Rigid External Distraction with Intranasal Bone-borne Traction Hooks for Midfacial Hypoplasia

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Rigid external distraction is currently performed to correct cases of severe maxillary hypoplasia. As an improvement of this technique, we propose the use of an intranasal bone-borne traction hook. This study is a retrospective chart review of the intranasal bone-borne traction hooks used in the treatment of severe maxillary hypoplasia. There were 110 patients treated with the hooks from 2005 to 2017. The maximum traction force was 7.75 kg, and there were few complications encountered during distraction. There were 76 patients who had the hooks removed under local anaesthesia. A cephalometric analysis was conducted in 56 patients. The average advancement of A-point was 9.9 ± 4.2 mm, 8.4 ± 2.5 mm, 11.0 ± 3.7 mm, 17.9 ± 4.4 mm for the trans-sutural distraction osteogenesis (DO), maxillary anterior segment DO, Le Fort I osteotomy DO, and Le Fort III/II osteotomy DO, respectively. The average changes of sella-nasion-point A (SNA) were 8.89 ± 4.30 degrees, 8.21 ± 3.17 degrees, 10.49 ± 3.26 degrees, and 15.10 ± 4.00 degrees, respectively. The A point-nasion-B point (ANB) also showed increases in all procedures with P < 0.001. In conclusion, this technique sufficiently advances the midface and ensures the scars are concealed in the nasal base. The traction hook can bear a large traction force, causes minimal complications and is easily removed.

Midfacial hypoplasia is a common dentofacial malformation associated with several congenital diseases, such as cleft lip and palate and Crouzon syndrome; this condition usually leads to significant problems. Patients often present with class III malocclusion, severe concave facial appearance, and/or teeth crowding1. Patients may have difficulty breathing, and the majority of cases require orthognathic surgery to achieve aesthetic and functional results.

In 1997 Polley and Figueroa2 first introduced the use of a rigid external distraction (RED) device to treat severe maxillary hypoplasia using distraction osteogenesis (DO). This approach was shown to be an effective technique. RED involves an external bow fixed to the cranium by screws and an intraoral splint cemented to the maxillary first molars. External traction hooks with eyelets are soldered to the splint via surgical wires. Due to the dental compensation and deformation of traction hooks and intraoral splint, several authors have suggested directly attaching the halo device to the bone with fixation plates3,4. However, increased traction forces may cause the skeletal plates to become loose due to bone resorption around fixation screws5, and there is a high risk for loss of osseointegration when tipping forces exceed 600 cN mm6. Therefore, we propose an intranasal bone-borne traction hook to replace the fixation plate. This technique sufficiently advances the midface while ensuring that scars are concealed in the nasal base; this technique also eliminates the need for an intraoral splint.

Results
Clinical review. There were 110 patients with midfacial hypoplasia treated using intranasal bone-borne traction hook distraction from 2005 to 2017. There were 73 patients who underwent trans-sutural DO, 19 patients who underwent maxillary anterior segment DO, 11 patients who underwent Le Fort I DO, 6 patients who underwent Le Fort II DO and 1 patient who underwent Le Fort III DO.

Within the cohort of 110 patients, 46 underwent trans-sutural DO and had a detailed record of traction force evaluated every 1 to 3 days. The average unilateral maximum traction force was 4.75 ± 1.03 kg (range, 3 to 7.75 kg) (Table 1).

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Improvement of 15.10° increased by an average of 9.84° was 8.4° (p < 0.001). The mean horizontal advancement of A-point was 9.9 ± 4.33 degrees (p < 0.001). The ANB also substantially increased; the average increase was 9.17 ± 4.29 degrees (p < 0.001). The mean horizontal advancement of A-point was 9.9 ± 4.2 mm (range, 2.6 to 20.8 mm).

In this study, 28 of 73 patients received cephalometric analysis during the treatment of trans-sutural DO. The skeletal angular and linear changes are shown in Table 2. The SNA was significantly increased when pre-operative images were compared with those obtained immediately post-operatively, and the average increase was 9.11 ± 4.33 degrees (p < 0.001). The ANB also substantially increased; the average increase was 9.17 ± 4.29 degrees (p < 0.001). The mean horizontal advancement of A-point was 9.9 ± 4.2 mm (range, 2.6 to 20.8 mm).

We conducted cephalometric analysis in twelve patients during the treatment of maxillary anterior segment DO (Table 3). The SNA was increased by an average of 8.20 ± 3.17 degrees (range, 3.01 to 13.80°). The ANB was increased by an average of 9.84 ± 3.65 degrees (range, 6.01 to 18.83°). The mean horizontal movement of A-point was 8.4 ± 2.5 mm (range, 4.1 to 11.4 mm).

Eleven patients accepted Le Fort I osteotomy DO. The skeletal angular and linear changes were measured in nine patients (Table 4). The SNA was improved with an average change of 10.48 ± 3.27 degrees (p < 0.001). The ANB was also improved, with an average change of 15.84 ± 4.67 degrees (p < 0.001). The mean horizontal advancement of A-point was 11.0 ± 3.7 mm (range, 6.0 to 17.8 mm).

There were 6 patients who underwent Le Fort III osteotomy DO and one patient who underwent Le Fort II osteotomy DO (Fig. 1). The outcome of cephalometric analysis is shown in Table 5. The SNA had an average improvement of 15.10 ± 4.00 degrees (p < 0.001). The ANB had an average improvement of 16.58 ± 2.30 degrees (p < 0.001). The mean horizontal advancement of A-point was 17.9 ± 4.4 mm (range, 11.1 to 25.1 mm).

Complications. There were four patients who had complications of loose cranial frame, and there were three patients with traction hook failure due to pyriform rim fracture during the treatment of trans-sutural DO. One patient developed an infection, which resolved after the hooks were removed. These complications occurred during the early treatment period when this technique was still under development. There were no complications in the other treatments.

Discussion

External DO is a well-established treatment for midfacial hypoplasia. In our study, the cephalometric analysis showed increases in horizontal advancement, SNA and SNB. The treatment sufficiently advances the midface. DO gradually advances the bony structures of the midface, which allows for progressive osteogenesis and adaptation of the surrounding soft tissues. The gradual surgical movement requires lower counterforce to pull the maxilla into the appropriate position, which makes the maxilla more stable than in traditional Le Fort I osteotomy.

External distraction has generally involved using traction hooks with eyelets and an intraoral splint to attach the maxilla through the dentition. The intraoral wires or splint can be unwieldy and uncomfortable for patients and impede oral hygiene. Additionally, in patients with unsound dentition and severe cleft who are treated with the use of dental anchorage with intraoral orthodontic splint, it is difficult to secure sufficient anchorage. An
### Table 2. Changes in the facial skeleton after trans-sutural distraction osteogenesis. F, female; M, male; UCLP, unilateral cleft lip and palate; BCLP, bilateral cleft lip and palate. P value, Paired t-test of pre- and post-operation with a 5% level of significance.

| Patients | Age (y) | Sex | Diagnosis | Change in A point Distance, mm | Change in SNA Degree | Change in ANB degree |
|----------|---------|-----|-----------|-------------------------------|----------------------|----------------------|
| 1        | 9       | F   | UCLP      | 17.3                          | 12.83                | 12.41                |
| 2        | 17      | M   | UCLP      | 11.2                          | 7.77                 | 6.83                 |
| 3        | 14      | F   | UCLP      | 8.2                           | 5.58                 | 8.83                 |
| 4        | 8       | F   | UCLP      | 13.6                          | 10.00                | 11.91                |
| 5        | 13      | F   | UCLP      | 12.4                          | 12.71                | 9.15                 |
| 6        | 13      | M   | UCLP      | 9.0                           | 7.94                 | 5.90                 |
| 7        | 13      | M   | UCLP      | 12.5                          | 12.58                | 11.83                |
| 8        | 13      | M   | UCLP      | 9.8                           | 11.51                | 9.65                 |
| 9        | 8       | M   | UCLP      | 4.1                           | 3.11                 | 5.59                 |
| 10       | 9       | M   | UCLP      | 20.8                          | 21.84                | 21.30                |
| 11       | 8       | M   | UCLP      | 19.0                          | 12.59                | 11.28                |
| 12       | 12      | M   | UCLP      | 8.5                           | 12.16                | 14.45                |
| 13       | 8       | M   | BCLP      | 9.7                           | 5.18                 | 2.19                 |
| 14       | 7       | M   | BCLP      | 10.9                          | 8.28                 | 11.77                |
| 15       | 12      | F   | UCLP      | 13.4                          | 13.24                | 14.79                |
| 16       | 11      | F   | UCLP      | 9.1                           | 8.54                 | 8.00                 |
| 17       | 12      | M   | BCLP      | 2.6                           | 1.14                 | 2.26                 |
| 18       | 8       | M   | BCLP      | 2.9                           | 3.77                 | 3.61                 |
| 19       | 8       | M   | BCLP      | 7.5                           | 7.36                 | 4.90                 |
| 20       | 9       | M   | BCLP      | 7.0                           | 8.69                 | 6.83                 |
| 21       | 8       | M   | UCLP      | 10.4                          | 12.34                | 13.40                |
| 22       | 7       | M   | UCLP      | 10.9                          | 13.33                | 12.72                |
| 23       | 12      | M   | UCLP      | 6.7                           | 5.21                 | 7.44                 |
| 24       | 11      | F   | BCLP      | 9.9                           | 12.30                | 11.33                |
| 25       | 11      | F   | BCLP      | 9.5                           | 10.17                | 12.03                |
| 26       | 10      | F   | UCLP      | 4.5                           | 2.77                 | 3.97                 |
| 27       | 9       | F   | BCLP      | 7.1                           | 7.13                 | 6.22                 |
| 28       | 10      | F   | UCLP      | 8.4                           | 5.05                 | 6.12                 |

Mean ± SD 10.4 ± 2.4 / / 9.9 ± 4.2 9.11 ± 4.33 9.17 ± 4.29

P value / / / <0.001 <0.001 <0.001

### Table 3. Changes in the facial skeleton after maxillary anterior segment distraction osteogenesis. F, female; M, male; UCLP, unilateral cleft lip and palate; BCLP, bilateral cleft lip and palate; MH, maxillary hypoplasia; P value, Paired t-test of pre- and post-operation with a 5% level of significance.

| Patients | Age (y) | Sex | Diagnosis | Change in A point Distance, mm | Change in SNA Degree | Change in ANB degree |
|----------|---------|-----|-----------|-------------------------------|----------------------|----------------------|
| 1        | 20      | M   | UCLP      | 4.1                           | 3.01                 | 6.01                 |
| 2        | 17      | M   | UCLP      | 8.2                           | 7.45                 | 7.49                 |
| 3        | 24      | M   | UCLP      | 11.2                          | 12.97                | 13.10                |
| 4        | 23      | F   | UCLP      | 5.4                           | 4.76                 | 8.67                 |
| 5        | 25      | F   | MH        | 5.0                           | 7.80                 | 12.29                |
| 6        | 18      | M   | MH        | 5.7                           | 6.97                 | 8.14                 |
| 7        | 22      | M   | UCLP      | 10.2                          | 13.80                | 13.58                |
| 8        | 22      | F   | UCLP      | 9.8                           | 7.17                 | 7.10                 |
| 9        | 22      | F   | UCLP      | 9.7                           | 12.78                | 18.83                |
| 10       | 20      | F   | UCLP      | 8.8                           | 7.85                 | 8.52                 |
| 11       | 19      | M   | UCLP      | 11.4                          | 6.69                 | 6.99                 |
| 12       | 18      | F   | BCLP      | 10.9                          | 7.17                 | 7.33                 |

Mean ± SD 20.8 ± 2.4 / / 8.4 ± 2.5 8.20 ± 3.17 9.84 ± 3.65

P value / / / <0.001 <0.001 <0.001
| Patients | Age (y) | Sex | Diagnosis. | Change in A point. Distance, mm | Change in SNA Degree | Chang in ANB degree |
|----------|---------|-----|------------|---------------------------------|---------------------|--------------------|
| 1        | 22      | F   | UCLP       | 6.0                             | 5.78                | 5.67               |
| 2        | 19      | F   | UCLP       | 9.1                             | 9.47                | 19.74              |
| 3        | 18      | M   | UCLP       | 14.0                            | 12.99               | 13.53              |
| 4        | 19      | M   | BCLP       | 17.8                            | 11.23               | 23.44              |
| 5        | 16      | M   | BCLP       | 14.2                            | 11.66               | 15.97              |
| 6        | 23      | M   | BCLP       | 9.6                             | 9.28                | 13.22              |
| 7        | 18      | M   | BCLP       | 8.5                             | 9.55                | 15.55              |
| 8        | 17      | F   | UCLP       | 12.7                            | 17.49               | 18.24              |
| 9        | 18      | M   | UCLP       | 7.2                             | 6.85                | 17.19              |
| Mean ± SD|         |     |            | 18.9 ± 2.1                      | 11.0 ± 3.7          | 10.48 ± 3.27       |
| P value  |         |     |            |                                 | <0.001             | <0.001             |

Table 4. Changes in the facial skeleton after Le Fort I osteotomy distraction osteogenesis. F, female; M, male; UCLP, unilateral cleft lip and palate; BCLP, bilateral cleft lip and palate. P value, Paired t-test of pre- and post-operation with a 5% level of significance.

Figure 1. Binder syndrome patient with a right-side unilateral cleft and midfacial hypoplasia. Le Fort II distraction osteogenesis was performed to draw the midface out. The preoperative photographs show severe depression of the midface (a–c). After 6 months of distraction osteogenesis the patient achieved a harmonious face (d–f). The lateral cephalometric analysis showed that the maxilla was advanced 21.5 mm and the SNA angle changed from 71.79 degrees to 90.87 degrees. After 12 months, a good appearance was still maintained (g–i).
decreasing the traction force and rate. Several studies have been published on the topic14–17, and all have demonstrated the usefulness of this approach.

The traction hooks failed in only three patients, and the failures were due to rapid distraction-induced pyriform rim fracture. These fractures happened during the early study period when this technique was still under development. The current strategy uses a variable distraction rate of 1 to 2 mm every 1 to 3 days, and there have been no fractures. Infection is a potential complication when using any external distraction device, including intranasal bone-borne traction hook. Only one patient developed an infection, which resolved after the hooks were removed. Several patients complained of pain during distraction. This complication was easy to resolve by decreasing the traction force and rate. Several studies have been published on the topic16–17, and all have demonstrated the usefulness of this approach.

In conclusion, the use of intranasal bone-borne traction hooks offers advantages over the use of an intraoral splint and fixation plates. The hooks produce scars that are better concealed, bear a larger distraction force and are easily removed. This approach caused minimal complications and is a reasonable option for midface DO.

Methods
This retrospective study was designed to investigate the effectiveness of intranasal bone-borne traction hooks in DO. We reviewed all the patients with intranasal bone-borne traction hooks for distraction osteogenesis in the Center of Cleft Lip and Plate, Plastic Surgery Hospital, Chinese Academy of Medical Sciences and Peking Union Medical College from 2005 to 2017.

Ethics. The Plastic Surgery Hospital, Chinese Academy of Medical Sciences, and Peking Union Medical College ethics committee approved the study, which was performed according to the principles of the Declaration of Helsinki. Written informed consent was obtained from the patients or from the guardians of the patients younger than 18 years. All identifying images released in this article were authorized for publication by the patient and his guardians.

Surgical technique. The distraction system consisted of an RED (Gibe Medical Treatment Appliance Co., Ltd., Ningbo, China), and nickel–titanium “shape memory alloy” spring and nickel–titanium bone-borne traction hooks (diameter: 1.5 mm; GEE Co., Beijing, China)16–17. The length of the traction hooks could be adjusted to suit different patients. The spring generated a continuous force of approximately 250 g/mm. The detailed parameters are shown in Fig. 2.

Maxillary vestibular incisions were made, and the buccal tissue was moved to expose the pyriform rim and canine root. A thick fissure burr was used to drill a hole approximately 1 cm outside the lateral pyriform rim and 5 mm above the teeth apices through the lateral nasal wall. The traction hooks were introduced through the hole

Table 5. Changes in the facial skeleton after Le Fort III/II osteotomy distraction osteogenesis. F, female; M, male; *p value, Paired t-test of pre- and post-operation with a 5% level of significance.
Figure 2. Detail parameters of the traction hook. $AB = 6\, \text{mm}$, $CD = 11\, \text{mm}$, $DE = 2.75\, \text{mm}$, $R = 6\, \text{mm}$, $r = 1.25\, \text{mm}$, $\angle 1 = \angle 2 = 10^\circ$, $\Phi = 1.5\, \text{mm}$

Figure 3. A hole was drilled through the lateral nasal wall (a) and the traction hook was introduced through the hole (b). Intranasal bone-borne traction hooks (c) and connections between rigid external distraction device components (d).
and the caudal ends extended out from the nostril base. The RED cranial frame was applied at 20–30° upward from the Frankfurt horizontal plane with the vertical rod 10–12 cm anterior of the nostril base. The spring was then usually used to connect the hooks to the RED device, especially in the treatment of trans-sutural DO. In several maxilla osteotomy DO cases, we also used firm surgical wires to directly connect the traction hooks and RED device (Fig. 3).

**Distraction Protocol.** The distraction commenced immediately after the operation with an initial force of 750 g on each side for the treatment of trans-sutural DO. An adaptive period of 3–5 days followed, and then the traction force was increased gradually with a variable distraction rate of 1 to 2 mm every 1 to 3 days. The traction force was recorded in some patients. When there was significant advancement of the maxilla observed the force was increased slowly to the maximum and was maintained until the required advancement was achieved. Then, the distraction was followed by a consolidation period of 1–3 months with gradually decreased traction force.

In the treatment of Le Fort I/II/III and maxillary anterior segment DO the distraction was initiated with a variable rate of 1 to 2 mm every day after a 5–7-day latency period. The end of the distraction was determined by clinical judgement and cephalometry.

After a consolidation period the RED frame and traction hooks were usually removed in the surgery room under local anaesthesia. We directly removed the hooks along their curved shape through the nostril base without maxillary vestibular incisions. If the operation time was over five minutes, it indicated difficulty removing the traction hooks and maxillary vestibular incisions were made to complete the removal. Several patients chose to remove the traction hooks under general anaesthesia when they underwent treatment of secondary deformities six months or twelve months later. Several patients also chose general anaesthesia because of their young age and limited cooperation.

**Imaging Analysis.** A single examiner performed all blind assessments based on a manual cephalometric analysis of lateral teleradiographs. The radiographs were obtained both pre- and post-operatively immediately after DO. The bony landmarks and reference lines used for analysis included the following points: sella (S), nasion (N), subspinal A-point (A), supramental B-point (B). The horizontal (X) reference line was constructed at 7 degrees relative to the sella-nasion (SN) line, and the vertical (Y) reference line was through the sella perpendicular to the horizontal reference. The distance from Y line to point A was measured both pre- and post-operatively. All the lateral cephalographs were traced and superimposed using the cranial base points. The following angular measurements were also assessed: sella-nasion-point A (SNA), A point-nasion-B point (ANB). Skeletal angular and linear changes were recorded.

Data sharing statement: The data can be assessed: https://pan.baidu.com/s/1pLp7Sk7; Extra data are available by emailing songtao2059@163.com.

**Statistical analysis.** The statistical analysis was performed using SPSS 20.0 (IBM Corp., Armonk, NY, USA). The same process was repeated 1 week later to assess measurement accuracy. The reliability analysis tests were used to assess the two sets of tracing measurements. Reliability was confirmed using a paired t-test with a 5% level of significance. The result showed no significant difference between the two sets of tracings. The paired t-test was used to analyse the difference of distance from Y line to point A, SNA and SNB between pre- and post-operation, with a 5% level of significance. The average advancements and changes of SNA and SNB for the four different procedures were described.

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Author Contributions
Y.L.Z., Z.M.Z. and T.S. conceived and designed the study. Z.M.Z., T.S. and N.B.Y. designed the traction hook. H.Z.T., F.N. and Y.L.Z. acquired the data. Y.L.Z. and T.S. performed the statistical analysis and had full access to all of the data in the study. Y.L.Z. and T.S. drafted the manuscript. N.B.Y., S.T. and Z.M.Z. revised the manuscript for important intellectual content.

Additional Information
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