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Hemifacial microsomia treated with a hybrid technique combining distraction osteogenesis and a mandible-guided functional appliance: Pilot study

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Introduction: The purpose of this study was to evaluate the therapeutic effect of a hybrid treatment for hemifacial microsomia that combines distraction osteogenesis and a mandible-guided functional appliance to correct mandibular asymmetry. **Methods:** This was a retrospective analysis of 10 patients with unilateral hemifacial microsomia who underwent mandibular ramus distraction osteogenesis in our hospital from February 2013 to July 2015. The cases were classified into 2 comparison groups: 5 patients were in the MG-DO group (distraction osteogenesis combined with an mandible-guided functional appliance) and 5 in the control group (distraction osteogenesis only). Anteroposterior cephalometric analyses were conducted before and after treatment. Soft tissue symmetry and the occlusal relationship were observed from facial and intraoral photographs. Statistical analyses were performed to determine changes between before and after treatment as well as intergroup differences. **Results:** The MG-DO group showed greater vertical elongation of the mandibular ramus and less overcorrection and mandibular deviation than the control group. Occlusal reconstruction was enabled by the mandible-guided functional appliance owing to a decrease in lateral shifting. The symmetry of both skeletal and soft tissues was significantly improved in the MG-DO group. **Conclusions:** The hybrid technique combining distraction osteogenesis and the mandible-guided functional appliance proved to be effective in correcting canting and deviation during mandibular elongation, which improved facial symmetry and occlusal balance in patients with hemifacial microsomia. (Am J Orthod Dentofacial Orthop 2019;155:801-11)

Hemifacial microsomia (HFM) is a common birth deformity affecting the first and second branchial arches.[1] It manifests typically as unilateral craniofacial skeletal hypoplasia, which mostly affects the external/middle ear, mandible, contiguous bony skeleton, and its overlying soft tissues.[2] HFM is the second most common congenital craniofacial malformation after cleft lip and palate.[3]

Distraction osteogenesis (DO) was first introduced to treat HFM in 1992[4] and has proved to be the preferred method in HFM therapy.[5-8] Instead of a conventional surgical intervention, DO has achieved good results in correcting deformities and shortening the treatment period through a course of autologous osteogenesis.[9] However, some secondary problems relevant to the skeleton and occlusion have been ignored. The increase

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in mandibular length was designed in 1 dimension without considering the changes that would occur 3-dimensionally.[10] Insufficient elongation of the mandibular ramus in the vertical dimension often occurs after DO treatment, which could be relevant to mandibular canting and deviation.[11] Moreover, malocclusion frequently occurs from unexpected chin shifting after DO, including an open bite or scissors bite on the affected side and a crossbite on the unaffected side,[7,10] which is consistent with our clinical observations. Therefore, after pubertal growth with skeletal maturation and the establishment of primary occlusion, patients have to undergo tedious and complicated orthodontic treatment and orthognathic surgery.[7]

To solve mandibular canting and deviation, a hybrid treatment combining DO of the mandibular ramus with a mandible-guided (MG) functional appliance was applied in early reconstructive therapy for HFM in the present study. Our aim was to conduct a retrospective analysis of patients with HFM, who underwent mandibular ramus DO guided by the MG functional appliance, to evaluate its effectiveness in obtaining a harmonious skeletal and occlusal relationship.

REASON FOR AND PRIMARY MECHANICAL ANALYSIS OF MANDIBULAR DEVIATION AFTER DISTRACTION OSTEOGENESIS

Grade II HFM manifests as both maxillary and mandibular asymmetry, the unilateral ramus is abnormally shaped and the features mostly characterized by a short ramus and mandibular canting. The priority in DO is to correct the mandibular asymmetry and to elongate the ramus on the affected side; however, this single surgical procedure ignores the complexity of mandibular movement after DO.

With evidence accumulated in the clinic, we found that ramus elongation always accompanied abnormal mandibular movement. Mandibular decanting is expected and plays a key role in HFM treatment, and accompanying shifting and deviation are unexpected. These unwanted movements lead to a crossbite on the unaffected side and a scissors bite or open bite on the affected side, as mentioned above, which may require orthognathic-orthodontic joint treatment in adulthood. After further observation was performed, we placed an emphasis on the mechanical analysis of mandibular movement to avoid its compensated deviation which caused mandibular canting and malocclusion. After unilateral mandibular ramus DO, the distraction of mandible does not follow a single path. This movement results in mandibular decanting, lateral shifting, and rotation as well. In addition, we also found that these unexpected movements are inevitable with DO alone because of limitations that probably originate from the mandibular anatomic structure, bilateral temporomandibular joint, and skeletal maturity (Figs 1 and 2). Therefore, to obtain the desired effect, use of the MG functional appliance is recommended because it is atraumatic and convenient. This device combined with orthodontic intervention significantly inhibited mandibular lateral shifting. With an MG functional appliance, we can create an ideal and reliable pattern that can guide mandibular movement while DO is underway. Meanwhile, this hybrid treatment composed of DO and an MG appliance as a bridge connecting the maxilla and mandible enables simultaneous stimuli promoting interaction between the maxilla and the mandible.

MATERIAL AND METHODS

The MG functional appliance has been used in HFM surgical cases in our hospital since February 2013. We retrospectively reviewed medical charts of cases from February 2013 to July 2015 to identify patients affected by a grade II mandibular deformity and maxillary asymmetry and in whom DO combined with an MG functional appliance (MG-DO) was performed as treatment for HFM.

After the retrospective review of HFM cases, 10 subjects (average age 7 years 7 months) were identified (5 male subjects and 5 female subjects). Of these 10 cases, 5 patients (2 male and 3 female) underwent MG-DO, forming the MG-DO group, and 5 patients (3 male and 2 female) underwent DO only, forming the control group. Permissions were obtained from all patients who were involved in the study. This study was approved by Ethical Committee of the Ninth People's Hospital Affiliated to Shanghai Jiao Tong University School of Medicine.

Both groups underwent preoperative surgical designs and were treated with unilateral mandibular ramus DO. The MG functional appliance was used simultaneously for patients in the MG-DO group while they were undergoing the mandibular ramus distraction course.

Surgical procedures were performed as described previously by our colleagues.[8] Preoperative computed tomographic (CT) scan data were obtained for all patients. CT imaging was performed with the use of a Philips Brilliance TM 64-slice (Philips Medical Systems, Best, The Netherlands) helical CT system. The imaging parameters were as follows: 1 mm section thickness reconstructions, 25 cm field of view, 120 kV tube voltage, 350 mA tube current, and 256 $\times$ 256 matrix. The CT

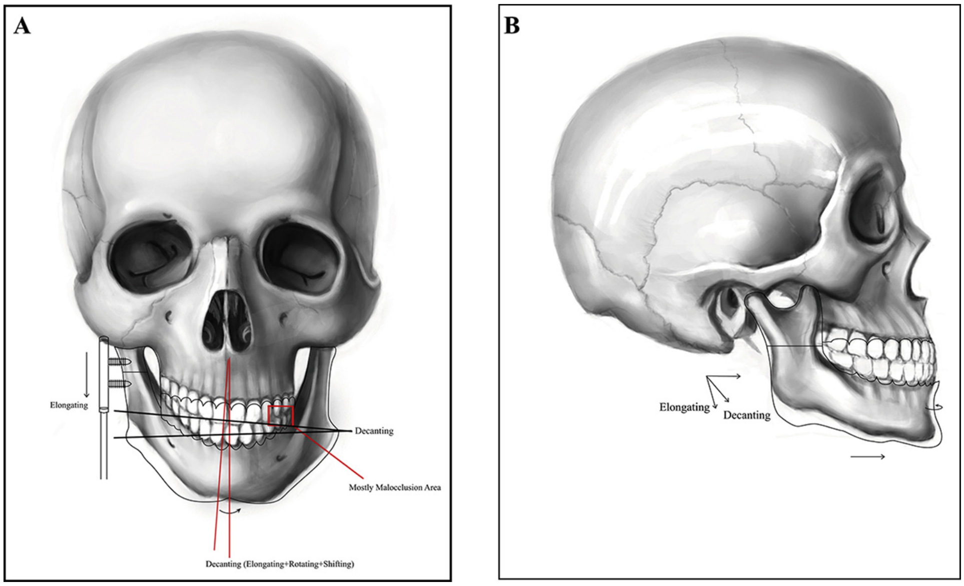

Fig 1. Schematic representation of mechanical analysis and maxillary and mandibular position and movement before DO and after DO (*outline*) **A,** Unilateral mandibular ramus osteotomy: a single-vector distractor was applied; mostly malocclusion area (*red box*) occurred on the unaffected side with the molars characterized as a crossbite; *arrows* indicate direction of the mandible and its overcorrection because of rotating and lateral shifting to the unaffected side; *red lines* show the different vertical line (VL) positions before and after DO amendment of facial asymmetry. **B,** Unilateral mandibular ramus osteotomy: expected changes and mandible movement of facial profile (*outline*); *arrows* indicate mandible with distraction osteotomy for 2 different dimensions: elongating (vertical) and decanting (both vertical and lateral).

scans cover the whole head, which were routinely conducted before DO operation for all the HFM patients. Based on the reconstruction of CT data, distraction was simulated on a virtual model and the new morphology of the mandible was predicted with the use of Proplan software (edition 1.0; Materialise, Leuven, Belgium). Each patient in this study underwent DO, and all distraction devices were accurately placed on the mandible with the help of a tooth-borne virtual guide as computer-assisted design before surgery. All surgeries were performed under general anesthesia by the same surgeon, who was a specialist in DO procedures. The surgical procedures comprised complete corticotomy and fixation of a unidirectional distractor. After 5 days (the latency period), the distractor was lengthened by 0.4 mm twice a day. A 6-month consolidation period was needed before the distractor was removed.

A maxillary impression was taken before DO surgery. The MG functional appliance (Fig 2), a type of removable orthodontic appliance, was manufactured and placed on the upper dentition at the commencement of distraction. A bite plate was designed for the affected side to guide mandibular decanting. Its thickness would be added according to elongation of the mandibular ramus until the end of distraction. The stability of the mandibular position was strengthened by a steady occlusal relationship due to the existence of the bite plate. Meanwhile, a lingual dam extended from the bite plate to the mouth floor on the same side and prevented the mandible from shifting to the unaffected side. Mandibular deviation in the horizontal direction could thus be avoided. Otherwise, temporary anchorage devices were implanted in both upper and lower alveolus on the unaffected side and 3.5-oz, 1/4-inch orthodontic elastics were applied to correct an open bite induced by elongation of the mandibular ramus. The patients were required to wear the MG functional appliance full time except when eating. Good patient compliance was considered to be indispensable.

Radiographic and photographic records were obtained for all the patients before DO (T0) and after DO (T1, after removal of the distractor) in a standard

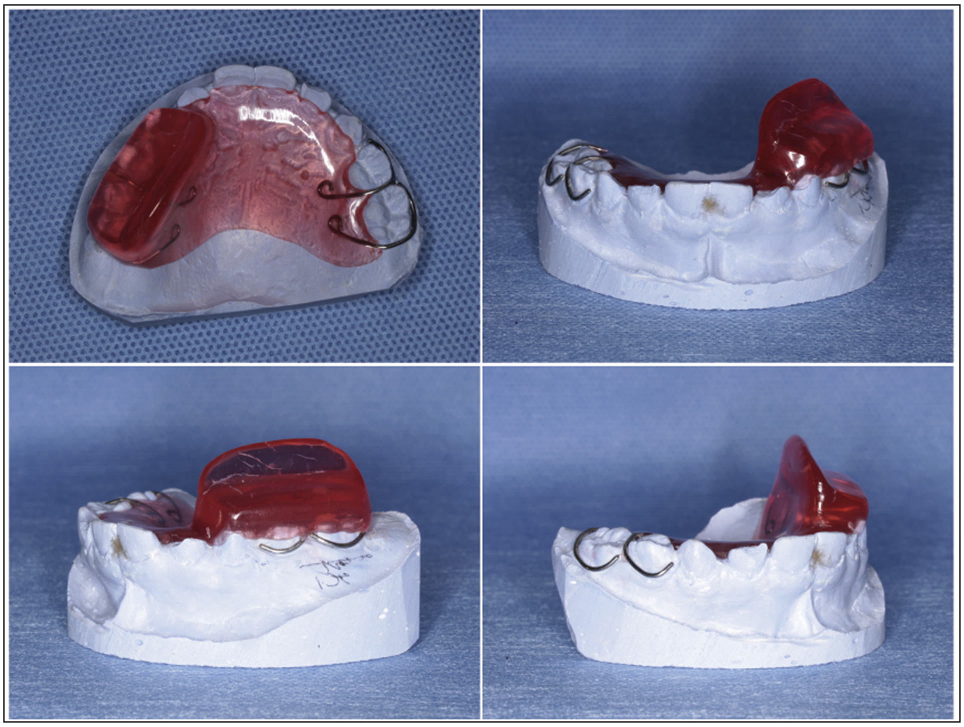

Fig 2. MG functional appliance used for a right HFM patient. A bite plate was designed on the right side and its thickness would be gradually added according to the elongation of mandibular ramus in clinic. A lingual dam extended from the bite plate to the mouth floor on the right side and prevented mandibular shifting to the left.

manner. In consideration of the radiation dose and medical ethics, CT could not be used as frequently as x-rays. Therefore, we used x-rays more often to monitor the direction of the distractor and osteogenesis as well as during the whole treatment for checking the therapeutic effect. Skeletal facial asymmetries were measured on anteroposterior (AP) cephalometric radiographs. Each measurement was repeated 3 times by the same operator, and the mean value was used for statistical analysis. The landmarks and planes of the AP cephalometric analysis are illustrated in Figure 3 and the measurements given in the Table I. Both soft tissue asymmetries and malocclusion were observed from frontal and intraoral photographs.

Statistical analysis

Paired *t* tests were used to examine differences between the pre-DO (T0) and post-DO (T1) measurements, and Mann-Whitney *U* tests were used to examine differences between the MG-DO group and the control group. The analysis was performed using IBM Statistical Product for Service Solutions software (version 19.0; SPSS, Chicago, Ill). A P value of <0.05 was considered to indicate a statistically significant difference.

RESULTS

Overall changes in maxillary skeletal base asymmetry were investigated by measuring the angular changes of the nasal floor (HL-NF′NF) and the maxillary jugal plane (HL-J′J). The results of the AP cephalometric analysis demonstrated vertical maxillary improvements in the control group (Table II) as seen by statistically significant decreases relative to the HL of the nasal floor angle ($P = 0.008$) and the maxillary jugal plane angle ($P = 0.043$). Also, the ratios of the affected-unaffected maxillary skeletal base heights (HL-J′/HL-J) were increased in the control group ($P = 0.034$), demonstrating that the maxilla had grown simultaneously with the mandible without mandibular restriction after DO. In the MG-DO group (Table III), the angular changes in the occlusal plane (HL-OCP) were significantly different ($P = 0.038$), which indicated that remodeling of the maxillary dentoalveolar portion improved after treatment. There was no statistical

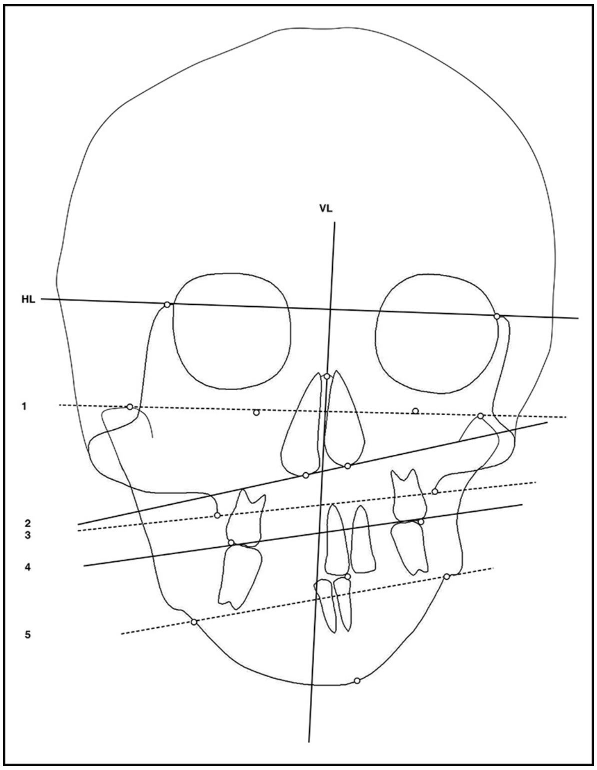

Fig 3. Anatomic landmarks and planes of AP cephalometric analysis: horizontal reference line (HL; the line connecting the right and left latero-orbitale (LOr) points), bicondylar plane (Co′-Co), condylion (Co), nasal floor plane (NF'-NF), nasal floor point (NF), maxillary jugal plane (J′-J), jugal process (J), occlusal plane (Oc′-Oc), occlusal plane point (Oc), antegonial plane (Ag′-Ag), antegonial point (Ag), vertical reference line (VL), the line perpendicular to HL through the center of crista galli, menton (Me), anterior nasal spine (ANS), ratio of the affected versus the unaffected antegonial height (HL-Ag′/HL-Ag) and mandibular ramus height (Ag′-Co′⊥/Ag′-Co′⊥).

significance among the maxillary measurements between 2 groups (Table IV).

Variations in mandibular position are indicated by angular changes in the antegonial plane. After treatment (T1), antegonial plane inclinations were reduced significantly both in the control group ($P = 0.010$) and in the MG-DO group ($P = 0.001$) (Tables II and III). Mandibular ramus symmetry is another extremely important indicator in the therapeutic evaluation of DO. The variations in antegonial plane canting can also be embodied in mandibular ramus symmetry changes. The ratios of the affected-unaffected antegonial heights (HL-Ag′/HL-Ag) significantly improved by 12.1% from 89.1% to 101.2% ($P = 0.001$) in the MG-DO group and by 5.9% from 86.8% to 92.8% ($P = 0.009$) in the control group. Mandibular ramus heights (Ag′-Co′⊥/Ag-Co⊥) significantly improved by 23.3% from 76.2% to 99.5% in the MG-DO group ($P = 0.030$) and by 12% from 78.2% to 90.2% in the control group ($P = 0.001$). The symmetry of the mandibular ramus improved significantly with both DO and hybrid treatment. Moreover, changes in antegonial height ($P = 0.032$) and mandibular ramus height ($P = 0.016$) in the MG-DO group were significantly different from the changes in the control group (Table IV). As seen in the Tables II and III, the maximum correction of mandibular ramus symmetry in the MG-DO group reached an average of ~100%, which implies ideal vertical symmetry. The value from the control group was ~90%.

Among the vertical measurements, menton deviation (VL-Me) significantly changed in the control group ($P = 0.006$), demonstrating that the chin shifted toward the midline or overcorrected toward the unaffected side (Table II). However, there was no statistical difference among the vertical measurements in the MG-DO group ($P = 0.105$), and the amount of VL-Me was significantly different between 2 groups ($P = 0.028$), which indicated no or little overcorrection and chin shifting (Tables III and IV). These findings were favorable and demonstrate the crucial guiding effect of the orthodontic functional appliance in mandibular ramus distraction.

Soft tissue symmetry and the occlusal relationship were observed on facial and intraoral photographs (Figs 4 and 5). Facial asymmetry was significantly improved by elongation of the ramus on the affected side and decanting of the mandibular plane after DO in both control and MG-DO groups. The inclinations of the nasal base plane and labial commissure plane were reduced as well. In the MG-DO group, mandibular deviation and chin shifting changed mildly toward the midline, and favorable facial symmetry was obtained by using the MG functional appliance accompanied by elastics during and after distraction. In the meantime, the lingual dam of the MG appliance effectively prevented the mandible from overcorrecting and shifting toward the unaffected side, which was consistent with the statistic results above. However, in the control group, mandibular deviation occurred and the chin shifted significantly toward the unaffected side. Thus, another kind of "facial asymmetry" occurred in the control group patients after DO which was derived from iatrogenic factors. In addition, a normal occlusal relationship was maintained on the unaffected side of patients in the MG-DO group, whereas a crossbite occurred on the unaffected side as a result of mandibular deviation and an open or scissors bite occurred on the affected side as a

Table I. Measurements of AP cephalometric analysis

Measurement	*Description*
Horizontal (°)	
HL-J′J	Acute angle between HL and maxillary jugal plane
HL-NF′NF	Acute angle between HL and nasal floor plane
HL-Ag′Ag	Acute angle between HL and antegonial plane
HL-Co′Co	Acute angle between HL and bicondylar plane
HL-OCP	Acute angle between HL and the occlusal plane
Vertical (°)	
VL-Me	Acute angle between VL and mental line
VL-ANS	Acute angle between VL and ANS line
Distance (ratio)	
HL-J′/HL −J	Ratio between the linear perpendicular distance from HL to affected J′ point and the linear perpendicular distance from HL to the unaffected J point
HL-Ag′/HL-Ag	Ratio between the linear perpendicular distance from HL to affected Ag' point and the linear perpendicular distance from HL to unaffected Ag point
Ag′-Co′/Ag-Co	Ratio between the linear distance from affected Ag′ point to affected Co′ point and the linear distance from unaffected Ag point to unaffected Co point
Ag′-Co′⊥/Ag-Co⊥	Ratio between the linear perpendicular distance from affected Ag′ point to affected Co′ point and the linear perpendicular distance from unaffected Ag point to unaffected Co point

′Affected side.

Table II. AP cephalometric analysis (paired-samples T Test) of the control group before (T0) and after (T1) DO

				95% CI of the difference		
Measurement	*T0*	*T1*	*T0 − T1*	*Lower*	*Upper*	*P*
Horizontal (°)						
HL-J′J	7.280 ± 2.611	3.633 ± 1.324	3.647 ± 2.789	0.184	7.109	0.043*
HL-NF′NF	10.780 ± 4.756	6.387 ± 6.464	4.393 ± 1.987	1.926	6.861	0.008†
HL-Ag′Ag	8.007 ± 3.011	4.407 ± 4.370	3.600 ± 1.750	1.427	5.773	0.010†
HL-Co′Co	2.027 ± 0.566	1.593 ± 1.737	0.433 ± 1.297	−1.177	2.044	0.497
HL-OCP	9.507 ± 3.089	6.320 ± 2.923	3.187 ± 4.101	−1.906	8.279	0.157
Vertical (°)						
VL-Me	7.180 ± 2.967	2.300 ± 3.311	4.880 ± 2.096	2.277	7.483	0.006†
VL-ANS	1.253 ± 2.166	0.167 ± 3.205	1.087 ± 2.313	−1.785	3.959	0.353
Distance (ratio)						
HL-J′/HL-J	0.858 ± 0.052	0.928 ± 0.026	−0.069 ± 0.049	−0.130	−0.008	0.034*
HL-Ag′/HL-Ag	0.868 ± 0.049	0.928 ± 0.070	−0.059 ± 0.028	−0.095	−0.024	0.009†
Ag′-Co′/Ag-Co	0.752 ± 0.046	0.895 ± 0.074	−0.143 ± 0.030	−0.181	−0.105	0.000†
Ag′-Co′⊥/Ag-Co⊥	0.782 ± 0.054	0.902 ± 0.079	−0.120 ± 0.030	−0.157	−0.083	0.001†

′Affected side.
*$P < 0.05$; †$P < 0.01$

result of mandibular elongation in control group patients. A side-effect of using the MG functional appliance was that an open bite appeared on the affected side because of the existence of the bite plate, which could be corrected in later treatment with another orthodontic device placed on the lower arch (Fig 6).

DISCUSSION

DO has been proven to be an effective method and is a standard procedure to correct craniomaxillofacial deformities. Despite the use of costochondral grafts and mandibular osteotomies combined with bone grafts, DO is an alternate method with a lower risk of absorption and morbidity at the donor site. The advantages of DO include depending on the patient's own healing mechanisms and growth potential to reconstruct the mandible and change the soft tissues. An enormous number of facial asymmetries from HFM have been corrected by DO surgical procedures at an early age.[12] Although the correction of mandibular ramus and soft tissue deformities can be accomplished, the continuous

Table III. AP cephalometric analysis (paired-samples *t* Test) of the MG-DO group before (T0) and after (T1) DO

Measurement	T0	T1	T0 − T1	95% CI of the difference: Lower	95% CI of the difference: Upper	P
Horizontal (°)						
HL-J′J	6.200 ± 1.961	1.673 ± 2.993	4.527 ± 4.357	−0.883	9.937	0.081
HL-NF′NF	8.913 ± 4.170	5.973 ± 2.617	2.940 ± 5.287	−3.624	9.504	0.282
HL-Ag′Ag	6.480 ± 2.654	−0.780 ± 2.964	7.260 ± 1.858	4.953	9.567	0.001†
HL-Co′Co	−1.573 ± 3.032	−0.960 ± 2.224	−0.613 ± 3.618	−5.105	3.879	0.724
HL-OCP	7.600 ± 3.420	3.140 ± 4.300	4.460 ± 3.255	0.419	8.501	0.038*
Vertical (°)						
VL-Me	4.027 ± 3.289	0.460 ± 2.760	3.567 ± 3.822	−1.178	8.312	0.105
VL-ANS	0.627 ± 0.675	−1.087 ± 4.030	1.713 ± 3.872	−3.094	6.521	0.378
Distance (ratio)						
HL-J′/HL −J	0.885 ± 0.040	0.971 ± 0.056	−0.085 ± 0.079	−0.183	0.012	0.073
HL-Ag′/HL-Ag	0.891 ± 0.052	1.012 ± 0.048	−0.121 ± 0.031	−0.160	−0.083	0.001†
Ag′-Co′/Ag-Co	0.744 ± 0.166	1.003 ± 0.148	−0.260 ± 0.166	−0.466	−0.053	0.025*
Ag′-Co′ ⊥/Ag-Co ⊥	0.762 ± 0.173	0.995 ± 0.149	−0.233 ± 0.158	−0.429	−0.037	0.030*

′Affected side.
*$P < 0.05$; †$P < 0.01$.

Table IV. Mann-Whitney *U* test

Measurement	Mean rank: Control	Mean rank: MG-DO	Z	P
Horizontal (°)				
HL-J′J	5.20	5.80	−0.317	0.841
HL-NF′NF	5.40	5.60	−0.104	1.000
HL-Ag′Ag	3.40	7.60	−2.193	0.032*
HL-Co′Co	4.60	6.40	−0.943	0.421
HL-OCP	5.40	5.60	−0.104	1.000
Vertical (°)				
VL-Me	7.60	3.40	−2.193	0.028*
VL-ANS	4.80	6.20	−0.731	0.548
Distance (ratio)				
HL-J′/HL −J	5.20	5.80	−0.313	0.841
HL-Ag′/HL-Ag	3.40	7.60	−2.193	0.032*
Ag′-Co′/Ag-Co	4.00	7.00	−1.567	0.151
Ag′-Co′ ⊥/Ag-Co ⊥	3.20	7.80	−2.402	0.016*

*$P < 0.05$.

mandibular canting, deviation, and malocclusion after DO have been ignored. Classic mandibular ramus DO is more like a temporary treatment (compared with long-period growth and development).[13-15] Thus, instantaneous changes in mandibular shape and the relation between the mandible and maxilla lead to postoperative alterations in dental occlusion.

Malocclusion manifests as a crossbite on the unaffected side and an open bite or a scissors bite on the affected side. Consequently, these postoperative changes exacerbate HFM patients′ occlusal relationships and require either orthodontic treatment over a long period of time or orthognathic-orthodontic joint treatment in adulthood.[16-18] Furthermore, considering the unpredictable course of maturation and limited cooperation levels, postoperative orthodontic treatment becomes much more difficult.

In this study, facial asymmetry in patients with HFM was substantially corrected both in the MG-DO group and the control group, which indicates that DO is certainly a valid technique. The frontal photographic observations showed that the nasal base and labial commissure reached a better position at the horizontal line. The chin point shifted toward the midline or overcorrected toward the unaffected side. Meanwhile, soft tissue symmetry was improved, especially in patients with mild HFM. The favorable effects of DO on synostosis deformities are not surprising. However, the correction of malocclusion in the MG-DO group was much better. We combined DO with an MG functional appliance during distraction as well as after removal of the distractor to diminish the time required for and difficulty of orthodontic management after DO. Furthermore, the mandible was more elongated in the vertical dimension on the affected side and demonstrated less deviation toward the unaffected side, which resulted in better facial symmetry.

Why did we choose intervention with an MG functional appliance during both the intradistraction and the postdistraction periods? We noticed that a gap resulting from an open bite on the affected side provided us with an exact location to use a bite plate. The desired outcome of obtaining normal occlusion can be accomplished by using this space caused by “abnormal”

Fig 4. Facial and intraoral photographs: **A,** pre-DO photographs of a 7-year-old girl with right HFM in the control group, **B,** before removal of the distractor, and **C,** after DO; **D,** pre-DO photographs of an 11-year old girl with left HFM in the MG-DO group, **E,** before removal of the distractor, and **F,** after DO. No orthodontic treatment was conducted during distraction in the control group (**B**). However, for the patient in MG-DO group, an orthodontic functional appliance was in position and elastics was applied during distraction and after the removal of distractor as well (**E** and **F**). After distraction osteogenesis, the patient's chin shifted to the unaffected side significantly and crossbite occurred in the ipsilateral side in the control group (**B** and **C**). Whereas facial asymmetry was improved and normal occlusal relationship was maintained in the MG-DO group patient (**E** and **F**).

occlusion on the affected side. Moreover, a functional appliance placed on the affected side gradually stimulates the body's osteogenesis course. Furthermore, according to the previous mechanical analysis result, we found that a single correction of mandibular canting and lateral chin shifting gave rise to a crossbite on the unaffected side. Issues related to mandibular movement complexity have been neglected. Mandibular movement during decanting and the reversal of deviation is a 3-dimensional action (Figs 1 and 7). This action is similar to the movement of a pendulum. As result, to reverse canting and deviation, a pendulum-like movement of the mandible is required. Opposing the pendulum-like movement, the length of the ramus on the unaffected side and obstruction from the fixed maxilla restrict the action. Therefore, unexpected and compensatory action must appear to reconcile this conflict. This motion appears as lateral shifting and axial rotation, which causes a crossbite on the unaffected side, and on occasion an anterior crossbite. The center of rotation is unpredictable owing to multiple factors, such as the stretching of muscles and the orientation of multivariant weak resistance (soft tissue or the individual's craniofacial structure).

The MG functional appliance was designed to augment autologous bone growth, navigate maxillary and mandibular repositioning, and stabilize the occlusal relationship during the entire distraction and consolidation period. It established a solid and continuous connection between the mandible and maxilla. The bite plate played an important role in guiding mandibular movement, to stabilize the mandible and to avoid overcorrection. Moreover, the use of a lingual dam and orthodontic elastics represents a new tool for controlling the osteogenic direction in orthodontic management during DO. DO provided not only an increase in bone mass but also a controlled and directive mandibular increment. Furthermore, the intraoral photos from the MG-DO group indicated that the occlusal relationship on the affected side was stable during DO. The lingual dam and bite plate prevented lateral shifting and patients in the MG-DO group had normal occlusion on the unaffected side. In contrast, the patients in the control group showed malocclusion on both affected and unaffected sides (Figs 4 and 5).

Previously, surgical procedures that combined maxillary osteotomy (Le Fort I) and mandibular distraction have been advocated to decrease the occurrence of malocclusion and to shorten the postoperative orthodontic treatment time.[7,19,20] Admittedly, this hybrid orthognathic surgery forced the maxilla to locate in the desired position and establish correct occlusion. However, overcorrection of the maxilla with secondary skeletal deformities can lead to prolongation of orthodontic treatment and can even necessitate a second surgery. Traumatic surgery has the

Fig 5. Occlusion photographs of the patients shown in Fig 4: **A-C,** pre-DO photographs of patient in control group, **D-F,** pre-DO photographs of patient in MG-DO group, **G-I,** post-DO photographs of patient in control group, **J-L,** post-DO photographs of patient in MG-DO group.

limitations of an acceptable patient age and different kinds of complications.

In the present study, an effective and less invasive device could be more acceptable. Hybrid treatment as described here required fewer surgical interventions and less stimulation, and the outcomes were closer to ideal and more reliable. We found that alterations in the nasal plane and maxillary plane resulted in additional changes to the maxilla that may have been induced by the MG functional appliance. The described orthodontic method would assist in managing this particular condition and would improve the error tolerance rate because of the nonimplanted devices which are easily adjusted. Further study and long-term follow-up are essential.

The present study has some limitations. First, it is a retrospective study with a relatively small sample size and therefore a low level of evidence. The difficulty in recruiting more cases might be due to the low morbidity of HFM[21,22] and the parents' lack of awareness about treating this deformity. Considering the small sample size, the intention of this pilot study was mainly to discuss and identify the trends and tendencies of a precision treatment for HFM. Second, our measurements were all based on AP cephalometric radiographs and photos. It would be more accurate if

Fig 6. The final facial and intraoral photographs of the patient with left HFM treated by DO and orthodontic functional appliance. The open bite on the affected side had been corrected at the end of treatment.

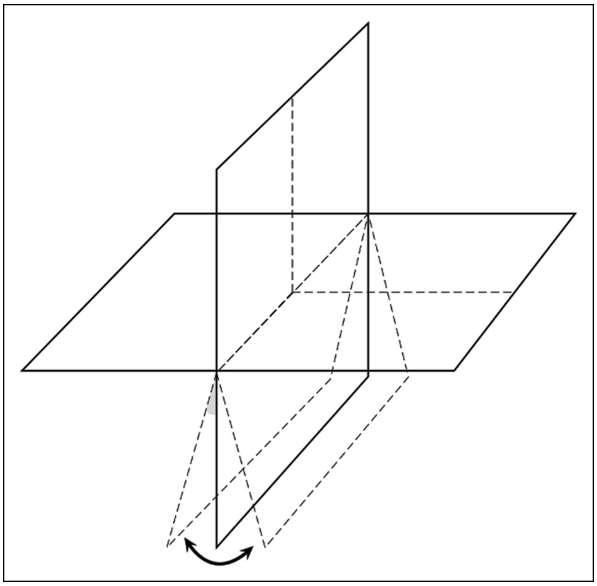

Fig 7. Schematic plot of mandibular movement: *arrow* shows mandibular "pendulum movement."

3-dimensional measurements based on CT 3-dimensional reconstructions could be performed, which would more closely represent the reality. Finally, a long-term follow-up is needed in the future. Further well designed randomized controlled trials and a comprehensive method of assessment are required to investigate the superiority of this hybrid treatment compared with DO.

CONCLUSION

The hybrid technique combining DO and the MG functional appliance proved to be effective in correcting canting and deviation during mandibular elongation, which improved facial symmetry and occlusal balance in HFM patients.

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