Spring-Assisted Cranioplasty vs Pi-Plasty for Sagittal Synostosis–A Long Term Follow-Up Study

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Spring-assisted cranioplasty (SAS) has been used for the treatment of selected cases of sagittal synostosis at our unit routinely since 1998. In order to assess the long-term outcomes of this procedure, we compared the clinical data and morbidity with the pi-plasty technique, our previous standard procedure for the treatment of such children.

The first 20 consecutive patients who underwent SAS for isolated sagittal synostosis with complete records, and who were 3 years old at the time of this study, were included. Twenty patients with a pi-plasty performed in the period immediately preceding the spring group acted as a control group. Cephalograms (preoperative, 1-year and 3-year), clinical examination, medical record data, medical photography, and a questionnaire (spring-group only) were used to evaluate and compare these two groups.

The mean age of the spring group was 3.5 months (2.5–5.5) and the pi-plasty group 7.1 months (4–15.5) of age at surgery. There were no deaths in either group. There was a higher rate of complications in the pi-plasty group. The skull morphology was similar preoperatively in both groups but slightly different at the 3-year follow-up. The mean cephalic index (CI) in the spring group was 72 at 1 year of age and 71 at 3 years of age, indicating a minor relapse. The pi-plasty group had a mean CI of 73 at 3 years of age. The length was the same in both groups however the pi-plasty group had a lower height (mean 2 mm) and wider biparietal distance (mean 5 mm). All parents of the spring group were highly satisfied with the aesthetic results achieved, would undergo the operation again, and would recommend it to others with scaphocephaly.

It was concluded that the two groups of surgery resulted in a quite similar morphologic outcome. The pi-plasty group had a cephalic index marginally closer to the normal range at 3 years of age. The spring group was superior with respect to blood loss, transfusion requirements, operative time, ICU time, recovery time, and total hospital stay.

Key Words: Spring-assisted cranioplasty, pi-plasty, cephalic index

The use of implantable springs in craniofacial surgery was pioneered at our unit 9 years ago. In 1998, it became a part of our routine protocol for treating various forms of craniosynostosis, and has been the treatment of choice for treating scaphocephaly in children less than 6 months of age. Prior to this time, a modified pi-plasty technique was used that had good aesthetic results, but required extensive dural undermining and significant blood loss. The use of springs has given the craniofacial surgeon a modality to treat craniofacial dysmorphologies in simplified ways not possible with traditional cranial vault remodeling techniques.

Guimaraes-Ferreira et al[1] compared the first 10 patients who were treated with spring-assisted strip craniectomy (SAS) at 1 year of age with a matched pi-plasty group from our institution. There were significant improvements in terms of skull shape and postoperative morbidity for the SAS group. In order to possibly improve the use of springs in surgery, this long-term, follow-up study was undertaken to compare the pi-plasty with the SAS.

Materials and Methods

A retrospective chart review that included all patients treated in the Craniofacial Unit at

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Sahlgrenska University was conducted for the patients diagnosed with sagittal synostosis. To meet inclusion criteria, the patients had to have a diagnosis of isolated premature sagittal synostosis and be 3 years old at the time of the chart review. Patients were excluded if they had multiple suture synostosis, syndromal craniosynostosis, suture closure secondary to ventricular shunting, previous craniofacial surgery, or who had incomplete records. Data collected included age at operation, gender, surgical procedure, length of hospital stay, time in the intensive care unit, operative time, blood loss, transfusion amounts, and cephalometric analysis.

At the time of this study, 37 patients had undergone SAS for treatment of isolated scaphocephaly in our unit. In this group, 20 patients met inclusion criteria due to the 3 year age requirement at the time of the data collection. The control group was made up of 20 consecutive patients who had undergone a pi-plasty technique for the same diagnosis during the prespring era. Statistical evaluation of the results was performed using the Student's two-tailed t-test for a comparison of means for data conforming to a parametric distribution. Data conforming to a nonparametric distribution was analyzed using the Mann-Whitney test for independent samples and the Wilcoxon's signed rank test for two related samples.

Radiographic Method

Cephalometric x-rays were taken preoperatively, at the time of spring-extraction (for the spring group) and postoperatively at 3 years of age for both groups. With the patients sedated, a custom designed cephalostat was used with LASER-guided focusing of the x-rays for exact positioning. Three standardized projections (lateral, frontal, and axial) were taken of the patient at each examination. Standard magnification errors for each projection were calculated and the cephalometric measurements were adjusted accordingly.

Surgical Technique

Spring Assisted Strip Craniectomy (SAS)

The SAS technique was conducted with the patients in the prone position through a midline lazy-S scalp incision (Fig 1). Dissection was performed in the extraperiosteal plane for exposure of the synostosed sagittal suture. A midline osteotomy was performed, extending from the coronal to the lambdoid sutures. Hemostasis was achieved using cautery and bone wax. The 1.2 mm stainless steel springs (Stockholms Fjäderfabrik AB, Lesjöfors, Sweden) were composed of 8% nickel, 17% chromium, 73% iron, and 2% other elements. The springs were manufactured on a sterile side table with orthodontic callipers to obtain 6–8 Newtons of initial force at an interarm distance of 10–15 mm. The dura mater was carefully dissected 10 mm lateral from the osteotomy on each side. The springs were then inserted into drill holes 5 mm lateral to each side of the midline osteotomies and adjusted to act perpendicularly to it. The skin incision was closed with resorbable sutures in 2 layers. Six months following the first operation the springs were removed. In each case, the springs retained their tension as tested manually.

Fig 1 SAS intraoperative technique of spring placement after sagittal osteotomy.

Modified Pi-Plasty Technique

The pi-plasty technique used in our study was a modification of the original pi-plasty described by Jane et al[2] in 1978. The details of our modification have been described in detail by Guimaraes-Ferreira et al.[3] Central to this technique is the use of a longitudinal compressive force and release of the parietal bones to shorten and widen the skull.

Skull Morphology Measurements

The calvarial length (CL), calvarial height (CH) and calvarial width (CW) were measured on the cephalograms to the nearest 0.5 mm and corrected for radiographic magnification error. CH was defined as the distance from basion to vertex. CW was defined as the maximum depth across the parietal bones on the axial cephalogram. CL was the maximum longitudinal distance across the outer surfaces of the frontal and occipital bone on the axial projection. The cranial index was calculated from cranial length and width. To describe the skull morphology, five objective variables were used for evaluation of the operational results:

1. Cephalic index given by the percentage ratio between maximum skull width and length (CL × CW/100).
2. Axial width ratio, which is defined as the percentage quotient between the width of the forehead at the intersection of a line tangential to the lateral orbital rims and the maximum width of the skull (derived from the axial projection of the cephalogram, hence the designation of the ratio).
3. Length ratio (2 × CL/(CW + CH) × 100).
4. Height ratio (2 × CH/(CW + CL)) × 100.
5. Width ratio (2 × CW/(CL + CH)) × 100).

Parental Questionnaire

A questionnaire was sent to all families in the spring-treated group to evaluate the level of satisfaction of the surgical procedure as determined by the parents. In the questionnaire the parents were asked to rate the pre-and postoperative general aesthetic appearance of the skull which included the length, width, appearance of the forehead and neck, and their satisfaction with the treatment. Additionally they were asked if they would recommend the procedure to an eligible family or if they would accept it again if needed. Evaluation was done using graded scales 1–5 (1 = the worst result, 5 = the best result) and visual analogue scales (VAS) graded 0–100 mm (0 = the best result, 100 = the worst).

Table 1. Perioperative Data Comparison for the Spring Assisted Surgery and Pi-Plasty Groups

Perioperative Data	*Spring Group (SD)*	*Pi-Plasty Group (SD)*	*P-Value*
Postoperative stay (days)	6 (3.1)	9 (1.7)	< 0.001*
Age at operation (months)	3.5 (0.8)	7.1 (2.4)	< 0.001*
Blood loss (ml)	170 (98)	425 (152)	< 0.001*
Blood loss (% EBV)	33 (20)	67 (29)	< 0.001*
OR time (min)	104 (42)	121 (22)	0.0103*
ICU stay (hrs)	25 (5)	46 (33)	0.03*

**P*-value with significance.

Table 2. Mean Cephalic Index for the SAS and the Pi-Plasty Groups

	SAS Group (SD)	*Pi-Plasty Group (SD)*	*P-Value*
Pre-operative	66.57 (4.06)	66.12 (2.88)	0.9676
Post-operative (3 years)	70.57 (3.68)	73.37 (3.34)	0.0128*

**P*-value with significance.

Results

Forty patients (20 SAS, 20 pi-plasty) were included in the study based on the inclusion criteria described above for treatment of nonsyndromic sagittal synostosis. The patients in group A underwent a spring-assisted cranioplasty and consisted of 18 males and 2 females (20 total). Group B were the patients who underwent a pi-plasty and consisted of 16 boys and 4 girls (20 total). The mean age at operation was 3.5 months in the SAS group and 7.1 months in the pi-plasty group. The mean operative time in the spring group was 104 minutes and 121 minutes in the pi-plasty group. Mean blood loss for the spring group was 170 ml and 424 ml in the pi-plasty group. The spring group was operated on at a significantly younger age and therefore blood loss was calculated as a percentage of estimated blood volume (EBV) for each patient. The blood loss was a mean of 33% of EBV in the spring group and 67% of EBV in the pi-plasty group. The SAS patients stayed in the ICU for a mean of 25 hours, while the pi-plasty group stayed a mean of 46 hours. The mean hospital stay for the SAS group was 6 days and the pi-plasty group was 9 days (Table 1).

Skull Morphology

The preoperative mean cephalic index was 66 in both groups. The absolute values between the groups preoperatively are not comparable because of the different mean ages at the time of operation. The measurements at 3 years of age can however be compared between groups. At 3 years of age the cephalic index was 71 in the spring group and 73 in the pi-plasty group. The mean cranial length was the same in both groups (18.2). The mean overall width was greater in the pi-plasty group than the SAS group (13.4 cm and 12.9 cm respectively), which explains the

Table 3. Mean Visual Scale Ratings in the Spring Assisted Surgery Group (n = 19)

Variable	*Scale*	*Preoperative (SD)*	*Postoperative (SD)*	*P-Value*
Length	1–5	3.0 (1.2)	4.3 (1.0)	0.005*
Width	1–5	3.8 (1.4)	4.2 (1.1)	0.315
Forehead	1–5	3.8 (1.1)	4.4 (0.9)	0.061
Neck	1–5	3.3 (1.6)	4.4 (0.8)	0.007*
Satisfaction of skull-shape	0–100 (0 = best, 100 = worst)	51.1 (20.3)	5.6 (7.5)	0.001*

**P*-value with significance.

difference in cephalic index. The mean height was greater in the spring group than the pi-plasty group (12.6 cm and 12.4 cm respectively) (Table 2).

Parental Questionnaire

Nineteen of the 20 parental questionnaire forms were completed by the families and returned for analysis. There were significant changes in the aesthetics rating of the length and posterior neck appearance, and in the overall postoperative result (Table 3). All patients were satisfied with the treatment, and would go through it again if necessary (4.3 SD, 12.4 VAS scale). Every family felt they would recommend other patients to go through the same treatment process if needed (0.6 SD, 1.9 VAS scale).

Discussion

The treatment of sagittal synostosis in our unit has come full circle. The earliest interventions by our neurosurgeons consisted of a midline strip craniectomy as advocated by Ingraham.[4] However, the bone gaps often reossified before the skull shape could normalize. Although this procedure, was occasionally effective, the results were variable and unpredictable. During one period, silicon sheets were placed in the osteotomy gaps to prevent reossification. The ability of the dura and the periosteum to lay down bone was underestimated, and

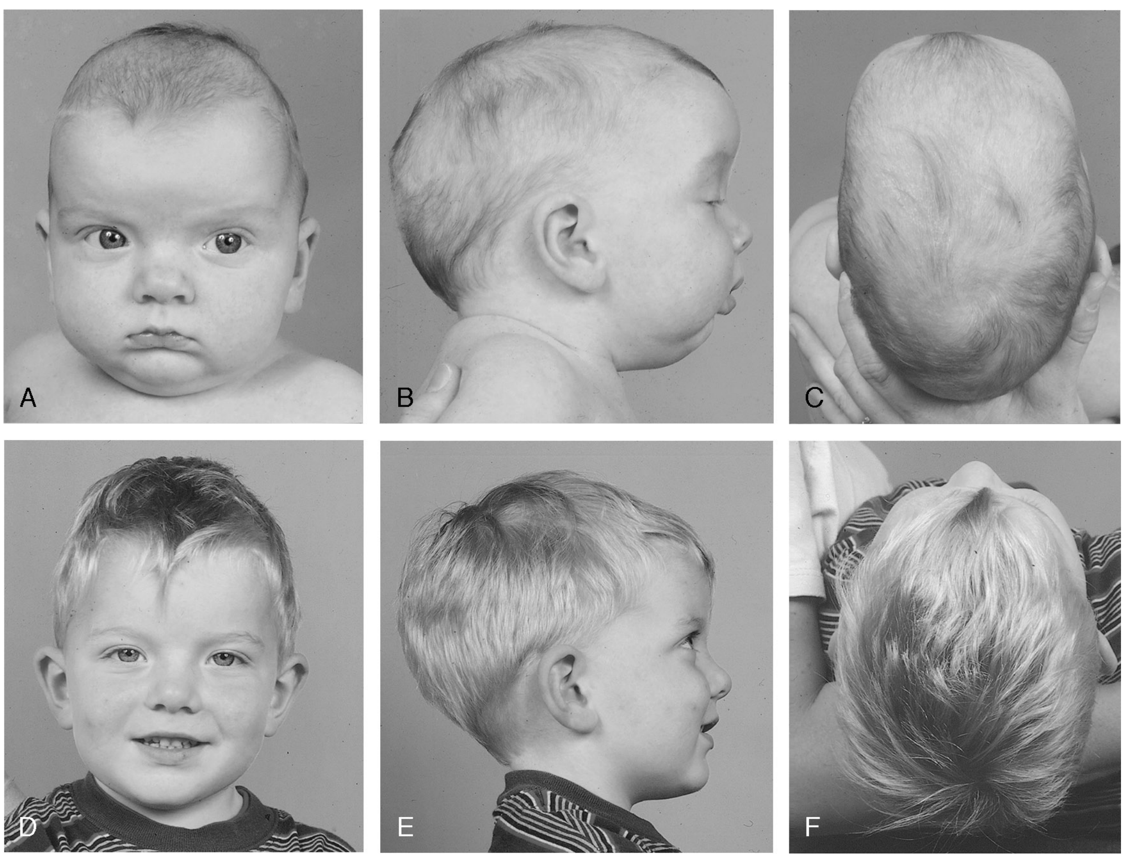

Fig 2 Patient with sagittal synostosis corrected using SAS at 6 months of age. Preoperative pictures at 3 months of age: (A) anterior-posterior view, (B) lateral view, (C) axial view. Postoperative follow-up pictures at 3 years of age: (D) anterior-posterior view, (E) lateral view, (F) axial view.

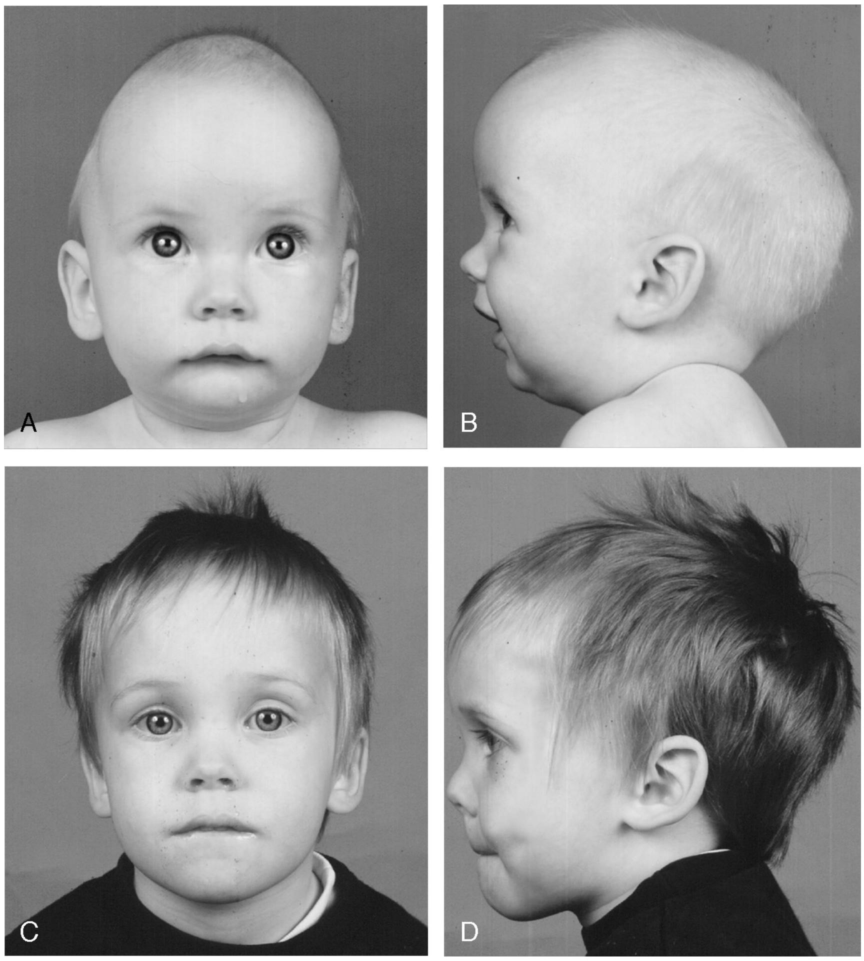

Fig 3 Patient with sagittal synostosis corrected with Pi-plasty procedure at 6 months of age. Preoperative pictures at 6 months of age: (A) anterior-posterior view, (B) lateral view. Postoperative follow-up pictures at 3 years of age: (C) anterior-posterior view, (D) lateral view.

the bone gaps closed over the silicone leading to ''osseointegrated'' silicone.[5] The pi-plasty described by Jane et al[2] resulted in immediate improvement in skull morphology and set the framework for active remodelling of the skull. We have modified the original pi-plasty by adding more osteotomies, but the basic principles of transverse widening and active compression in the longitudinal direction remain the same.

A pi-plasty procedure is typically performed between 6 and 9 months of age. In order for spring-assisted cranioplasty to be most effective, surgery is undertaken prior to 6 months of age while the skull is still malleable and there is rapid brain growth to drive subsequent cranial remodelling. The results obtained by the pi-plasty technique are excellent and consistent, but the procedure has limitations and risks. Extensive undermining of the dura is required and the amount of blood loss requires blood transfusions. Additionally, the amount of correction is limited by the amount of compressive force the brain is able to endure on the operative table. In our hands, all patients, apart from requiring blood transfusion, require a minimum of one week postoperative hospital stay. The application of the springs for this condition has reduced the operative time by 14% and the blood loss by 60%, leading to a 66% reduction in blood transfusion for patients undergoing surgical treatment for sagittal synostosis. It also facilitates the earlier discharge from the hospital of patients with a 45% reduction in ICU-stay, and a 41% reduction in total hospital stay.

The technique of using a single-strip craniectomy, or an osteotomy alone, is particularly appealing to the surgeon as the procedure reduces operative time and causes very little blood loss in comparison to more invasive techniques. Adding springs has brought back the idea of the strip craniectomy and the single sagittal osteotomy as a treatment modality, thereby markedly reducing the risks while retaining the high standards of correction. Springs serve to expand the parietal bones slowly over weeks to months, overcoming the restricting forces caused by the neo-osteogenesis.

The different mechanics of each procedure explains the slight differences in skull morphology between the 2 groups. The pi-plasty actively shortens the cranial length with wires between the shortened synostosed suture and the frontal bone. Tension along this axis seems to limit the cranial height. In contrast, the spring procedure distracts the parietal bones laterally, which facilitates complimentary brain growth laterally but does not limit the vertical skull growth (Figs 2 and 3).

The severity of the skull morphology in scaphocephaly is highly variable and depends upon the age of onset of the synostosis and the site at where it starts. The cephalic index does not single out frontal bossing or the pronounced occipital protrusion seen in some patients, but it renders an objective measurement that gives an overview of changes in skull shape. Both groups had a cranial index close to normal at 3 years of age. There was, however, a small but statistically significant difference for the pi-plasty group being closer to normal. In contrast to many other studies where the clinical cephalic index is used, we have measured the bony cranial index,[6–7] as we feel this is more accurate.

The parental questionnaire was completed by 19 out of 20 families (95%). Apart from a generally positive attitude towards questions of hospital care, there was an overwhelmingly positive opinion of the aesthetic outcome of surgery. Apart from the fact that parents may want to show their gratitude, there can be no doubt that the results were satisfactory. The small difference in the cephalic index seen between the 2 groups is not clinically noticeable.

In the spring group, the cephalic index decreased somewhat between 1 and 3 years of age. As comparable data were not available, no conclusion could be drawn on this for the pi-plasty group. The reason for the change in cephalic index is difficult to explain, but could indicate that springs in fact should be left longer before removal.

CONCLUSIONS

The spring-assisted cranioplasty and the pi-plasty are both safe procedures, which render good long-term results with significant objective changes towards a normalization of the skull morphology. However, the spring technique is less traumatic, requires minimal dural undermining, decreased blood loss, and provides excellent long-term results.

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