Endoscopic-assisted repair of craniosynostosis

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Object. The goal of the craniofacial surgeon has always been the correction of form and function with prevention of associated morbidity and death. Through the pioneering work of Jimenez and Barone, minimally invasive approaches to the surgical correction of craniosynostosis are now gaining wider acceptance. Here the authors review the technique for endoscopic-assisted repair of craniosynostosis from the perspective of a new minimally invasive approach. They also assess the safety, efficacy, and results of the early treatment of infants with craniosynostosis in a small series of children who underwent surgery at this institution.

Methods. Data regarding synostosis type, operative time, patient age, blood loss, transfusion rates, duration of hospitalization, and complications were collected. Nineteen patients (12 girls and seven boys) between the ages of 1.2 and 5 months of age were treated with the endoscope-assisted technique. The mean operative time was 97 minutes. Five (26%) of 19 children received a blood transfusion. Most patients were discharged home the morning after surgery. The clinical courses of two patients who required additional major craniofacial reconstructions are discussed. There were no deaths, dural sinus tears, cerebrospinal fluid leaks, neurological injuries, or infections, and there were no complications related to the use of helmet therapy. Seventeen of the 19 patients achieved excellent cosmetic results with a single surgery.

Conclusions. This small series supports larger experiences and indicates that early treatment of craniosynostosis with minimally invasive, endoscope-assisted techniques is safe; limits blood transfusion, hospital stay, and operative time; and represents a valuable alternative to the traditional calvarial reconstruction methods.

KEY WORDS • endoscopic surgery • minimally invasive surgery • craniosynostosis • pediatric neurosurgery • strip craniectomy

Craniosynostosis, or the premature closure of calvarial sutures, may result in progressive skull deformity in children. It is a common cause of deformational cranial changes and has an estimated frequency of 0.4 of 1000 persons. Approximately 80 to 90% cases involve isolated defects, while the remaining cases are part of a recognized syndrome such as Crouzon or Apert. Although the cause is frequently unclear, recent work suggests that mutations of the fibroblast growth factor signaling pathway play a role. In the isolated cases, the sagittal suture is affected most often (55%), followed by the coronal (20%), lambdoid (5%), and metopic (5%) sutures. The fused suture restricts growth of the calvaria, thus leading to a characteristic deformation, each associated with a different type of craniosynostosis. Premature closure of skull sutures is associated with compensatory cranial and facial deformational changes that by 6 months of age often present with changes requiring major reconstructive procedures.

The first surgical treatment of craniosynostosis was undertaken by Lannelongue in 1892, and involved the correction of a sagittal synostosis. Since then, multiple procedures have been used for the treatment of this condition, ranging from simple suturectomies to extensive calvarial vault remodeling. Experience has shown that more extensive reshaping yields excellent results, particularly in older children with severe deformity. On the other hand, children undergoing more extensive reconstructions have a high requirement for blood transfusion, may experience hypothermia caused by prolonged surgery, and often have lengthy stays in the ICU. Surgery for craniosynostosis has evolved rapidly over the past two decades, with increased emphasis on early operations and on less invasive procedures. Because of changes in surgical timing and techniques, earlier series may not accurately reflect more recent experience. Currently, surgeons at many craniofacial centers favor surgical correction before the age of 6 months to avoid the morbidity caused by extensive cranial vault remodeling in older children.

Jimenez and Barone first described endoscopic synostosis repair in 1998. This technique allows for a less invasive method of craniosynostosis repair. When detected early, minimally invasive repair combined with a postop-
The endoscopically assisted, minimally invasive repairs for children younger than 4 months of age. No preoperative blood tests are done unless the family wishes to have donor-directed blood available. For children with sagittal synostosis, we do not obtain any preoperative images. Computerized tomography scans are obtained in children with all other types of craniosynostosis. The patient is brought to the major operating suite, and general anesthesia is induced. Our pediatric anesthesiologists prefer to place two intravenous catheters and an arterial line similar to that used in major craniofacial procedures; however, if difficulty is encountered in arterial line placement, this step can be deferred. Bladder catheters are not used. A precordial Doppler ultrasonography procedure is advantageous for the identification of intraoperative air emboli. A single preoperative dose of cefazolin (30 mg/kg) is administered. Warmers are placed under and on top of the child.

Positioning and Skin Preparation

For metopic, unicoronal, or bicoronal repairs the patient is positioned supine with the head supported in a pediatric horseshoe headrest (Mayfield; Integra Lifesciences Co., Plainsborough, NJ). For sagittal repairs, the child is positioned prone in a beanbag horseshoe (Soule Co., Lutz, FL) with the neck extended. This provides good access to most of the calvaria. No hair is shaved. The scalp is then prepped for 5 minutes with povidone iodine scrub. Povidone iodine paint is then applied. Incisions are marked for the particular repair being performed and 0.25% bupivacaine with 1:100,000 epinephrine is injected. The head is then draped in the standard fashion.

Incision and Subgaleal Dissection

Incisions are made by scoring the skin with a No. 15 blade and dividing the scalp using monopolar cautery and a Colorado needle (Stryker Instruments, Portage, MI) at 15 W. This technique results in little, if any, blood loss. Monopolar cautery at 25 to 35 W with a suction coagulator (Valleylab, Boulder, CO) is then used to separate the galea from the periosteum. The dura is then evaluated using a Colorado needle at 25 W. If blood or cerebrospinal fluid is drained, the dura is reapproximated using a Colorado needle. The dura is then painted with povidone iodine and 0.25% bupivacaine with 1:100,000 epinephrine.

We began using minimally invasive techniques with endoscopic assistance at the University of Florida Craniofacial Center 2 years ago. Our goal was to minimize the need for blood transfusion, shorten scalp incision length, and reduce operative time and postoperative recovery in patients younger than 6 months of age undergoing craniosynostosis repairs. As in the series published by Jimenez and Barone, all children were fitted for calvarial orthoses postoperatively to optimize long-term outcomes. The experience of and techniques used at the University of Florida are described.
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the underlying pericranium. Taking advantage of this dissec-
tion plane rather than the subpericranial plane is im-
portant in minimizing blood loss. An angled, lighted rhin-
noplasty retractor (Aufricht; Techman International Co.,
Charlton City, MA) allows for visualization during this step
(Fig. 2). To avoid damage to the skin when cauterizing, he-
mostasis is achieved with the monopolar cauter and insu-
lated bipolar cautery.

Initial Craniectomy and Dural Dissection

A high-speed drill is used to fashion a burr hole over the
stenotic suture. Dural stripping is begun using Penfield dis-
sectors and curettes. Rigid endoscopes (0 and 30°) are then
used to aid in visualization during the stripping of the dura
mater from the involved suture (Fig. 2). This maneuver is
usually a straightforward one that is performed with suction
dissection.

Bone Removal and Hemostasis

Once the dura has been adequately separated from the in-
ner table of the skull, curved Mayo scissors are used to cut
a strip craniectomy of the involved suture. Additional bone
removal is performed using rongeurs. We find the Jansen
Middleton nasal ronge (Weck Surgical Instruments, Re-
search Triangle Park, Raleigh, NC) particularly helpful for
the most distal aspect of certain bone cuts. Bone bleeding
is controlled with bone wax and the use of the suction coag-
ulator at a setting of 50 W (Fig. 3). Care is taken to retract
the dura away from the coagulator with a flexible insulat-
ed brain retractor. Similarly, the galea is protected with the
lighted angled retractor. Additional hemostasis is obtained
with a combination of spray thrombin, thrombin-soaked
Gelfoam, and a slurry of collagen-absorbable hemostat (In-
stat; Ethicon, Somerville, NJ) mixed with normal saline.
This is applied with a syringe and large angiocath catheter.
All topical hemostatic agents and debris are then irrigated
from the epidural and subgaleal space with warm saline.
The incisions are closed with interrupted inverted subcutic-
ular 4-0 absorbable suture (Polysorb or Vicryl) and a sim-
ple running 4-0 absorbable suture (Vicryl Rapide) on the
skin. The head is then thoroughly washed and the incisions
are dressed with antibiotic ointment only.

Postoperative Care

Patients are extubated in the operating room. We require
the children to spend 1 night in the pediatric ICU, but the
regular pediatric surgical floor is completely acceptable.
A single postoperative hematocrit is checked. We do not use
a specific cutoff for blood transfusion and have allowed
children to go home with hematocrit values as low as 16%.
Packed cells are administered to patients with symptomatic
anemia only. All patients are allowed to leave the morning
following surgery. Additional hospital time has primarily
been for alleviation of parental anxiety.

Posthospital Care and Cranial Orthoses

Parents are instructed to wash their child’s hair 4 days
after surgery and with their normal bathing routine thereaf-
ner. Helmets are fitted by an orthotist 1 to 2 weeks after sur-
gery. Although several types of cranial molding devices are
available commercially, we prefer a custom-made helmet
with a closed top (Fig. 4). We have noticed some protrusion
of skull and osseous knob formation in children treated
with open devices. Frequent visits are made to the orthotist
for the 1st month to ensure proper fit and lack of pressure
points. Follow-up visits are then made every 3 months for
a recommended minimum of 12 months. Most children
will require two helmets due to head growth. Patients with
initially good cosmetic results who come out of the helmet
prematurely because of poor compliance or parents’ inabil-
ity to pay for subsequent helmets may have some reversion
of their head shape (Fig. 4).

Suture-Specific Considerations

Sagittal Synostosis. The patient is positioned prone. The
malar eminences are supported and the beanbag posi-
tioner is connected to suction to maintain extension (Fig.
1). The anterior fontanelle and lambda are palpated and
marked. A 5-cm midline strip craniectomy is marked on
the scalp. Additional craniectomies are marked bilaterally
just posterior to the coronal sutures and just anterior to the
lambdoid sutures. Two small transverse incisions approxi-
ately 2 cm in length are then marked just posterior to
the anterior fontanelle and anterior to the lambda (Fig. 5).
After scalp preparation, draping, and skin incision, the ga-
lea is dissected from the pericranium, exposing the anteri-
or and posterior fontanelles and the coronal and lambdoid
sutures as far laterally as can be reached. Burr holes over
the sagittal suture are fashioned at each incision site. The
dura is dissected around each burr hole and craniecto-
cies 5-cm wide are performed using rongeurs. The dura is
stripped and the craniectomy is extended into the anteri-
or fontanelle. The sagittal sinus is then separated from the
skull using the endoscope, suction dissection, and Pen-
field dissectors. Opposing bone cuts are then made with
Mayo scissors from the anterior and posterior incisions,
resulting in a 5-cm craniectomy. This bone plate must then
be cut in half to deliver the pieces through the scalp inci-
sion. Once complete hemostasis has been achieved, the
dura is stripped immediately posterior to the coronal su-
tures and immediately anterior to the lambdoid sutures ex-
Fig. 4. Lateral (left) and anterior (right) views of a custom-made cranial helmet with a closed top.

Fig. 5. Photograph of a patient positioned prone in horseshoe beanbag for sagittal synostosis repair. Skin incisions are marked in black and the fontanelles in green. The midline craniectomy and bilateral parietal bone cuts are outlined in blue.

Fig. 6. Schematic drawing showing bone cuts for sagittal synostosis repair. The midline strip is approximately 5 cm wide and the parietal cuts are 1 cm wide.
tending to the squamous sutures bilaterally. Craniectomies of approximately 1 cm width are then made as far as possible using Mayo scissors and the Jansen Middleton rongeur (Fig. 6). Hemostasis and closure are then performed as described previously.

**Coronal Synostosis.** The incision is placed over the midportion of the involved coronal suture. A burr hole is made and the dura is dissected with endoscopic assistance. Dural separation is extended medially into the anterior fontanelle. A removal of the suture approximately 1 cm wide is performed with scissors and rongeurs (Fig. 7).

**Metopic Synostosis.** An incision is made over the metopic suture just behind the hairline. A burr hole is fashioned and the dura is separated from the metopic suture posteriorly into the anterior fontanelle. The dura is dissected anteriorly to the nasofrontal suture with endoscopic assistance. A bridging vein is frequently found near the nasion that must be cauterized with the bipolar. The metopic suture is typically thicker and more vascular than the other sutures. The suture is removed with rongeurs as part of a 1-cm-wide craniectomy down to the nasion (Fig. 8). Due to the thick bone, the high-speed drill with a long, curved guarded bit (Midas Rex T12 Dissector; Medtronic, Inc) is used for the most anterior portion of the craniectomy.

**RESULTS**

Nineteen patients between 1.2 and 5 months of age (12 girls and seven boys) were treated with the endoscopic technique over a 2-year period. Eleven patients had isolated sagittal suture involvement, five patients had metopic synostosis, two patients had coronal synostosis with one bicoronal involvement, and one patient had both sagittal and metopic synostosis. The mean operative time was 97 minutes. Longer operative times were required in the patients with multiple suture synostosis. The mean estimated blood loss was 39 ml; two patients underwent intraoperative blood transfusion, and three patients (26%) had postoperative blood transfusion. Most patients were discharged the morning after surgery.

Complications were minimal. No deaths, dural sinus tears, cerebrospinal fluid leaks, neurological injuries, or infections occurred, and there were no significant complications related to the use of helmet therapy. Seventeen of 19 patients had good cosmetic results with a single surgery (Figs. 9–11).

Two patients had outcomes of note. One, a girl, underwent uneventful sagittal synostosis repair at 7 weeks of age with an initial good result. A 3D CT scan performed elsewhere prior to surgery indicated isolated sagittal synostosis (Fig. 12). Postoperatively, she was fitted with an open-topped helmet. She returned after 5 months with irritability and a bulging fontanelle. Computerized tomography scanning did not reveal hydrocephalus or intracranial mass but on 3D reconstructions pansutural synostosis was evident (Fig. 12). When she underwent surgery a second time, an open technique was used. Hyperostotic bone was encountered in the craniectomy site, and the metopic, coronal, and lambdoid sutures were stenotic. A complete calvarial remodeling was performed and her irritability resolved. Five months later she had recurrent signs and symptoms after moving to another state, and a repeat calvarial reconstruction was performed. Results of a fibroblast growth factor...
receptor analysis were nondiagnostic. The other child had multiple medical problems and underwent simultaneous sagittal and metopic repair. He had a prolonged hospital stay because of airway problems associated with his unknown genetic disorder. He subsequently underwent orbitofrontal advancement and tarsorrhaphies for corneal exposure caused by severe proptosis.

DISCUSSION

Although clinical descriptions of craniosynostosis date back to Hippocrates and Galen, the first modern scientific investigator to describe the anatomical structure of calvarial sutures and the results of their premature closure was Sömmering in 1800. In 1894, Jacobi reported a series of complications and deaths associated with craniosynostosis surgery that led to its discontinuation for the next 30 years. Surgical intervention was subsequently reintroduced and has evolved over the years to include a variety of reconstructive procedures. Several different techniques for the repair of sagittal synostosis have been described, including complete calvarial remodeling, the pi procedure, and ex-

Fig. 9. Preoperative (left) and 3-month postoperative (right) photographs of a boy with sagittal synostosis.
tended vertex craniectomy. The most common procedure performed for metopic, unicoronal, or bicoronal synostosis is an orbitofrontal advancement. The reported blood loss, operative time, need for transfusion, hospital stay, and complications associated with these procedures can be significant and are well described in the craniofacial literature. In addition, traditional craniosynostosis repairs typically require a bicoronal scalp incision, which has the potential for suboptimal cosmesis due to alopecia and hair parting. The long-term cosmetic outcomes with these procedures are excellent, however, and cranial orthoses—with their associated expense and inconvenience—are avoided.

Minimally invasive techniques for craniosynostosis repair have several potential advantages over traditional open surgery for selected patients with synostosis. Transfusion rates, operating room times, and ICU and hospital stays are reduced. Postoperative swelling, discomfort, and the associated parental anxiety are lessened. Finally, scars are substantially smaller and are often cosmetically superior to bicoronal incisions. Drawbacks include less exposure and control of dural sinuses and the importance of a postoperative helmet. We have found the latter to be the greatest obstacle to success for our patients. Although compliance is nearly universal and the devices are well tolerated, they are expensive and are not paid for by most insurance carriers. Cost is not an issue in the value analysis of these procedures compared with open surgery because the savings in ICU costs and hospital days dwarf the helmet expense.
which varies from approximately $800 to $2000. Nonetheless, several families of limited means have chosen traditional surgery instead of endoscopic-assisted surgery because they could not pay for a helmet.

**CONCLUSIONS**

New, less invasive techniques for the early treatment of infants with craniosynostosis have been presented. Our small series supports the excellent results of previous reports of these methods, including low morbidity and no deaths, as well as decreased need for blood transfusion and shorter ICU and hospital stays. Early diagnosis of craniosynostosis and prompt referral for surgical evaluation, as well as postoperative helmet therapy are paramount in obtaining the best possible results. Although minimally invasive methods will likely never replace traditional calvarial reconstructions, these techniques should be considered as important additions to modern craniofacial surgery.

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Fig. 11. Preoperative (left), 6-month (center), and 15-month postoperative (right) photographs of a girl with left unicoronal synostosis. Note progressive improvement of nasal deviation. Some mild flattening of the left forehead can still be appreciated at 15 months postoperatively.
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