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Clinical Analysis of the Effects of Cranial Suture Reconstruction and Frontal Frame Retraction in the Operation of Premature Closure of the Sagittal Suture in Infants

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ABSTRACT

AIM: To compare and analyze the effects of cranial suture reconstruction and frontal frame retraction for surgical treatment of premature closure of the sagittal suture.

MATERIAL and METHODS: Infants with premature closure of the sagittal suture were included in this study. All infants underwent preoperative skull model reconstruction using imaging techniques and 3D printing. The infants were then allocated to either the experiment group, where the frontal frame retraction was used to guide the surgical treatment of cranial stenosis, or the control group, where traditional cranial suture reconstruction was performed. All interventions were performed by the same operator. The surgical effects of the two groups were compared.

RESULTS: Overall, 28 infants were enrolled in this study, with 15 infants in the experimental group and 13 in the control group. In the one-year post-operative follow-up visit, the cephalic index of scaphoid malformation was 78.3 ± 1.4 in the experimental group and 69.0 ± 4.2 in the control group. The difference between the two groups was statistically significant.

CONCLUSION: Frontal frame retraction surgery can guide the surgical procedure for cranial stenosis, significantly improve the treatment outcome in children with premature closure of the sagittal suture, and improve the form of the head aesthetically in children, and the effect is better than traditional operation; therefore, the technique is worth popularizing in the clinic.

KEYWORDS: Infant, Cranial stenosis, Surgery, Premature closure of the sagittal suture, 3D printing technique

ABBREVIATIONS: CI: Cephalic index, **CVAI:** Cranial vault asymmetry index

INTRODUCTION

Infantile cranial stenosis, also known as congenital cranial suture premature closure, is characterized by the premature closure of one or more bone sutures in the cranio-maxillofacial region (10), which limits the volume of the cranial cavity and negatively affects the development of the brain tissue. Compensatory development presents as different types of deformed head, among which, the scaphoid head caused by sagittal suture premature closure is the most prevalent and accounts for 40% of the head deformities due to cranial stenosis (12). Surgical treatment of premature closure of sagittal suture is a high-risk and challenging procedure (7), as it predisposes young patients with poor surgical tolerance to extensive surgical trauma (16).

Currently, 3D printing technology is being widely used in medicine, providing the perfect combination of medicine and engineering to attain excellent scientific achievements. Since the technology allows for shape restoration at a 1:1 ratio, it can be used to simulate the surgical approach and customize individual implants, thus reducing the risk of operation. 3D printing is frequently used in the field of neurosurgery, but it is rarely used in the surgical treatment of infantile narrow

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crania. Combining this preoperative approach with frontal frame retraction is even less frequently attempted while treating these patients (4). In the present study, we used a 3D printing technique to assist frontal frame retraction for surgical treatment in 15 cases of infantile cranial stenosis, and compared the outcomes with 13 cases of cranial suture reconstruction assisted by 3D printing technique as a control to compare the effects of cranial suture reconstruction and frontal frame retraction in the treatment of premature closure of the sagittal suture in infants and young children.

MATERIAL and METHODS

Infants with premature closure of the sagittal suture, who were treated at our department from July 2012 to November 2020, were included in this study. Inclusion criteria were as follows: 1) scaphoid head deformity was the main symptom; 2) simple closure of the sagittal suture without the closure of other cranial sutures was observed on cranial CT images; 3) there was no history of surgery for cranial stenosis; and 4) the clinical data were complete. Exclusion criteria were: 1) scaphoid head malformation was not the main symptom; 2) cranial CT suggested the closure of other cranial sutures; 3) history of surgery for narrow skull; and 4) absent or incomplete clinical data. In the control group, 13 children with sagittal suture stenosis were treated with preoperative 3D printing on a voluntary basis, and were then treated with cranial suture reconstruction. In the experimental group, we introduced a new surgical method, frontal frame retraction, and 15 patients who were treated with 3D printing auxiliary frontal frame retraction were included in the experimental group. This study was approved by the hospital ethics committee, and the families of patients signed the informed consent form (Date: 11.01.2021; No: 2021-011-01).

All operations were performed by the same operator. All patients underwent routine CT and MRI examinations prior to the operation. Data were processed, and the skull model was 3D printed with a 1:1 ratio. This provided a solid anatomical model of the skull consistent with the actual size. The values for cephalic index (CI) and cranial vault asymmetry index (CVAI) were measured on preoperative images and compared with the normal values range. Using the 3D printed model, the ideal range of movement for frontal frame retraction was calculated. In the experimental group, a 3D printing technique was used to assist the frontal frame retraction. The scalp was peeled through a coronal incision to expose the frontal and orbital areas of the skull. Direct osteotomy was then performed to cut the frontal bone. The osteotomy line was aligned to the coronal suture. The anterior osteotomy line was set about 1.5–2.0 cm above the supraorbital margin. After removing the frontal bone, the fronto-orbital band (the superior orbital wall, the zygomatic frontal suture, and the temporal bone) was cut off horizontally. The lower frontal band of the temporal bone was then moved forward to form a wedge. The fronto-orbital band was removed and the bilateral temporal bone wedge was moved closer to the medial side, which needed amputation and fixation. Based on the preoperative calculation for distance for retraction, the newly shaped fronto-orbital band was retracted horizontally and fixed to the root of the nose, the lateral orbit, and the temporal areas with an absorbable internal fixation system. The frontal bone flap was then fixed on the newly positioned fronto-orbital band with an absorbable internal fixation system. The traditional cranial suture reconstruction was modified to decompress the temporal bone window (Figure 1A-H). In the control group, data from preoperative imaging examinations and the 3D printed model were used to accurately determine the location of the prematurely closed cranial suture. The closed cranial suture was opened, the hyperplastic bone fibers were removed without frontal frame retraction, and reconstruction was performed traditionally.

The following variables were included in statistical analysis: CI: (maximum transverse diameter of the head/maximum anterior and posterior diameter of the head)*100; CVAI: (the difference between the length of the two oblique paths at 30° angle from the nose to the anterior and posterior poles of the skull/the shorter oblique path)*100. The duration of operation and the amount of intraoperative blood loss were also recorded. The head circumference, CI, and CVAI were recorded before and 12 months after the operation.

SPSS version 26.0 (IBM Corp., Armonk, NY, USA) was used to analyze the data. The measurement data are expressed as $\bar{X} \pm S$, and the counting data were expressed as examples and percentages. The changes in head circumference, CVAI, and CI were compared using paired t-test before and 12 months after operation. The test level was set at $\alpha=0.05$, and differences with $p<0.05$ were considered statistically significant.

RESULTS

Head Circumference, CI, and CVAI Before and 12 Months After the Operation

In the experimental group, the CI of scaphoid head deformity was significantly different before (66.4 ± 3.0) and 12 months after the operation (79.2 ± 1.5, $p<0.05$). In the control group, no significant differences in CI measurements were observed before and 12 months after the operation ($p>0.05$) (Table I).

Comparison of Head Circumference, CI, and CVAI 12 Months After the Operation Between the Two Groups

No significant differences in preoperative head circumference, CI, and CVAI measurements were observed between the two groups. The CI of scaphoid head deformity in the experimental group was significantly different from the control group (79.2 ± 1.5 vs. 72.3 ± 3.5) (Table II).

Comparison of Intraoperative Blood Loss and Operation Time Between the Two Groups

There were no significant differences in the average operation time (2.8 ± 0.75 hours vs. 3.1 ± 0.42 hours) and the average intraoperative blood loss (108.9 ± 37.7 mL vs. 112.6 ± 35.9 mL) between the experimental and control groups (Table III).

DISCUSSION

In this study, we present a novel approach for the surgical treatment of children with premature closure of the sagittal

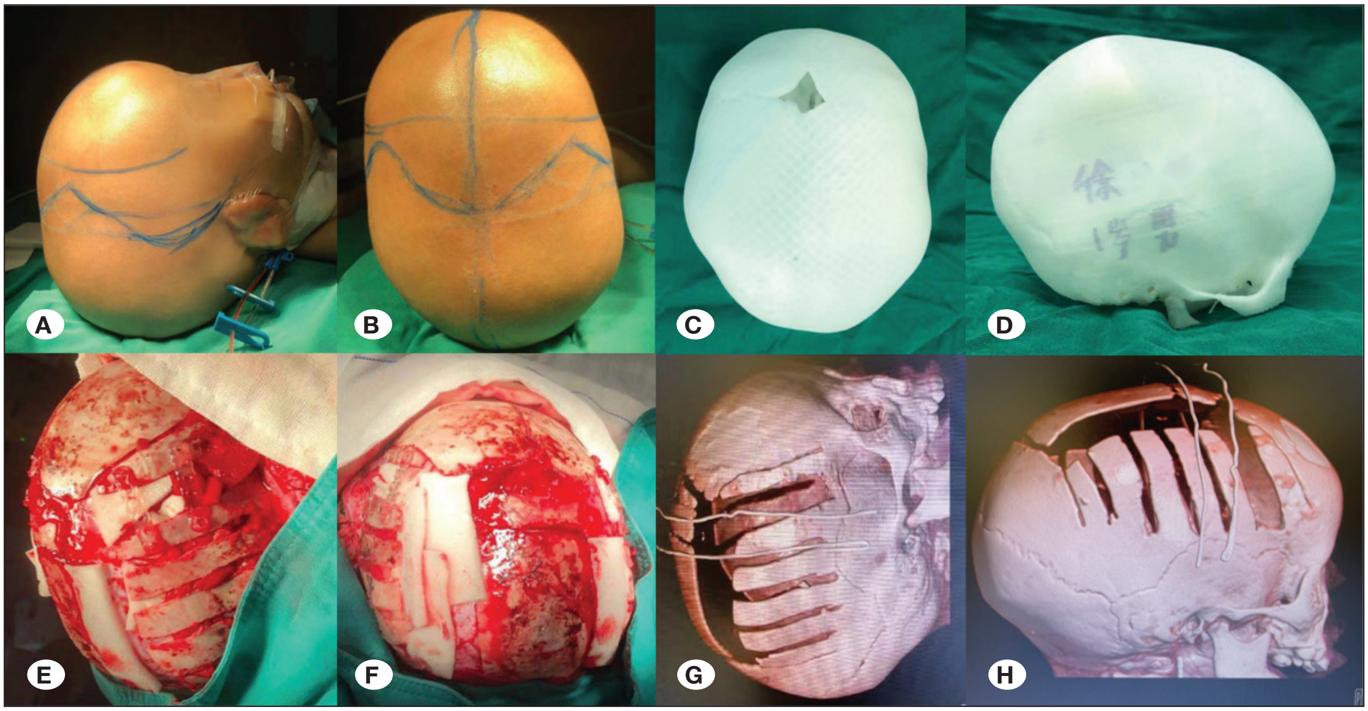

Figure 1: 3D printing technique assisted surgical treatment of infantile cranial stenosis. **A, B)** Preoperative Head type; **C, D)** preoperative 3D printing model: assist the frontoorbital band retraction technique and guide the formulation of the operation plan; **E, F)** 3D printing model during operation to guide the operation of frontoorbital band retraction; **G, H)** The CT images reexamined after operation.

Table I: Comparison of Head Circumference, CI and CVAI 12 Months Before and After Operation in the Same Group

	Preoperative head circumference (cm)	Head circumference 12 months after operation (cm)	p	Preoperative CI	CI 12 months after operation	p	Preoperative CVAI (%)	CVAI 12 months after operation (%)	p
Test group	46.8 ± 3.1	50.1 ± 3.3	0.15	66.4 ± 3.0	79.2 ± 1.5	0.01	0.4 ± 0.6	0.4 ± 0.5	0.93
Control group	48.1 ± 3.4	50.6 ± 3.6	0.19	66.7 ± 3.8	72.3 ± 3.5	0.29	0.6 ± 0.6	0.6 ± 0.6	0.90

Table II: Comparison of Head Circumference, CI and CVAI 12 Months After Operation Between the Two Groups

	Head circumference 12 months after operation (cm)	CI 12 months after operation	CVAI 12 months after operation (%)
Test group	52.1 ± 3.3	79.2 ± 1.5	0.4 ± 0.5
Control group	51.6 ± 3.6	72.3 ± 3.5	0.6 ± 0.6
p	0.58	**0.01**	0.57

Table III: Comparison of Intraoperative Bleeding Volume and Operation Time Between the Two Groups

	Operation time (h)	Intraoperative bleeding volume (ml)
Test group	2.8 ± 0.75	108.9 ± 37.7
Control group	3.1 ± 0.42	112.6 ± 35.9
p	0.66	0.58

suture. We used 3D printed skull models in combination with the fronto-orbital band retraction technique. We actively explored the clinical benefit of frontal frame band retraction in surgical treatment of children with premature closure of the sagittal suture (3,5). Premature closure of the sagittal suture is a common condition in pediatric neurosurgery and often occurs in infants (11,13). Scaphoid malformation is the main clinical manifestation of this condition (6); however, abnormal increase in the head circumference, mental and motor retardation, rise in intracranial pressure, headache, vomiting, and optic papilla edema may also be observed (1). In severe cases, the closure may result in brain hernia, leading to life-threatening respiratory arrest, seriously endangering the infant's health. The condition is treated surgically (9). Despite many complications and high risk of the operation, traditional surgery cannot effectively correct head deformities and the shape of the skull (2,8). At present, 3D printing technology is widely used in many general neurosurgical procedures. However, 3D printing technology is rarely used to assist in treating the premature closure of the sagittal suture in infants and young children (14,15). According to the novelty search report, there is no control study in the literature.

To the best of our knowledge, this is the first study to use 3D printing technology for determining the frontoorbital zone retraction and guide surgical treatment in 15 infants with premature closure of the sagittal suture. Thirteen patients with premature closure of the sagittal suture were treated with 3D printing-assisted cranial suture reconstruction as control, and the effects of cranial suture reconstruction and frontal frame belt retraction in the operation for premature closure of the sagittal suture in infants were compared and analyzed. Based on our results, using 3D printing to assist in the fronto-orbital band retraction procedure significantly improved the outcome of surgical treatment in infants with premature closure of the sagittal suture. The head circumference, CI, and CVAI had significantly improved in the experimental group 12 months after the operation, while such a difference was not observed in the control group, suggesting that fronto-orbital band retraction technique combined with 3D printing could significantly improve the effect of surgical treatment in infantile cranial stenosis. Using 3D printing, the deformed skull was modeled at a 1:1 ratio allowing for the displacement of the bone flap to be designed prior to the operation. The shrinking distance of the frontal frame band could also be accurately calculated using the imaging indices. This approach allows for designing the head type of the patients more in line with their normal skull type and planning the appropriate surgical approach, the incision site, and the size of the skin flap, thereby reducing the operation time, the amount of blood loss during the operation, and the risk involved in the procedure compared to the traditional approach. Besides, it allows for personalization of the operation plan and provides some level of familiarity with the mode of operation for the operator and control the effect of operation, which can significantly improve the therapeutic effect of skull orthopedic surgery for narrow skulls.

Using 3D printing as a guide in the fronto-orbital band retraction procedure improves the outcomes for patients with premature closure of the sagittal suture compared to the traditional cranial suture reconstruction technique. In this study, there were no significant differences in preoperative head circumference, CI, and CVAI between the experimental group and the control group. One year after the operation, CI and CVAI were closer to normal ranges in the experimental group, which indicated that the treatment outcome of the fronto-orbital band retraction technique assisted by 3D printing was better than that of traditional cranial suture reconstruction. Besides, the proportions of the head after the operation were more symmetrical. Since 3D printing prior to fronto-orbital band retraction allows for the normal range of CI, CVAI, and the distance for the fronto-orbital zone retraction to be accurately calculated, the operation plan is more personalized and detailed, the effect of intraoperative correction will be more significant, and the head proportions will be closer to normal after correction.

Although we did not observe any significant difference in the operation time or the amount of intraoperative blood loss between the two groups, fronto-orbital band retraction technique assisted by 3D printing allowed for the operation of narrow skull to be simulated prior to the operation leading to individualized and more accurate operations with shorter operation time and less blood loss during the operation. This approach also reduces the risks associated with general anesthesia, surgical trauma, and blood loss and infection, while significantly improving the safety of the operation and the outcome for infants with premature closure of the sagittal suture.

CONCLUSION

Based on our findings in this study, using 3D printing as a guide for the fronto-orbital band retraction procedure to treat cranial stenosis can improve treatment outcomes in children with premature closure of the sagittal suture compared to the traditional cranial suture reconstruction. The cohort in this study was small and the follow-up period was short. Future studies with bigger cohorts and longer follow-up periods should be conducted to further prove the efficacy of this technique. Nonetheless, we believe that this procedure should become the treatment of choice in cases with premature closure of the sagittal suture. We will continue to follow up the patients to determine the long-term effects of the operation.

AUTHORSHIP CONTRIBUTION

Study conception and design: MF

Data collection: QQ

Analysis and interpretation of results: QQ

Draft manuscript preparation: QQ

Critical revision of the article: MF

Other (study supervision, fundings, materials, etc...): HW

All authors (QQ, HW, MF) reviewed the results and approved the final version of the manuscript.

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