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Aligner therapy in treating bimaxillary dentoalveolar protrusion

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Key words *aligner orthodontics, bimaxillary dentoalveolar protrusion, dental occlusion, protrusion, temporary anchorage device (TAD), tooth extraction*

Bimaxillary dentoalveolar protrusion is challenging to treat with aligners. Such patients have not only dental protrusion problems, but often a combination with skeletal protrusion problems. This article presents different bimaxillary protrusion case types, including treatment by extraction of the four first premolars, and non-extraction treatment. In the non-extraction case, temporary anchorage devices were used as anchorage to achieve molar distalisation and to prevent a 'rowboat' effect during the treatment. A special movement called the 'caterpillar motion design' is also described, which according to the authors helps to prevent the bowing effect in extraction space closure treatments. All described treatments were performed using the Invisalign System; extraction treatments are possible with aligner systems but require a profound knowledge of the biomechanics and forces of aligner orthodontics. Several possible approaches are presented.

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Introduction

Bimaxillary protrusion is a condition characterised by protrusive and proclined maxillary and mandibular incisors and an increased procumbency of the lips. It is seen commonly in African-American and Asian populations, but it can be seen in almost every ethnic group.

Bimaxillary dentoalveolar protrusion frequently coexists with dental crowding, which represents one of the most common types of malocclusion[1]. In a study of patients examined between 8 and 18 years of age, crowding was present in 47.3%[2]. Treating dentoalveolar protrusion patients often requires extraction, temporary anchorage devices (TADs), headgear, or any of these in combination with traditional orthodontic therapy. Depending on the degree of crowding severity along with other related circumstances, the orthodontist has to choose between extraction and non-extraction treatment in order to gain space to relieve crowding. In non-extraction treatment, many different options can be used to gain space, such as expansion, protrusion, distalisation or, especially in adult patients, interproximal reduction (IPR)[3,4]. In cases of severe crowding and certain skeletal components, extraction may be the only option.

At this time, the proportion of extraction cases in orthodontics averages about 18%[5] (but the ratio could possibly be higher in Chinese people), with premolars constituting the most commonly extracted teeth[6]. Tooth size–arch length discrepancy (TSALD) is the most decisive source of crowding and contributes significantly to the decision of premolar extractions[7]. However, many patients can be treated with or without extractions, such as those McNamara determined as borderline crowding patients, with mandibular crowding of 3 to 6 mm[8].

With the advent of aligners and their advantages that include aesthetics, less invasive treatment, virtual treatment advantages, comfort and fewer office visits, orthodontists have explored the capabilities of aligners by testing them in the field. Treating bimaxillary dentoalveolar protrusion is the new frontier of aligner treatment[9,10].

Bimaxillary protrusion was originally discussed by Dr Calvin C. Case, although it has a higher prevalence in Asia[11,12]. In the Asian population, clinical bimaxillary protrusion is one of the most commonly diagnosed orthodontic problems. It is defined by the protrusive and proclined positions of the maxillary and mandibular incisors and an increased procumbency of the lips. Treating this kind of malocclusion usually requires extraction of the four first premolars, allowing for retraction and retroclination of the maxillary and mandibular incisors. Moreover, significant skeletal conditions are to be treated with orthognathic surgery[13].

Clinically, these patients usually have lip incompetence due to flared maxillary and/or mandibular incisors often manifested with strain of the perioral muscles[14]. Generally, bimaxillary dentoalveolar protrusion has two subdivisions: the skeletal-origin subdivision and the dental-origin subdivision. Differential diagnosis for the bimaxillary dentoalveolar protrusion subdivisions is crucial, because skeletal bimaxillary dentoalveolar protrusion often demands orthognathic surgeries to create an ideal outcome[15]. In 1983 Creekmore and Eklund[16] introduced the possibility of skeletal anchorage, and in 1997 Kanomi[17] reported on the use of market-available orthodontic mini-implants as anchorage to allow certain types of tooth movements. TADs have become common tools in the armamentarium in orthodontic offices today[18].

The following treatments illustrate the typical treatment strategies of implementing aligner therapy for the dental subdivision of bimaxillary dentoalveolar protrusion in both extraction and non-extraction modalities.

Patient 1 (Treatment by Dr Chang and team)

The treatment of Patient 1 involves maxillary and mandibular first premolar extractions.

Diagnosis

A 12-year-old girl sought orthodontic treatment (Fig 1). Her chief concern was lip protrusion. Clinical findings were as follows (Fig 2): mild mandibular anterior crowding, maxillary midline deviated to the right, deep bite and 4 mm horizontal overlap. The diagnosis was Angle Class I malocclusion with mild crowding and bimaxillary dentoalveolar protrusion.

Treatment objectives

The treatment goals in this case were:

- to maintain the skeletal pattern
- to retract the maxillary incisors by approximately 5 mm and reduce lip protrusion
- to relieve crowding
- to reduce vertical overlap
- to maintain Class I molar relationship
- to coincide maxillary and mandibular midlines.

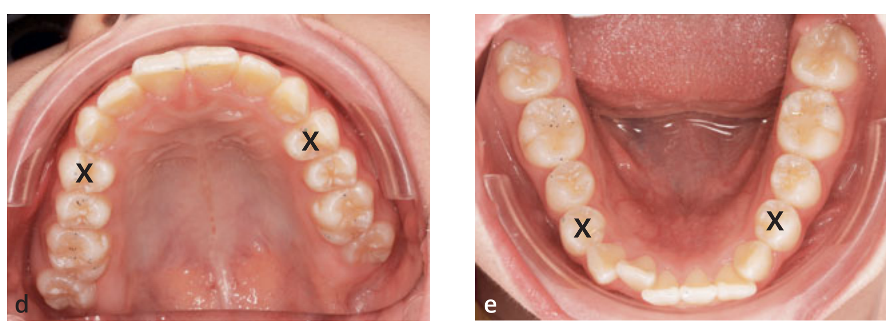
Treatment protocols

One of the traits of aligner therapy is the use of computer software to simulate tooth movement throughout the entire orthodontic treatment. Using software to show virtual tooth movement is one of the most important steps in aligner treatment (Fig 3). A complete treatment simulation includes three parts, as described below.

The pattern of tooth movement

In order to have more control, especially in extraction cases, and to avoid off-track and bowing effects, the fewer teeth involved and the shorter the moving distance in each stage, the better. For this patient, the design was to consider the four incisors as one unit and the two canines as another unit in each arch. Moving the canine unit back by 1 mm and then moving the incisal unit back to contact the canines was

Figs 1a to c Initial lateral radiograph and photographs showing lip protrusion and inter-labial gap at rest.

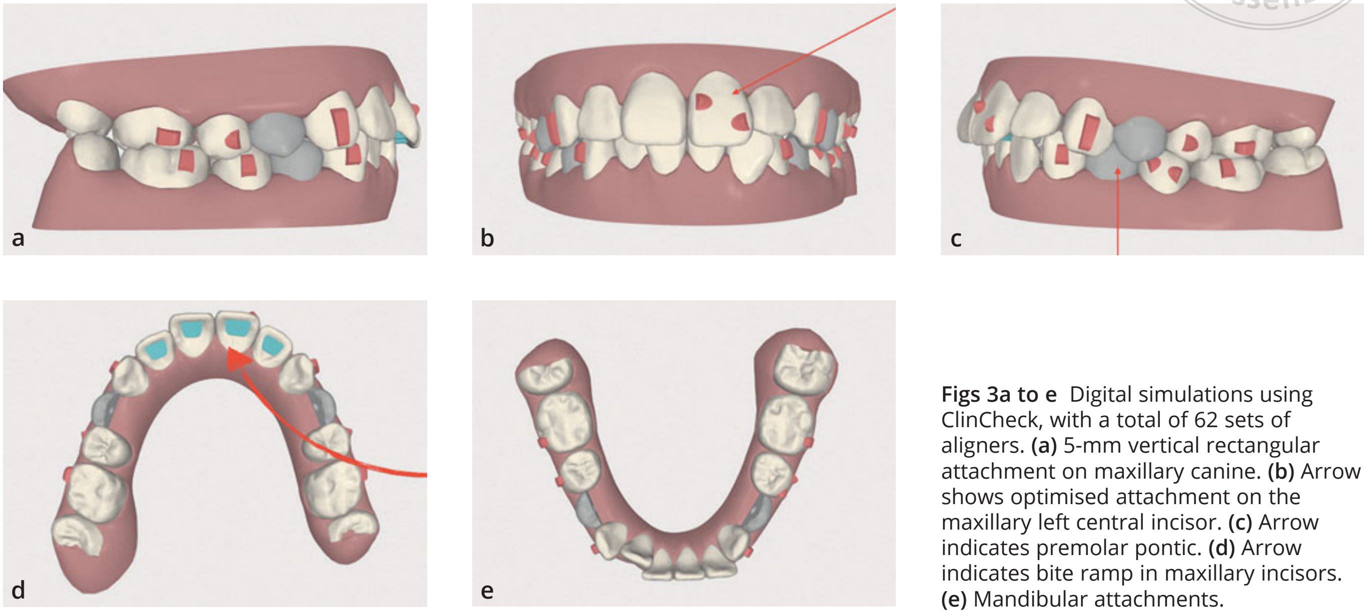


Figs 2a to e Intraoral photos at baseline, showing Class I bimaxillary protrusion. The four first premolars were planned to be extracted.

the strategic approach. This approach was repeated until the extraction spaces were closed. Comparing either canine retraction alone or en masse retraction with the aforementioned strategic approach, it seemed this could allow aligners to have more time to fully express the designed detail movements (Fig 4). The alternating tooth movement is similar to the movement of a caterpillar; therefore, it is called 'caterpillar motion design'. A customised staging procedure for a predictable space closure with segmental aligners has been described by Samoto and Vlaskalic[19].

The auxiliaries

The implementation of attachments, bite-ramps (Fig 5), precision cuts and button cut-outs cannot be overemphasised. Usually, keeping the default designs from the engineers is a good start. In deep vertical overlap patients, bite ramps on



Figs 3a to e Digital simulations using ClinCheck, with a total of 62 sets of aligners. **(a)** 5-mm vertical rectangular attachment on maxillary canine. **(b)** Arrow shows optimised attachment on the maxillary left central incisor. **(c)** Arrow indicates premolar pontic. **(d)** Arrow indicates bite ramp in maxillary incisors. **(e)** Mandibular attachments.

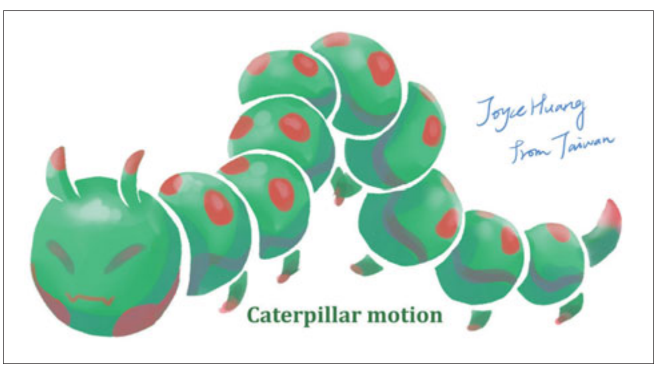
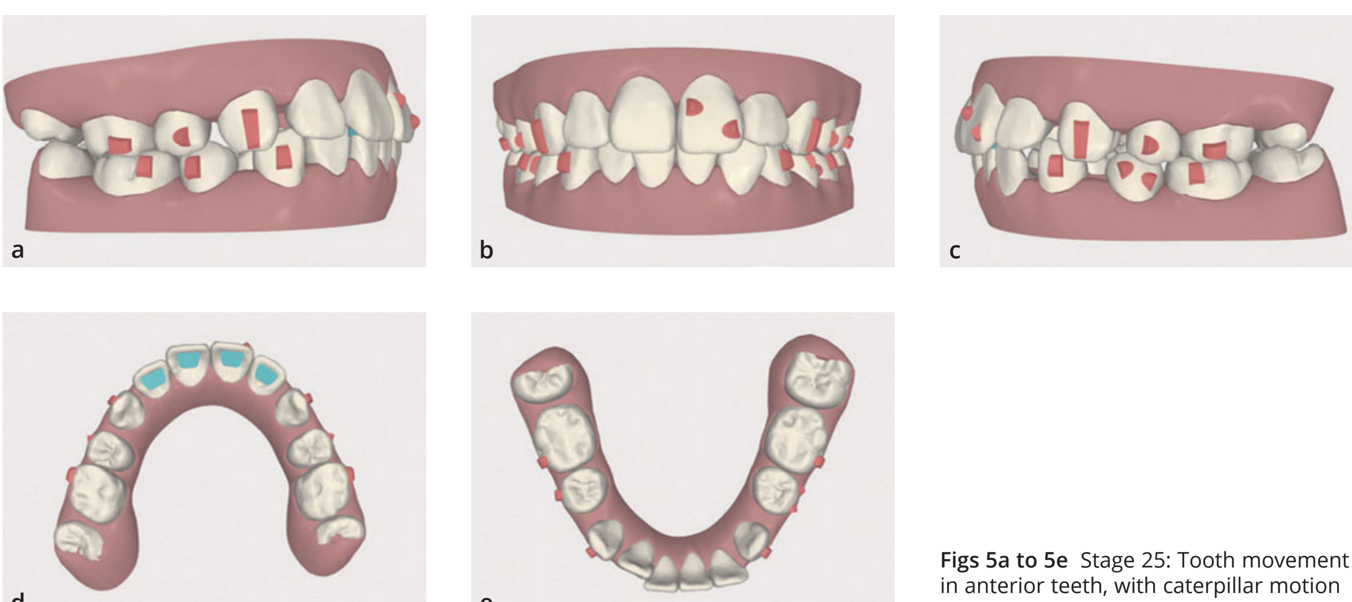
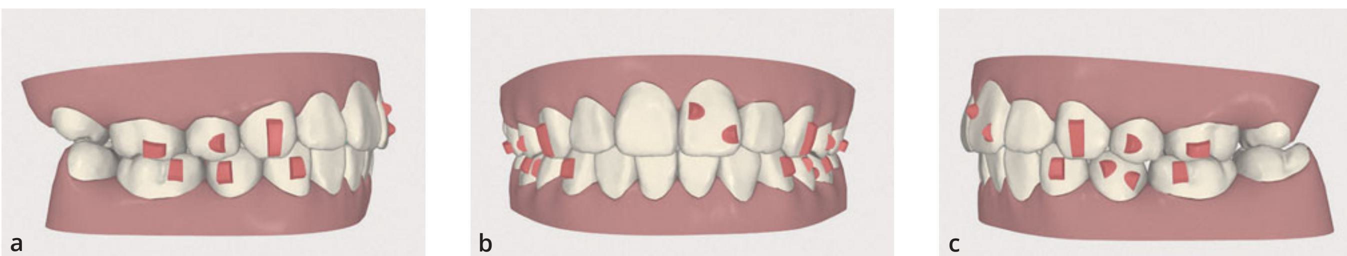


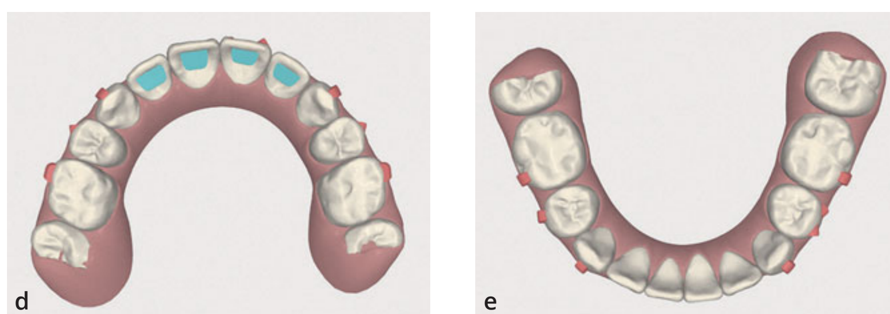
Fig 4 The alternating tooth movement is similar to the movement of a caterpillar.



Figs 5a to 5e Stage 25: Tooth movement in anterior teeth, with caterpillar motion design.

Fig 6 Aligner including lingual bite ramps: mandibular incisors are behind the lingual bite ramps with severe retraction of the mandible.





Figs 7a to e Final ClinCheck design.

the palatal surfaces of the maxillary incisors are often suggested to allow for disocclusion of the posterior teeth and to apply forces that help to intrude the incisors (Fig 6). Nonetheless, bite ramps in this area tend to irritate patients' tongues and decrease the encapsulations of these teeth.

In Fig 6, the mandible occludes behind the bite ramps, which might occur during treatment with bite ramps. This results in a retrognathic displacement of the mandible and thus the condyles. The modification or removal of these bite ramps in the following virtual simulation presents an absolute necessity.

The final occlusal scheme

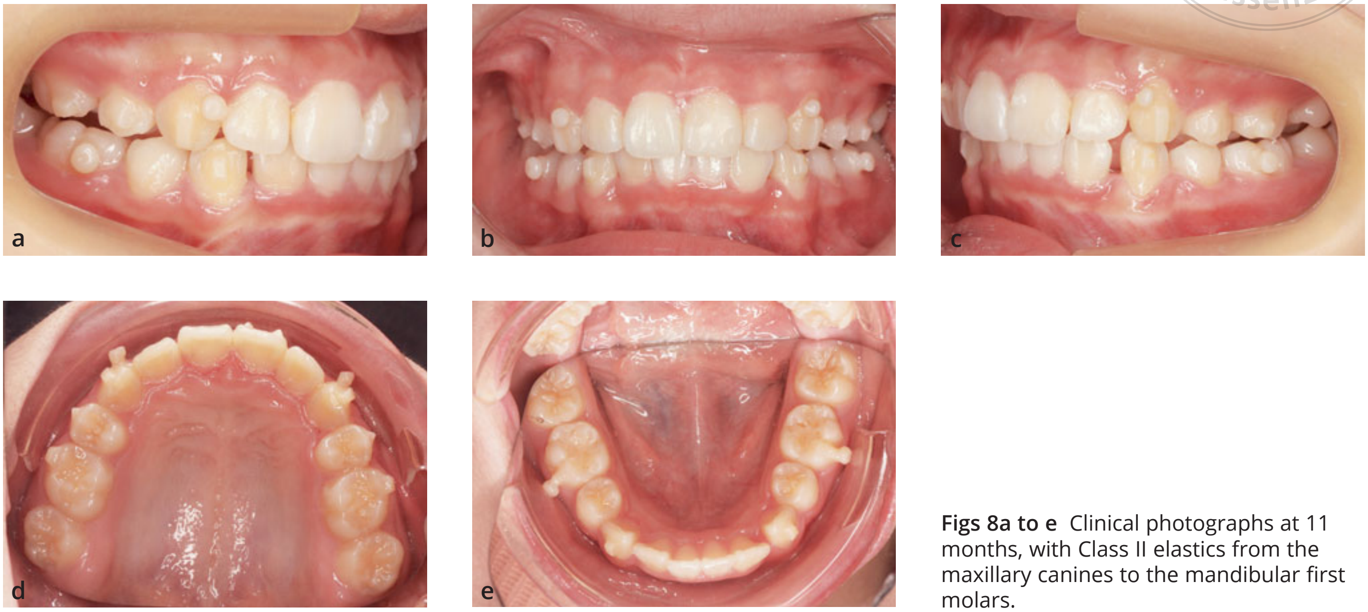
The final occlusal scheme is shown in Fig 7. In extraction cases, the discrepancies between the software's ideal simulations and chairside clinical results can happen quite often. Bite ramps result in laterally missing occlusal support during the period of aligner application and can therefore cause jaw joint pathologies[20-22].

Patients should be checked at short time intervals to avoid occluding behind the bite ramps.

One way to minimise the discrepancies is to incorporate the overcorrection concept. For instance, it is good practice to alter the software simulation with a slight open bite in deep bite patients, and vice versa.

Treatment progress

After 11 months of treatment (Fig 8), the extraction spaces had been closed. Interarch elastics had been used in the early stages of treatment in order to minimise molar mesial



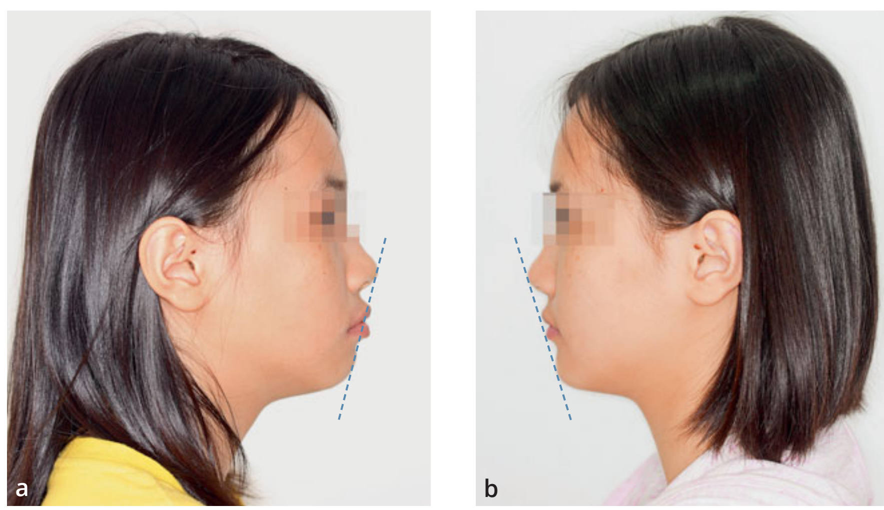
Figs 8a to e Clinical photographs at 11 months, with Class II elastics from the maxillary canines to the mandibular first molars.

Figs 9a to e Clinical photographs at 24 months. The vertical overlap has increased.

tipping and a posterior open bite. After 24 months of treatment (Fig 9), the maxillary and mandibular midlines were matching, and yet the vertical overlap had been deepened. Therefore, a refinement had been designed to alleviate the deep bite.

At the end of treatment at 32 months (Fig 10), the midlines were coincided, and normal vertical and horizontal overlap had been established, along with Class I canine and molar relationships. The last set of aligners was used as retainers. Two refinements had been used, with 64 + 38 + 29 = 131 sets of aligners in 32 months of overall treatment time.

Figs 10a to e Final situation at 32 months. Class I canine and molar relationship.

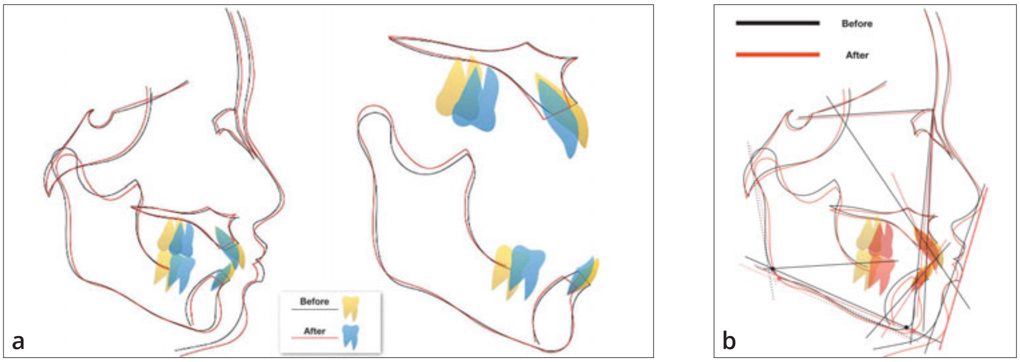


Figs 11a and b Profile photograph comparison: **(a)** initial compared with **(b)** end of treatment.

Treatment results

As shown in the pre- and posttreatment profile photographs (Fig 11) and cephalometric superimpositions (Fig 12):

- the anterior-posterior maxillomandibular relationship had been maintained
- the mandibular plane angle had been reduced by 2 degrees
- both the upper and lower lips were 2 mm behind the E-line.



Figs 12a and b **(a)** Pre- and **(b)** posttreatment cephalometric superimpositions. Measurements are given in Table 1.

Table 1 Cephalometric measurements pre- and posttreatment, as shown in Fig 12

Measurement		Norm	Initial	Final	Change
Skeletal	SNA (degrees)	79.8–83.2	85	85	0
	SNB (degrees)	75.7–78.7	82	82	0
	ANB (degrees)	3.2–5.0	3	3	0
	Mandibular plane to SN (degrees)	33.8–38.4	27	25	−2
Dental	U1–NA (mm)	4.3–8.1	7	4	−3
	U1–SN (degrees)	103.85–108.75	121	111	−10
	L1–NB (mm)	5.4–10.2	7	4	−3
	L1 to mandibular plane (degrees)	93.4–99.2	107	101	−6
Soft tissue	E-line to upper lip (mm)	0.7–3.1	1	−2	−3
	E-line to lower lip (mm)	0.2–3.4	3.5	−2	−5.5

Patient 2 (Treatment by Dr Chang and team)

The treatment of Patient 2 involved non-extraction and molar distalisation to treat bimaxillary dentoalveolar protrusion.

Diagnosis

A 31-year-old woman presented with the chief complaint of anterior teeth crowding and lip protrusion (Fig 13). Clinical findings were as follows: upper/lower lip protrusions, Angle Class I molar relationship, mild crowding in anterior teeth region, mild periodontitis, and bimaxillary dentoalveolar protrusion.

Treatment objectives

The ClinCheck design is shown in Fig 14. The treatment goals in this case were:

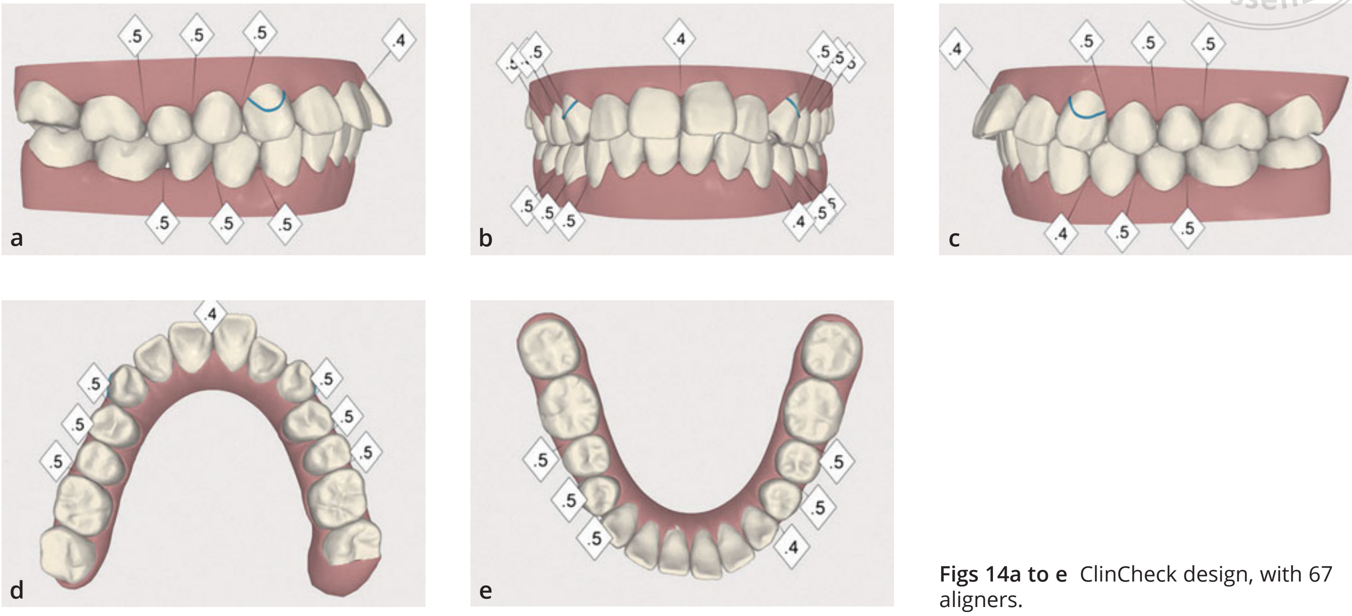
- periodontal treatment
- to relieve crowding
- to reshape the gingival line of the anterior teeth using Er-YAG laser
- to straighten and retract the anterior teeth by 3 mm or more

Figs 13a to h Pretreatment photographs and cephalometric radiograph.

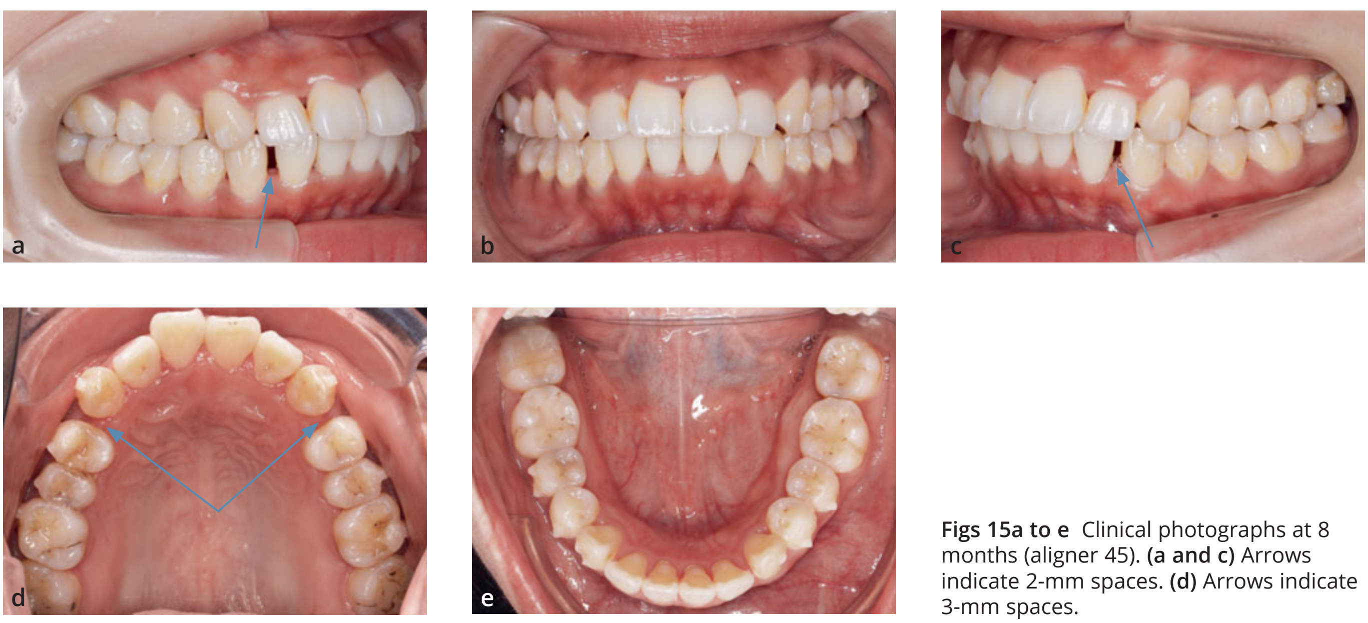
- to maintain a Class I molar relationship
- to intrude (or at least to maintain) molars to reduce posterior vertical height in order to have mandibular autorotation and improve facial aesthetics
- to decrease the black triangles of the anterior teeth by IPR.

Treatment protocols and progress

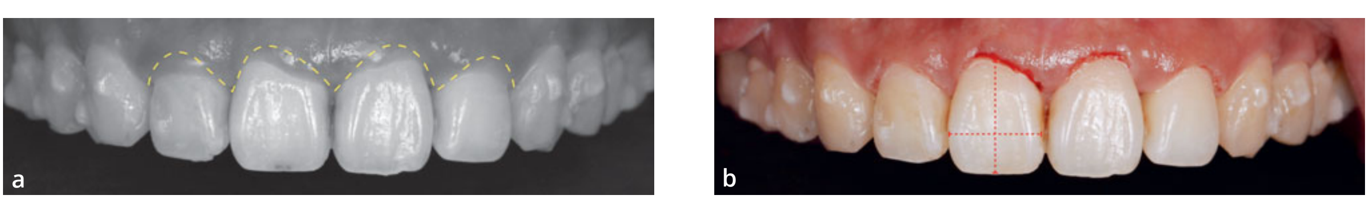
Before the start of treatment the mandibular left third molar was extracted. In order to increase anchorage, TADs were placed between the maxillary first and second molars. Maxillary and mandibular posterior teeth were moved distally for 3 mm to gain anterior retraction space. A space of 3 mm between the canine and lateral incisor was created before starting retraction of the anterior teeth (Fig 15). Anterior occlusal clearance of 1 mm was planned in the final computer simulation. This patient had gone through two refinements and used 67 + 39 + 11 = 117 sets of aligners in 26 months of treatment.



Figs 14a to e ClinCheck design, with 67 aligners.

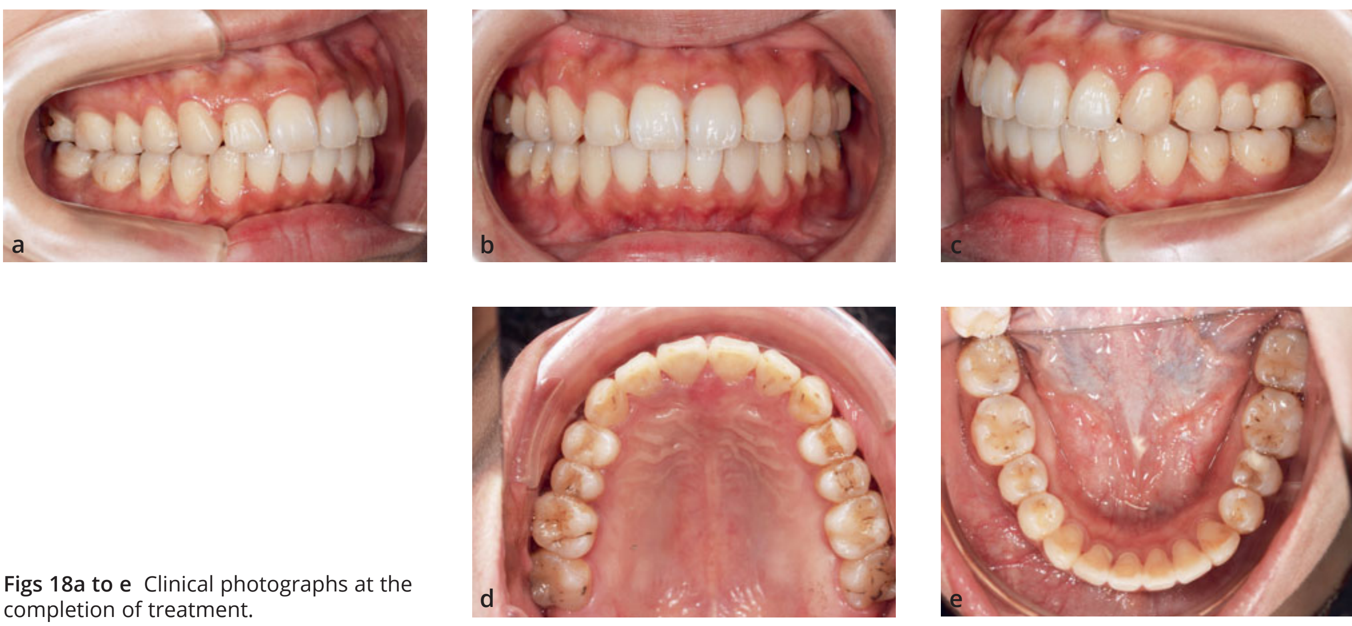


Figs 15a to e Clinical photographs at 8 months (aligner 45). **(a and c)** Arrows indicate 2-mm spaces. **(d)** Arrows indicate 3-mm spaces.



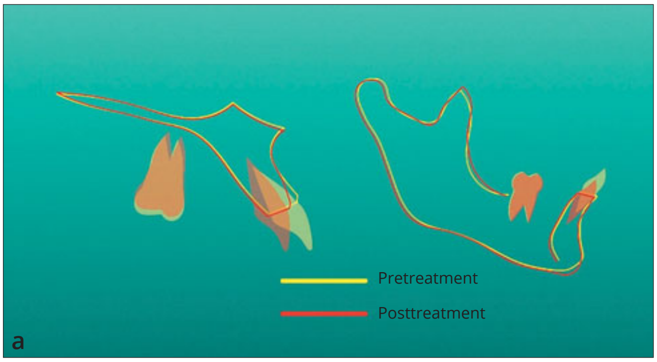
Figs 16a and b Laser crown lengthening surgery was performed after orthodontic treatment: **(a)** Dotted line indicates planned laser surgery. **(b)** Constructed aesthetic crown ratio.

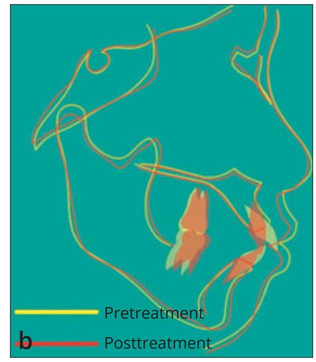
Figs 17a and b Comparison **(a)** pre- and **(b)** posttreatment.



Figs 18a to e Clinical photographs at the completion of treatment.

Figs 19a and b Comparison of the cephalometric radiographs after the non-extraction aligner orthodontic strategy of TADs + sequential distalisation + interproximal reduction. **(a)** Pretreatment. **(b)** After 26 months.





Figs 20a and b Cephalometric analysis. Measurements are given in Table 2.

Table 2 Cephalometric measurements pre- and posttreatment, as shown in Fig 20

Measurement		Norm	Initial	Final	Change
Skeletal	SNA (degrees)	79.8–83.2	85	85	0
	SNB (degrees)	75.7–78.7	80	80	0
	ANB (degrees)	3.2–5.0	5	5	0
	Mandibular plane to SN (degrees)	33.8–38.4	33	34	1
Dental	U1–NA (mm)	4.3–8.1	10.5	2	−8.5
	U1–SN (degrees)	103.85–108.75	121	95	−26
	L1–NB (mm)	5.4–10.2	14.5	10	−4.5
	L1 to mandibular plane (degrees)	93.4–99.2	108	108	0
Soft tissue	E-line to upper lip (mm)	0.7–3.1	3	0	−3
	E-line to lower lip (mm)	0.2–3.4	6	2	−4

Treatment results

The results of treatment (Figs 16 to 20) were as follows:

- normal vertical and horizontal overlap
- midline coordination
- Class I molar occlusion
- symmetrical and even gingival line of anterior teeth
- solid occlusal interdigitation
- proportional aesthetic unit.

Fig 21 Pretreatment panoramic radiograph.

Fig 22 Pretreatment lateral cephalogram. Measurements given in Table 3.

Table 3 Cephalometric measurements pretreatment, as shown in Fig 22.

Measurement		Norm	Initial
Skeletal	Convexity of A (mm)	1.2 ± 2.0	5.6
	Lower facial height (degrees)	47.0 ± 4.0	49.4
	Mandible plane angle (degrees)	27.2 ± 4.5	39.7
Dental	$\overline{1}$-APo (mm)	1.0 ± 2.3	3.8
	$\underline{1}$-APo (mm)	3.5 ± 2.3	6.7
Soft tissue	Lower lip–E-plane (mm)	−1.2 ± 2.0	1.1

Patient 3 (Treatment by Dr Schupp and team)

The treatment of Patient 3 involved extraction of the four premolars and treatment with aligner orthodontics.

Diagnosis

A 12-year-old boy presented with bimaxillary protrusion and a large TSALD that had resulted in severe anterior crowding and labially positioned canines in both arches. The panoramic radiograph showed the existence of all permanent teeth including unerupted third molars in a good periodontal state (Fig 21). In addition, the pretreatment photographs and cephalometric analysis revealed an increased mandibular facial height and a convex profile type characterised by forward face sloping backward (Fig 22). The cephalometric findings included a skeletal Class II base with proclined mandibular incisors, and a skeletal open bite tendency with an increased mandibular plane angle (Table 3). The Ricketts cephalometric analysis also demonstrated high convexity measuring 5.6 mm, which implied a Class II skeletal pattern. The initial maxillary and mandibular incisor position was deviating from the norm values as reflected in the considerable anterior positions of the maxillary and mandibular incisors. A positive value of lower lip (LL)–E-plane was detected, suggesting a forward position of the lower lip with 2.4 mm deviation from the standard range.

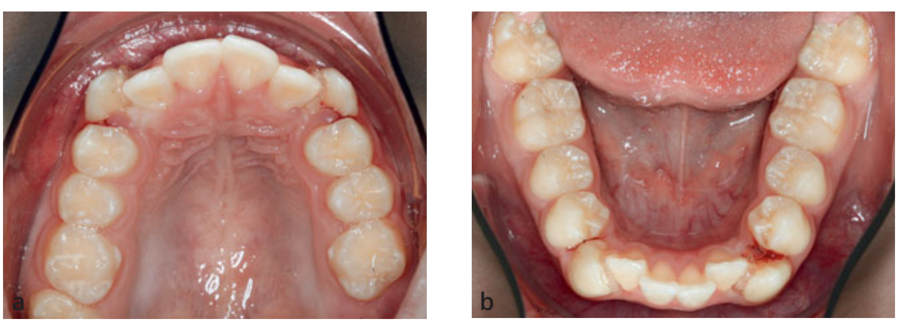
The patient was diagnosed as Angle Class I on the left side and Class II on the right side. In the maxillary arch the midline was shifted 1.5 mm to the left with vertical overlap of 3.5 mm and horizontal overlap of 3 mm. In addition, multiple dental rotations, severe pre-contact on the maxillary left and right lateral incisors, as well as a cross bite tendency on the maxillary left lateral incisor and mandibular left canine were detected. Bolton tooth ratio analysis showed no deviations from the normal range (Fig 23).

Treatment objectives

The treatment goals in this case were:

- to relieve crowding
- to correct proclination of incisors

Figs 23a to f Pretreatment intraoral views.

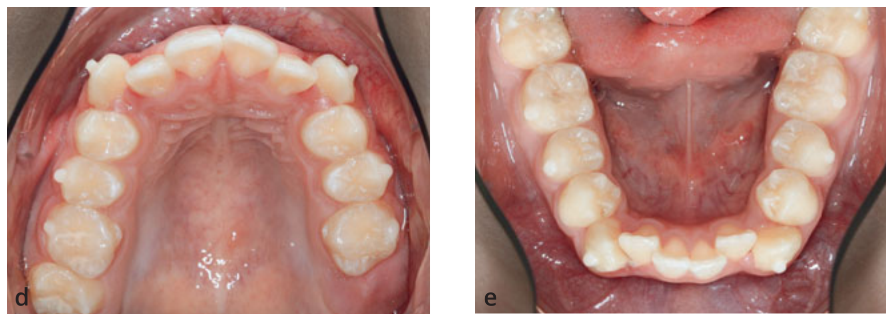


Figs 24a and b Situation after removal of interproximal elastics mesial and interproximal reduction distal of maxillary and mandibular canines before beginning aligner therapy.

- to adjust bilateral class I canine relationship with ideal horizontal overlap and vertical overlap
- to improve soft tissue profile.

Because of the enormous TSALD and due to the thin bone lamella in the anterior region, the treatment of choice for crowding was premolar extraction in four quadrants and space closure by means of aligner therapy[23]. Predictable space closure by means of the 'caterpillar motion design' of sequential aligners is essential[19]. Premolar extractions were required to retract massive protruded anterior teeth, thereby achieving an improved profile along with a functional and stable occlusion. A 'bowing effect', which is characterised by the tipping of anterior and posterior segments resulting from en masse space closure after four-premolar extractions, should be avoided[24].

In extraction treatment with aligners, besides the increased aligner surface around the canine and incisor crowns, the sequential canine and incisor retraction in three separate cycles also improves the anchorage value of the posterior segment in contrast to the actively staged segment. Apart from the fact that the overall anchorage loss equals that of en masse retraction, the frequent anchorage-taxing stages result in a more precisely guided movement in each stage. Patient treatments with mild to moderate crowding, in particular those including more required space closure, are associated with less tendency for molar tipping and less relative extrusion of the anterior segment, which in turn leads to less potential for incisal interference and posterior disocclusion – often observed as a side effect in aligner treatment[25].



Figs 25a to e Intraoral views with individually bonded attachments on the buccal dental surfaces at the beginning of aligner therapy.

Treatment protocol

Preparation

Before starting the aligner treatment all canines were separated mesially with interproximal elastics for a few days in order to create space to ensure sufficient aligner fitting and effective movement of the crowded canines. IPR was performed distal of all maxillary and mandibular canines prior to the scanning process (Fig 24). To maintain the spaces until the arrival of the aligners, a removable retainer (Duran, Scheu-Dental) was inserted for night-time wear.

After obtaining space mesial of all canines, the initial measurements for the aligner treatment could take place. For this, individually bonded attachments were placed on the required buccal surfaces of maxillary and mandibular canines, second premolars and first molars (Fig 25). The following intraoral scan and treatment instructions were sent to the technician to create the first virtual treatment plan.

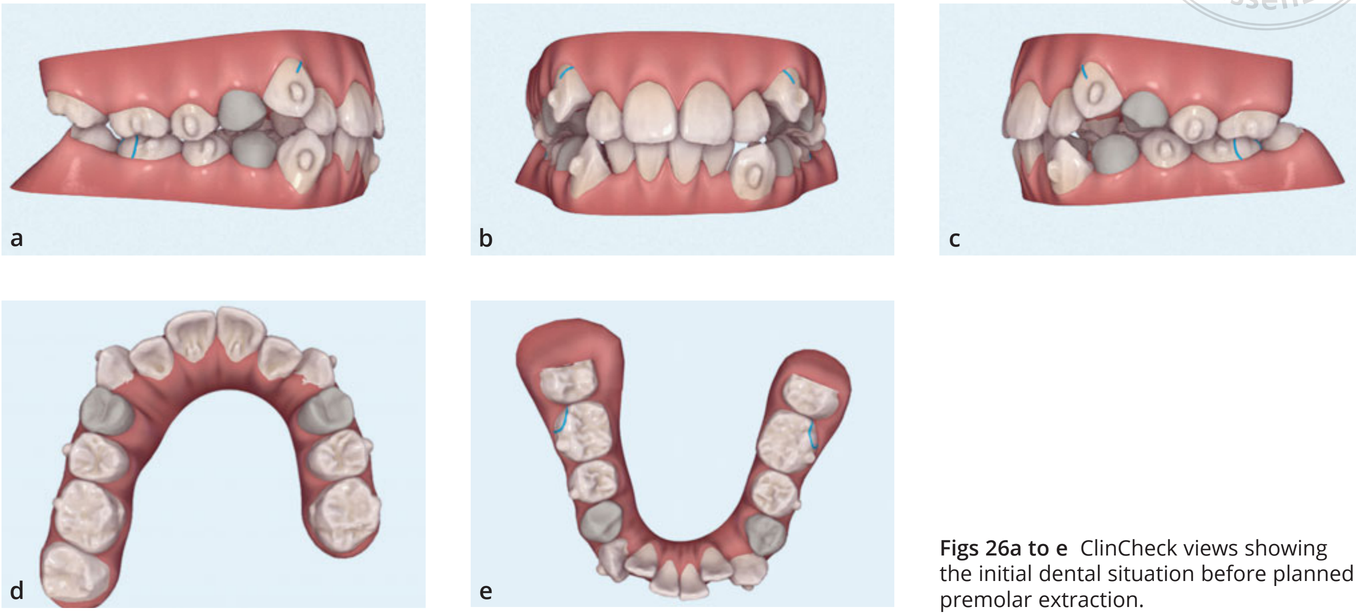
Virtual treatment planning

The technician created the computer-generated simulation and the corresponding modifications were made according to the submitted instructions (Figs 26 to 28). As the treatment plan included the extraction of all first premolars, these teeth were virtually removed in the given simulation. The extraction spaces were closed by retraction of maxillary and mandibular anterior teeth. For this purpose, the use of Class II elastics was essential in order to guarantee sufficient anchorage and to ensure additional force for the planned distalisation. On the maxillary right side, posterior teeth were distalised in order to achieve a full Class I molar relationship. Simultaneously, the mandibular right molars and second premolar were also slightly mesialised.

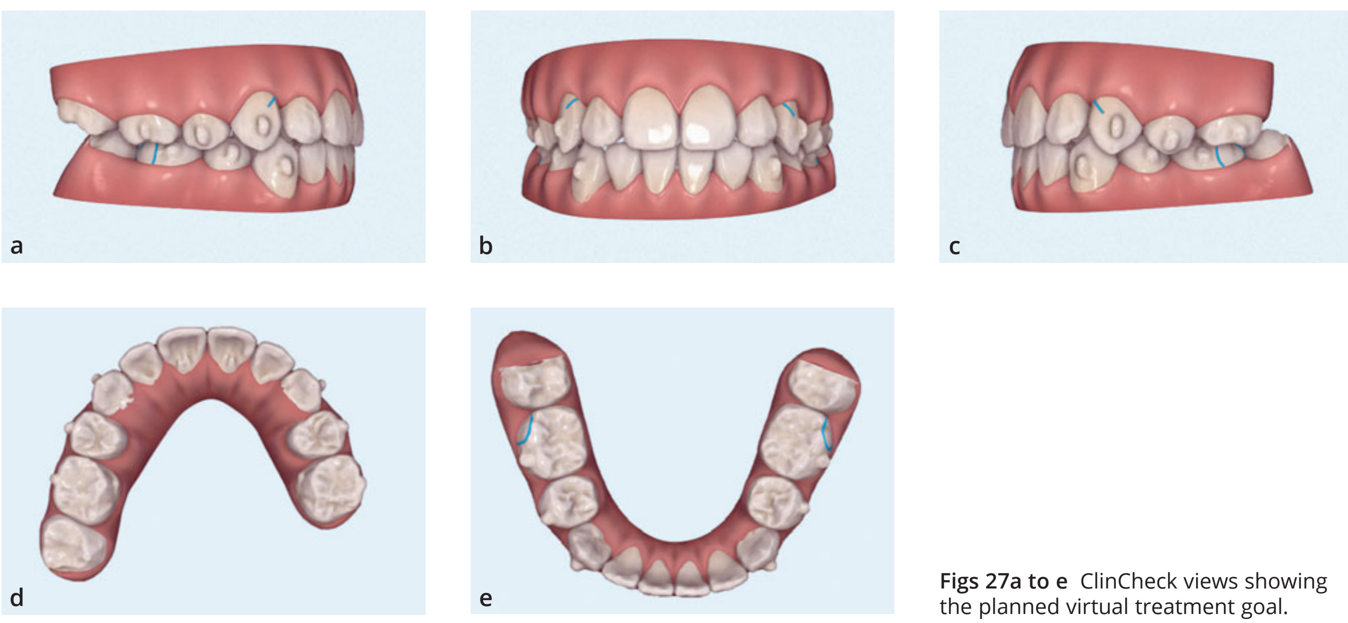
Furthermore, the maxillary midline was moved to the right to match the mandibular midline. During the whole treatment, all premolars and molars were derotated in small increments, anterior crowding was solved and both arches were harmonically aligned. The premature contact on the mandibular left lateral incisors was removed and occlusal contact points were allocated uniformly on posterior teeth to insure a stable occlusion. This first phase consisted of 34 pairs of aligners for both arches. The virtual treatment planning from the initial situation to the predetermined results including dental overlap are shown in Figs 26 to 28.

Treatment progress

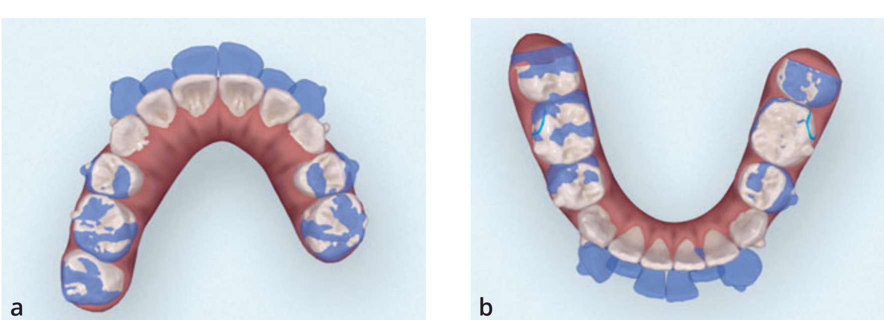
The aligner treatment consisted of the first main phase and three following refinement phases in which remaining problems were corrected. The total number of aligners was 71 in the maxillary arch and 71 in the mandibular arch.



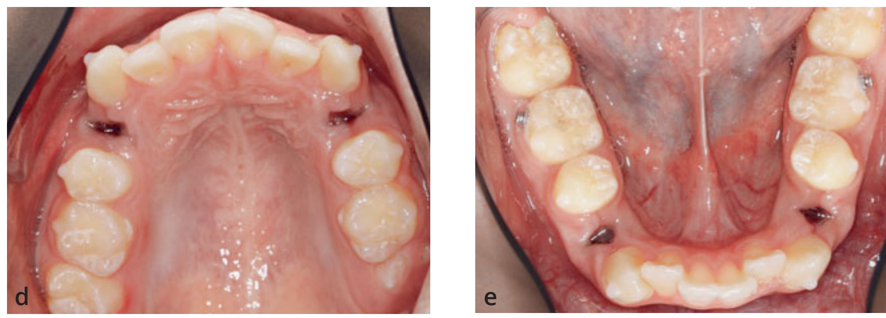
Figs 26a to e ClinCheck views showing the initial dental situation before planned premolar extraction.



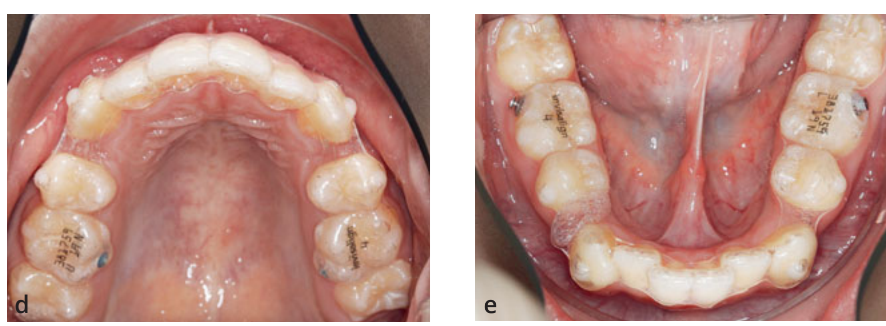
Figs 27a to e ClinCheck views showing the planned virtual treatment goal.



Figs 28a and b ClinCheck views including virtual overlap of planned dental movements demonstrating the amount of retraction of the maxillary and mandibular anterior segment after extraction of the first premolars.



Figs 29a to e Intraoral situation after extraction of all first premolars.



Figs 30a to e Intraoral views with good fitting of aligner number 19.

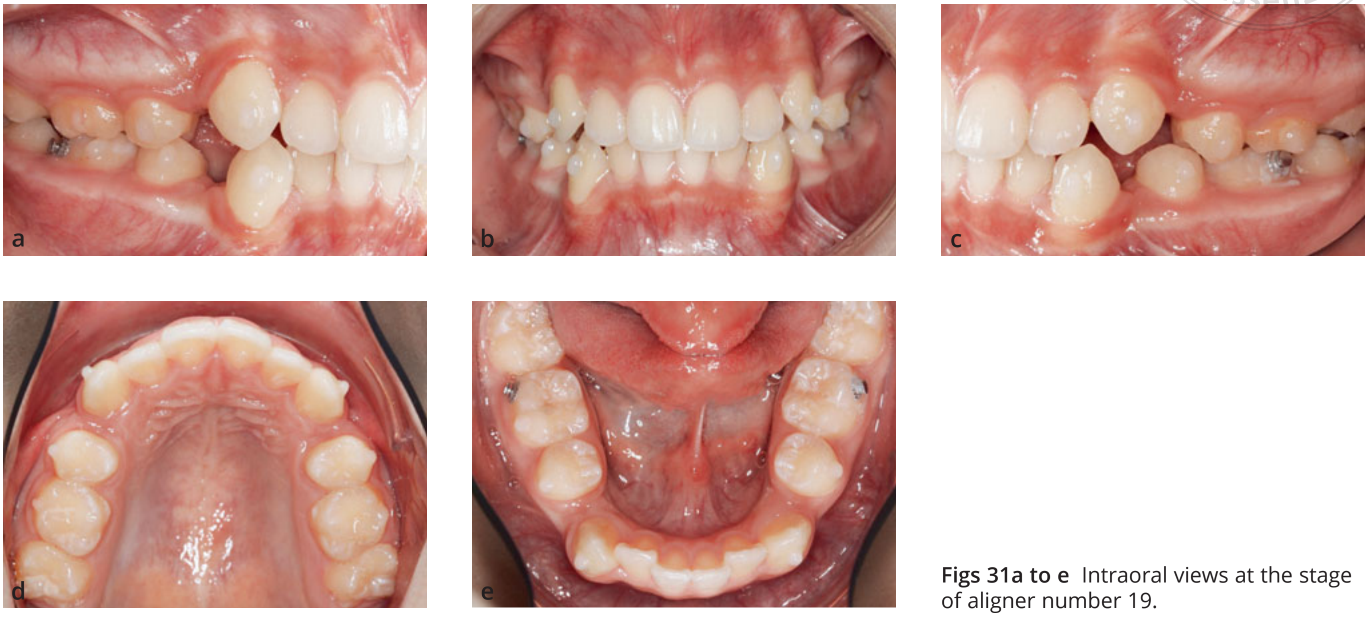
Phase I

As planned in the virtual treatment simulation, the maxillary and mandibular first premolars were extracted before the inset of the first pair of aligners (Fig 29).

At frequent intervals, the sufficient fitting of the appliance and the state of achieved dental movements were checked in order to observe proper treatment progress (Figs 30 and 31).

Phase II

After the first treatment phase goals were achieved, other aspects of treatment could be addressed (Fig 32). In the first refinement, the mandibular anterior teeth were intruded and retracted slightly more in order to reduce the dental deep bite and to resolve the anterior contact. For this purpose, interproximal enamel reduction of 0.2 mm was performed at the mandibular anterior incisors and canines.



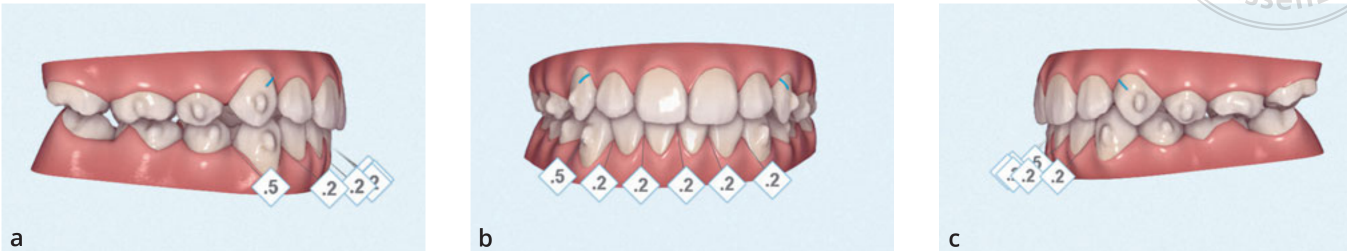
Figs 31a to e Intraoral views at the stage of aligner number 19.

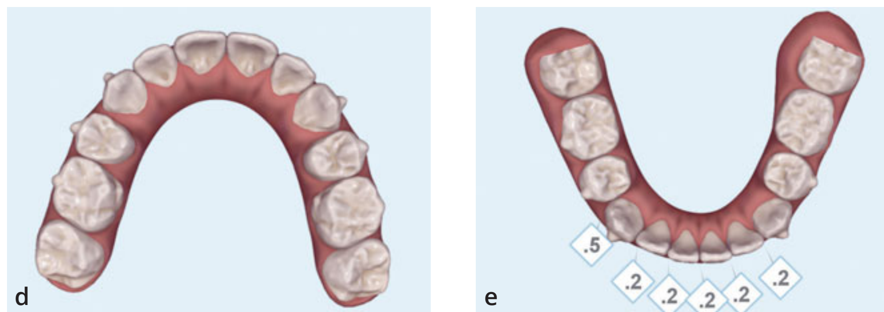
Figs 32a to e Intraoral views after phase I.

The maxillary midline was moved to the right according to the position of the mandibular midline. Additionally, a final mandibular jump was inserted to simulate a perfect Class I canine relationship, to be obtained by the patient wearing Class II elastics. This treatment phase consisted of 10 pairs of aligners (Figs 33 to 35).

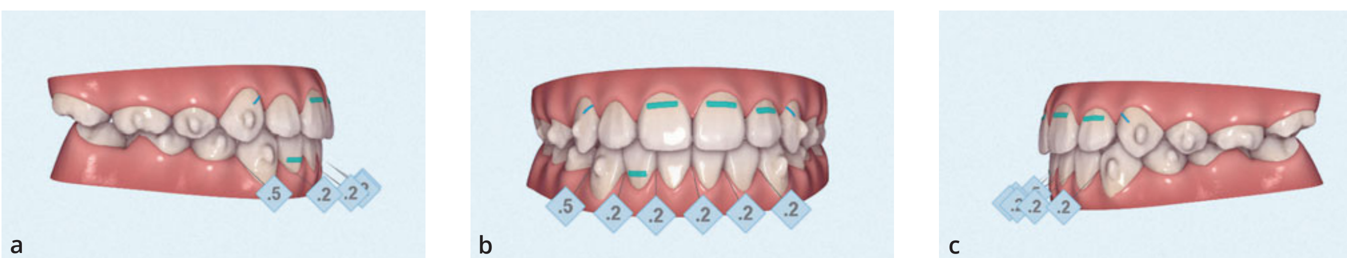
Phase III

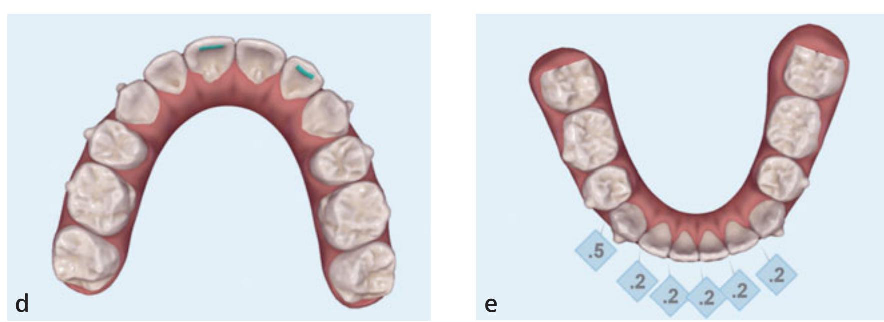
After the second phase some aspects still remained to be corrected (Fig 36). The Class I canine relationship and midlines were improved with the aid of Class II elastics and a simulated final mandibular jump. Due to the obstinate position of the mandibular anterior teeth, more intrusion and retraction was necessary as well as alignment to create



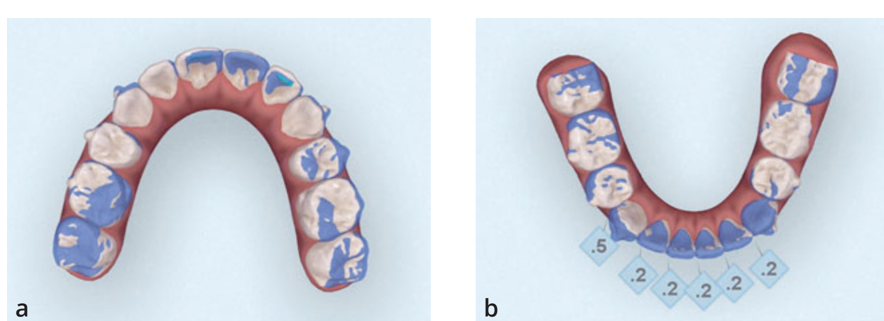


Figs 33a to e Initial dental situation at the beginning of phase II.



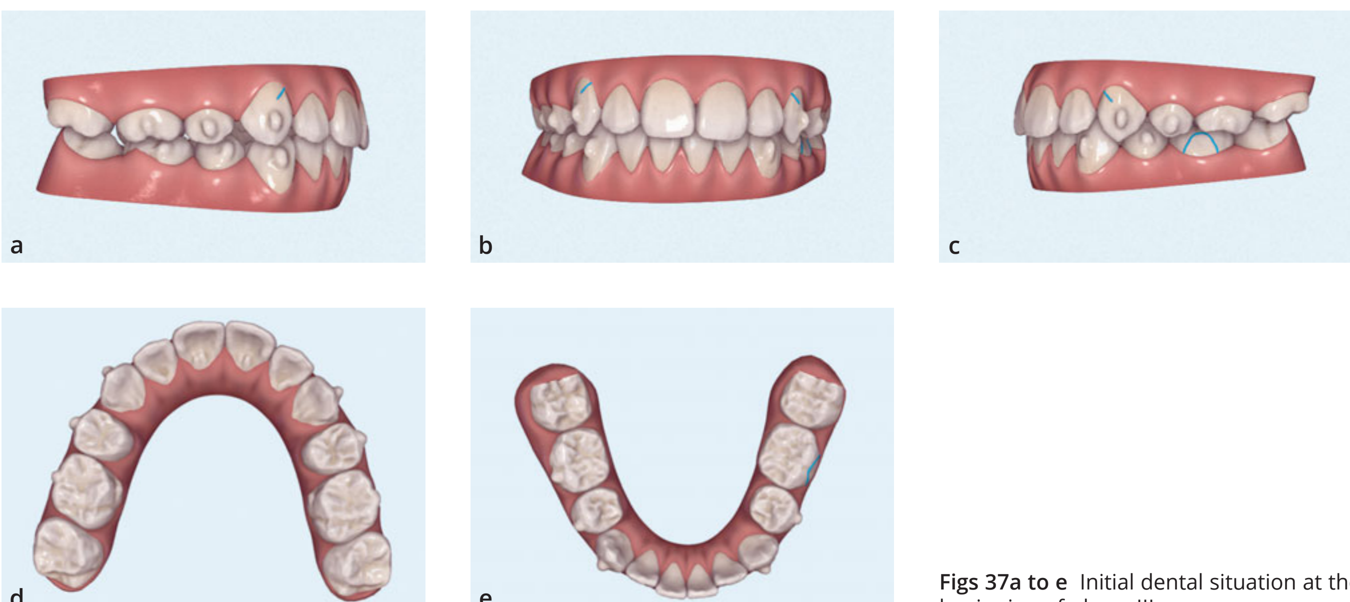


Figs 34a to e ClinCheck views showing the planned virtual treatment goal of phase II.



Figs 35a and b ClinCheck views including the virtual overlap of planned dental movements at phase II.

Figs 36a to e Intraoral views after phase II.

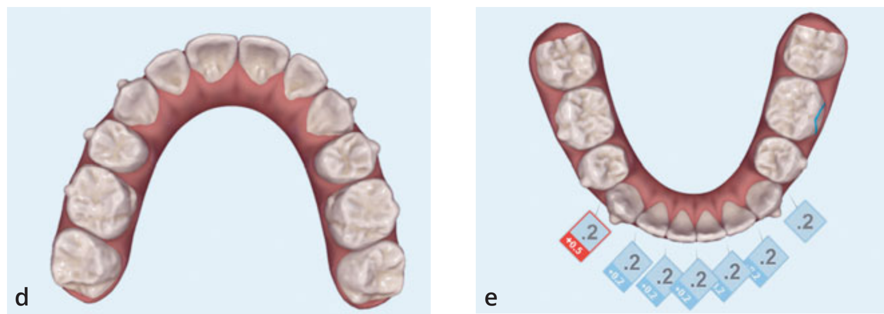


Figs 37a to e Initial dental situation at the beginning of phase III.

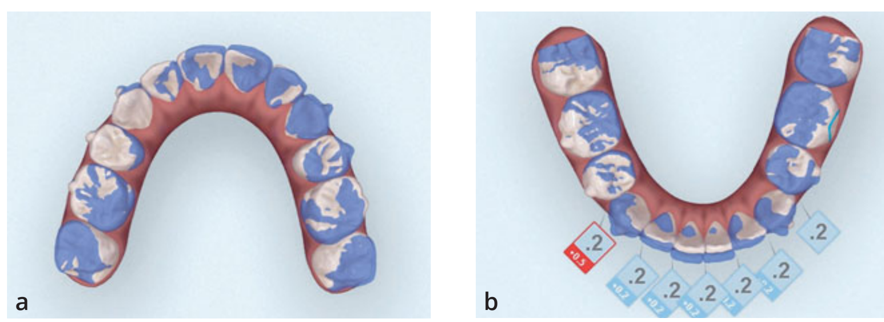
greater horizontal overlap and to end without any anterior contact. Additional overall 13 + 15 aligners were necessary to obtain the final treatment result (Figs 37 to 39).

Treatment results

As presented in this clinical report, the aligner technique demonstrated efficiency in performing extraction treatment. At the end of the orthodontic treatment all dental movements were performed as required and the arches were harmoniously aligned (Fig 40). The closure of the extraction spaces and the solution of crowding resulted in a perfect Class I canine relationship with ideal horizontal and vertical overlap. Furthermore, a stable occlusion with posterior support and canine guidance was achieved (Fig 41).

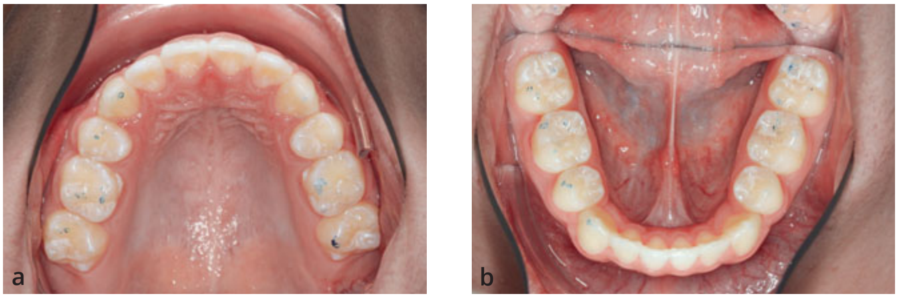


Figs 38a to e ClinCheck views showing the planned virtual treatment goal of phase III.

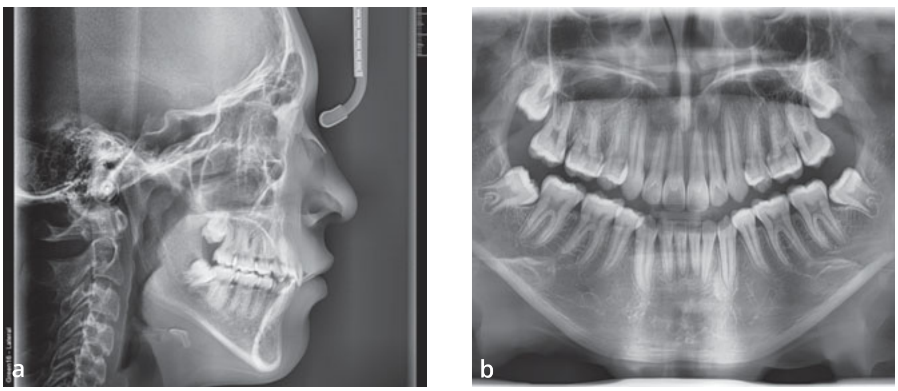


Figs 39a and b ClinCheck views including virtual overlap of planned dental movements at phase III.

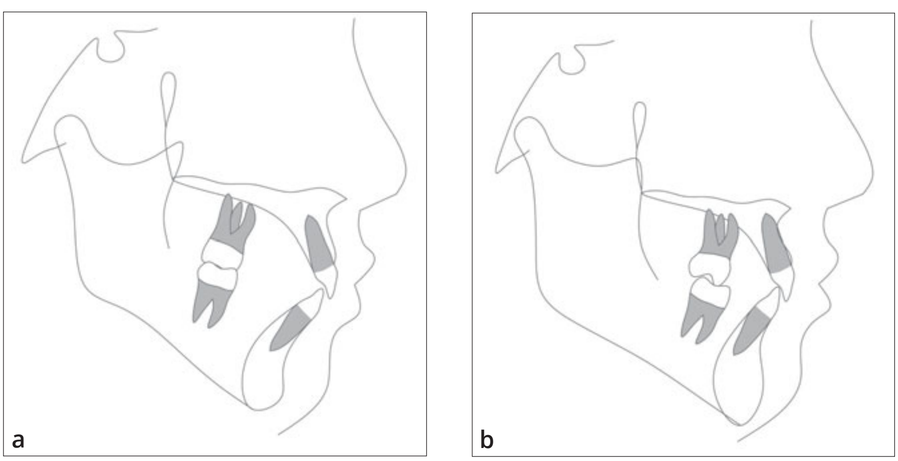
Figs 40a to f Posttreatment intraoral views.



Figs 41a and b Intraoral situation with marked occlusal contact points after equalising the spread of occlusal contact points.



Figs 42a and b Lateral cephalogram and panoramic radiograph at the end of the treatment.



Figs 43a and b **(a)** Pre- and **(b)** posttreatment cephalometric measurements, as detailed in Table 4.

Table 4 Cephalometric measurements pre- and posttreatment, as shown in Fig 43.

Measurement		Norm	Initial	Final	Change
Skeletal	Convexity of A (mm)	1.2 ± 2.0	5.6	0.8	−4.8
	Lower facial height (degrees)	47.0 ± 4.0	49.4	45.7	−3.7
	Mandible plane angle (degrees)	27.2 ± 4.5	39.7	40.3	+0.6
Dental	$\bar{1}$-APo (mm)	1.0 ± 2.3	3.8	2.6	−1.2
	$\underline{1}$-APo (mm)	3.5 ± 2.3	6.7	5.2	−1.5
Soft tissue	Lower lip–E-plane (mm)	−1.2 ± 2.0	1.1	1.4	+0.4

The lateral cephalogram (Fig 42a) showed a corrected skeletal Class I base with a reduced skeletal open bite tendency (Fig 43). According to the Ricketts analysis and as presented in Fig 43b, a significant convexity decline down to 0.8 mm was detected after the completion of orthodontic extraction therapy (Table 4). Moreover, the measurements of incisor positions were in the standard range, measuring 2.6 mm for the maxillary incisor position and 5.2 mm for the mandibular incisors. The lower lip moved back an average of 2.0 mm to Ricketts E-plane.

The panoramic radiograph showed a good periodontal state and the extraction of all third molars was recommended (Fig 42b).

Discussion

The fundamental element of successful treatment of bimaxillary dentoalveolar protrusion is the differential diagnosis between skeletal and dental subdivisions. The characteristics of skeletal subdivision bimaxillary dentoalveolar protrusion are as follows: SNA and SNB are greater than norms, and U1–SN and incisor-mandibular plane angle (IMPA) are within normal ranges[26]. The measurement of A-Pog shows protruded upper and lower lip positions in relation to Ricketts E-plane. Dental values such as $\overline{1}$-APo and $\underline{1}$-APo are typically increased, expressing a protruded maxillary and mandibular incisor position[27]. Some bimaxillary dentoalveolar protrusion patients also have gummy smiles resulting from increased vertical height of the maxilla. Usually, orthognathic surgeries for the skeletal subdivision bimaxillary dentoalveolar protrusion will have a better aesthetic and functional result than orthodontics alone[11].

Various points can be considered for each patient discussed in the present article.

Patient 1

There are some technical difficulties in using aligners to treat extraction cases, because aligner materials have very good elasticity but not rigidity. Therefore, aligners can hardly provide enough uprighting moments during extraction space closure and hence molar mesial tipping often happens. When molar mesial tipping is not detected early, tipping will get much worse during the course of treatment. In order to prevent this, incorporating short Class II elastics can provide more vertical forces, therefore more uprighting moments. When molars are severely tipped, posterior regional brackets with segmental wires and anterior aligners can solve this situation or even prevent it.

- It is recommended that anterior retraction should be done by alternating canine retraction and incisal retraction. For example, move canines back for 2 mm and halt, then move incisors back. When incisors are moved back, repeat previous cycle to the desired positions. This repetitive movement is called the caterpillar motion.
- Due to the nature of aligner therapy, molar intrusion can happen because of occlusal forces acting on the two layers of plastic. Nevertheless, when short Class II elastics are used, its vertical component of force can reduce molar intrusion and decrease vertical overlap deepening during space closure.
- In extraction cases, each aligner should be worn more than 20 hours a day, 7 days a week. In this way, each aligner has enough time to move the roots to reduce crown tipping.

Patient 2

- In non-extraction patients, there are not many remedies to gain space for anterior retraction. Molar distalisation, arch transverse expansion and IPR have been reported in gaining space for incisal retraction. Generally, 2 to 4 mm of space can be expected by pushing a molar distally. However, there are some anatomical limitations, such as the amount of space distal to the second molars, and the size of the third molars. Partially burial of second molars in retromolar gingiva may occur even after third molars are extracted.
- Even with perfect anchorage, molars can be pushed much more distally, but the anterior alveolar A-P width should be taken into account. In cases with very limited width of anterior alveolar bone, when a great amount of incisal retractions is performed, fenestration and dehiscence may occur and induce periodontal diseases.
- In Patient 2, the treatment simulations included 2 mm of molar distalisation. In fact, from the cephalometric superimpositions, clinical molar distalisation was not apparent to the level shown by the software. The space for anterior retraction was from 2 mm transverse arch expansion, and 5.8 mm IPR (Fig 20).

- Molar intrusions resulted in forward mandibular autorotation.
- TADs were placed buccally between the maxillary first and second molars for increased anchorage, reducing the rowboat effect, and reducing anterior flaring when the molar moved back.
- The mandibular incisors showed genuine intrusions rather than relative intrusions. In comparison with traditional labial or lingual brackets, aligners fully encapsulate the entire crowns, so aligners could much easier apply intrusive forces through the centre resistances of the teeth. This hypothesis needs further studies for verification.

Patient 3

The extraction of four premolars presents a common treatment method to correct crowding and bimaxillary dentoalveolar protrusion. For this purpose, the required dental movements have been proven to be feasible by means of aligner orthodontics[28,29]. It is important to ensure that the staging is not too fast[30]. Moreover, correct selection of the aligner material and strength[31,32] and attachments[33,34], as well as sufficient virtual treatment planning under strict consideration of biomechanics have to be considered[35,36]. Even with precise planning of the treatment in the software and good patient compliance, several phases of aligners might be still needed to obtain an aesthetic and occlusally stable result, because the computer software did not require a transferral of the articulation into the software or a virtual articulator.

- As shown in Fig 24a, a small gap had been created mesial of the canines with separation using interproximal elastics before the beginning of the treatment. Thereby, the aligner could optimally grab the canine also on the mesial surface and with this allow better transmission of the force. The use of interproximal elastics to open gaps prior to scanning or impressions might help to increase the fit of the aligners and expression of the planned movement onto the teeth.
- Three additional aligner phases seem quite a high number. Some changes in the virtual outcome of the ClinCheck software might have helped to avoid the three additional refinements. These include changing the angulation of the maxillary canines during the distalisation in the first ClinCheck, and keeping the roots tipped distally throughout the treatment time, to avoid loss of canine root angulation during the movements.
- With focus on the dynamic occlusion, in particular the canine guidance, the overall treatment included several aligner phases to obtain the final optimal occlusion outcome. Virtual articulation with dynamic and static occlusion patterns would be helpful to overcome this challenge.

Conclusion

From these case studies, clear aligner therapy could successfully treat bimaxillary dentoalveolar protrusion. Ideally, clear aligner therapy should not need additional aligners (refinements) if clinicians could foresee every stage of tooth movement and their side effects, and patients could demonstrate excellent compliance. However, in reality there are other factors to influence tooth movement and occlusion. The temporomandibular joint, in particular, and the static and dynamic occlusion remain factors not yet included in the ClinCheck software. Therefore, refinements are necessary, especially in complex cases. With accurate differential diagnosis, careful clinical observation, and patient compliance, clear aligners can conquer this frontier.

It has been more than 100 years since Angle gave us orthodontic brackets. The force systems within brackets and wires have been studied and revealed. In extraction cases, loop mechanisms and increased stiffness of the wires with traditional brackets can move teeth without major side effects, such as the bowing effect. With aligner therapy, chairside procedures have been simplified, but simply handing over the treatment purely to the computer software simulations and manufacturers will not suit clinical practices. On the contrary, with digital designs of tooth movement, orthodontists must pay more attention to the details and clinical observations. In this day and age, pharmaceutical companies manufacture medicines, but it is still the physician's responsibility to successfully treat the patient.

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