.

Materials and methods

To examine the quality of the models printed using FFF, a maxillary arch was taken from a randomly selected digital dental model and modified in OnyxCeph 3D Lab (Image Instruments, Chemnitz, Germany) by slicing at the bottom of the gingiva and distally from the maxillary right first premolar and maxillary left central incisor. Subsequently, additive attachments and a subtractive recess were added to this sectioned digital model. With the aid of the resulting master STL file (Fig 2), two identical physical models with a layer height of 20.0 µm were printed using DLP technology (SprintRay, Los Angeles, CA, USA, with die and model resin provided by the same company) (Fig 2), representing the control group. Then, 18 sectioned maxillary models were produced with FFF printing (TEVO Tornado, TEVO 3D Electronic Technology, Zhanjiang, China) with two different biopolymers: the polylactide PLA NX2 and the lignin-based polymer Green-TEC PRO (Extrudr, Lauterach, Austria) (Fig 2), each divided into nine different groups: 50.0 µm, 80.9 µm, 100.0 µm, 150.0 µm, 161.8 µm, 200.0 µm, 250.0 µm, 300.0 µm and 332.6 µm.

All the physical maxillary models were then digitised using a 3D model scanner (S600 Arti, Zirkonzahn, Gais, Italy, resolution 10 µm) to produce stereolithography (STL) test files. Utilising GOM Inspect 2019 (GOM, Braunschweig, Germany), the test files were superimposed onto the STL master file with the aid of an automated best fit algorithm matching the two virtual models according to the characteristics of the teeth. Applying the module “Surface comparison to CAD”, the accuracy was evaluated using measurement tools analysing 101671-point deviations, and also visually, using a continuous colour spectrum. Blueish nuances revealed deficiencies of the scanned model surface in comparison to the master file, whereas reddish nuances indicated an excess of scanned material and green indicated measurement agreement. With reference to previous studies[3,8,11,12], the critical threshold was set at 0.25 mm. Using the inspection tool, arithmetic mean (AM), standard deviation (SD), minimum absolute deviation and maximum absolute deviation were calculated. These values were gained by measuring the orthogonal distance between the corresponding points of the CAD polygon mesh and the point cloud of the test file. Subsequently, reports were drawn up from each 3D superimposition, including colour maps and measurement data (Figs 3 and 4). In the interest of examining the reliability of the 3D superimposition method of measurement, all the test files that originated from the models printed using FFF and lignin-based polymer were measured twice.

Statistical analysis

To evaluate the trueness of the dental models produced, the AMs of the deviation of the corresponding points of the superimposed surfaces of the test and master files were analysed. Precision was estimated by assessing the SD of the discrepancy between the compared surfaces of the files. For further evaluation, the percentage of points within the critical bounds of ± 0.25 mm and within the nominal bounds of ± 0.05 mm were analysed based on the normality of measurement points[13]. With the aid of the colour map analysis of the 3D superimposition, information was gained concerning the location and degree of deviation or congruence of the corresponding surfaces. Reliability was evaluated using SPSS Statistics (version 26 2019, IBM, Armonk, NY, USA). First, the intraclass correlation coefficient (ICC) of repeated measurements for a single observer on the basis of absolute agreement was calculated. Second, the Dahlberg error was analysed to assess variability due to technical inconsistencies.


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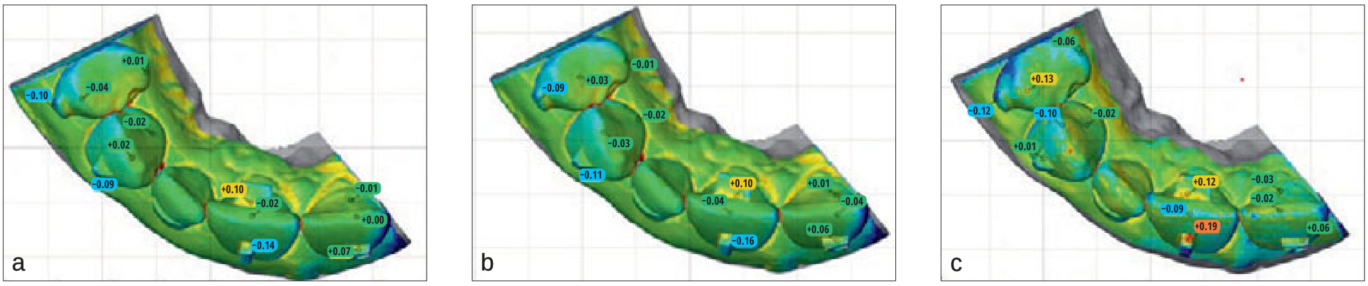
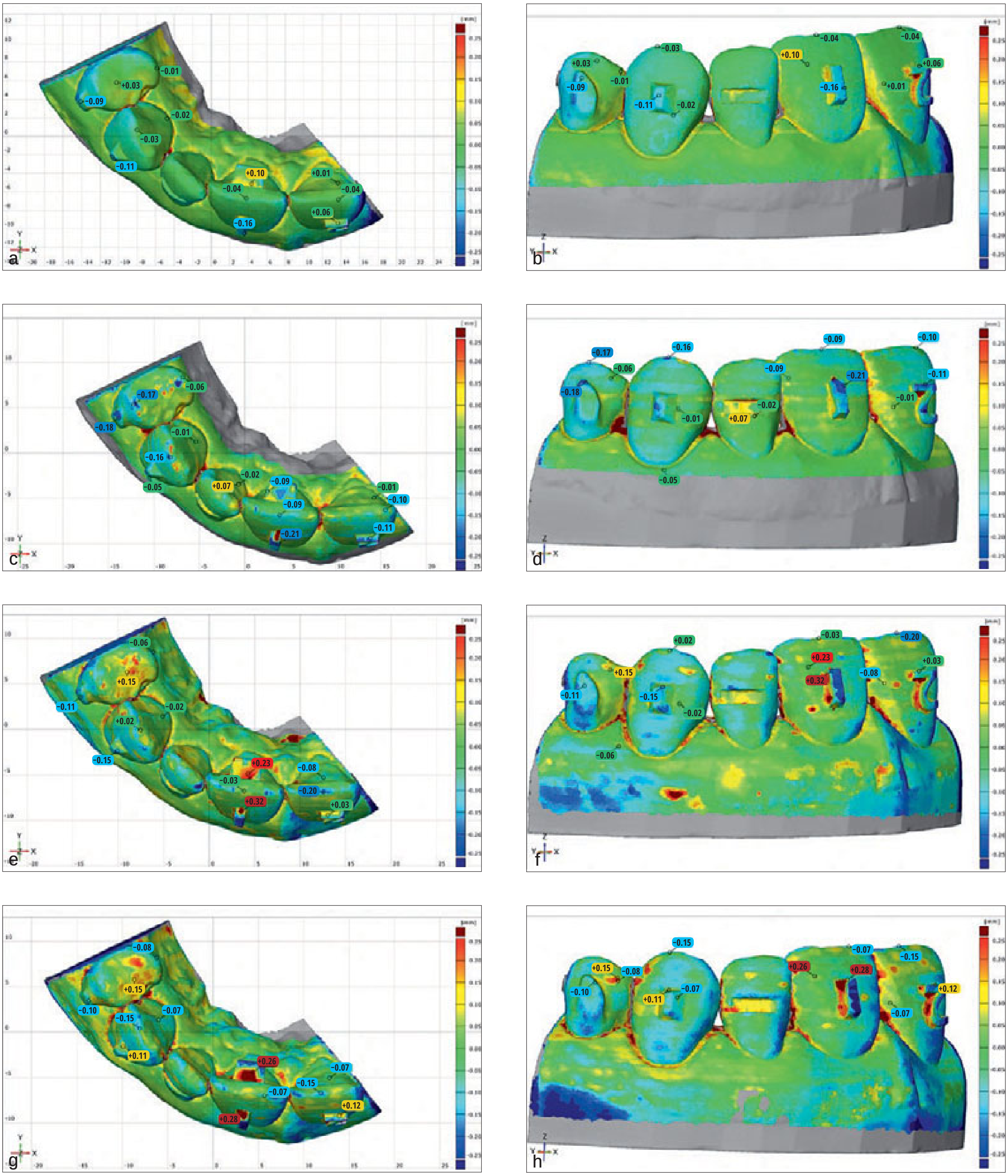
Figs 2a to x Sectioned maxillary dental model: **(a to c)** STL master file; **(d to f)** DLP control model (layer height 20.0 µm); **(g to i)** Lignin-based model (layer height 50.0 µm); **(j to l)** Polylactide model (layer height 50.0 µm); **(m to o)** Lignin-based model (layer height 150.0 µm); **(p to r)** Polylactide model (layer height 150.0 µm); **(s to u)** Lignin-based model (layer height 300.0 µm); **(v to x)** Polylactide model (layer height 300.0 µm).



Figs 3a to c 3D superimposition colour map analysis of test files and CAD reference file: **(a)** DLP control model (layer height 20.0 µm); **(b)** Lignin-based model (layer height 100.0 µm); **(c)** Polylactide model (layer height 100.0 µm).



Figs 4a to h 3D superimposition colour map analysis of FFF printed lignin-based dental model with different layer heights and CAD reference file: **(a and b)** Layer height 100.0 µm; **(c and d)** Layer height 150.0 µm; **(e and f)** Layer height 200.0 µm; **(g and h)** Layer height 250.0 µm.

Table 2 Reliability of 3D superimposition method of measurement in GOM Inspect 2019 for AM and SD

Layer height (µm)	AM measurement 1 (mm)	AM measurement 2 (mm)	SD measurement 1 (mm)	SD measurement 2 (mm)
50.0	−0.03	−0.03	0.11	0.11
80.9	−0.04	−0.04	0.10	0.10
100.0	−0.03	−0.03	0.09	0.09
150.0	−0.04	−0.04	0.10	0.10
161.8	−0.03	−0.03	0.10	0.10
200.0	−0.03	−0.02	0.12	0.11
250.0	−0.03	−0.03	0.12	0.12
300.0	−0.02	−0.02	0.12	0.12
332.6	−0.02	−0.02	0.13	0.13
Dahlberg error (mm)	0.002357		0.002357	
ICC (absolute agreement)	0.900		0.967	

Results

The reliability examination of the 3D analysis is shown in Table 2. From the values of the intraobserver ICCs (ICC AM 0.9; ICC SD 0.967), it can be stated that the applied measurement method via 3D superimposition has high reliability. Moreover, having quantified the technical measurement error by implementing the Dahlberg formula (Dahlberg error AM ≈ 0.002 mm; Dahlberg error SD ≈ 0.002 mm), the excellent suitability of 3D analysis using GOM Inspect is reinforced.

The outcome of the comparison of the 3D superimposition of test and source files is summarised in Table 3. Further statistical calculations of the percentage of points within nominal bounds for the lignin-based polymer models printed using FFF and the DLP control group are presented in Table 4.

Examining the parameters of accuracy, namely the AM, SD and percentage of points within the critical bounds, the overall differences between the experimental groups (FFF printed lignin-based polymer, FFF printed polylactide and DLP control group) were determined (Table 3).

The AM of the deviation of the corresponding points of the superimposed surfaces ranged from −0.04 to −0.01 mm in the groups that used FFF printing and from −0.02 to −0.01 mm in the DLP control group. Concerning trueness, FFF printed models seemed to have smaller overall dimensions[10], whereas those fabricated using DLP printing only had slightly smaller dimensions.

In terms of precision, the lignin-based polymer models printed using FFF displayed overall lower SDs and a higher amount of measurement points within the critical bounds of ± 0.25 mm than the polylactide models printed using FFF (Table 3, Fig 3). When compared to the DLP control group, the precision requirements were only met by lignin-based models with layer heights between 80.9 and 161.8 µm considering the SD and percentage of points within the critical bounds (> 98%). Moreover, all the lignin-based models printed using FFF, with the exception of the model with a layer height of 332.6 µm, had over 95% of points within the critical bounds, displaying a high level of consistency over a wide range of layer heights (50.0 to 300.0 µm). Interestingly, only the FFF printed polylactide model with a layer height of 250.0 µm also met these requirements.

Table 3 Measurement data for the 3D superimposition and percentage of points within the critical bounds as a function of layer height, technology and material of the dental models studied

Material/ technology	Layer height (µm)	AM (mm)	SD (mm)	Points within critical bounds ± 0.25 mm (%)
Lignin-based/FFF	50.0	−0.03	0.11	97.18
	80.9	−0.04	0.10	98.02
	100.0	−0.03	0.09	99.18
	150.0	−0.04	0.10	98.02
	161.8	−0.03	0.10	98.35
	200.0	−0.03	0.12	95.65
	250.0	−0.03	0.12	95.65
	300.0	−0.02	0.12	96.04
	332.6	−0.02	0.13	94.28
Polylactide/ FFF	50.0	−0.01	0.22	74.31
	80.9	−0.02	0.19	80.91
	100.0	−0.03	0.18	82.94
	150.0	−0.02	0.20	78.64
	161.8	−0.02	0.20	78.64
	200.0	−0.02	0.21	76.58
	250.0	−0.03	0.12	95.65
	300.0	−0.03	0.24	70.02
	332.6	−0.03	0.15	89.85
Control group/DLP	20.0	−0.01	0.10	98.58
	20.0	−0.02	0.10	98.71

Table 4 Comparison of models printed using FFF with lignin-based polymer and the DLP control group based on the percentage of points within the nominal bounds

Material/ technology	Layer height (µm)	Points within nominal bounds ± 0.05 mm (%)
Lignin-based/FFF	50.0	33.87
	80.9	35.57
	100.0	40.04
	150.0	35.57
	161.8	36.74
	200.0	31.61
	250.0	31.61
	300.0	31.77
	332.6	29.64
Control group/DLP	20.0	37.59
	20.0	38.11

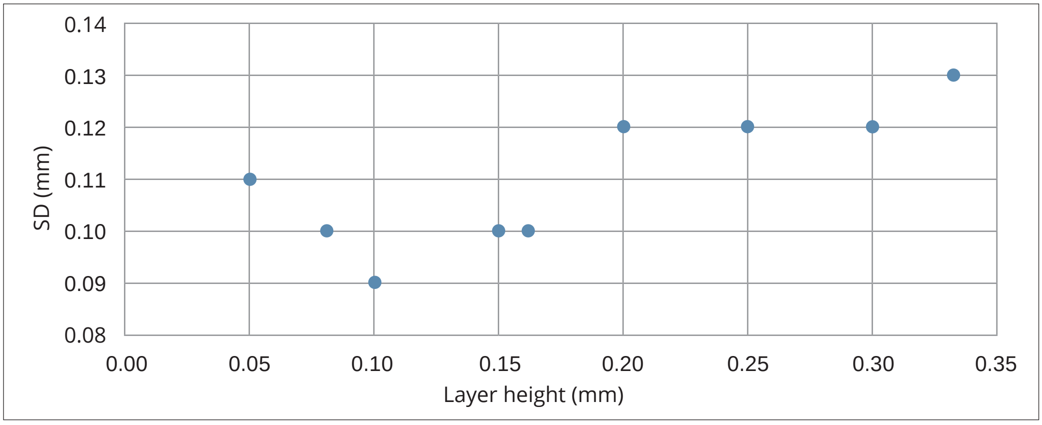


Fig 5 Relation between layer height and SD with an increase below 100.0 µm and above 100.0 µm through the example of FFF printed lignin-based models.

After examining the influence of Z-resolution in each of the experimental groups, some assumptions can be made (Table 3). In the lignin-based group, the most accurate and precise values were reached at a layer height of 100.0 µm (AM −0.03 mm; SD 0.09 mm; 99.18% of data points within the critical bounds and 40.04% within the nominal bounds), even surpassing the precision parameters of the DLP control group (Table 4). In contrast, the lowest consistency was found at a layer height of 332.6 µm (AM −0.02 mm; SD 0.13 mm; 94.28% of data points within the critical bounds). Interestingly, the best results for consistency in the FFF printed polylactide group were observed at a layer height of 250.0 µm (SD 0.12 mm, 95.65% of data points within the critical bounds), whereas polylactide models with a layer height of 300.0 µm (AM −0.03 mm, SD 0.24 mm, 70.02% of data points within the critical bounds) were the least accurate in their experimental group.

Analysing the SD independently of the layer height of the lignin-based models printed using FFF, an increase in SD was observed as layer height increased from 100.0 to 332.6 µm (Figs 4 and 5), whereas the SD decreased as layer height increased from 50.0 to 100.0 µm. Aside from the correlation between layer height and SD, a dependence was also observed between trueness and layer height in the lignin-based group, representing a slightly increasing AM with increasing layer height. In the FFF printed polylactide group, a similar relation was found between SD and layer height with the exception of layer heights of 250.0 and 332.6 µm (Table 3).

With the aid of the colour map analysis (Figs 3 and 4), the extent and location of the deviation of the corresponding surfaces of the test and source file could be explored. Greenish areas indicated an excellent match of the compared surfaces within the tolerated bounds, a transition into blue nuances indicated deficiencies or smaller dimensions of the tested surface in relation to the source file, and reddish areas represented an excess of scanned material. Generally, very precise greenish areas were found on cusp slopes and vestibular and oral smooth surfaces. Blueish colour patches were detected interdentally, at the cervix dentis and incisal edges, and on the vestibular, oral, mesial and gingival attachment surfaces. Reddish nuances, namely excessive dimensions, were found on the occlusal and distal attachment areas, occlusal fissures, cusp tips, cavity surfaces, and interdentally.

Discussion

The present study assessed the influence of layer height on the accuracy of FFF printed dental models applying a 3D superimposition and investigated the clinical suitability of FFF printing by comparing the printing quality to DLP, the gold standard.

When assessing trueness and precision, the model in printed, scanned and STL file form was compared to the source file, measuring point deviations between the test and master file in both negative and positive directions. Taking the Dahlberg error and the intraobserver ICC into account, an excellent measurement method can be ascertained (Table 2); however, additional sources of error were encountered during the scanning process that were not inspected in the present study. First, since the model scan utilised a light beam that dispersed linearly, certain locations were at greater risk of scanning error, such as obscured surfaces, namely occlusal grooves, interdental spaces and retractions on attachments[10,14]. Thus, to avoid artefacts, scanning images taken from different angles were combined. Second, the transformation of the scan data into an STL file may have caused errors due to data conversion[10]. Nonetheless, the clinical suitability of the S600 Arti model scanner was proven in a previous study[15].

Interestingly, the increase in accuracy that was anticipated to occur with a decrease in layer height, i.e., an increase in Z-resolution, did not entirely occur with the FFF printed sequential dental models. With the lignin-based group in particular, a continuous improvement in accuracy with regard to SD and the percentage of points within critical bounds was noted as layer height decreased within the range of 336.2 to 100.0 µm (Table 3). When layer height decreased beyond 100.0 µm, however, accuracy also decreased (Fig 5). In general, there appeared to be an optimal layer height of 100.0 µm in the lignin-based group, which was not found in the highest Z-resolution recommended in the manufacturer's instructions for the FFF printer. This may have been because, on the one hand, reducing the height of each layer leads to an increase in the number of layers and heightens the risk of printing errors such as artefacts or failure during the printing process itself[8]. To illustrate this point, a layer height of 50.0 µm has six times more layers than a dental cast with a layer height of 300.0 µm, and the former increases the likelihood of printing errors simply due to the additional number of layers to be printed. On the other hand, the FFF printer used exhibited obvious difficulties in pulling the previous layers from the printing platform due to an inaccurate distance between the nozzle and the platform at the beginning of the printing process when printing smaller layer heights such as 50.0 and 80.9 µm. It was difficult to level the print bed in first layer distances under 100.0 µm in practical handling, even if the printer being used was equipped with an auto-levelling system (BLTouch, Antclabs, Seoul, South Korea).

Comparing the accuracy between both FFF printed experimental groups with regard to printing material, models made from lignin-based polymer had a consistently lower SD and thus more measurement points within the clinical bounds than the PLA models (Table 3, Fig 3); as such, the printing material also seemed to affect accuracy. A previous study found that both polylactide and lignin-based polymers have excellent printing properties[16]. Differences could arise due to temperature resistance, as indicated on the data sheets for the materials provided by the manufacturer[17,18]. The lignin-based polymer Green-TEC PRO received a maximum of 10 points for temperature resistance according to the data sheet, whereas the polylactide PLA X2 only received 4 points[17,18]. Likewise, the lignin-based polymer scored slightly higher in the categories of impact resistance and maximum stress than the polylactide did. Equal values were recorded for visual quality, layer adhesion and elongation at break. In general, better accuracy seemed to arise due to the better material attributes of the lignin-based polymer utilised[17,18].

In terms of clinical suitability, it would be interesting to know how accurate and precise dental casts need to be to ensure the delivery of successful orthodontic therapy with aligners; however, there is currently no consensus concerning accuracy. Previous studies set limits of clinical agreement ranging from 0.2 to 0.5 mm[19-21]. Given that a considerable number of previous studies set their clinical threshold at 0.25 mm[3,5,8,10-12], the present study did the same. One reason for which a deviation of 0.25 mm was accepted was that the American Board of Orthodontics Grading System (ABO-OGS), established to evaluate dental casts for finished orthodontic treatments, considers a deviation of up to 0.50 mm to be clinically suitable in terms of alignment and marginal ridges[3,22]. The 3D superimposition algorithm applied compared the point deviations of corresponding surfaces, whereby a maximum deviation of 0.25 mm in both a positive and negative direction would equal a linear deviation of 0.50 mm maximum according to the ABO-OGS. Nonetheless, further studies are required to define a reasonable boundary for clinical suitability depending on the actual incoming transmission of tooth movement from the printed dental model to the vacuum-formed aligner.

The advantages of FFF printing are the cost-effective acquisition and maintenance of the printer, high variability and duration of the printing materials, ease of handling, time effectiveness in production and adequate reliability of the printing results[2]. Moreover, increased layer height offers significant economic benefits due to the slightly lower filament consumption and exponentially shorter printing times (Fig 1)[4]. Thus, printing time doubles when layer height decreases from 100.0 to 50.0 µm; as such, the total production time for nine 50.0-µm dental models would be 44 hours and 58 minutes, whereas printing the same number of models with a layer height of 100.0 µm would take half the time, namely 22 hours and 28 minutes. For a layer height of 300.0 µm, printing nine models would take no longer than 7 hours and 31 minutes, which is six times less time than that required to print nine models with a layer height of 50.0 µm (Table 1).

Although printing dental models with a high Z-resolution such as 50.0 µm is a more time-consuming process, it is not necessarily justified by proportionally higher accuracy. Despite the fact that the most accurate and precise printing result in the present study was found in the lignin-based group at a layer height of 100.0 µm (AM −0.03 mm; SD 0.09 mm; 99.18% of data points within the critical bounds and 40.04% within the nominal bounds), the benefit gained in accuracy was not in reasonable proportion to a printing time over 1.5 times longer compared to a layer height of 161.8 µm (AM 0.03 mm; SD 0.10 mm; 98.35% of data points within the critical bounds and 36.74% within the nominal bounds). Based on this, it would be interesting to determine whether even models with a layer height of 300.0 µm (AM −0.02 mm; SD 0.12 mm; 96.04% of data points within the critical bounds and 31.77% within the nominal bounds) transform adequate forces to the tooth using vacuum-formed aligners. Further research is required for clarification.

A clinical study by Davis at al[23] focused on the potential health concerns arising from volatile gases and particles during the FFF printing process. The commonly determined hazardous volatile compounds emitted by FFF printers were formaldehyde, a human carcinogen; styrene and methylene chloride, considered probably carcinogenic for humans; and toluene, a toxic hydrocarbon[23]. Nevertheless, the total volatile air compound emissions (TVOC ERs) were generally two orders of magnitude lower than those from dry process copiers, laser printers and personal computers[23]. Among the analysed printing filaments, namely nylon, acrylonitrile butadiene styrene, high impact polystyrene, polyvinyl alcohol and polylactic acid, the latter released the least TVOC ERs, and was the only one whose primary emitted monomer, lactide, was not considered a health risk[23]. Thus, an enclosed printer with an air filtration system may be recommended.

In terms of environmental longevity, polylactide and lignin-based polymer are excellent printing materials due to the quantity of renewable resources they contain. Furthermore, both filaments are biodegradable to some degree; indeed, the manufacturer's specifications state that the lignin-based polymer is compostable[17,18], although no time span is indicated for this.

Overall, FFF printing with cost-efficient, high quality and environmentally sustainable printing filaments represents an ingenious additive technology to be used in aligner orthodontics.

Conclusions

Considering the limitations of the system studied, it can be concluded that layer height affects accuracy and precision, but that other parameters, such as printing materials and settings, influence the results of FFF printing. A higher Z-resolution does not necessarily lead to higher accuracy and precision; rather, there seems to be an optimum range of layer heights depending on FFF print settings and material. In the present study, the lignin-based polymer was shown to be an excellent FFF printing material with an optimum layer height of 100.0 µm, even surpassing the precision requirements of the DLP printing control group.

FFF printing is a high quality, cost-effective and sustainable technology for producing aligner models with respect to optimised layer height, print settings and material. Indeed, a higher layer height results in a higher printing velocity and thus exponentially shorter printing times (Fig 1, Table 1). The optimal layer height with regard to accuracy and precision in printing is approximately 100.0 µm. For FFF printing, a lower layer height offers no advantages in terms of accuracy, but rather leads to long printing times and thus non-efficient print loads. Ultimately, a Z-resolution lower than 100.0 µm does not seem to yield any economic or clinical benefit. Moreover, dental models printed using FFF with layer heights higher than 100.0 µm show barely any loss of accuracy within a certain range. It would be interesting to investigate how the high precision of FFF printed models correlates with the clinical efficacy of orthodontic aligners. Thus, future studies are required to determine the minimum effective layer height that transforms optimal forces onto the teeth using vacuum-formed aligners.

Declaration

The authors declare these are no conflicts of interest relating to this study.

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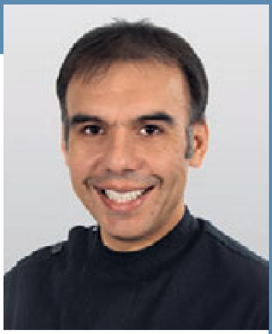
CASE REPORT

John Andrew Hagiliassis, George Abdelmalek

Aligners and smile makeovers: The benefits are clear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KEY WORDS *adult orthodontics, aesthetic orthodontics, aesthetics, anterior reverse articulation, case report, crowding, diagnostic procedure, digital dentistry, facial dimension, interdisciplinary treatment, Invisalign, malocclusion, restorative dentistry*

Although the benefits of orthodontic treatment are well documented, the adult population has long been resistant to wearing metal braces. Smile makeovers have commonly consisted of masking misalignment with disproportionate restorative material and heavier tooth preparations. The advent of clear aligners, however, has allowed dental professionals to offer a smile makeover that is biological and minimally invasive. Moreover, by utilising technology and a simple 3D scan, it is possible to simulate the end result that patients can expect with different modalities, thus increasing the chances of case acceptance, patient motivation and informed consent.

Introduction

The benefits of orthodontic treatment have long been recognised by dental professionals and patients alike. The need or desire to correct crowded or misaligned teeth dates back to at least 1000 BCE[1]. Generational changes such as ubiquitous marketing, the advent of social media, the 'selfie camera' and, more recently, beautifying smartphone applications have resulted in drastically increased emphasis on having a 'straight, white smile' amongst other aesthetic enhancements[2].

Adults have generally displayed reluctance to wear braces due to their visually obtrusive nature[3,4]. Some have instead chosen to undergo restorative dental procedures to mask underlying misalignment or to simply tolerate the misalignment, with many adopting a closed-lip smile and/or experiencing decreased social and psychological wellbeing in consequence[5-7].

The aggressive consumer-facing marketing strategy adopted by Align Technology (San Jose, CA, USA) has seen the number of patients requesting Invisalign treatment rise steadily, particularly in the adult population[8]. Beyond its aesthetic benefits, Invisalign also results in improved patient comfort, reduced pain, better periodontal health, reduced soft tissue irritation and fewer clinical emergencies when compared to braces[4,9-11].

When patients present with a desire to improve their smile, it is prudent for the clinician to not only focus on teeth, but also to make a complete assessment of facial aesthetics. Various authors have described many different approaches and landmarks to use when assessing facial aesthetics, perhaps highlighting the subjectivity of the notion of beauty[12-14].

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Smile design is as much an art as it is a science. The principles of smile design commonly followed by the present authors are as follows:

- Buccal corridors: these are a critical aspect of smile aesthetics, and the aim is to achieve medium corridors where possible (5% to 15% negative space, where 0% refers to teeth filling the buccal corridor);
- Smile cant: to achieve facial harmony, the smile line must coincide closely with the interpupillary line[15];
- Reduction of gingival display: excessive gingival display can detract from an aesthetic smile. Reduction of gingival display can be achieved via intrusion of the maxillary teeth, use of facial injectables such as Botox or fillers in the labia oris elevators, crown lengthening, or a combination of all three;
- Smile arc: where the incisal edges of the maxillary teeth follow the lower lip and have a 'central/lateral step', meaning the incisal edge of the lateral step is 0.5 mm shorter than the central step;
- Golden ratio: the golden ratio of tooth size is followed as closely as possible to achieve visual harmony;
- Facial and maxillary midline: coincident midlines, particularly the facial and maxillary midline, can lead to less distraction of attention to the eye;
- Incisal edge shape: rounded edges generally indicate youth, whereas flatter/square edges indicate wear/age;
- Tooth colour: most patients consider a whiter smile to be more aesthetically pleasing, though this is subjective and should be discussed with patients individually.

Diagnostics and treatment planning

The patient underwent a thorough clinical examination and interview and a complete set of records were taken to help determine potential treatment modalities (Fig 1). Using a digital platform, the patient was provided with several different options which allowed her to visualise the benefits and risks of treatment, as well as the end results (Fig 2).

Clinical examination

The clinical examination showed that the patient had multiple missing posterior teeth and anterior tooth decay. She had recently had her maxillary right first and second molars removed at another practice due to decay. Her periodontal health was sound and she had no periodontal pockets; however, she had 2 mm recession on the mandibular right central incisor. Her anterior teeth were chipped and showed wear. The patient also had a tongue piercing.

The patient's extraoral facial characteristics were as follows:

- equal horizontal thirds;
- unequal vertical fifths, with the left maxillary region being wider;
- nasal septum deviation to the right-hand side;
- smile line in line with the interpupillary line;
- dolichofacial tendency.

Her perioral facial characteristics were as follows:

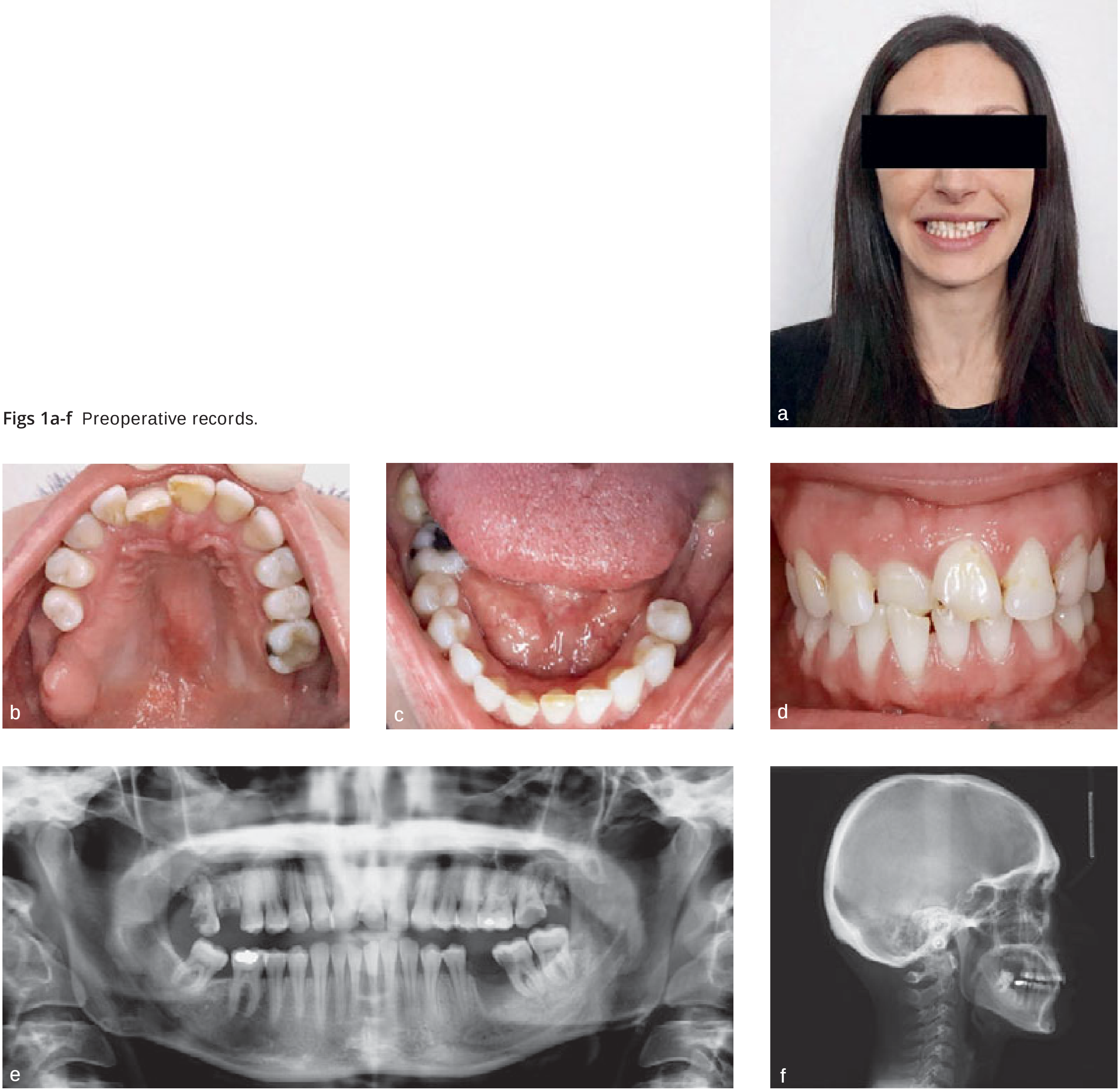
- lip canting to the right-hand side;
- maxillary first premolar to first premolar and mandibular second premolar to second premolar visible on smiling;
- 70% maxillary tooth display, 90% mandibular tooth display;
- medium to low lipline;
- maxillary central incisor midlines symmetrical to the facial midline;
- nasolabial line angles wider on the right-hand side, with narrow buccal corridors.

Her dental condition was as follows:

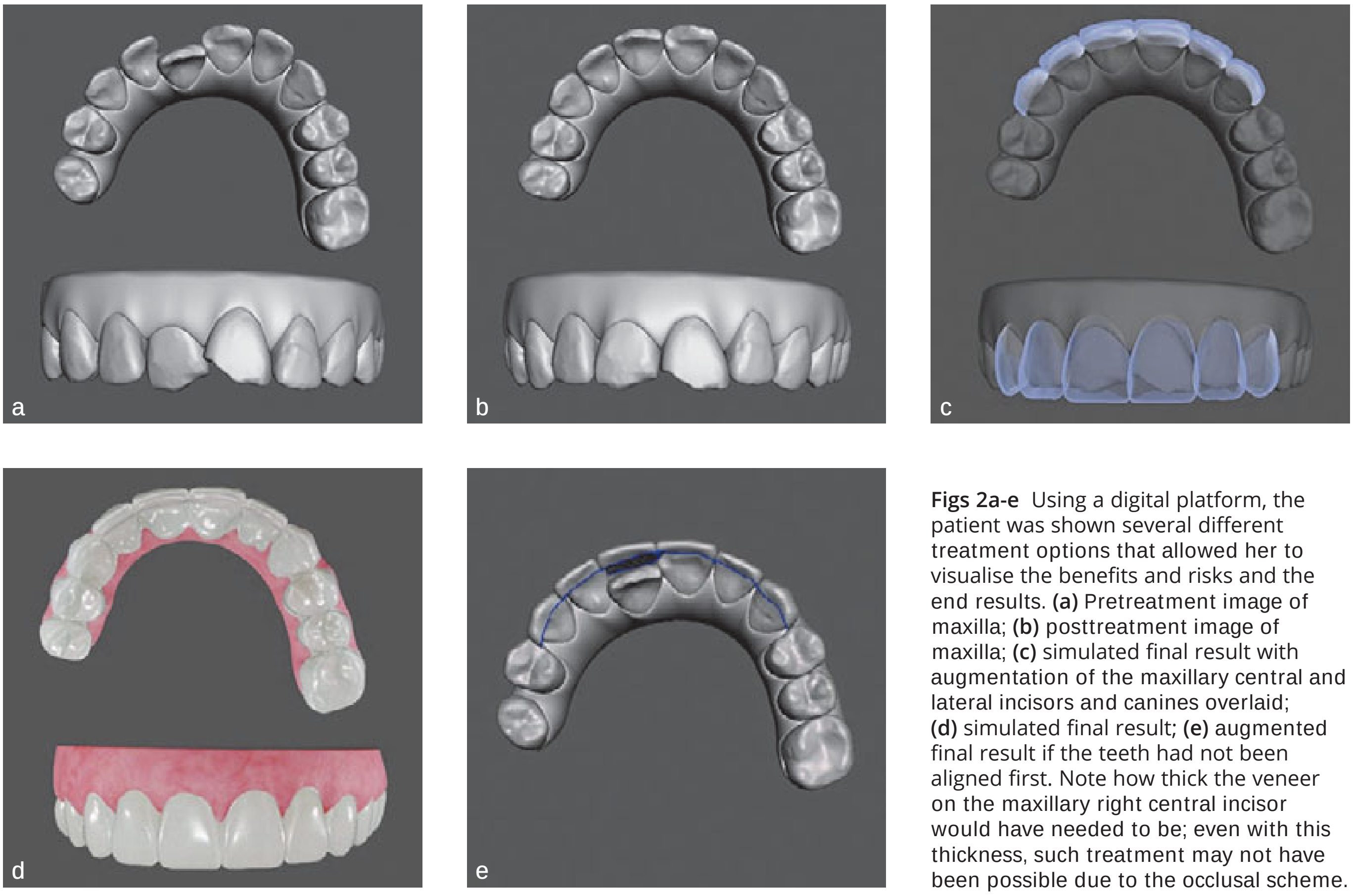
- maxillary and mandibular right central incisors in reverse articulation;
- uneven wear/chipping to the maxillary and mandibular central incisors;
- uneven gingival heights anteriorly;
- recession present on the mandibular right central incisor (2 mm);
- missing posterior teeth;
- periodontal heath otherwise sound.

Treatment options

Owing to the anterior reverse articulation, veneers (whether ceramic or composite) were considered unsuitable because of the risk of repetitive fracture due to non-axial loading. The use of third-party orthodontic software tools and simulations helped the patient to convey her concerns and requirements, such as further tooth movement and improvements to the tooth shape, position and colour, golden



Figs 1a-f Preoperative records.



Figs 2a-e Using a digital platform, the patient was shown several different treatment options that allowed her to visualise the benefits and risks and the end results. **(a)** Pretreatment image of maxilla; **(b)** posttreatment image of maxilla; **(c)** simulated final result with augmentation of the maxillary central and lateral incisors and canines overlaid; **(d)** simulated final result; **(e)** augmented final result if the teeth had not been aligned first. Note how thick the veneer on the maxillary right central incisor would have needed to be; even with this thickness, such treatment may not have been possible due to the occlusal scheme.

proportions and smile. Additionally, the improvement of bite alignment provided the clinician and patient with confidence that any future anterior restorative work would not be undertaken under concentrated force.

Given the software setup and the presenting complaint, the patient understood the importance of first undergoing orthodontic tooth movement. Gingival heights, ongoing maintenance and the risk of the tongue piercing were discussed. The treatment options offered to the patient were as follows:

- sequential aligner therapy to improve anterior crossbite and overall alignment;
- tooth whitening;
- composite resin Class IV restoration of the maxillary and mandibular central incisors and strategic enameloplasty on the other anterior teeth post–orthodontic treatment;
- composite veneers on the maxillary canines and incisors and the mandibular central incisors post–orthodontic treatment;
- ceramic veneers post–orthodontic treatment;
- gingivectomy to improve gingival heights if required post–orthodontic treatment;
- replacement of posterior teeth.

The patient selected sequential aligner therapy, tooth whitening and ceramic veneers.

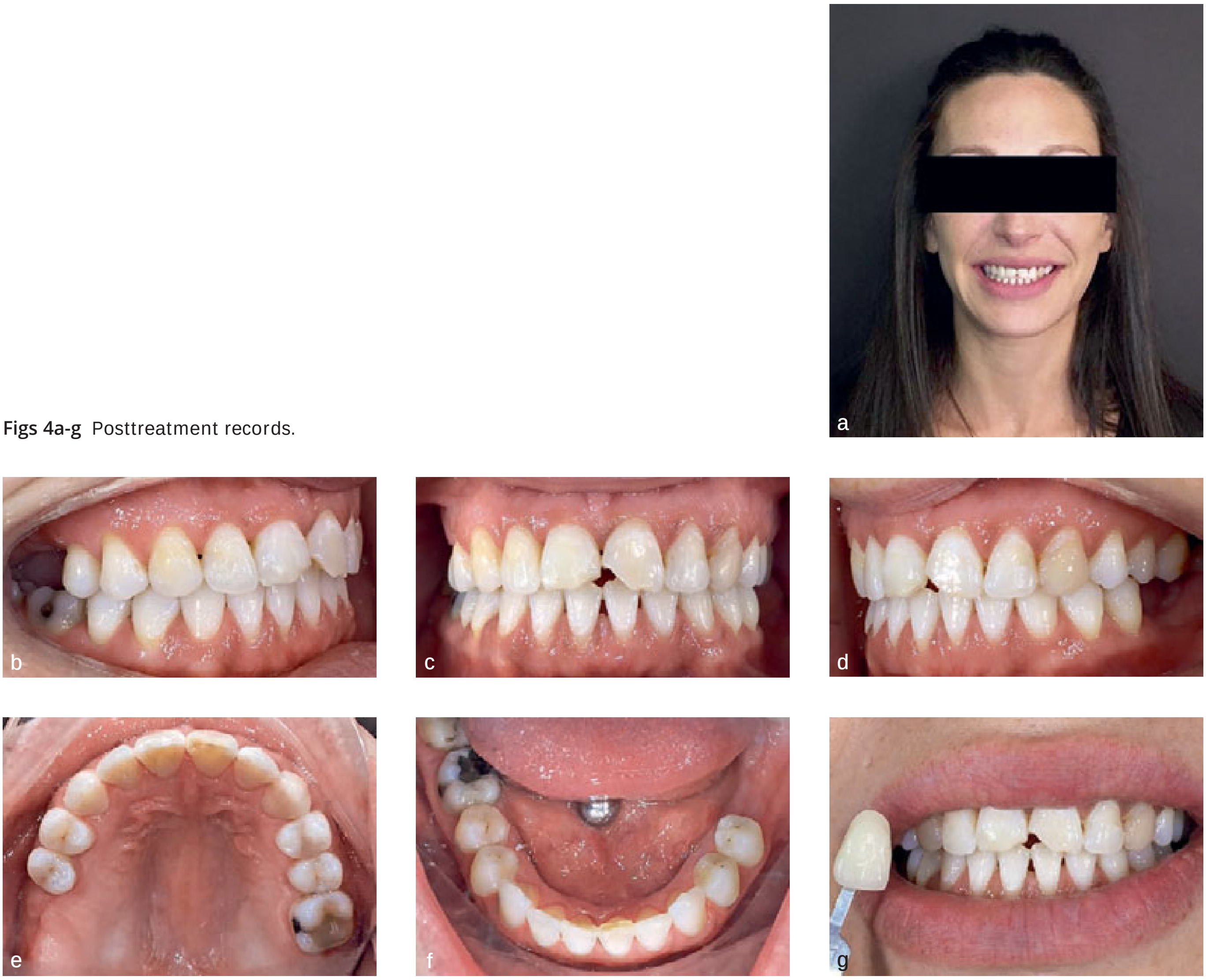
Risks and considerations

When embarking on a clear aligner treatment (CAT) plan that applies aesthetic teeth movements, the clinician needs to take into consideration patient consent and understanding of all the treatment options, the importance of compliance, alternative treatment options and side-effects of orthodontic and/or restorative treatment such as recession, increased periodontal bone loss, tooth whitening relapse, maintenance of whitening, lifelong retention, debonding and/or staining of bonding, and risk of pulpal devitalisation.

Treatment with orthodontic aligners

Using Invisalign aligners and with strategic movement velocities, 10-day changeovers, correct attachments and good patient compliance, progress was achieved in 13 months (Fig 3). Prior to and during reverse articulation changes, the patient was made aware that she would experience a period during which she would have an edge-to-edge bite on the maxillary right central incisor and was advised to limit consumption of hard foods during this time. One of the advantages of CAT with anterior reverse articulation is that the plastic in the maxilla and mandible (approximately 0.75 mm per aligner) disengages the teeth, reducing interference during movement. Photographs (Fig 4) and scans were utilised for evaluation and future planning.

Fig 3 Midtreatment frontal intraoral photograph.



Figs 4a-g Posttreatment records.


[redacted]

Figs 5a-e Final records following treatment with anterior e-max veneers.

Restorative treatment

Once alignment was complete, the attachments were carefully removed and the teeth were whitened using Zoom NiteWhite 16% CP take-home whitening treatment (Phillips, Amsterdam, The Netherlands). Options for augmenting the dentition were assessed and simulated using digital software (Meshmixer, Autodesk, San Rafael, CA, USA) and a polycarbonate try-in in the patient's mouth made from a digital wax-up.

A total of six e-max veneers (Ivoclar Vivadent, Schaan, Liechtenstein) were placed using minimal preparation principles on the maxillary canines, and two further veneers on the mandibular central incisors. The patient opted for whitening, ceramic veneers on the maxillary canines and incisors and composite bonding on the mandibular central incisors (Fig 5).

Retention

The retention protocol involved wearing thermoplastic maxillary and mandibular retainers for 3 months on a full-time basis. The 3-month clinical review showed stable soft and hard tissues, and as such, the patient was moved to nightly retainer wear with the expectation of lifetime retention. The positive anterior vertical overlap also acted as a retention aid.

Conclusion

This case would have been highly challenging and unpredictable had orthodontic treatment not been incorporated. The patient was open to CAT, but stated that she was not interested in fixed braces. Using technology, it was possible to design a stable, functional and aesthetic smile that incorporated a mix of orthodontics, restorative treatment, whitening and routine hygiene. The total treatment time was 16 months and involved a combination of sequential aligner therapy, external tooth whitening, enameloplasty and ceramic veneers. The patient's condition was reviewed after 1 year and was found to be stable.

Declaration

The authors declare there are no conflicts of interest relating to this study.

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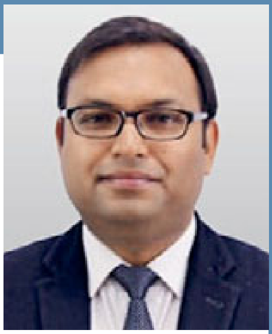
CASE REPORT

Prabhat Kumar Chaudhari, Ilser Turkyilmaz, Edlira Zere, Ramandeep Kaur Sokhi

In-house aligners for correction of relapse in mandibular incisor alignment



Prabhat Kumar Chaudhari

KEY WORDS *3D printing, 3D scanning, aligners, incisor crowding, orthodontics, relapse*

Objective: *To describe a technique for fully digital in-house aligner fabrication to treat orthodontic problems encountered during the coronavirus pandemic.*

Case description: *A 21-year-old woman presented to the outpatient department of the Division of Orthodontics and Dentofacial Deformities at the Centre for Dental Education and Research, All India Institute of Medical Sciences in New Delhi, India with the chief complaints of impingement due to a broken mandibular fixed retainer and relapse of mandibular incisor alignment. After resolving the impingement problem, a fully digital in-house aligner was used to correct the misalignment of the mandibular anterior teeth over a treatment period of 2 weeks without any support from an external laboratory.*

Conclusion: *The use of CAD/CAM technology together with 3D printing and thermoforming, as described in the present report, may represent a feasible approach for treating mild orthodontic problems without the need to outsource laboratory support; it is therefore a practical treatment option during the coronavirus pandemic.*

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Introduction

The coronavirus (COVID-19) pandemic is currently having a direct impact on all social settings and professions, including orthodontics[1]. As the circumstances surrounding the pandemic continue to evolve and the world suffers the consequences, orthodontic offices are resuming their services by taking precautions to reinforce infection prevention and control measures and minimise the number of appointments scheduled for treatment[1].

Maintaining the alignment of the mandibular anterior teeth in the corrected position and preventing them from returning to their initial pretreatment positions is challenging for orthodontists. Despite receiving the best possible care, only 50% of orthodontic patients are able to retain the alignment of their mandibular anterior teeth for the next 10 years[2].

Orthodontic relapse can be managed using fixed or removable appliances. The fixed appliances commonly used to correct relapse are labial braces, lingual braces and flexible wire bonded to the lingual surface of the mandibular anterior teeth after using brackets, and the frequently used removable appliances are the conventional Hawley appliance and clear aligners[2]. Fixed retainers prevent not only relapse but also tertiary crowding[3]. Aligner therapy facilitates the treatment of mandibular anterior crowding (mild spacing or crowding ≤ 4 mm) or relapse that occurs during the retention phase. Clear aligners are an aesthetic, efficient and comfortable appliance but require meticulous digital planning and clinical and laboratory procedures[4]. There are two types of clear aligners: analogue and digital. Analogue aligners are vacuum formed on the conventional physical stone cast and the teeth are reset. Fabrication of digital clear aligners begins with acquisition of a digital 3D model of the dental arch either by direct or indirect 3D scanning, the former using an intraoral scanner and the latter using desktop scanners, of the dental impression or stone cast. All the desired tooth movements are manipulated digitally and a series of models of the different treatment stages are 3D printed for thermoforming of aligners[4].

Currently, the most common application of 3D printing in orthodontics is in the commercial production of digital aligners to correct misaligned teeth[5]. First, digital models of the maxilla and mandible are acquired through intraoral or desktop scanning. Second, specifically designed computer-aided design (CAD) software is used to perform the digital tooth movement with the aim of placing the teeth in the desired position. Third, patient-specific digital models are created for various treatment stages in standard tessellation language (STL) file format. This is the most extensively used file format for 3D printing[4,5]. It encodes the surface geometry of a 3D object into a tessellated triangular mesh, a pattern consisting of small, non-overlapping adjoining triangles. Fourth, a 3D printer is used to produce rapid prototypes of these STL files of dental models for different treatment stages. Finally, orthodontic aligners are fabricated on these 3D printed dental models by thermoforming using thermoplastic sheets[6,7].

State-of-the-art clinical experience and high-quality evidence have shown that clear aligners are able to treat mild to moderate malocclusion with acceptable clinical outcomes comparable to those obtained with fixed appliances[8-10]. Furthermore, in the midst of the COVID-19 pandemic, aligner therapy offers the advantage of reducing the number of follow-up visits, which translates into fewer orthodontist–patient–parent encounters and may therefore help to prevent the spread of the virus and reduce the requirements for personal protective equipment (PPE). As a result, orthodontists could consider using aligners to treat mild to moderate malocclusion[11].

Thermoplastic clear aligners have attracted great attention from dental professionals and patients[12]; however, the main disadvantages of the Invisalign system (Align Technology, San Jose, CA, USA) and other similar systems are the dependency of orthodontists on laboratory support provided by these companies and the increased laboratory cost. The provision of in-house laboratory support would enable orthodontists to plan and deliver clear aligners for minor tooth movements.

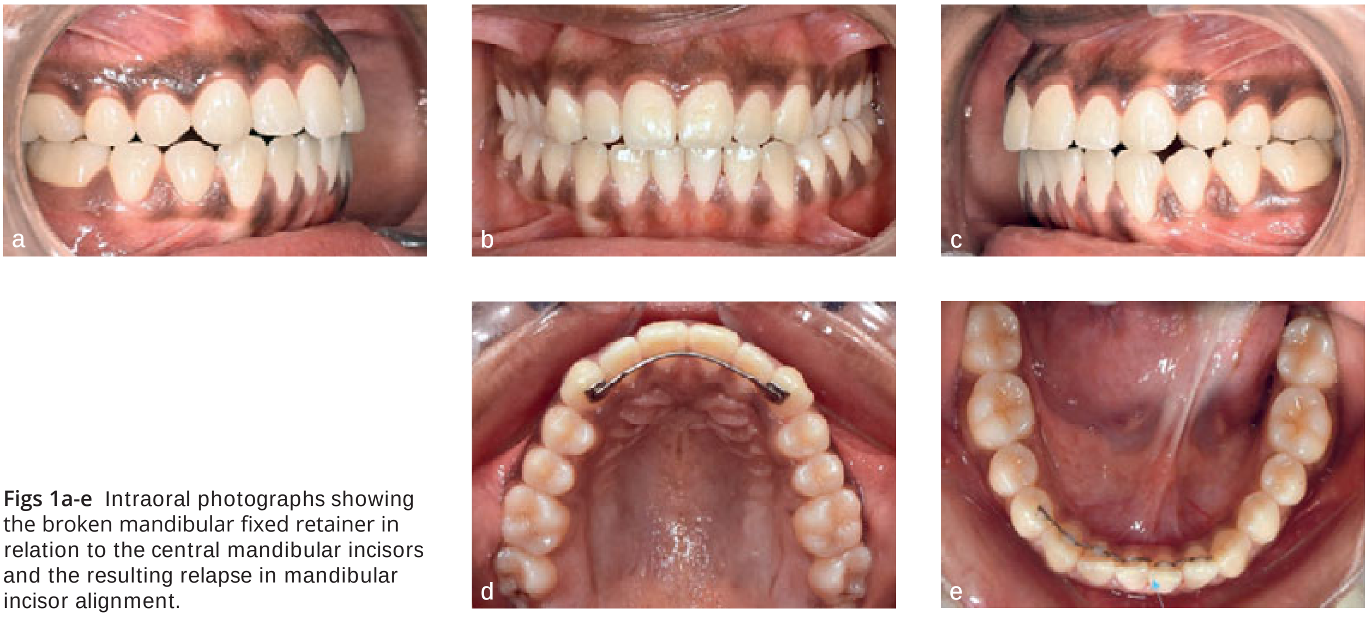
The present clinical report illustrates the application of in-house digital clear aligner therapy to correct mandibular incisor crowding and misalignment due to orthodontic relapse during the COVID-19 pandemic.

Case presentation

A 21-year-old woman called the Orthodontic Outpatient Department of the All India Institute of Medical Sciences, New Delhi, India, on the patient teleconsultation number introduced during the COVID-19 crisis with the chief complaints of impingement due to a broken mandibular fixed retainer and relapse in the alignment of the mandibular anterior teeth. As she had no COVID-19 history or symptoms, the patient was scheduled for an in-person visit. The broken fixed retainer was cut and adjusted using the appropriate PPE. Because the patient was concerned about the relapse of mandibular anterior alignment, a plan was made to align the mandibular anterior teeth using aligner therapy.

The patient stated that she had undergone nonextraction fixed orthodontic treatment and had been following a retention protocol for the previous 3 years; however, the pandemic situation meant that she had not been able to attend follow-up visits in the past 6 months. On clinical examination, the mandibular fixed retainer was found to be broken between the mandibular central incisors, while the maxillary fixed retainer was intact (Fig 1).

The broken retainer had caused relapse of the mandibular incisor alignment. The broken lingual fixed retainer was



Figs 1a-e Intraoral photographs showing the broken mandibular fixed retainer in relation to the central mandibular incisors and the resulting relapse in mandibular incisor alignment.

cut and adjusted to provide relief from the impingement. On clinical examination, the mandibular left central and lateral incisors and right lateral incisors showed mesiopalatal rotation and the right central incisor was labially positioned. The options to correct the relapse of mandibular incisor alignment using either fixed appliances or aligners were explained to the patient and her mother. After discussing the advantages and disadvantages of both appliances and the precautions required for follow-up during the COVID-19 pandemic, a joint decision was made to use aligner therapy to correct the relapse. Due to the pandemic situation, certain modifications were made to the digital plan and the complete in-house laboratory workflow to fabricate the aligners, which made the present case unique when compared to a previously published report using commercially available clear aligners[13].

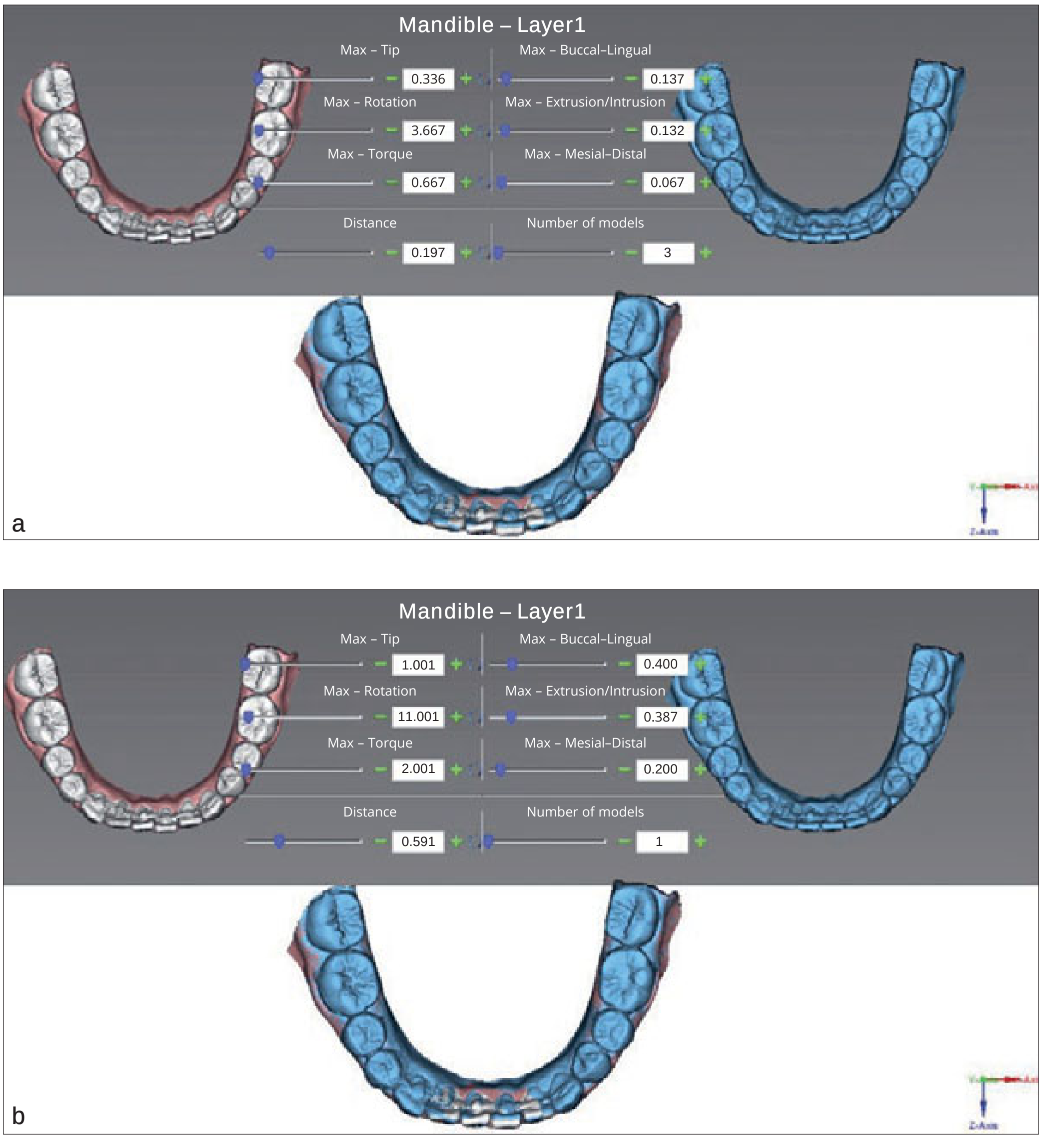
Treatment

Day 1

As per protocol, patients were required to wear a mask at all times when in the clinical area of the department except during treatment, as a preventive measure to limit the spread of COVID-19. The Indian government had classified the clinical area of the dental operatory as “moderate risk” and recommended use of PPE (N95 masks, goggles, latex examination gloves and face shields during aerosol-generating procedures) during clinical procedures. The patient was asked about her COVID-19 history and whether she was displaying any symptoms. She was also asked to rinse with povidone-iodine (0.23%) mouthrinse for 15 to 30 seconds prior to the clinical examination. The dental chair was sanitised after each patient using freshly prepared sodium hypochlorite solution. The doors of the postgraduate operatory were kept closed, with high-efficiency particulate air (HEPA) filters and separate PPE donning and doffing areas outside. The operatory was fumigated every day after clinical procedures.

The mandibular arch impression was taken using an alginate impression material, then immediately disinfected with alcohol-based (71% to 80%) instant surface disinfectant (Bacillol 25, Raman & Weil, Mumbai, India) and sent to the laboratory in a sealed plastic bag to pour. The stone cast of the mandibular arch was then scanned using a desktop scanner (Maestro 3D Desktop Scanner, AGE Solutions, Pisa, Italy). The scanning time was approximately 3 minutes and 30 seconds, and the scanned cast was saved as a digital model in STL file format. The STL file was then cleaned and repaired using orthodontic CAD software (Maestro 3D Ortho Studio Software, AGE Solutions).

Digital setup began with tooth segmentation and the mesiodistal dimensions of the teeth were measured. After marking the mesiodistal dimensions, the software auto-



a

Mandible – Layer1

Max – Tip: 0.336
Max – Buccal–Lingual: 0.137
Max – Rotation: 3.667
Max – Extrusion/Intrusion: 0.132
Max – Torque: 0.667
Max – Mesial–Distal: 0.067
Distance: 0.197
Number of models: 3

b

Mandible – Layer1

Max – Tip: 1.001
Max – Buccal–Lingual: 0.400
Max – Rotation: 11.001
Max – Extrusion/Intrusion: 0.387
Max – Torque: 2.001
Max – Mesial–Distal: 0.200
Distance: 0.591
Number of models: 1

Figs 2a-b Software showing **(a)** three aligners (set of three models) to achieve the desired result based on automatic planning and **(b)** manual planning to limit the majority of tooth movement in the mandibular incisors to ≈0.59 mm to align the teeth using one aligner.

matically computed a trim line along the tooth margins. The next step involved completion of tooth segmentation and definition of the local axis of the tooth, followed by the final step of tooth movement (translation and/or rotation) individually or in a group to obtain the expected final position. The final position of the mandibular teeth was planned digitally and saved in STL file format. Initially, the automatic plan in the CAD software showed that a total of three aligners were required to achieve the desired tooth positions with 0.197 mm movement with each aligner (Fig 2a). As irregularities were only present in the mandibular incisor region and the COVID-19 pandemic necessitated a reduction in the number of patient visits, a decision was made to limit tooth movements to the incisor region. Thus, a maximum of 0.590 mm tooth movement was planned in the mandibular anterior region using a single aligner (Fig 2b). Interproximal reduction of 0.2 mm was performed at each interproximal contact in the mandibular incisors, extending from the mesial aspect of the lateral incisor on one side to the mesial aspect of the lateral incisor on the other to create space for the correction of the misaligned incisors. The final digital model was generated using a 3D printer (Objet30 OrthoDesk, Stratasys, Minneapolis, MN, USA) and printed with commercially available 3D printable material (VeroWhitePlus for the dental model and SUP710 PolyJet as support material, both Stratasys) in 3 hours (Fig 3a). The aligner

Figs 3a-d **(a)** Final 3D printed model; **(b)** fabrication of aligner on the 3D printed model; **(c)** aligner fabricated for the patient; **(d)** FSW retainer adapted on the same 3D printed model that was bonded post–aligner treatment.

Figs 4a-c **(a)** Intraoral photograph of the patient wearing the aligner; **(b)** posttreatment intraoral photograph with rebonded mandibular FSW fixed retainer; **(c)** STL file of superimposition showing the initial situation and final position.

was fabricated using a thermoplastic sheet (0.75 × 125.00 mm; Duran, Scheu-Dental, Iserlohn, Germany) and a pressure moulding machine (Biostar, Scheu-Dental), then trimmed and finished before being delivered to the patient (Figs 3b and c). The product datasheet for Duran states that its chemical composition is polyethylene terephthalate glycol (PET-G). The aligner was trimmed in straight line margins at 2 mm beyond the gingival zenith[14]. The same 3D printed mandibular model was used to adapt the mandibular fixed retainer using flexible spiral wire (FSW) and bond this FSW retainer onto the lingual aspect of the mandibular incisors during the next visit after correction with aligner treatment (Fig 3d). FSW retainers are multistranded (0.0150- to 0.0215-inch) bonded lingual retainers used as a means of permanent retention to maintain the alignment of the correctly positioned anterior teeth[15]. As per the recommendations, a five-stranded coaxial wire was used; this is considered the gold standard[16]. The flexibility of the wire helps to maintain periodontal health. The present authors used 0.0160-inch coaxial stainless steel wire (Ortho Organizers, Carlsbad, CA, USA).

Day 2

After the intraoral fit of the in-house aligner was verified, the aligner was delivered to the patient and she was instructed to wear it for 24 hours a day, except during meals and oral hygiene care. A follow-up appointment was scheduled for 2 weeks later.

Day 15

At the 2-week follow-up, the misalignment of the mandibular anterior teeth was found to have been corrected and the teeth had been aligned to their normal position. The mandibular fixed retainer was bonded from canine to canine as per standard protocol during the same appointment. The standard bonding procedure was performed for the FSW retainer. The patient was advised to continue wearing the same aligner for 4 weeks as a retainer (Fig 4). The fit of the aligner was checked intraorally via visual and manual inspection and the position of the aligner was also verified to ensure it was completely flush against the teeth without any gaps, fitting snugly over the distal surfaces of the most posterior teeth.

Outcomes and follow-up

The present case report described a safe and successful approach to using CAD software, 3D printing and thermoforming to manage an orthodontic problem without the need for outsourced laboratory support. This may be a feasible option to treat mild orthodontic problems and prove useful during the COVID-19 pandemic.

Discussion

The COVID-19 pandemic, which originated in Wuhan, China in 2019, has now spread to over 200 nations throughout the world[17]. Dental practitioners and orthodontists were initially advised to treat only non-deferrable emergencies during the pandemic, such as pain or discomfort due to the sharp wire on a fixed appliance or bonded retainer, a broken bracket or tube, irreversible pulpitis pain and abscesses[11]. Patients requiring emergency orthodontic treatment and with no COVID-19 related history or symptoms should be treated with the appropriate PPE and in accordance with the guidelines set by their national/local authority[17-19]. Treatment may result in higher costs due to the requirement for PPE.

The duration of fixed orthodontic treatment ranges from 18 to 24 months and requires multiple visits at a 3- to 4-week interval over the course of treatment[20]. At the Division of Orthodontics and Dentofacial Deformities, the scheduled care of patients undergoing orthodontic treatment was abruptly suspended due to the national lockdown, and consequently many patients experienced complications due to this disruption of routine follow-up visits. In the absence of regular visits, Dental Monitoring (Paris, France) would be advantageous to track the patient wearing aligners. A recent study found that Dental Monitoring with Invisalign treatment reduced the number of appointments by 33.1%[21]. Dental Monitoring services are not currently available in New Delhi, India; however, in the present case, the patient visited on days 1, 2 and 15 of treatment, so there was no major requirement to monitor her.

Recent studies suggest that aligners are a suitable option to treat mild orthodontic problems during the COVID-19 pandemic as they reduce the number of follow-up visits and the spread of the virus[11,19]. Although clear aligners are useful for correcting mild to moderate orthodontic problems, treatment is dependent upon outsourcing laboratory services for clear aligner fabrication[8-10], a process that has become more complicated during the pandemic. As such, the present authors used a completely in-house facility for aligner treatment planning and manufacture. Aligner treatment comprises several steps, and the present report outlines the details of the clinical and laboratory procedures involved in in-house clear aligner fabrication and treatment. A recent systematic review found that aligners produced a result comparable to that obtained with fixed appliance therapy for correction of buccolingual inclination in the maxillary and mandibular anterior teeth[11].

Bushang et al[22] found that aligner therapy reduced treatment time by 67% as compared to conventional edgewise bracket treatment, and that doctor time varied depending on the experience of the treating orthodontist[22]. The clinical outcomes of aligner treatment can be comparable to those achieved with fixed appliance therapy for mild to moderate malocclusion[11] and also reduce the number of follow-up visits required; thus, in the current situation, orthodontists could consider using aligners to treat mild to moderate malocclusion. The pandemic is compelling and inspiring the orthodontic community to conduct further research with a view to making aligner therapy not only cost-effective, but also a clinically effective orthodontic treatment modality for complex cases[11,12].

In the present case, aligner treatment facilitated tooth movement in the anterior region to correct orthodontic relapse and reduced the total treatment time. The ability to manufacture aligners in-house facilitated rapid orthodontic care in this patient without needing to wait for laboratory support from aligner manufacturers during the COVID-19 crisis.

Conclusion

The present case report discussed a completely in-house method of aligner manufacture and treatment planning. The desired tooth movements for the correction of orthodontic relapse were planned on the digital models, and specifically designed CAD software was used to generate models for the different treatment stages in STL file format. The STL file was used for 3D printing to create the dental model on which the thermoforming was done to fabricate the clear aligner.

Declaration

The authors declare there are no conflicts of interest relating to this study.

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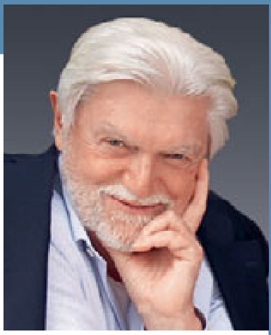
Summaries of Publications



Rainer-Reginald Miethke

The hybrid approach: A solution to overcome unpredictable movements in clear aligner therapy

Lombardo L, Albertini P, Siciliani G.
APOS Trends Orthod 2020;10:72–77.

Introduction

The current popularity of clear aligners is based on the superior aesthetics and comfort they offer. Adults, children and adolescents appreciate devices that are unobtrusive in appearance when undergoing orthodontic intervention. All aligner systems have developed remarkably in recent years, with improvements made in terms of materials, procedures and adjuncts. They are now able to generate optimal forces and moments that guarantee excellent biomechanical performance. Although clear aligners have become a widely applicable option, they still require sensible selection of a suitable patient. This patient will most likely be one who does not require extraction of any permanent teeth. If the orthodontic intervention is more challenging, fixed appliances are yet superior to removable aligners. This fact has been confirmed by other publications including one meta-analysis. Everything, though, depends on the tooth movements planned; however, the software will replicate every movement that is requested regardless of whether it can be accomplished with plastic splints or not, even if it will only be achievable in combination with orthognathic surgery. As such, no digital treatment plan/prediction should be accepted without critical examination. To a certain extent, aligner experts agree on tooth movements that are feasible with aligners and those that are categorically not. There is no question that anterior crowding can be corrected successfully and posterior teeth moved distally some 2.5 mm with aligners, but any bodily buccal expansion of lateral teeth, rotation of canines and premolars, extrusion of maxillary incisors and control of vertical overlap (deep/open bite) will not be reliably and efficiently corrected using this type of appliance.

In situations like extraction therapy and those involving complicated tooth movements, it seems reasonable to return to and rely on fixed (lingual) appliances. Because these devices will impact the patient's appearance, an acceptable compromise could be to assign all difficult movements to

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partial fixed braces and resolve everything else with clear aligners.

This publication is centred on hybrid solutions in which fixed multibracket appliances undertook tasks that would have been less predictably accomplished by aligners.

Correction of tooth rotations

Derotations depend to a large extent on the morphology of the affected tooth and therefore the first contact between the aligner and the tooth surface. The relevant literature is generally in agreement regarding the teeth for which rotational movements are most difficult to achieve: canines and premolars. Only about one-third of the programmed rotation can be effectually accomplished; this is in stark contrast to incisors due to the flatter configuration and greater mesiodistal width of the latter. For the aforementioned reasons, in the hybrid approach fixed appliances will be used which alternately will lead to fewer aligner attachments and aligners overall. Ultimately, these partial fixed braces reduce the treatment duration. The heavily rotated tooth and its neighbours are concretely bonded with tubes. A precise impression is then taken and the space for a wire (e.g., 0.013-inch CuNiTi) and the derotation are blocked out on the setup before the aligners (in this case F22 Sweden & Martina, Due Carrare, Italy) are thermoformed. In the example shown, the rotation was completely corrected after 4 months, and other symptoms were dealt with simultaneously.

Correction of maxillary constrictions

The specialist literature is again quite united in the view that transverse expansion is problematic to manage with aligners, particularly if bodily movements are intended, and even more so if the amount of expansion exceeds 2.0 to 3.0 mm. This implies that in situations where the crowns of posterior teeth are inclined palatally, aligners are the treatment option of choice. In all other circumstances, effective and efficient bodily expansion should be attempted with rapid maxillary expansion with (primarily in adults) or without miniscrew anchorage. Especially if miniscrew supported, the expander can be left in place and regular aligner therapy can still take place.

Correction of distoocclusion

According to the common orthodontic opinion, in Class II patients, maxillary posterior teeth can be consecutively moved 2.25 mm distally in 0.25-mm increments with the appliance being replaced every 2 weeks. This could be sufficient if the distoocclusion does not exceed a maximum of half a cusp. If larger, movement of arch segments or the Carriere Motion Appliance (Henry Schein Orthodontics, Carlsbad, CA, USA) with Class II traction are preferable. Ultimately, even miniscrews or pendulum devices should be considered. Progress can be accelerated if the wisdom teeth are extracted because this induces a regional acceleratory phenomenon. In any case, the final detailing is taken care of by aligners.

Correction of mesioocclusion

According to these authors, there are no known examples of treatment of Class III patients in which the mandibular posterior teeth have been pushed distally and the maxillary lateral teeth simultaneously relocated mesially. An approximation of this approach is the use of Class III elastics with clear aligners mainly if the mesioocclusion is not severe. In more serious situations, however, the hybrid technique requires traditional or skeletally anchored rapid maxillary expansion in combination with some type of facemask. After the occlusion is corrected, including a regular anterior vertical overlap, treatment can be continued with aligners. An impressive example is presented in this paper.

Correction of deep/open bite

The orthodontic literature expresses doubts as to whether achieving significant amounts of pure vertical movement (intrusion/extrusion) with aligners is feasible. Thus, what is often presented as an adversary 'proof' is merely a reflection of concomitant protrusions or retrusions. This means that any bite raising is in fact often the effect of a protrusion of the mandibular anterior teeth. What holds true for intrusions is even more the case for extrusions because only some 30% of the intended elongation is actually visible at the termination of therapy. The likely reason for the deviation is the insufficient grip of aligners on the individual teeth. The corrections of open bites that have been observed thus far are every so often counterfeited by palatal tipping of the incisor crowns.

To enhance the desired movements if only a few teeth are affected by an incorrect vertical position, tubes can be bonded at different heights (!). Again, the area of the brackets/tubes, the (CuNiTi) wire and the space required in the direction of movement must be blocked out. Beyond this, the aetiology of the vertical problem must be uncovered and addressed in the treatment plan.

Summary

To increase the predictability of aligner treatment if problematic tooth movements are involved, a hybrid approach with partial (lingual) fixed appliances is advisable. This technique may shorten the total treatment duration without a noticeable increase in cost.

Commentary

For the following comment, two ideas crossed this reviewer's mind. Both are a consequence of the recently closed 1st Virtual Congress of the German Association for Aligner Orthodontics (DGAO), which was a tremendous success with over 720 registrations (Schwarze Konzept, Stephanie Schwarze, Cologne, Germany). One of the many interesting lectures was given by the Viennese orthodontic specialist Dr Dietmar Zuran, with the striking title "All aligners are equal – but some are more equal than others…". In his presentation, Dr Zuran demonstrated what the most popular aligner systems currently offer, but even more eye-opening was his list of demands that are still to be fulfilled – an orthodontic requirements specification sheet, so to speak. For this reviewer this implies that yes, the advanced aligner companies are already very good and the orthodontic community appreciates their systems, but there is still considerable room for improvement so that the individual software can deliver all the applications an experienced clear aligner provider wishes to have at their disposal. In short, what is really needed is not the umpteenth generation of something, but greater choice/freedom in the function of the software rather than the hardware.

Generally, aligner companies want to make their customers believe that their proprietary system can correct every malocclusion without exception. This is time and again 'proven' in 'case presentations' by speakers who often have a certain (financial) relationship with the individual aligner manufacturer. Every clear aligner veteran, however, recognises that the one example/few examples are more exceptions than what can be practically expected in daily office routine. There is no doubt that the orthodontic fabric can be stretched to its maximum with innumerable aligners and endless additional aligners (case refinements). In other words, efficacy might exist, but not realistic effectiveness and efficiency; however, in this author's opinion, this, the optimal indicated and within biological limits fastest treatment, is what we owe those who come to us to for treatment of their orthodontic problem(s).

Fortunately, this commentator is not alone in his belief. He felt very much assured when listening closely during the 1st Virtual Congress of the DGAO to the lecture by Dr Achille Farina entitled "Efficient hybrid aligner treatment: When and how to apply this approach". Dr Farina is a specialist from Brescia, Italy who impressively elaborated why it is no disgrace to combine aligners with (partial) fixed lingual appliances. The presentation given by Dr Tommaso Castroflorio, Vice-Chair of the Specialisation School in Orthodontics at the University of Turin, took the same direction as Dr Farina's discourse. Both specialists can be considered excellent orthodontists with decades of experience in clear aligner therapy.

The aforementioned 'one example' reminds this critic of one of his own, many years ago: he planned the treatment for a teenager with a slight distoocclusion, some rotation and moderate crowding in the maxilla and mandible. He bonded the brackets and ligated the first wire. The patient left the office and forgot the orthodontist as he (and his excellent assistant) forgot the patient. One year later, during a routine control of patient records, he came across the file for this young woman. Flabbergasted, he asked his assistant to immediately make an appointment for the poor patient. She came and had no complaints, and her teeth were all perfectly straight so the fixed appliance could be removed on the spot. Orthodontic therapy was completed in two visits. Is this reality? Did it happen because the orthodontist was so good, his brackets so superior, his bonding so outstanding, his one wire so unmatched? No, it was undeserved good fortune accompanied by other positive facts. In short: every orthodontist (who is honest with themselves) has this one ‘case’ where they failed in many aspects and yet the treatment was successful. Beyond this, all orthodontic appliances have an optimal indication. That is why every capable orthodontist should have more arrows in their quiver. That is why it often takes 3 years of specialist training to become an orthodontist, and undoubtedly a lifetime to become a fairly decent one.

Quantitative evaluation of implemented interproximal enamel reduction during aligner therapy: A prospective observational study

Kalemaj J, Levrini L.
Angle Orthod 2021;91:61–66.

Introduction

The excitement around aligner therapy has increased the relevance of interproximal reduction (IPR), as the latter is one of the most frequently used methods to generate the space required to correct existing crowding. In contrast to IPR, sagittal and transverse expansion of the dental arches are limited by the available cortical bone. Another alternative is tooth extraction, but this entails the significant drawback of consistently creating excess space. IPR can also help to correct any anterior or overall Bolton discrepancy. The total space gained by IPR can amount to almost 10.0 mm in the mandible if it is predominantly the mesiodistal width of the premolars and molars that is reduced. Another benefit is that the intercanine distance can remain unchanged, as can the incisor inclination. Furthermore, it is feasible to opt for IPR to correct embrasures between adjacent teeth (black triangles) or, better still, avoid their development, particularly in truncated and/or periodontally compromised teeth that will additionally benefit from an increase in interradicular spongious bone volume.

If carried out using the correct method and with control of the patient’s oral hygiene, IPR is completely harmless to all dental tissues even in the long term. IPR techniques are numerous and range from the use of handheld abrasive strips to machine-driven blades/discs/disc segments. IPR is exceptionally helpful in aligner treatment primarily to guarantee an optimal splint fit and thus ultimately the intended outcome, including tight interproximal contacts. Precise in vivo execution (i-IPR) of the virtually planned (p-IPR) slenderising is therefore essential. These two types of reduction can be compared using a subroutine Bolton analysis in the ClinCheck software (Align Technology, San Jose, CA, USA).

The primary goal of this investigation was to compare p-IPR to i-IPR under typical clinical circumstances, and its secondary aim was to establish the causes of any discrepancies between the two.

Subjects and methods

The sample for this clinical study consisted of 50 consecutive Invisalign patients who were treated by six different practitioners (each contributing between five and ten individuals). All patients underwent Invisalign Lite or Comprehensive treatment in the maxilla and mandible including IPR in the anterior and/or posterior segment, in some cases only in one arch. The inclusion criteria were no periodontal pathology, cooperation with all treatment requirements and no restorations during aligner therapy. The practitioners’ level of experience (years practising/number of patients treated with aligners) was classed as either moderate (n = 4) or extensive (n = 2). The moderately skilled practitioners variably used handheld strips, burs or machine-driven strips for enamel removal. Most used measuring instruments to control the amount of hard tissue eliminated. The more experienced practitioners performed IPR either with burs or manual strips, and only one of the two used a space measuring gauge.

In all cases, impressions (manual or digital) were taken at the beginning of (t0) and after discontinuation of use of the initial set of aligners (t1 = end of treatment/start of refinement). All impressions were converted into digital ClinCheck models. On these, the mesiodistal width from the second premolar to the second premolar in the maxilla and mandible was measured using the Bolton tool in the

ClinCheck software. Thus, the i-PPR was calculated assuming that the width of two adjacent teeth was reduced equally unless precluded by specific circumstances (e.g., macrodontic teeth, prosthetic restorations).

The normality of the data distribution was controlled with a Shapiro-Wilk test, then standard descriptive statistics (mean, median, standard deviation) for data related to characteristics of the patients (affected arch and teeth) and practitioners (experience, impression/IPR tool and measuring device used) were calculated. A Wilcoxon signed-rank test was applied to examine the deviation between p-IPR and i-IPR. Finally, the three IPR techniques were subjected to a Kruskal-Wallis test whereas, due to data clusters, the variation between i-IPR and p-IPR on the one hand and IPR techniques, measuring tools, specialists' experience, impression methods and slenderised teeth on the other was studied using a multilevel multiple regression analysis. The reliability of the Bolton analysis tool in the ClinCheck was tested (calculation of intraclass correlation coefficient) by comparing the mesiodistal width of teeth that were spared from IPR. The level of statistical significance was set at $P = 0.05$.

Results

The sample size was based on an initial calculation with an additional 10% individuals to compensate for those who might be lost during the lengthy investigation. The reliability of the Bolton measuring function was high (mean difference 0.06 ± 0.02 mm), leading to an intraclass correlation coefficient of 0.98 with no noteworthy variation between the two impression techniques.

The mean age of the cohort was 31.4 ± 10.5 years (range 16 to 63 years). The majority were female (n = 36) and less than one-third (n = 14) were male. A total of 27 patients were treated with Invisalign Lite and 23 with Invisalign Comprehensive. IPR in the maxilla was planned for 43 patients (≙ 227 teeth) with a mean of 0.25 ± 0.13 mm, and in the mandible for 38 individuals (≙ 237 teeth) with a mean of 0.28 ± 0.12 mm. IPR in both the maxilla and mandible was carried out in 33 participants. It was scheduled either at the beginning of (n = 24, ≙ 231 teeth) or after arch alignment (n = 26, ≙ 233 teeth). Digital impressions were taken in 38 out of 50 cases. Unit-driven discs were used in 106 teeth, manual strips in 139 teeth and burs in 219 teeth.

The mean disparity between p-IPR and i-IPR was −0.15 ± 0.14 mm; in other words, i-IPR was generally and significantly less than p-IPR. Large deviations were observed, however, since the situation ranged from −0.43 mm (shortfall) to 0.50 mm (excess). The biggest and most significant discrepancies became apparent with use of manual strips for IPR and the smallest when burs were employed. Relating this to the individual tooth groups, it became obvious that the targeted IPR most often fell short in the mandibular canines, specifically when compared to the maxillary canines and premolars in both arches.

What held true for the different tooth groups could not be substantiated when the entire dental arches were contrasted. The side of the tooth that was scheduled for IPR made a difference, however: on the distal side, the intended value was obtained less exactly than on the mesial aspect. The practitioner's level of experience and impression method used and the patient's sex or age did not have an impact on the disparities between p-IPR and i-IPR; however, the discrepancy decreased if a measuring device was utilised. Finally, it was proven that the programmed IPR was closer, but not significantly, to the realised one if the teeth were aligned prior to slenderising. To describe this course of action, the authors of this study themselves used the term "round tripping".

Discussion

Initially, the authors highlight the fact that this was a clinical study, i.e., it did not take place under controlled conditions but in typical practice environments. The finding that i-IPR was generally smaller than that predicted by the ClinCheck is confirmed by other investigations. When this discrepancy was severest in the mandibular canines, this may have been due to the fact that they are frequently tipped forwards, distorotated and in close contact with their neighbouring units. On the other hand, if the mandibular premolars were very precisely reduced in size, this could be because IPR was seldom prescribed for them; this again was most likely based on the desire not to change the posterior occlusion.

If the discrepancy between p-IPR and i-IPR was greatest when the enamel was reduced using manual abrasive strips, this is not overly surprising given that this procedure is quite painstaking, especially in posterior teeth. Another factor might be the separating effect that arises when the strip is forced into the contact area and the affected teeth yield slightly, giving the illusion of existing space. The greater precision when performing IPR with subsequent control of the created distance with a measuring gauge does not require any further comment. The improved performance of IPR after initial alignment (round tripping) is a consequence of the increased accessibility of the interproximal spaces but comes at a biological 'price', potentially leading to more frequent root resorption.

In their study, these authors regarded a discrepancy of 0.15 mm as clinically significant. This was because the minimum prescribed amount of IPR between two teeth ordinarily amounts to at least 0.20 mm. Overall, the observed failure to complete the IPR prescribed by the system was minor and not fundamentally influenced by practitioner or patient characteristics. The strength of this typical multicentre clinical study is also one of its limitations because it involved many confounding personal and technical variables. One can also question the precision of the Bolton subroutine measuring tool.

Summary

- The outcome of this clinical study was that clinicians most often fail to attain the exact amount of IPR originally planned in the ClinCheck system. The general tendency was to remove less enamel than foreseen during the virtual treatment simulation.
- The mandibular canines were the teeth where the discrepancy between virtual and factual reality was greatest. The same was true if only the dimension of the distal tooth surfaces needed to be reduced.
- IPR was most frequently carried out with burs. Using these cutting tools also led to the smallest deviations between i-IPR and p-IPR.

Commentary

Overall, this paper offers a look into the daily work of our colleagues in Italy where they cook with water – like everywhere in the world. They use different pots (IPR techniques), are a bit more accurate or relaxed (IPR control), but ultimately get what they wanted – boiling water (a patient with an aesthetic smile). But is that the final truth? Almost certainly not, because it looks as though the patients/practitioners were every so often not satisfied and requested additional aligners ("... after the first set of aligners..."). Was insufficient IPR one cause, one of the main causes, or indeed the main cause for the second phase of treatment? It would also be interesting to know how completely the results of therapy would meet the requirements of a Board Certification if the amount of IPR matched that suggested by the Invisalign system exactly, and how good these results were in cases where the real IPR deviated significantly from that calculated by the system. Just a few initial questions.

The authors then state: "Therefore, IPR in adult patients seems to have a positive effect on interradicular bone volume, particularly in the presence of periodontal bone loss." Reading this, this reviewer was shocked to realise that he had become so old and yet was not aware that performing IPR would increase the bone volume between the affected teeth. He would actually have expected the opposite (i.e., that there would be a negative effect on the bone between roots), because originally anterior teeth in particular can be sagittally staggered, which allows for more space between their roots than if they are lined up next to one another like fenceposts. Reading the quoted reference increased this commentator's confusion since he noted: "Overall, treatment of adult crowding using Invisalign and IER, particularly in patients with severe conditions (with periodontally high-risk dentition), appears to have a positive effect on the interradicular bone volume, at least in adult female patients. The effect is also apparently **independent of IER** (bold emphasis by this author)"[1].

In the second reference, a statement is found that proves more the inverse than what this article's authors used the quote for: "Drawbacks (of IPR – this author) are marginal bone loss and periodontal damage, especially if the distance to adjacent tooth roots is under 0.8 mm [44]"[2].

Furthermore, it should be commonly agreed that volume is a 3D entity, and should thus be described by a dimension to the power of three. Also, in the text by Hellak et al[1], the word 'volume' only appears sporadically, but the term 'distance' is found regularly, measured in millimetres. In short, distance can be captured/comprehended easily – in contrast to volume which is far more demanding to compute and understand.

Again, this critic and perchance his readers will conclude: learning/acquiring new/better knowledge never ends. In the old thriller “Altered States”, the scientist (!) Eddie Jessup drops this hint: “The final truth of all things is that there is no final truth. Truth is what’s transitory. It is human life that is real.”

References

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2. Reichert C, Hagner M, Jepsen S, Jäger A. Interfaces between orthodontic and periodontal treatment: Their current status. J Orofac Orthop 2011;72:165–186.

Periodontal parameters in adult patients with clear aligners orthodontics treatment versus three other types of brackets: A cross-sectional study

Mulla Issa FHK, Mulla Issa ZHK, Rabah AF, Hu L.

J Orthodont Sci 2020;9:4.

Introduction

One of the main motivations for patients to consider orthodontic treatment is to improve their appearance and smile. Standard therapy with fixed braces, metal wires and various unavoidable auxiliaries makes oral hygiene quite demanding. If inadequate, the intervention can severely affect the periodontium and ultimately the enamel due to plaque and a subsequent change in the oral bacterial flora. Thus, healthy tissues are a prerequisite for successful orthodontic treatment. Plaque adhesion is a corollary of electrostatic interactions and the Van der Waal forces depending on the retention capability of the surface structure for microbiota.

There are typical physical and clinical disparities between different brackets that influence the extent to which biofilm is accumulated. The general understanding is that self-ligating (SL) brackets retain less debris than conventional metal (CB) and conventional ceramic (CCB) ones because the elastomerics used to attach the wire are the main source of pollution. When comparing bracket-based braces to aligners, it must be acknowledged that clear aligners cannot be the appliance of choice in every instance when orthodontic therapy is required.

Since these authors thought there were not sufficient data regarding how conventional and self-ligating braces plus clear aligners relate to each other periodontically, they sought to analyse this by means of seven gingival parameters.

Subjects and methods

This was a cross-sectional study on 80 orthodontic patients (40 men, 40 women) treated and monitored at different hospitals between December 2015 and February 2016. The sample was divided into four groups of 20 patients according to the type of appliance with which they were treated:

- Group 1: Conventional edgewise metal brackets with steel ligatures (Equilibrium 2, Dentaurum, Ispringen, Germany); 7 men and 13 women, mean age 26.7 ± 5.2 years.
- Group 2: Conventional ceramic brackets, ligation mode not mentioned (steel ligatures?) (Damon Clear Smile, Ormco, Orange, CA, USA); 11 men and 9 women, mean age 27.7 ± 8.2 years.
- Group 3: Self-ligating brackets (Tomy International, Tokyo, Japan); 10 men and 10 women, mean age 26.9 ± 5.2 years.
- Group 4: Clear aligners (AngelAlign, Shanghai, China/Invisalign, Align Technology, San Jose, CA, USA); 12 men and 8 women, mean age 26.9 ± 4.8 years.

The inclusion criteria were age ≥ 18 years, skeletal Class II or III and at least 6 months in therapy with fixed braces in the maxilla and mandible. The exclusion criteria were smoking, pregnancy, diabetes, circulatory disease, medication that could affect the gingival status, use of disinfectant solutions or mouthrinses in the last 6 months, recent periodontal interventions, and extensive restorations close to the gingival margin.

The assessed periodontal parameters collected by just one calibrated examiner were Plaque Index (PI), Gingival Index (GI), Gingival Bleeding Index (GBI), Sulcus Bleeding Index (SBI), Papillary Bleeding Index (PBI), Basic Periodontal Examination (BPE) index and bleeding on probing (BOP).

For statistical purposes, standard data (mean, standard deviation) were calculated. A multivariate and Bonferroni correction were also implemented ($P < 0.008$).

Results

The mean values for the individual indices and information about significance found were as follows:

- PI: Group 1 = 1.7, group 2 = 1.6, group 3 = 1.5 and group 4 = 0.2; groups 1, 2 and 3 were significantly higher than 4.
- GI: Group 1 = 1.3, group 2 = 0.9, group 3 = 0.8 and group 4 = 0.0; the differences between groups 1 and 3, 1 and 4, 2 and 4, and 3 and 4 were significant.
- GBI: Group 1 = 11.3, group 2 = 4.2, group 3 = 0.7 and group 4 = 0.0; the differences between groups 1 and 2, 1 and 3, 1 and 4, 2 and 3 and 2 and 4 were significant.
- SBI: Group 1 = 1.9, group 2 = 1.3, group 3 = 0.5 and group 4 = 0.0; the differences between groups 1 and 3, 1 and 4 and 2 and 4 were significant.
- PBI: Group 1 = 1.6, group 2 = 1.2, group 3 = 0.5 and group 4 = 0.0; the differences between groups 1 and 2, 1 and 3, 1 and 4 and 2 and 4 were significant.
- BPE: Group 1 = 2.2, group 2 = 1.1, group 3 = 0.1 and group 4 = 0.0; the differences between groups 1 and 2, 1 and 3, 1 and 4, 2 and 3 and 2 and 4 were significant.
- BOP: Group 1 = 0.7, group 2 = 0.1, group 3 = 0.3 and group 4 = 0.0; there were no significant differences between any of the groups.

Discussion

Somewhat repetitive is the information that overall, the plaque level/height for each of the seven periodontal indices was highest with standard metal braces, particularly in comparison to clear aligners. This can be easily explained by the difference in retentive elements used/oral hygiene impediments encountered, as also noted in previous publications. No disparities were seen for BOP, and the authors explain this as being due to “patient compliance of hygienic instructions”, without explaining what these instructions were. They also attest that clear aligner treatment produces “better results aesthetically and functionally” – a statement that cannot be substantiated by any passage in the text. If self-ligating brackets fared better than conventional attachments, this is a consequence of the “[lower] number of modules needed to hold the brackets as well as less angels and wings”. The clear aligner group comprised the highest number of female patients; information about the possibility of choosing a specific appliance/the reason for any preference (costs?) is almost completely concealed in the script.

The authors finally point out that their investigation was the first to assess the BPE index. They think the limitation of their study is the fact that “... the number of patients with [clear aligners] is less because of the higher cost of such treatment”, which again is hard to understand because each of the four groups consisted of 20 individuals.

Summary

Clear aligners and, to a somewhat lesser extent, self-ligating brackets result in higher periodontal index scores. The predominance of self-ligating brackets over traditional ones is due to the reduced size of the former and their absence of paraphernalia. Clear aligners allow for optimal oral hygiene during orthodontic treatment and are therefore recommended.

Commentary

A publication with an enormous quantity of numbers and very decorative pictures and yet the overall verdict has to be: “much ado about nothing” (Shakespeare). Nothing new, at least, because even all the impressive data about the individual periodontal parameters are worthless for two main reasons: first, there is no information about the time points at which the data were recorded in “different hospitals”. Would it not make a difference if the SBI was registered within the first month of therapy for the aligner group, and in the second year of treatment for the conventional bracket cohort? And second, no measurement error assessment is reported, which is a no-go in any present-day scientific research.

Furthermore, the discussion is more a repetition of the results in words than anything else. The references are partially misleading which forced this reviewer to go to the original articles and read them to come to this conclusion; very time-consuming. But the longer this list of deficiencies gets, the more bored the readers of the Journal of Aligner Orthodontics will become. Worse still – they might ask why this commentator summarised this publication anyway? In his defence, he argues that he tried to expand the scope of journals from which he extracts the articles he reviews; this one comes from the Journal of Orthodontic Science, the official publication of the Saudi Orthodontic Society. Also, this reviewer is lucky enough to have repeatedly visited different places (including universities) in Saudi Arabia and been impressed by the level of knowledge of his local colleagues, a large number of whom received specialist training overseas.

The fact is, the text was initially declined by the review panel and thus revised for 3 months – certainly not long/thoroughly enough. Were the reviewers already tired during the second attempt or preoccupied by other projects?

This commentary began with a reference to Shakespeare and so it should end with a quote from “The Merchant of Venice”. As good as the journal derivation of this article is, as inspiring its title may be (though not quite correct since aligners are not “other types of brackets”), as impressive as its enormous quantity of data is and as superb as its illustrations are, this critic’s decision remains: “All that glisters is not gold.”

Short communications from the scientific societies

Societies and meetings

This issue of the JAO includes the details of our affiliated societies and their forthcoming meetings, with a question and answer section. Please refer to society websites for the latest details.

Sociedad Argentina de Ortodoncia con Alineadores (Argentine Society of Aligner Orthodontics – SAOA)

https://www.ortodoncia.org.ar/saoa-principios-fundacionales
https://www.instagram.com/saoa.2020/

Forthcoming meetings

Due to the uncertainty generated by the COVID-19 pandemic, we have scheduled only the GEOA meetings (SAOA study group). We also continue with our 1-year course to obtain a degree in orthodontics with aligners, directed by Dr Gabriela La Valle and Dr Betina Iaracitano and team at the SAO.

Q&A

In-office aligner orthodontics has become more and more popular. What software is most commonly used in your country?

It is true, in-office aligner orthodontics has become more and more popular. We believe that the software that is most commonly used in Argentina is OrthoAnalyzer (3Shape) and Nemotec. Some orthodontists use Blue Sky Plan.

European Aligner Society (EAS)

www.eas-aligners.com
Contact: Dr Leslie Joffe, EAS Executive Secretary
48 London House, 172 Aldersgate Street,
London EC1A 4HU, UK
E-mail: secretary@eas-aligners.com

3rd EAS Congress, 7-9 October 2021

The 3rd EAS Congress will take place from 7–9 October 2021, in Malta.

The EAS has curated an absorbing programme which progressively builds on the knowledge from its first two congresses (and meetings), and continues to explore the perpetual advances in technologies and techniques in aligner orthodontics. The Congress will draw together the latest innovations presented by an international line-up of expert speakers. The programme's curators have put together two and a half days of plenary lectures, peppered with break-out sessions and workshops, so that the learnings are delivered in a measured way, and everyone can dip in or delve deeper into the subjects that interest them most.

EAS looks forward to seeing you all in Malta in October 2021, as this may be one of the first large congresses allowed after a year of coronavirus closedown.

Further information is available at www.eas-aligners.com

EAS
European Aligner Society

WHAT *an* INVISIBLE WORLD

3rd EAS CONGRESS

October 7 - 9, 2021- MALTA

We all understand just how much Corona virus has threatened and upset our living and working lives since February 2020.
EAS 3rd Congress had to be postponed three times to accommodate social distancing.
BUT now we are setting up again and getting ready to go.

All our delegates, staff, accompanying persons, sponsors and exhibitors who have remained registered to 3rd Congress are still with us, with the option to cancel before July 31st 2021.
There are those who have already opted out, who may want to re-register, and those who are not yet registered, who want to attend.
FOR YOU, registration will re-open on July 1st 2021.

Keep watching for updates and the EAS 3rd Congress website on **www.eas-aligners.com**

REGISTRATION OPENS ON

JULY 2nd

www.eas-aligners.com

Carlson S.

Park HS.

Kaku J.

D’Antò V.

Laspos C.

Gomez Arango JP.

KEYNOTE SPEAKERS

AUSTRALASIAN CLEAR ALIGNER SOCIETY

Australalasian Clear Aligner Society (ACAS)

https://acasociety.com

Contact: Dr George Abdelmalek, ACAS Vice President
11/37-39 Albert Road, Melbourne, VIC 3004, Australia
E-mail: info@acasociety.com

Forthcoming meeting

ACAS2021 Clear Aligner Symposium: 11–12 February 2022, Melbourne, Australia. Pre-symposium workshop: 10 February 2022.

Thank you for your patience while we have been assessing the best option for ACAS2021. We have always said we are committed to only holding ACAS as a physical event at a time when it is safe to do so and that we can all be together. The health and safety of our members and sponsors has always been our main priority.

Due to current lockdowns and restrictions across the country, we have made the difficult decision to postpone ACAS201 until 10–12 February 2022. This date change was not taken lightly, and was made after many committee meetings and lengthy conversations with all stakeholders. If we chose to proceed in December, without the attendance of our Sydney/NSW we would have been without our highly respected Sydney speakers, 30% of our members as well as NSW based sponsors. We felt the event would not be the same without our valued NSW speakers, sponsors and members, and this played a major part in making this hard decision.

The location remains at Crown, Melbourne, Australia. The event will be held in the same space as planned for August, so the floor plan and booth builds will remain the same.

We appreciate your support over the past 18 months, and continued support during this time!

If you have any questions, please do not hesitate to contact us! We will keep in touch over the next few months and although disappointed we won't be seeing you in 2021, we cannot wait to have everyone join us face to face in February 2022.

Tickets purchased after 1 April 2021 will be fully refunded or credited for 2023 symposium if the 2021 symposium is unable to proceed due to COVID-19 or if you cannot attend due to a state border closure. Ticket+membership packages purchased after 1 April 2021 will be refunded minus membership fee or credited for 2023 symposium if the 2021 symposium is unable to proceed due to COVID-19 or if you cannot attend due to a state border closure.

Deutsche Gesellschaft
für Aligner Orthodontie
dgao

Deutsche Gesellschaft für Aligner Orthodontie (German Association for Aligner Orthodontics – DGAO)

www.dgao.com

Contact: DGAO Headquarters
Lindenspuerstrasse 29C, 70176 Stuttgart, Germany
Tel: +49 711 27395591
Fax: +49 711 6550481
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Forthcoming meeting

The 7th Scientific Conference for Aligner Orthodontics will take place in Cologne, Germany, on 18–19 November 2022. Pre-Congress 17 November 2022. Further information will be available soon at https://www.dgao-virtual.com.

What we subsequently present to you can't be described any more appropriately. What stays: Treatment with aligners is still a relatively young orthodontic therapy, which's former opponents are more and more becoming its users, plus the system is yet developing rapidly. What is really new and applicable in your office can best be discovered at congresses by attending its lectures, but also by contact with its exhibitors. That remains, and probably will always remain. What is different is, what we invite you to: discover the "the latest and best" in Angle's words with us, but not at a "regular" congress. Because complete capitulation was never an option the board of the German Association for Aligner Orthodontics (DGAO) decided after an extensive e-mail correspondence and many lengthy telephone conferences to change the format of this convention entirely. Unlike in the past, we are entering a new territory with the 1st Virtual DGAO Congress. A new territory yes, but not a pitch of thin ice, because what other societies have achieved, we can do at least as well. But we need your help: your registration for this conference, which is not just another Zoom event, but an interactive virtual meeting, i.e., nothing digital can be any more analogue than this!

Speaking of support: We thank our very generous industry partners for their financial support: Align Technology, Ormco and Straumann. They are hot to make finally direct contact with you at this congress. There is so much that is different, but - nothing ventured, nothing gained (understanding, insight, experience).

Everything is the same – your/our congress on aligner orthodontics – different is only its format, and we promise that you will profit as you did in the past. But what will it be like in the future? The best answer is a quote by the Danish physicist Niels Bohr: Prediction is very difficult, especially when the future is concerned.

SFOPA
Société Française d'Orthodontie Par Aligneurs

La Société Française d'Orthodontie par Aligneurs (French Society for Aligner Orthodontics – SFOPA)

http://sfopa.org

Contact: Dr Yves Trin, SFOPA President
34 rue du Plateau, 75019 Paris, France.
E-mail: contact@sfopa.org

Forthcoming meeting

The 5th SFOPA congress at the Intercontinental Hotel in Lyon, France, has been postponed. The final dates will be available soon.

Japan Academy of Aligner Orthodontics (JAAO)

http://aligner-orthodontic.com/

Contact: japan.aligner.ortho@gmail.com

Forthcoming meeting

The 8th Japan Academy of Aligner Orthodontics Annual Congress 2021: Breakthrough of Aligner Orthodontics, 5–6 December 2021.
More information available at: http://aligner-orthodontic.com/events/8th-jaao-anual

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Swiss Society for Aligner Orthodontics (SSAO)

www.aligner-ortho.ch/

Contact: SGAO Schweizerische Gesellschaft für Aligner Orthodontie
Hans-Caspar Hirzel, Theaterplatz 5, 5400 Baden,
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Tel +41 (0)79 438 40 40
E-mail: hello@aligner-ortho.ch

Taiwan Association of Aligner Orthodontics (TAAO)

www.taao.com.tw

Forthcoming meetings

Save the date! The 7th Taiwan International Aligner Symposium will be held on 12–13 December 2021, in Taipei, Taiwan.

After careful consideration at the TAAO, we decided to postpone the international symposium, which was originally scheduled for 15–16 August 2021, to 12–13 December 2021. We apologise for any inconvenience caused by this change.

The topic “Be simple! Back to the Origin” seeks to enhance attendees’ practical knowledge by sharing experiences to help them avoid and address the problems that may arise from each type of case, discussing what can and cannot be done when dealing with aligners.

Further information is available at: www.taao.com.tw

Q&A

In-office aligner orthodontics has become more and more popular. What software is most commonly used in your country?

At present, the commonly used tooth movement design software on the market are Clear Aligner Studio (3Shape), Ortho Analysis (Inteware), PlaniMax Orthodontic Planning (CHOICE).

Guidelines for Authors

General Information

The Journal of Aligner Orthodontics publishes clinically relevant articles in the field of Aligner Orthodontics. The journal is peer reviewed and intends to be the reference journal for Aligner Orthodontics, showing the whole potential of the field. The journal aims to provide in-depth knowledge to orthodontists and people interested in orthodontics, from beginners to the most advanced practitioners. Articles deal with basic procedures, case reports about special situations, multidisciplinary treatment including aligner procedures, and original studies (clinical studies, studies on materials and devices, literature reviews). Auxiliary procedures such as scanning, 3D printing etc are also covered. In addition, the journal contains editorials, expert discussions, tips and tricks, learning from mistakes, summaries of publications from other journals, book reviews, and news from the industry.

Please read the guidelines and instructions below for details on the submission of manuscripts, and the journal's requirements and standards.

Original articles are considered for publication on the condition that they have not been published or submitted for publication elsewhere.

- The publisher reserves the right to edit manuscripts for length and to ensure conciseness, clarity, and stylistic consistency, subject to the authors' final approval.
- Manuscripts are reviewed and selected in a blinded process by editors and appropriate content experts. Therefore, it is important that submitted manuscripts and illustrations do not contain information that will identify the manuscript's origin (except for the title page, which will not be sent to reviewers).
- Manuscripts that do not follow these instructions will be rejected.

Appeal of Decision

The editorial board's decision is final and cannot be appealed.

Manuscript Submission Procedure

Upload manuscripts as Word files, with tables and downsized figures at the end of the document. Authors are required to use the journal's online submission service: www.manuscriptmanager.net/jao.

Permissions and Waivers

If all or part of previously published material is used, permission must be obtained from the copyright holder. It is the authors' responsibility to obtain this.

Waivers must be obtained for photographs showing identifiable people. If a waiver has not been obtained, faces must be masked to prevent identification.

The Mandatory Submission Form should be sent to the Managing Editor.

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Ethical Guidelines

Authorship

Authors submitting a manuscript do so on the understanding that it has been read and approved by all the authors and that they all agree to the submission of the manuscript. The number of authors is limited to six.

Acknowledgements

Specify contributors to the article other than accredited authors. Also include any funding sources for the study, as well as any potential conflicts of interest.

Conflicts of Interest/Source of Funding

It is necessary that information on potential conflicts of interest be part of the manuscript. The *Journal of Aligner Orthodontics* requires all sources of institutional, private, and corporate financial support for the work within the manuscript to be fully acknowledged and any potential conflicts of interest noted. Grant or contribution numbers should be acknowledged, and principal grant holders should be listed. Please include the information under *Acknowledgements*.

Ethical Approval

Experimentation involving human subjects will be published only if such research has been conducted in full accordance with ethical principles, including the World Medical Association Declaration of Helsinki, and any additional requirements of the country in which the research was conducted. Manuscripts must include a statement that the experiments were undertaken with the understanding and written consent of each subject, and according to the abovementioned principles. A statement regarding the fact that the study has been independently reviewed and approved by an ethical board should also be included. Editors reserve the right to reject manuscripts if there is doubt as to whether appropriate procedures have been followed.

Clinical Trials

Report clinical trials using the CONSORT guidelines at ww.consort-statement.org.

Manuscript Format and Structure

Presentation

The presentation must clearly convey clinical reports, research findings, or review objectives. Try to avoid using technical jargon, but clearly explain its meaning where its use is unavoidable. Titles, abstracts, and the main text should be written using language that can be easily understood by any dentist.

Abbreviations/Acronyms

Abbreviations should be kept to a minimum, particularly those that are not standard. Terms and names that are abbreviated, or acronyms, should be written out when first used, with the abbreviation in parenthesis. Standard units of measurement need not be spelled out.

Tooth names

The full names of individual teeth must be given in the text. Only in tables and figures should individual teeth be identified using the FDI 2-digit system, if full tooth names are too unwieldy.

Structure

Include a title page, *Abstract*, main text, *References*, and *Acknowledgements*, as well as tables, figures, and legends, as appropriate.

Title Page

Include the title of the article and the full name, title, qualifications, and professional affiliations of every author. List up to six key words in alphabetical order. Provide the physical address and email address of the corresponding author.

Tables and Figures

Tables and figures should be numbered and cited in the text in order of appearance and grouped in the manuscript at the end of the text. When necessary, high-resolution images should be sent to the Managing Editor, Elizabeth Ducker (elizabeth.ducker@gmail.com), upon article acceptance.

Note that original artwork or slides may still be required after acceptance of the manuscript, and that manuscript acceptance depends on the receipt of acceptable images. Although low-quality images may be adequate for review purposes, print publication requires images to be of the quality specified here: Submit EPS (line art) or TIFF/JPG (photographs) files only. Photographs should have a resolution of 300 dpi, and line drawings 600 to 1200 dpi in relation to the reproduction size. EPS files should be saved with fonts embedded.

Figure Legends

Figure legends should begin with a brief explanation of the whole figure, and continue with a short description of each panel, including the symbols used.

Reference List

Literature reference numbers should be cited in superscript in the text (before punctuation) in order of appearance, and correspond to the numbered reference list. All references cited in the text should be listed at the end of the manuscript. Do not include unpublished data or personal communications in the reference list.

Standard Scientific Journal
Franchi L, Baccetti T, McNamara JA Jr. Mandibular growth as related to cervical vertebral maturation and body height. Am J Orthod Dentofacial Orthop 2000;118:335–340.
Standard Textbook
Pancherz H, Ruf S. The Herbst Appliance: Research Based Clinical Management. Berlin: Quintessence, 2008.

Manuscript Types

All articles should be clinically relevant and scientifically based.

Original Scientific Articles

Original scientific articles must be of the highest international standard in the field and should be relevant to dental/orthodontic practice. The articles should describe significant and original experimental observations and provide sufficient details so that the observations can be critically evaluated and, if necessary, repeated.

The article *Abstract* should be no more than 250 words, giving details of what was done, using the following structure: *Objectives*: A clear statement of the main goal of the study and any tested hypotheses. *Materials and Methods*: Describe the methods, study design, and data analysis. *Results*: Main results of the study, including the outcome of any statistical analysis. *Conclusion*: State the major conclusions of the study, as well as their implications and relevance to the practice of orthodontics.

The main text should include *Introduction*, *Materials and Methods*, *Results*, *Discussion*, and *Conclusion* sections.

The *Introduction* should summarise the background of the research objectives and should emphasise the relevance of the study to the practice of orthodontics.

The *Materials and Methods* section should contain sufficient detail so that, in combination with the references cited, all clinical trials and experiments reported can be fully reproduced. Manufacturers of materials should be named (including where the manufacturer is based – town/city and country), known methods should be referenced, and data analysis should be described.

The *Results* should be presented in this section in a logical sequence in the text, using tables and illustrations, where appropriate.

The *Discussion* section should include references to previous studies, and implications of the findings to the practice of orthodontics should be included.

The *Conclusion* section should not summarise the findings. Instead, the conclusions should relate to the aims of the study and the relevance to orthodontic practice. The conclusions should be supported by the data.

Original scientific articles may focus on clinical procedures, materials, and devices.

Review Articles

The review can be a topic review or systematic review. It should cover a topic of interest for the practitioner and should address a clinical problem, diagnosis, or treatment. Reviews should offer a broad view of the field. Systematic reviews should follow the PRISMA guidelines.

The review *Abstract* should be no more than 250 words and include: *Objectives*, *Data Sources*, and *Conclusion*.

The main text should be divided into *Introduction*, *Data Sources*, *Resources Selection*, *Review*, *Discussion*, and *Conclusion*. Search strategies must be described, and evidence-based systematic approaches are expected. The *Discussion* and *Conclusion* should address the relevance to the general practitioner, and should be supported with clinically relevant photographs.

Case Reports

Case reports should either have importance and significance for the practitioner, or offer well-known and established conditions, or they should be methods of treatment that are educational for beginners. Case reports should include: *Abstract*, *Introduction*, *Case Presentation*, *Discussion*, and *Conclusion/Recommendation* when necessary. The *Abstract* should be no more than 250 words and summarise the case. The report should emphasise the new information provided and its relevance to practitioners, or the importance of a known procedure. A sufficient follow-up period is required, and high-quality images should be included.

Method Presentation Articles

The method presentation must offer significant improvements for clinical practice (a novel technique, new appliance, technological breakthrough, or practical approaches to clinical challenges). The main text should be divided into an *Introduction*, *Report*, and *Discussion*. All parts should be well illustrated with clinical images, radiographs, diagrams, and supporting tables and graphs where appropriate.

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JOURNAL OF ALIGNER ORTHODONTICS

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The *Journal of Aligner Orthodontics* is published quarterly by Quintessenz Verlags-GmbH, Ifenpfad 2–4, 12107 Berlin, Germany. Court domicile and place of performance: Berlin, Germany.

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ISSN 2514-7552 (Print)
ISSN 2514-7560 (Online)


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