The Evolving Role of Springs in Craniofacial Surgery: The First 100 Clinical Cases

Claes G. K. Lauritzen, M.D., Ph.D.
Charles Davis, F.R.A.C.S.
Anna Ivarsson, M.K.
Claire Sanger, D.O.
Timothy D. Hewitt, F.R.A.C.S.

Göteborg, Sweden; Wellington, New Zealand; Winston-Salem, N.C.; and Perth, Western Australia, Australia

Background: The use of springs in craniofacial surgery originated at Sahlgrenska University Hospital in 1997 as a way of remodeling the cranial vault postoperatively.

Methods: The hospital records of the first 100 operations involving spring placement were analyzed retrospectively. Demographic, perioperative, and postoperative data were recorded.

Results: Two hundred forty-six springs were used in 96 patients. Results for sagittal, metopic, bicoronal, multiple synostoses, and midface surgery are presented. In total, five patients (5 percent) required further surgery because of undercorrection. There were no major complications. Spring dislodgement (5 percent) was the most common complication in early cases. Raised intracranial pressure resulted in a protocol change with the use of compressive springs. The data compare favorably with those of standard craniofacial procedures performed in the same unit.

Conclusions: This therapeutic modality in craniofacial surgery has allowed minimization of the extent of surgery without compromising clinical outcomes. Springs have now become part of the authors' treatment protocol for craniosynostosis and midface surgery. The authors have shown the use of these techniques to be safe and, in selected situations, to offer significant advantages over other methods of treatment. (*Plast. Reconstr. Surg.* 121: 545, 2008.)

The use of implantable springs in craniofacial surgery was pioneered at Sahlgrenska University Hospital in 1997. The concept of using springs was developed to dynamically further remodel the cranial vault postoperatively using expander elements that could be individually designed and constructed by the surgeon in the operating room. Dynamic cranial vault alteration has been performed with pi-plasties and during procedures for brachycephaly; however, elevation of the intracranial pressure sets a limit on the extent to which these can safely be performed.[1]

In the very young skull, in which the bone is still pliable and membranous in nature, a spring applied across a strip craniectomy will not only force the bone ends apart but will also remodel much of the adjacent cranial vault. As such, osteotomies and springs are now our routine treatment modalities for all patients of appropriate age with sagittal, metopic, and bicoronal synostosis. The same principles are also used for gradual cranial expansion in selected complex cases of cranial deformation and following midfacial advancement to counteract relapse.

From the Craniofacial Unit, Department of Plastic Surgery, Sahlgrenska University Hospital; Craniofacial Unit, Department of Plastic Surgery, Lower Hutt Hospital; Department of Plastic and Reconstructive Surgery, Wake Forest University Medical Center; and Craniofacial Unit, Department of Plastic Surgery, Princess Margaret Hospital.
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PATIENTS AND METHODS

Unit records of 96 patients who had undergone a total of 100 operations with springs were analyzed retrospectively. Data were collected for diagnosis, age of the patient, operative technique and time, number of springs used, estimated blood loss, perioperative and postoperative transfusion, hospital stay (intensive care unit and ward), complications (intraoperative and postoperative), secondary operation details, and follow-up details. Cephalograms were obtained immediately preoperatively and at

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regular postoperative intervals. Photographs were taken preoperatively, intraoperatively, and postoperatively by our medical photographer. Parental questionnaires on aesthetic outcomes were administered at 3 years of age to the first 20 sagittal synostosis patients using the five-point Likert scale and the visual analogue scale.

Spring Manufacture

Omega-shaped springs were manufactured from stainless steel wire (Stockholms Fjäderfabrik AB, Lesjöfors, Sweden). The composition of the wire was as follows: nickel, 8 percent; chromium, 17 percent; and iron, 73 percent. The wire was hand-bent, and sterile standard pliers were used to shape the bayonet. The strength of each spring was measured in the operating room by using a sliding pressure gauge equipped with a dial measuring newtons and kilograms (PIAB AB, Åkersberga, Sweden) (Fig. 1). A compressing spring was constructed from a standard spring with the midportion of the arms bent inward at right angles so as to pass each other and point in the opposite direction. In that way, opening of the spring would narrow its end points (Fig. 2).

Springs for sagittal synostosis were 1.2 mm thick and 16 cm long. For metopic synostosis, the same wire was used but was 2 to 3 cm longer. For midface support, the 1.8-mm-thick wire was used after having been individually tailored.

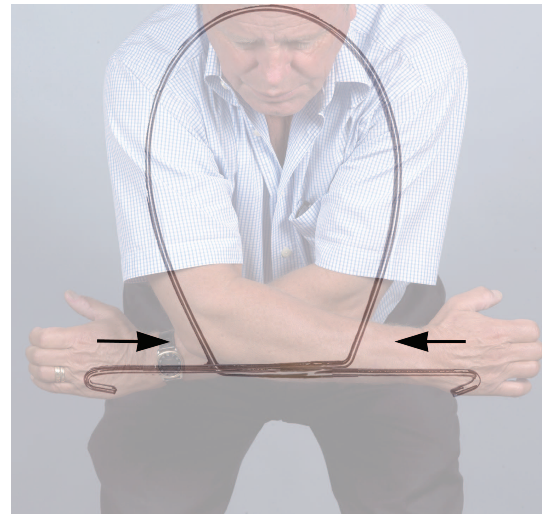

Fig. 2. To make the spring compress instead of spread, its arms have to be crossed. The spring action is demonstrated by the man in the background who abducts his arms to pull from lateral to medial. *Arrows* indicate the vectors of spring action.

Table 1. Demographic Data of 100 Operations in 96 Patients*

Diagnosis	No. of Operations	Sex: Male	Sex: Female	Age (mo): Mean	Age (mo): Range
Sagittal	35	29	6	3.8	2.5–8
Metopic	16	13	3	3.8	3–5.5
Bicoronal	11	5	6	5	3–7.5
Multisuture	16	12	4	16	2.5–81
Other	10	6	4	23	3–151
Midface	12	8	4	6.8	10–14.5

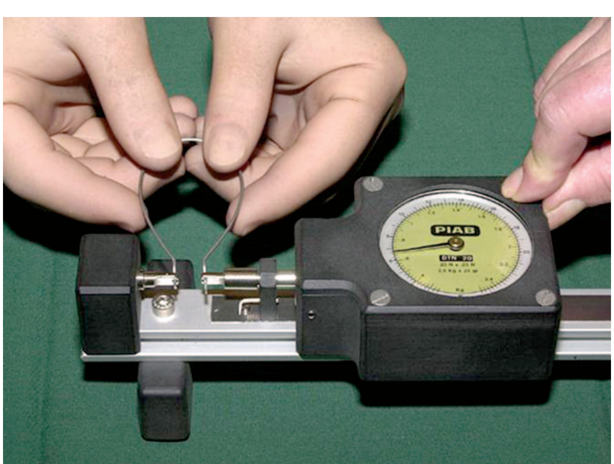

Fig. 1. The strength of each spring is measured using a sliding pressure gauge with a dial. The spring is inserted into sterile sockets mounted to the otherwise nonsterile apparatus. Once the spring is mounted, an assistant gently slides the meter, approximating the arms of the spring while it is being supported by the surgeon. The force needed to compress the spring can be read on the dial and recorded.

Surgery for sagittal synostosis was performed with the patient in the prone position. A lazy-S skin incision was made between the anterior and posterior fontanel. The fused and the adjacent sutures were checked for patency. Hemostasis was achieved with wax and diathermy. In the first seven cases, parasagittal osteotomies were made, but with increased confidence thereafter, a midline osteotomy was made between the anterior and posterior fontanelle. Care was taken to limit dural dissection in the area where the spring was to be placed. The ends of the spring were placed in obliquely drilled holes 1 to 2 cm apart with the body of the spring bent to conform to the curvature of the skull (Figs. 3 and 4). The incision was closed in layers. For cases with a particularly prominent occipital bulge, a crescent-shaped segment of bone was excised in the parietal region and a low-force compression spring added at the occiput for reduction of the skull length (Fig. 5).

For metopic synostosis, surgery was performed with the patient in the supine position. The an-

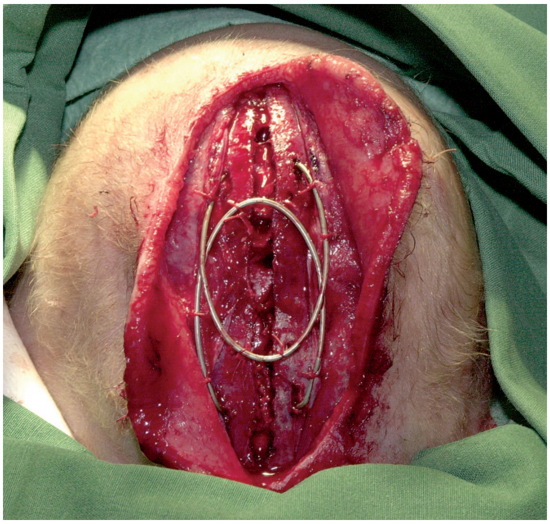

Fig. 3. Two omega-shaped springs were inserted over the osteotomized synostosed sagittal suture in a 4-month-old boy. The two skin flaps created by the lazy-S incision are held aside using loosely knit stay sutures.

terior skull was exposed to the orbital rims through a coronal incision. An osteotomy was made through the synostosed suture to the nasofrontal suture. Bitemporal retrusion was corrected by making osteotomies in the frontal bone and then bending and fixing the flaps for a more convex projection. The protruding ridge of the synostosed suture was burred flat. A spring was manufactured and inserted into two holes positioned low in the frontal bone on either side of the metopic osteotomy 10 to 12 mm apart (Fig. 6). These holes were placed sufficiently caudally for the force to act on the interorbital tissues but high enough so that if a spring were to become dislodged it would not enter into the orbit. A thin wire was placed at the apex of the spring to stabilize its position.

In 11 patients with bicoronal synostosis, osteotomies were performed according to our previously described dynamic cranioplasty for brachycephaly, except that no dural dissection was performed.[1] Osteotomies were cut in the region of the fused coronal sutures and the normal lambdoid sutures, and the widening of the skull was arrested by multiple transverse wires. In five early cases, compression springs were placed transversely across the skull. Springs were thereafter not placed in this location but instead in the coronal osteotomies. In later cases, the normal lambdoid sutures were expanded with a spring but without an osteotomy.

Springs were used for stabilization after midfacial advancement. After disjunction of the midface from the skull, 1.8-mm-thick springs were placed bilaterally. Posteriorly, the spring was initially hooked around the origin of the zygomatic arch and anteriorly by means of a metal plate with prongs to the posterior aspect of the zygomatic buttress. The gaps behind the maxilla were not bone grafted, and plating was performed only in the upper region of the orbital ring and sometimes the zygomatic arches (Fig. 7). In later cases, the spring was hooked posteriorly into a hole in the cranium above the ear. Anteriorly, the spring was straight, resting along the zygomatic buttress. This design was developed to facilitate spring removal.

Springs were also used for cranial remodeling in ventriculoperitoneal shunt–induced deformity, multisutural synostosis, unicoronal synostosis, lambdoid synostosis, a severe craniofacial cleft, and peri-

Fig. 4. Sagittal synostosis in a 3.5-year-old boy treated with osteotomy of the sagittal suture and three transversely acting springs. (*Left*) Preoperative view. (*Right*) Six-month postoperative view.

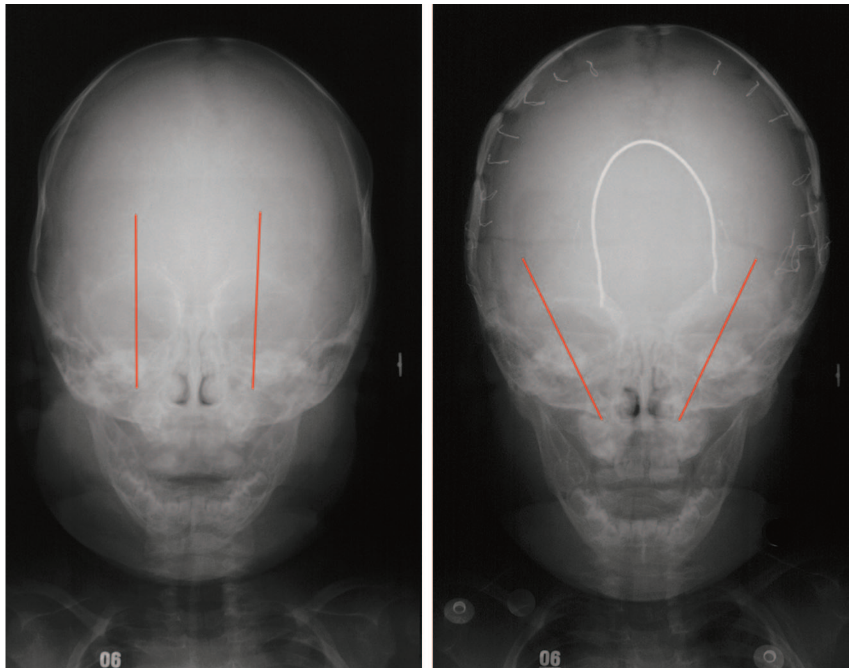

Fig. 5. (*Left*) Cephalogram of a boy with sagittal synostosis obtained preoperatively at the age of 4 months. A transversely oriented posterior crescent-like strip of bone was removed, the synostosed sagittal suture was osteotomized, and three springs were added. Two of these were spreading the parietal bones laterally and one was compressing the occiput. (*Right*) Cephalogram obtained postoperatively, 2 months later. Skull dimensions are normal. The compressive spring has markedly shortened the skull length.

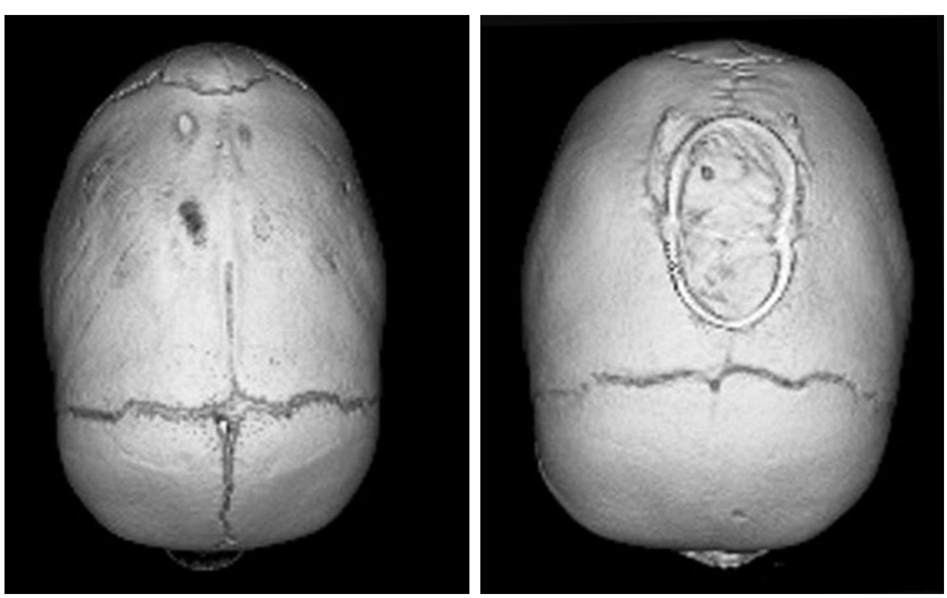

Fig. 6. A 3.5-year-old girl with metopic suture synostosis treated with a midline osteotomy and one spring. The preoperative and postoperative cephalograms demonstrate the correction of the orbital hypotelorism and the normalization of the orbital vertical axis in 6 weeks.

orbital remodeling in Crouzon syndrome. Because of low numbers and heterogeneous procedures performed, no statistical analysis of this group was possible, but complications if any were noted.

Multiple Procedures

Four patients underwent two operations. A patient with Crouzon syndrome underwent a two-stage dynamic correction of his posterior skull deformity

Fig. 7. A 9-year-old girl with Apert syndrome. (*Left*) Preoperative view demonstrating her marked midfacial retrusion. (*Right*) Six-month postoperative views after monobloc advancement. A lateral cephalogram is superimposed to visualize the position of the retaining springs used in these cases to counteract skeletal relapse.

at 6 months and the anterior deformity at 10 months. A boy with lambdoid synostosis underwent two cranial remodeling procedures, first at 4 months and later at 20 months. A girl with Pfeiffer syndrome had her skull expanded at 10 weeks and her midface advanced at 10 months. A boy with Saethre-Chotzen syndrome who was initially treated for a bicoronal synostosis at 6 months later needed further treatment and had a posterior spring-assisted cranioplasty at 2 years of age.

RESULTS

During the 7-year period from June of 1997 to June of 2004, 96 patients underwent 100 craniofacial spring placement procedures. Data for all patients regarding operative time, intensive care unit length of stay, hospital stay, and intraoperative blood loss are listed as means and ranges in Table 2.

Sagittal Synostosis

Of the 35 patients with sagittal synostosis, nine had a prominent occipital bulge needing correction. One of these patients was operated on at 23 months of age using a different surgical technique than previously described and therefore was excluded from further analysis. The remaining patients were as old as 8 months (range, 2.5 to 8 months). In most cases of sagittal synostosis, two springs were used. In six cases, three springs were placed, and in two cases, only one spring was used. The average time of spring removal was 7 months postoperatively, and when possible, a three-dimensional computed tomographic scan was then obtained (Fig. 8). In this group of sagittal synostosis patients, the average cephalic index preoperatively was 67 (range, 58 to 74), improving to 74 (range, 66 to 82) at the 6-month postoperative cephalogram. This improvement was found to be consistent in a

Table 2. Perioperative Data on 100 Operations Using Springs in 96 Patients

	Operation Time (min)		ICU Stay (hr)		Hospital Stay (days)		Blood Loss (ml)	
Diagnosis	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Sagittal	97	40–225	25	20–45	5	2–17	143	35–350
Metopic	116	78–205	27	17–46	5	3–8	238	120–625
Bicoronal	170	12–220	32	22–47	6	3–9	278	150–550
Multisuture	215	64–360	41	19–70	6	2–11	503	150–2100
Other	185	65–510	31	22–46	7	3–14	344	70–1700
Midface	334	270–595	46	23–142	10	7–19	1682	460–4200

ICU, intensive care unit.

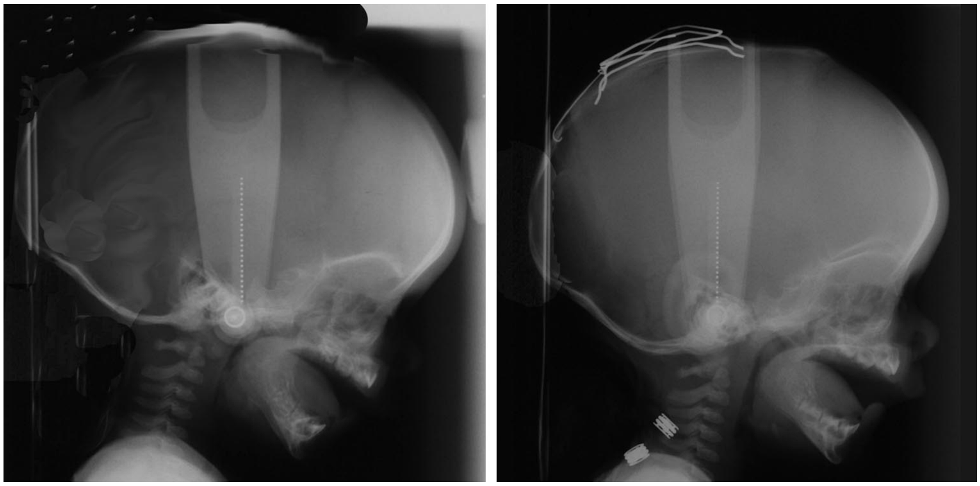

Fig. 8. Three-dimensional computed tomographic scans of the girl in Figure 6. The marked widening of the skull can be seen when compared with the relatively unaffected skull length at 9.5 months of age.

3-year follow-up of the first 20 patients in this group. A favorable response on aesthetic outcomes was recorded, with a preoperative mean of 3.48 and a postoperative mean of 4.33 on the Likert scale. The visual analogue scale showed an improvement from 51.1 to 5.6 (0 = best and 100 = worst).[2]

Metopic Synostosis

Of the 16 cases of metopic synostosis, a single spring was used in 14 cases. In the remaining two cases, two springs were used. The average measured force of the spring was 6.4 N (range, 3.75 to 8.1 N). The average timing of spring removal was 4.8 months (range, 1.5 to 9 months) postoperatively. In 10 cases, the springs were removed routinely at 6 months; however, in six cases they were removed earlier because of threatening overexpansion. Correction of the hypotelorism was evident in each case, with an outward rotation of the orbits demonstrable on cephalograms as a result of the spring (Fig. 6). The forehead contour was normalized because of the conventional osteotomies.

Bicoronal Synostosis

Bicoronal synostosis was treated in 11 patients with satisfactory results. The group included two patients with Apert syndrome, two with Saethre-Chotzen syndrome, and one with Munke syndrome. In five early cases, a spring compressing the skull in the biparietal dimension was added in addition to the four springs expanding the skull anteroposteriorly. In three of these cases, the intracranial pressure became elevated and in at least two cases was attributable to the compression spring. The springs loaded across functional lambdoid sutures acted as effective distractors. The placement of an intracranial pressure monitor in some cases was one of the reasons for a prolonged intensive care unit stay. In three cases, the springs were difficult to remove. This was particularly the case with the serrated clasp-shaped end used early in the series.

Multisutural Synostosis

The multisuture group was composed of 16 patients successfully treated who would otherwise have had more extensive cranial remodeling surgery. There were 12 male patients and four female patients. The patient group included seven with Crouzon syndrome, five with Pfeiffer syndrome, one with Jackson-Weiss syndrome, and one with Saethre-Chotzen syndrome. Five patients were operated on well after the first year of life. The average number of springs used in case was 3.5 (range, one to six springs), reflecting the more complex multivector remodeling attempted in these cases (Fig. 9). In most cases, a 1.2-mm-thick wire was used. Three patients had a spring dislocation, and in one case this caused an erosion of the overlying skin necessitating early removal. All other springs were removed routinely. Two patients with severe Pfeiffer syndrome were noted to have an irregular and less-than-perfect skull contour at the 12-month check but did not require further surgery.

Midfacial Advancement

Twelve cases—three Apert, four Crouzon, and five Pfeiffer syndrome patients—underwent mid-

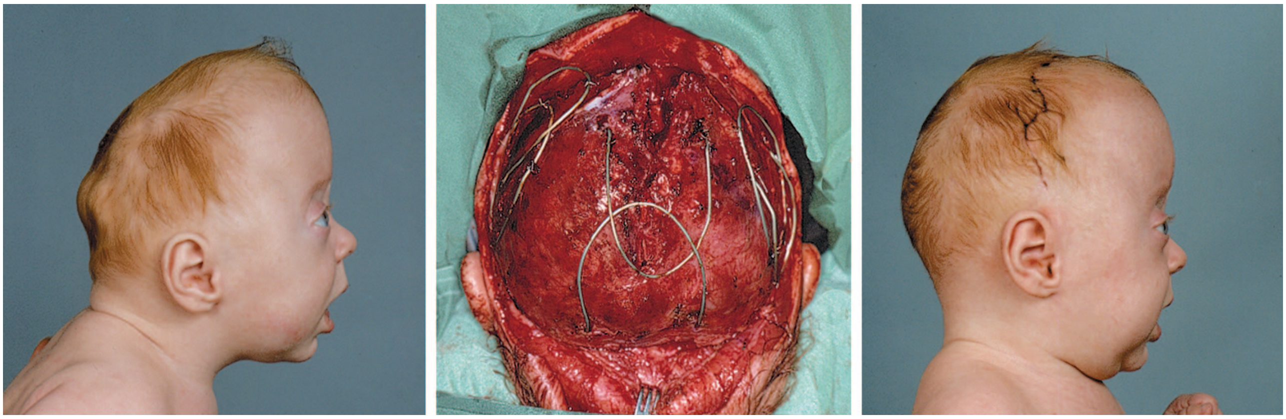

Fig. 9. Nonsyndromal multiple suture synostosis in a 4-month-old boy treated with six springs after osteotomies without dural dissection. The postoperative photograph was taken 9 days after surgery.

facial advancement. The operations consisted of three subcranial Le Fort III and nine monobloc procedures. The thicker, 1.8-mm-diameter springs were used with measured forces between 10 and 16 N. Five early cases had some form of spring dislodgment. In three of these cases, a minor procedure was required to reposition the spring. In one case, the spring cut through the body of the zygoma 8 months postoperatively and had to be removed. One spring was difficult to remove. A prolonged postoperative fever was noted in three cases that had a monobloc procedure. All settled quickly with supportive treatment. Cephalometric analysis established that although no further advancement of the face took place after surgery with the springs in place, no relapse was seen during the 2-year postoperative period.[3]

Miscellaneous Diagnoses

Ten remaining patients in this series of 100 operations constituted such a heterogenous group that analysis focused on spring-related complications. In three cases, springs were used to reshape skulls deformed by the combination of ventriculoperitoneal shunt over drainage and positional deformity (Fig. 10). In two of these cases, no osteotomies were used, and in the third case, a simple osteotomy of the (secondarily fused) sagittal suture was performed. In these cases, the improvement of head shape was dramatic. It was noted that the spring was difficult to remove in three of these patients. One dislocated early postoperatively and a minor procedure was performed to reposition it. One patient with a unicoronal synostosis was undercorrected and a further traditional remodeling procedure was performed.

Summary of Complications

In this series of 100 spring procedures, 246 springs were placed. There were no deaths or any serious complications. Thirteen springs dislodged (5 percent), and five of these (2 percent) required surgery to reposition the spring. In two cases, there was a pressure wound over the spring, and in one case, there was skin penetration. The springs were difficult to remove in seven cases. Compression springs were used in 16 cases, and in three cases, this caused increased intracranial pressure. Irregular skull contour was seen in two cases, although it was not enough to warrant further surgery. In five cases, the desired correction was not achieved and further surgery was or will be required. In one case of metopic synostosis, the spring was too effective, producing hypertelorism, and further surgery will be required. Prolonged postoperative fever was seen in four cases and delayed healing of the scalp wound was seen in three cases, although these events were not related directly to the springs themselves.

DISCUSSION

The use of springs has made it possible to continue the process of dynamic reshaping of the growing infant skull using low forces to safely achieve significant remodeling while concurrently using less extensive surgery. Persing et al. demonstrated in rabbits that springs could enhance growth when placed across a linear craniectomy in a rabbit model.[4] We have found this to be true in the clinical situation also and published our results in 1998.[5] With increasing experience, enthusiasm has grown and several reports have been delivered at plastic surgical congresses and craniofacial meetings.[2,3,6–11] However, this is the first comprehensive report of a significant body of experience—100 consecutive cases—using springs in craniofacial surgery.

The rapid sutural growth of the infant skull up to 1 year of age is gradually replaced by the slow

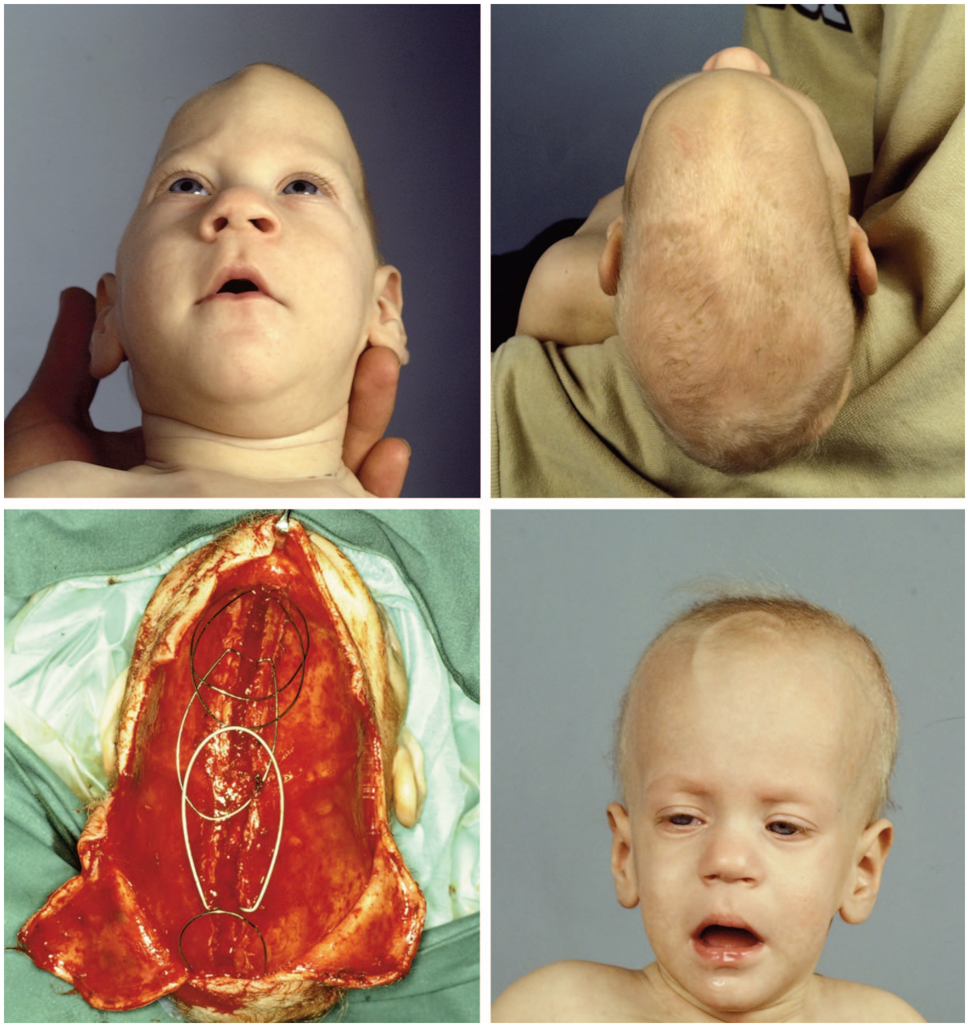

Fig. 10. (*Above*) A 4-month-old twin boy born 3 months prematurely. The severe skull deformity with secondary sagittal synostosis was a result of inadequate positioning and a lack of counter-pressure caused by a ventriculoperitoneal shunt. (*Below, left*) An osteotomy of the sagittal suture was performed and five springs were placed. No dural dissection was undertaken. (*Below, right*) Photograph of the boy at 11 months of age.

Table 3. Summary of Complications after Placing 246 Springs in 96 Patients (100 Operations)*

Diagnosis	Spring Dislodgement	ICP Elevation	Difficult Spring Removal	Overcorrection	Undercorrection	Surgical Repositioning	Early Removal
Sagittal	3	0	0	0	0	0	0
Metopic	1	0	3	1	3	0	0
Bicoronal	0	3	3	0	1	0	0
Multisuture	3	0	0	0	2	0	1
Other	1	0	3	0	1	1	0
Midface	5	0	1	0	0	3	1

ICP, intracranial pressure.
*The numbers refer to patients.

appositional growth thereafter. The cephalic index 6 months postoperatively for the sagittal synostosis group was essentially normalized. This was found to be consistent at a 3-year follow-up of the first 20 patients in this group, with high parental satisfaction.[2] Guimaraes-Ferreira has also shown in the case of sagittal synostosis that spring-mediated cranioplasty achieves essentially the same outcome as a pi-plasty in terms of cephalometric data and parental appreciation of aesthetics.[12] Furthermore, blood transfusion, postoperative analgesia requirements, and intensive care unit and hospital stay were significantly lower than in the pi-plasty group. The same findings have also been confirmed by Windt et al.[2]

One spring together with an osteotomy of the metopic suture effectively corrects the orbital hypotelorism seen in metopic synostosis, which is not accomplished by any other method.[13] Initially, in three cases, nothing else was done, which resulted in undercorrection of the lateral forehead. Therefore, the spring is now used, but as an adjunct to conventional means of treating metopic synostosis. To avoid overcorrection of the interorbital distance, cephalometric monitoring was necessary starting at 1 month postoperatively.

With the addition of springs to our dynamic cranioplasty for brachycephaly technique for the correction of brachycephaly,[1] the extent of surgery was minimized, with fewer osteotomies and little dural dissection. Functional lambdoid sutures were not osteotomized. Instead, springs were placed across the suture as distractors. This minimizes blood loss and has not been described before. Transverse compressing springs were abandoned early in dynamic cranioplasty for brachycephaly because of unacceptable elevation of the intracranial pressure. However, in cases of extreme sagittal synostosis, compressing springs when combined with transversely spreading springs are effective in shortening the occiput.

The use of springs pushing forward to counteract the soft-tissue forces following midfacial repositioning has been a major advance for us in eliminating the relapse previously seen (Fig. 6). Although no further advancement was accomplished, the 2-year cephalometric follow-up demonstrated that the springs in this situation completely eliminated relapse. These data have recently been presented.[3]

Severe skull deformities are seen after ventriculoperitoneal shunting and inadequate positioning, especially in premature infants. Because of the enormous dead space that would have to be created and the lack of bone needed for reshaping, the condition has up to now been untreatable. The gradual reshaping with springs of the malleable skull bone and minimal dural dissection has meant a breakthrough in the treatment of this condition.

There were a few minor complications related to the springs, most of them related to spring dislocation. The modification of spring ends to the bayonet shape reduced the number of dislocations and difficult removals. Placement of the springs was such that a dislodged spring arm could never reach inside the skull or into the orbit. In the beginning, the force and number of springs to be used were decided on instinctively. With time, empiric knowledge was gained so as to create guidelines for each group that have since remained the same and have been modified only to meet each individual patient's skull anatomy.

The two most common objections to the use of springs within the craniofacial community are the feeling of a lack of control of spring action and the reluctance to undergo a second operation for spring removal. Lack of control of spring action is no longer a valid objection, as clinical experience is massive and based on the use of several hundreds of springs over many years.[11,14–17] The expansion of a spring is a slow process and is simple to monitor both clinically and radiologically. Removal of springs is an operation performed under general anesthesia as a same-day operation entailing a small cut in the skin and a few minutes of manipulation. This second small procedure is in our opinion acceptable in view of the alternative.

CONCLUSIONS

Spring-assisted cranioplasty is able to be used alone or in combination with more traditional techniques. It offers improved quality of care for each patient by providing decreased overall risk and trauma with excellent outcomes. Springs offer a versatile tool for quality patient care in craniofacial surgery.

Claes G. K. Lauritzen, M.D., Ph.D.
Craniofacial Unit
Department of Plastic Surgery
Sahlgrenska University Hospital
S-413 45 Göteborg, Sweden
claes.lauritzen@plast.gu.se

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