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# The Directive Growth Approach for Nonsyndromic, Unicoronal Craniosynostosis: Patient and Clinical Outcomes

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**Abstract:** Deformities of the cranium in patients with nonsyndromic single-suture synostosis occur because of growth restriction at fused sutures and growth over compensation at normal sutures. Traditional surgery includes osteotomies of the synostotic suture to release these restricted areas and osteotomies to enable immediate cranial remodeling. In the process of reshaping the cranium, traditional approaches usually involve obliteration of both the normal functioning suture and the pathologic suture. The directive growth approach (DGA) is a new, simpler, more natural way to repair deformities caused by single-suture cranial synostosis. The DGA works by reversing the original deforming forces by temporarily restricting growth in areas of over compensation and forcing growth in areas of previous synostotic restriction. Most importantly, it preserves a normal functioning suture to allow for improved future cranial growth. Eighteen consecutive nonsyndromic patients with unilateral coronal synostosis were used to illustrate the efficacy of the DGA. Ten patients who underwent DGA treatment were compared with a control group of 8 patients treated with traditional frontal orbital advancement. Postoperative three-dimensional computed tomography (CT) comparison measurements were taken, including bilateral vertical and transverse orbital dimensions, lateral orbital rim to external auditory canal, and forehead measurements from the superior aspect of the orbital rim to the pituitary fossa. The traditional treatment group showed absence of the coronal sutures bilaterally on long-term CT scans. The DGA group showed normal coronal sutures on the unaffected sides. Postoperative CT measurements showed no statistical difference between the 2 techniques ( $P < 0.05$ ).

**Key Words:** Coronal, craniosynostosis, directive growth, frontal orbital advancement

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Single-suture craniosynostosis occurs in 1 in 2500 live births and is the most common type of craniosynostosis treated in most craniofacial centers.<sup>1</sup> Of the various synostoses, unicoronal synostosis is the third most common, with an estimated incidence of 1 in 15,000 live births.<sup>2–4</sup> Deformities of the cranium in patients with nonsyndromic single-suture synostosis occur because of growth restriction at fused sutures and growth over compensation at normal sutures.

Many consider the standard of care for open surgical treatment to be the frontal orbital advancement reconstruction, based off of Tessier's original "tongue in groove" technique.<sup>5–9</sup> In the process of reshaping the cranium, the traditional approach usually involves obliteration of both the normal functioning suture and the pathologic suture. Others consider an alternative treatment to be endoscopic osteotomies of the synostotic suture and cranial remodeling with helmet therapy. The disadvantage of endoscopic approach with helmet therapy is the limited immediate correction of the synostotic deformity, as no bony repositioning can be accomplished endoscopically. One advantage, however, is the preservation of the contralateral, normal functioning suture.

Until recently, there were no open techniques for unicoronal, nonsyndromic craniosynostosis that preserved the unaffected suture, documented postoperative orbital symmetries, and intraoperative outcomes. We present here a patient series of consecutive patients treated with our directive growth approach (DGA) that incorporates the benefits of synostotic orbital reshaping, seen with traditional open surgery, and the effective advantage of contralateral suture preservation from endoscopic approaches. This study follows a clinical patient report,<sup>10</sup> and is the first patient series describing outcomes of the DGA.

## METHODS AND TECHNIQUE

A retrospective patient series review of 18 consecutive nonsyndromic patients with unilateral coronal synostosis was used to illustrate the efficacy of the DGA. Both treatment groups averaged 7.7 months of age at surgery.

The control group consisted of 8 patients treated with traditional surgery, including wide osteotomy of the synostosis, osteotomy, and removal of the full forehead and orbital bar. Orbital reshaping was performed by advancing the synostotic side followed by setback of the contralateral side. Rim grafts were used as needed. The reshaped forehead was then stabilized to the rest of the skull with bridging absorbable plates. Follow-up averaged 34 months.

The 10 patients in the DGA treatment group underwent wide osteotomy at the synostosis. This technique has been previously described and published by the senior author.<sup>10</sup> No osteotomy was performed near the uninvolved coronal suture. The forehead was

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advanced on the affected side via osteotomy of the mid forehead including the affected orbit, hinging the orbital advancement in a cantilever fashion off of the opposite stable forehead using absorbable plates. No bridging plates were placed across the osteotomy synostosis side, leaving the opened suture unrestricted. The orbital treatments included affected side rim grafts and nonaffected side orbital rim burring. To reverse the compensatory growth, thin, absorbable Lactasorb plates were secured with screws across the unaffected coronal and anterior sagittal suture. Follow-up averaged 6 months.

Postoperative three-dimensional computed tomography (CT) comparison measurements were taken, including bilateral vertical and transverse orbital dimensions, lateral orbital rim to external auditory canal, and forehead measurements from the superior aspect of the orbital rim to the pituitary fossa (Fig. 1A and B). These measurements were compared side-to-side and made into a ratio with 1:1 being normal. Ratios between the traditional group and DGA group were analyzed for statistical significance. Imaging studies were obtained, on average, 8 months postoperatively. One patient in the DGA group was not included in the statistical analysis for improvements in postoperative measurements as there was no preoperative CT scan for comparison.

Intraoperative blood loss, blood product administered, and operative times were also recorded and compared to investigate for significant differences. Statistical analysis was performed using SPSS to conduct an independent *t* test of the respective means. The traditional group was coded as “0”. The DGA group was coded as “1”. The version of SPSS was IBM SPSS Statistics (Version 21).

### RESULTS

We retrospectively analyzed 18 patients who underwent treatment for unicoronal, nonsyndromic craniosynostosis with either traditional surgery (*n* = 8) or the DGA (*n* = 10). There were a total of 12 females and 6 males in the series. The traditional surgery group and DGA group were predominantly female, 62.5% and 70.0% respectively (Table 1). The average age of surgery for both groups was 7.7 months of age. Follow-up averaged 34 months for the traditional surgery group and 6 months for the DGA group.

Both groups showed excellent early clinical and radiographic results. The traditional treatment group showed absence of the coronal sutures bilaterally on long-term CT scans (Fig. 2A and B). The DGA group showed normal coronal sutures on the unaffected sides (Fig. 2C and D). Postoperative CT measurements (Tables 2 and 3), showed no statistical difference between the 2 techniques at any of the defined measurements (*P* > 0.05).

The mean blood loss, mean blood product administered, and operative time for each treatment group are illustrated in Table 4. The DGA group had an overall shorter operative time

TABLE 1. Patient Group Demographics

|                             | Male | Female | Age at Surgery (mo) | Follow-Up (mo) |
|-----------------------------|------|--------|---------------------|----------------|
| DGA ( <i>n</i> = 10)        | 3    | 7      | 7.7 ± 1.7           | 6              |
| Traditional ( <i>n</i> = 8) | 3    | 5      | 7.6 ± 1.7           | 34             |

DGA, directive growth approach.

(299.7 minutes; 240–397 minutes), and this was found to statistically significant (*P* < 0.0001; 95% CI: –145.60, –77.00) when compared with the operative time for the traditional surgery group (411 minutes; 390–438 minutes). The DGA group clinically demonstrated less mean blood loss and blood product administered (212; 20–550, 272; 80–700 mL) than the traditional group (246.25; 75–450, 303.75; 150–450 mL), however, this was not found to be statistically significant (*P* = 0.62 and *P* = 0.68).

### DISCUSSION

The traditional frontal orbital advancement reconstruction can effectively reshape the craniofacial skeleton. Studies have shown its efficacy in reversing the compensatory growth deformities from unicoronal synostosis.<sup>11–13</sup> Despite this, there are some who believe these procedures are technically difficult, time-consuming, and damage other normal functioning sutures. Some have devised alternate methods for treating unicoronal synostosis, such as endoscopic osteotomy with postsurgical helmeting and complex variations of the frontal orbital advancement.<sup>14,15</sup> Though they may diminish blood loss and produce immediate contour correction of the face and skull, the definitive outcomes to these alternate approaches are heavily dependent on surgeon’s expertise and postoperative patient compliance with helmet therapy.

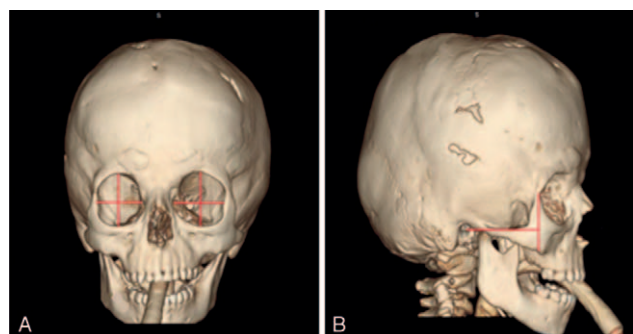


FIGURE 1. Pre- and postoperative measurements. (A) Horizontal and vertical orbital measurements. (B) Transverse orbit to auditory canal measurement.

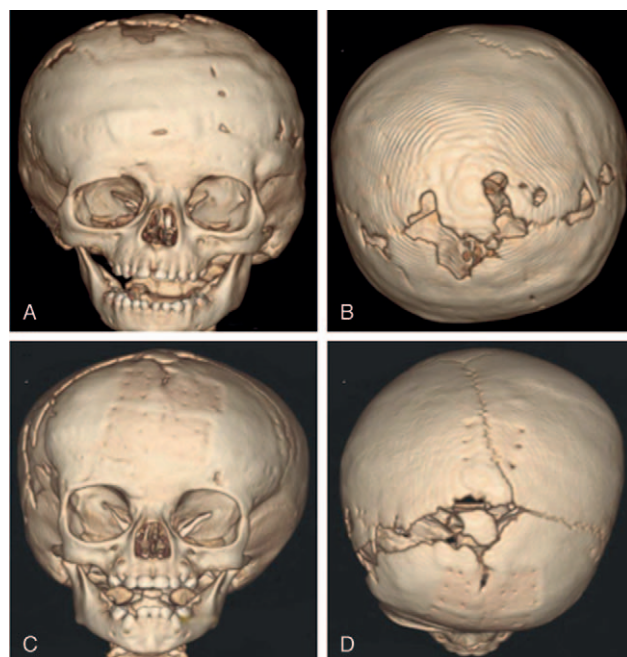


FIGURE 2. Traditional FOA and DGA postoperative views: (A) traditional FOA 16-month anteroposterior view. (B) Traditional FOA 16-month cranial-caudal view. (C) Directive growth approach 8-month anteroposterior view. (D) Directive growth approach 8-month cranial-caudal view. DGA, directive growth approach; FOA, frontal orbital advancement.

**TABLE 2.** Directive Growth Approach Pre- and Postoperative Computed Tomography Measurements

| Patient | Op Side | Right Vertical | Right Horizontal | Left Vertical | Left Horizontal | Right ZF | Left ZF | Right Rim | Left Rim |
|---------|---------|----------------|------------------|---------------|-----------------|----------|---------|-----------|----------|
| 1       | (R)Pre  | 31.2           | 27.2             | 28.3          | 30.3            | 35.2     | 52      | 42.7      | 54       |
|         | Post    | 29.3           | 29.6             | 28.9          | 32.9            | 49.3     | 55.3    | 43.1      | 43.5     |
| 2       | (L)Pre  | 32.5           | 29.6             | 30.3          | 30.9            | 59.4     | 48.5    | 45.3      | 44.9     |
|         | Post    | 31.2           | 29.8             | 30.5          | 29.6            | 55.1     | 43.8    | 52.9      | 45.8     |
| 3       | (R)Pre  | 27.6           | 27.3             | 24.7          | 29.3            | 47.8     | 53.6    | 37.3      | 42.6     |
|         | Post    | 30.5           | 29.8             | 30.7          | 33.4            | 52.2     | 60.8    | 50.2      | 45.8     |
| 4       | (R)Pre  | 24.4           | 26.5             | 25.6          | 28.4            | 41.8     | 51.6    | 37.3      | 42.6     |
|         | Post    | 26.7           | 28.2             | 31.8          | 27.4            | 52.2     | 59.8    | 50.2      | 45.8     |
| 5       | (L)Pre  | 24.5           | 28.5             | 26.9          | 25.1            | 51       | 41.2    | 44        | 34.7     |
|         | Post    | 26.7           | 30.3             | 27.4          | 29.4            | 55.2     | 49.2    | 47.1      | 51.1     |
| 6       | (R)Pre  | 31.1           | 28.9             | 29.6          | 29.2            | 42.9     | 48.3    | 63        | 47.4     |
|         | Post    | 31.9           | 33.1             | 33.1          | 33.6            | 52.5     | 60.7    | 57.1      | 54.2     |
| 7       | (L)Pre  | 24.5           | 29.1             | 25.6          | 27.3            | 49       | 40.7    | 44.8      | 40.8     |
|         | Post    | 24.7           | 30.2             | 24.7          | 28.2            | 51.6     | 42      | 47.4      | 47.4     |
| 8       | (R)Pre  | 25.4           | 27.6             | 20.9          | 30.3            | 45.5     | 48.7    | 41.8      | 45.3     |
|         | Post    | 25.4           | 28.9             | 25.4          | 30.7            | 56       | 63.4    | 54.2      | 56       |
| 9       | (R)Pre  | 33.1           | 29.4             | 28.7          | 33.6            | 46.2     | 59      | 46.3      | 57.3     |
|         | Post    | 30.2           | 30.7             | 30.9          | 34              | 50.7     | 64.7    | 52.8      | 52.4     |
| 10      | (L)Post | 29.6           | 30.4             | 29.6          | 27.1            | 57.4     | 52.4    | 51.9      | 57.7     |

All values reported in millimeters.

The DGA combines the best aspects of various traditional frontal orbital advancement and endoscopic helmet techniques. This is accomplished through a combination of advancement osteotomies and selective growth restriction. Unlike traditional frontal orbital advancements, the contralateral coronal suture is preserved with osteotomies to only synostotic areas and absorbable plating across normal sutures restricts growth. In doing so, we temporarily create an “internal helmet” allowing for a reversal of the over compensating growth forces affecting the cranium. This “internal helmet” eliminates the potential issues caused by patient noncompliance with postsurgical helmets in endoscopic remodeling techniques.<sup>16</sup>

Our patient series is the first to demonstrate the efficacy of the DGA compared with traditional frontal orbital advancement techniques by comparing pre- and postoperative CT scans. This is seen by the lack of statistically significant differences in postoperative CT ratios between the 2 groups (Tables 2 and 3). Improvements in the harlequin orbit, deviated nasal root, and deviated chin can be remedied with the DGA. Our approach allows for directed self-correction of these changes over time without sacrificing the

contralateral suture. Figure 3 illustrates the contour corrections in our patient with the longest follow-up to date. Preoperative, horizontal, and vertical orbital ratios were 0.875 and 0.867. These improved to 0.903 and 0.977, respectively. Additionally, one can see the improvements in the harlequin orbit and compensatory frontal bossing; 0.808 to 0.992. Similar changes were seen in the remainder our DGA group (Table 2).

Furthermore, this patient series is the first to present intraoperative outcomes for the DGA (Table 4). In focusing our osteotomies on involved sutures, we reduced our operative time. This was quicker than the traditional surgical approach and found to be statistically significant ( $P < 0.0001$ ; 95% CI:  $-145.60, -77.00$ ). A brief review of reported craniostylosis repair operative times showed our DGA operative times to be well within and/or below those documented in the literature.<sup>15,17-19</sup>

Limiting our bony resection also reduces the amount of trauma to the cranium, reducing overall blood loss and transfusion rates. The DGA group clinically demonstrated less mean blood loss and blood product administered than the traditional group (Table 4). The authors have reported blood losses greater than 500 mL for

**TABLE 3.** Traditional Surgery Pre- and Postoperative Computed Tomography Measurements

| Patient | Op Side  | Right Vertical | Right Horizontal | Left Vertical | Left Horizontal | Right ZF | Left ZF | Right Rim | Left Rim |
|---------|----------|----------------|------------------|---------------|-----------------|----------|---------|-----------|----------|
| 1       | (L) Post | 32             | 33.1             | 32            | 32.2            | 57.6     | 55.1    | 49.8      | 48.4     |
| 2       | (R) Post | 36             | 34.9             | 35.6          | 37.9            | 60.1     | 73.7    | 60.3      | 60.3     |
| 3       | (L) Post | 30.1           | 32.4             | 30.5          | 31.2            | 68       | 60.9    | 59        | 60.9     |
| 4       | (R) Post | 31.8           | 28.5             | 36.5          | 31.8            | 55.9     | 69.9    | 56.4      | 55.1     |
| 5       | (R) Post | 35.5           | 32.8             | 34.6          | 33.7            | 53.7     | 67      | 54.1      | 55.9     |
| 6       | (L) Post | 29.9           | 33.6             | 29.9          | 31.6            | 66.9     | 59.9    | 54.3      | 54.8     |
| 7       | (L) Pre  | 23.4           | 28.2             | 27            | 26.2            | 51.6     | 40.6    | 45.3      | 40       |
|         | (L) Post | 23.4           | 28.2             | 27            | 26.2            | 51.6     | 40.6    | 45.3      | 40       |
| 8       | (R) Pre  | 26.2           | 26.4             | 20.7          | 26.7            | 37.3     | 46.5    | 41.3      | 31.5     |
|         | (R) Post | 29.8           | 29.3             | 34.1          | 31.1            | 57.4     | 69.2    | 61        | 56.5     |

All values reported in millimeters.

**TABLE 4.** Comparison of Intraoperative Values

|                     | Blood Loss (mL) | Blood Product (mL) | Operative Time (min) |
|---------------------|-----------------|--------------------|----------------------|
| DGA (n = 10)        | 212; 20–550     | 272; 80–700        | 299.7; 240–397       |
| Traditional (n = 8) | 246.25; 75–450  | 303.75; 150–450    | 411; 390–438         |

All values reported as means with respective ranges.  
DGA, directive growth approach.

craniosynostosis patients, with means around 300 mL.<sup>15,17,20–22</sup> Our DGA demonstrates lower means and similar blood loss ranges. Furthermore, the DGA transfusion requirements fell within or below current literature values. Although blood loss and operative rates were not statistically significant in our study, they may be clinically significant as reduced blood loss translates into fewer transfusions and possible transfusion-related complications. This inability to achieve significance may have been related to our sample size.

Traditional endoscopic approaches combined with helmet therapy are usually only effective if initiated in the first 3 to 6 months of life. After this, more traditional therapies are required. The DGA, being a combination of both therapies, extends the effective advantages of helmet therapy through the first year of life. In our patient series, patients were able to receive the benefits of “internal helmet” therapy starting at an average of 7.7 months of age, extending all the way to 9.4 months of age at the latest. The DGA was not combined with postsurgical helmet therapy in this series to demonstrate the effectiveness of the DGA without postsurgical helmets. It can however, be added to specific patients as required.

This small patient series demonstrates that the excellent results routinely obtained through traditional surgery for nonsyndromic,

unilateral, craniosynostosis are equally achievable using the DGA. It is our belief that children who have a higher compliment of normal functioning skeletal sutures will have less of the late skull growth deformities often observed from the traditional approach. Our patients from this series will be followed long-term to confirm this hypothesis. Future studies will also investigate the applicability of the directive growth approach to treat any form of nonsyndromic craniosynostosis.

## CONCLUSION

The directive growth approach is a new, simple treatment for unicoronal, nonsyndromic craniosynostosis that works by reversing the deforming forces previously present on the skull; expanding former synostotic areas, and temporarily restricting growth in areas of over compensation. The directive growth approach significantly reduces operative time, is as efficacious as traditional surgical approaches, and results in less operative blood loss. The DGA can be implemented later in life than endoscopic approaches with helmet therapy. Most importantly, it preserves a normal functioning suture to allow for improved future cranial growth.

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**FIGURE 3.** Directive growth approach contour corrections 4 years postoperatively. (A) Directive growth approach preoperative orbital contour. (B) Directive growth approach postoperative orbital contour. (C) Directive growth approach preoperative frontal contour. (D) Directive growth approach postoperative frontal contour.

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