

Endoscope-Assisted Versus Open Repair of Craniosynostosis: A Comparison of Perioperative Cost and Risk

Jennifer W.H. Chan, MD,* Camille L. Stewart, MD,* Mark W. Stalder, MD,†
Hugo St. Hilaire, MD, DDS,*‡ Lori McBride, MD,‡ and Michael H. Moses, MD*†

Background: Craniosynostosis, the premature closure of calvarial sutures, results in characteristic skull deformations. Correction of craniosynostosis has traditionally involved an open cranial vault remodeling procedure. A technique recently developed uses an endoscope to perform a strip craniectomy in conjunction with a postoperative molding helmet to guide cranial growth. Few studies compare these 2 approaches to the treatment of the various forms of craniosynostosis. In this study, we present a single institution's experience with open cranial vault remodeling and endoscope-assisted strip craniectomy.

Methods: This study is a retrospective review of 57 patients that underwent craniosynostosis repair by either the endoscope-assisted or open techniques, and compared operating room times, blood loss, volume of transfused blood, length of hospital stay, and overall costs.

Results: The endoscopic technique is performed on younger children (4.7 months vs 10.6 months, $P = 0.001$), has shorter operating room times (2 hours 13 minutes vs 5 hours 42 minutes, $P = 0.001$), lower estimated blood loss (74.4 mL vs 280.2 mL, $P = 0.001$), less transfused blood (90.6 mL vs 226.9 mL), shorter hospital stays (1.2 days vs 4.9 days, $P = 0.001$), and decreased cost (\$24,404 vs \$42,744, $P = 0.008$) relative to the traditional open approach.

Conclusions: Issues with the endoscope-assisted procedure primarily concerned the postoperative helmet regimen, specifically patient compliance (17.1% noncompliance rate) and minor skin breakdown (5.7%). The endoscope-assisted repair with postoperative helmet molding therapy is a cost-effective procedure with less operative risk and minimal postoperative morbidity. This is a valuable treatment option in younger patients with compliant caregivers.

Key Words: Endoscope assisted, craniosynostosis, cost analysis

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Craniosynostosis is the premature closure of calvarial sutures, resulting in characteristic skull deformations. This developmental defect occurs in 1:2000 to 2500 live births, and the etiology remains unknown.¹ Untreated, deformation of the skull can progress to involve the entire facial skeleton, ultimately causing facial asymmetry, dystopia, and malocclusion.² In severe cases, or with multiple suture involvement, this can lead to a rise in intracranial pressure, with the potential for developmental delay, neurological impairment, and even blindness.^{3–6} The cosmetic and developmental morbidities associated with craniosynostosis have prompted a variety of corrective surgical techniques over the last hundred years. The treatment of craniosynostosis has changed drastically over time, and there continue to be new surgical options available. However, there are few studies available that compare the associated perioperative morbidities and costs.⁷ In this retrospective study, we aimed to provide an effective comparison of the perioperative morbidities and costs associated with 2 treatment options that are currently used for the correction of craniosynostosis, that is, the endoscope-assisted strip craniectomy with postoperative helmet molding versus the traditional open cranial vault remodeling.

MATERIALS AND METHODS

This study is a retrospective chart review of 57 patients with craniosynostosis, approved by the institutional review boards at Children's Hospital in New Orleans and Tulane University School of Medicine. Subjects in this study underwent corrective surgery for craniosynostosis with either an endoscope-assisted strip craniectomy with postoperative helmet molding therapy or an open cranial vault procedure between October 1998 and April 2009. Seventy-nine subjects were initially identified; 57 subjects were ultimately included in this study. Twenty-two patients were excluded because of insufficient data. All patients who presented before November 2006 underwent an open cranial vault procedure. The endoscope-assisted technique was introduced at our institution in November 2006. After that date, all patients were initially considered for the latter if they were less than 9 months of age at presentation and met criteria for compliance with the postoperative helmet regimen. Open cranial vault remodeling for sagittal synostosis had traditionally been performed by the neurosurgical service. Cases where the craniofacial service was not involved were not included in this study. Comparisons between the 2 groups were made for age at operation, operating room time, estimated blood loss, rate of packed red blood cell (pRBC) transfusion, volume of transfused pRBC, length of hospital stay, and overall cost of the individual therapeutic regimens (including postoperative helmet molding).

From the *Division of Plastic and Reconstructive Surgery, Tulane Health Sciences Center; †Division of Plastic and Reconstructive Surgery, Louisiana State University School of Medicine; and ‡Department of Neurosurgery, Children's Hospital, New Orleans, LA.

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Address correspondence and reprint requests to Hugo St. Hilaire, MD, DDS, Louisiana State University School of Medicine, Division of Plastic and Reconstructive Surgery, 1542 Tulane Ave Room 758A, New Orleans, LA 70112; E-mail: hugost1@gmail.com

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TABLE 1. Patient Demographics

	Open Cranial Vault Remodeling (n = 21), %	Endoscopic-Assisted Repair (n = 36), %
Male	38	50
Female	62	50
Syndromic	29	8
Coronal	52	31
Metopic	19	22
Sagittal	14	44
Mixed	14	3

Component breakdown of the 2 treatment populations with regard to sex, syndrome, and individual suture involvement.

Operating room (OR) time was measured from when the patient entered the operative suite to when the patient left the operative suite. Procedural time designates the length of the actual operation. Rate of transfusion and the volumes transfused were measured over the entire hospital stay and included both intraoperative and postoperative transfusions. Preoperative hematocrit was generally obtained on the morning of the operation, although in some instances, this value was obtained several days prior. Postoperative hematocrit was obtained in the recovery room immediately after the procedure.

The overall cost for patients who received the open cranial vault procedure was determined by the hospital bill at discharge. The overall cost for patients who received the endoscope-assisted procedure with postoperative helmet molding therapy included the hospital bill at discharge as well as the cost of the orthotic helmets. Surgeon's fees and follow-up visits were not included in the determination of costs, and monetary values were not adjusted for inflation. All parameters were compared using a Student *t* test and considered significant for $P < 0.05$.

RESULTS

Patient Demographics

This study reviewed the charts of 57 patients who underwent surgical correction of craniosynostosis between October 1998 and April 2009 (Table 1). Of the 57 patients, 21 underwent open cranial vault remodeling, and 36 underwent endoscope-assisted craniosynostosis release. The 21 open cases were performed between October 1998 and February of 2008. Of these cases, 38% of the patients were male subjects and 62% female subjects. Approximately 29% of these patients had syndrome-associated craniosynostosis. Regarding individual sutures affected, 14% of the patients had sagittal suture

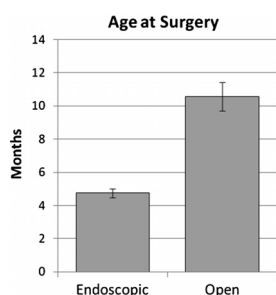


FIGURE 1. Average age of patients in each of the treatment subgroups. Patients undergoing the endoscope-assisted procedure (4.74 months) were significantly younger than patients undergoing open cranial vault surgery (10.56 months; $P = 0.0005$). Endoscopic = endoscope-assisted strip craniectomy with postoperative helmet molding therapy. Open = open cranial vault remodeling.

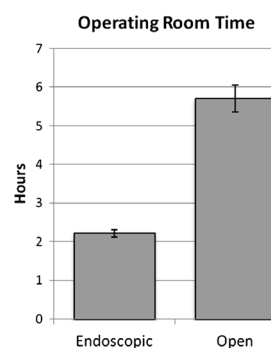


FIGURE 2. Average operating room times for each of the treatment subgroups. The operating room time for patients undergoing the endoscope-assisted procedure (2 hours 13 minutes) was significantly less than that for patients undergoing open cranial vault surgery (5 hours 42 minutes) ($P < 0.0001$). Endoscopic = endoscope-assisted strip craniectomy with postoperative helmet molding therapy. Open = open cranial vault remodeling.

involvement, 52% had coronal involvement, 19% had metopic involvement, and 14% presented with mixed synostoses.

The endoscope-assisted cases included were performed between November 2006 and April 2009. Of these cases, 50% of the patients were male subjects, and 50% were female subjects. Approximately 8% of these patients had syndrome-associated craniosynostosis; 44% of the patients in this treatment group had sagittal suture involvement, 31% had coronal involvement, 22% had metopic, and 3% presented with mixed synostoses.

Age at Time of Operation

The age of patients receiving the open cranial vault procedure ranged between 5.33 and 21.23 months, with an average age at surgery of 10.56 months (Fig. 1). The age of patients receiving the endoscope-assisted strip craniectomy ranged between 1.93 and 9.1 months, with an average at surgery of 4.74 months. This represents a significant difference of 5.82 months ($P = 0.0005$). These numbers excluded an outlier in the open cranial vault group who was 6 years of age at the time of the procedure.

Operating Room Time

The operating room time for patients undergoing the open cranial vault procedure ranged between 3 hours 25 minutes and 11 hours 10 minutes, with an average operative time of 5 hours 42 minutes (Fig. 2). The operating room time for patients undergoing the endoscope-assisted procedure ranged between 47 minutes

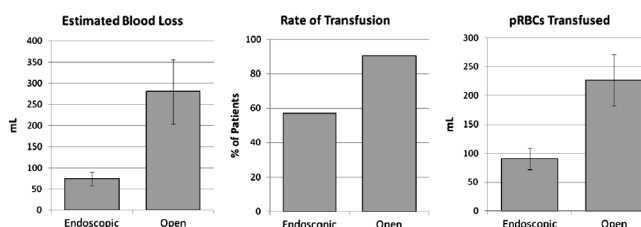


FIGURE 3. Left, The average estimated blood loss for patients undergoing the endoscope-assisted procedure (74 mL) was significantly less than that for patients undergoing open cranial vault surgery (280 mL; $P = 0.001$). Middle, The need for pRBC transfusion was decreased in patients undergoing the endoscope-assisted procedure (55%) versus open surgery (86%). Right, The total volume of pRBCs transfused for patients undergoing the endoscope-assisted procedure (90.63 mL) was significantly less than the total volume transfused for patients undergoing the open cranial vault procedure (226.9 mL; $P = 0.001$). Endoscopic = endoscope-assisted strip craniectomy with postoperative helmet molding therapy. Open = open cranial vault remodeling.

TABLE 2. Transfusion Data for the Endoscope-Assisted Treatment Group

	Endoscopic Transfused (n = 20)	Endoscopic Not Transfused (n = 16)	Aggregate Endoscopic (n = 36)
Age (mo)	4.83	4.67	4.74
Procedure time*	1 h 25 min	53 min	1 h 10 min
Preoperative Hct	33	34	34
Postoperative Hct*	20	27	24
EBL (mL)*	112	28	74

*Denotes statistical significance. There was no difference observed in the age at the time of procedure between the transfused and nontransfused patients in this group ($P = 0.7$). There was a significant difference of 32 minutes observed between these 2 groups with regard to procedural time ($P = 0.001$). No difference was noted in preoperative Hct levels ($P = 0.1$); however, the postoperative Hct of 20 in the transfused group compared with 27 in the nontransfused group was statistically significant ($P < 0.0001$). Also, the observed EBL in the 2 groups had a significant difference of 84 mL ($P = 0.007$).

and 3 hours 46 minutes with an average operative time of 2 hours 13 minutes. This represents a significant difference of 3 hours 29 minutes ($P < 0.0001$).

Estimated Blood Loss and Rate of Transfusion

The estimated blood loss (EBL) for patients undergoing the open cranial vault procedure ranged from 50 to 500 mL, with an average EBL of 280 mL (Fig. 3A). The EBL for patients undergoing the endoscope-assisted procedure ranged from 10 to 500 mL, with an average EBL of 74 mL. This represents a significant difference of 206 mL ($P = 0.001$). When the extreme outliers in both groups were removed, the EBL was 219 and 62 mL, respectively. Of note, the patient excluded in the endoscope-assisted group was born 7 weeks premature and had a sagittal sinus perforation. The patient excluded in the open cranial vault procedure is the same patient that was excluded previously based on age at operation. This patient was 6 years of age at surgery and had a previous sagittal strip craniectomy and tracheostomy performed at a different institution. He was unable to be weaned from the ventilator and remained in the pediatric intensive care unit for 3 days.

Approximately 86% of patients that underwent open repair received a pRBC transfusion either intraoperatively or postoperatively. In comparison, 55% of the patients that underwent the endoscope-assisted repair received a blood transfusion either intraoperatively or postoperatively (Fig. 3B).

A more in-depth analysis was conducted for the endoscope-assisted patient population to further characterize the timing and need, as well as the actual group of patients that underwent transfusion (Table 2). Approximately 20 of the 36 patients in this group ultimately received pRBCs. The average age at surgery for those patients that were transfused was 4.83 months, versus 4.67 months in the nontransfused group ($P = 0.75$). The average procedure time (as opposed to operating room time) was 1 hour 24 minutes versus 53 minutes in the transfused and nontransfused groups, respectively. There was a significant difference of 32 minutes ($P = 0.01$) between these 2 groups. Preoperative hematocrit (Hct) in the transfused group was 33, versus 34 in the nontransfused group ($P = 0.12$). Postoperative Hct was 20 in the transfused group, versus 27 in the nontransfused group. This difference was significant, with $P < 0.0001$. The aggregate average postoperative Hct for the endoscope-assisted treatment group was 24. The average EBL for the transfused group was 112 mL, whereas it was 28 mL for the nontransfused group. This represents a statistically significant difference of 84 mL ($P = 0.007$). Of note, 8 of the patients received intraoperative transfusions, whereas the remaining 12 patients in this group received transfusions at some point postoperatively.

The volume of pRBCs transfused for patients undergoing the open cranial vault procedure ranged from 0 to 640 mL, with an average transfusion volume of 227 mL (Fig. 3C). The volume of pRBCs transfused for patients undergoing the endoscope-assisted procedure ranged from 0 to 485 mL, with an average transfusion volume of 91 mL. This represents a significant difference of 136 mL ($P = 0.001$). When excluding patients who did not receive any transfusion, and comparing only the patients in each group who actually received pRBCs, the average volumes transfused were 252 mL for the open repair group, and 163 mL for the endoscope-assisted repair group, which was a difference of 89 mL ($P = 0.07$).

Length of Hospital Stay

All patients included in this study were admitted to the hospital for the sole purpose of surgical correction of craniosynostosis. The patients who underwent the open cranial vault procedure spent between 3 and 9 days as an inpatient in association with the procedure. The average length of stay in the hospital for this group was 4.9 days (Fig. 4A). Those patients that underwent the endoscope-assisted procedure spent between 0 and 4 days as inpatients, with an average hospital stay of 1.25 days (excluding 1 outlier). This represents a significant difference of 3.65 days ($P < 0.0001$).

Use and Cost of Helmet Therapy

All patients who underwent the endoscope-assisted craniosynostosis release were required to use an orthotic molding helmet for a minimum of 12 months or for as long as the patient was able to tolerate the helmet. Typical therapy was begun within the first postoperative week and was continued until the patient "starting pulling the helmet off." Helmets were replaced as needed with the natural progression of head growth. The number of helmets used by these patients ranged from 1 to 3, with an average of 2.31 per patient. Length of helmet therapy ranged from 125 to 463 days, with an average time of 345.4 days. The average cost per helmet was \$1773, resulting in an average per patient cost of \$4200 for the duration of helmet therapy. Issues encountered with this regimen included patient noncompliance, which occurred at a rate of 17.14%. The helmets were also occasionally associated with scalp skin breakdown, which was seen in 2 patients (5.71%). This complication was readily treated with a brief respite from helmet therapy and simple wound care. Of note, none of these patients have required reoperation to date.

Total Cost of Procedure

The total hospital costs for patients who underwent an open cranial vault procedure ranged between \$23,082 and \$373,626, with

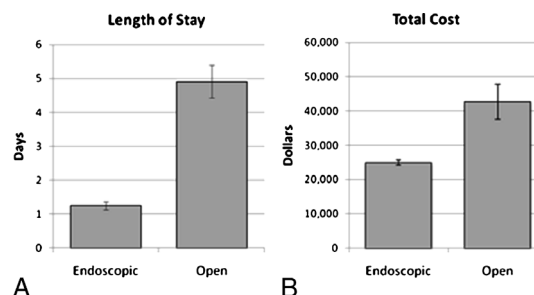


FIGURE 4. A, The average length of hospital stay for patients undergoing the endoscope-assisted procedure (1.25 days) was significantly shorter than for those undergoing open cranial vault repair (4.9 days; $P < 0.0001$). B, The total cost of therapy for endoscope-assisted release with helmet therapy (\$24,404.17) was significantly less than that of the open cranial vault remodeling procedure (\$42,744.00; $P = 0.008$). Endoscopic = endoscope-assisted strip craniectomy with postoperative helmet molding therapy. Open = open cranial vault remodeling.



FIGURE 5. Preoperative (top) and 11-month postoperative (bottom) photograph of a patient with sagittal synostosis that was corrected with endoscope-assisted strip craniectomy, barrel stave osteotomies, and postoperative helmet molding therapy.

an average total of \$63,424. Excluding an outlier with total costs of \$373,626 (the same patient described in the EBL and volume of transfusion section), the average total cost was \$42,744, with a range of \$23,082 to \$82,324 (Fig. 4B). The total hospital costs for patients who underwent the endoscope-assisted with postoperative helmet molding therapy ranged between \$17,899 and \$34,166, with an average total cost of \$24,404. This represents a significant difference of \$18,339 in cost between the 2 procedural regimens ($P = 0.008$).

DISCUSSION

A historical perspective of the surgical correction of craniosynostosis will help clarify why the endoscope-assisted technique and the open procedure are both used today. The first reported surgical procedure for the correction of craniosynostosis was performed in 1890 by Lannelongue, who released, but did not resect the fused sagittal suture.⁷ Two years later, Lane⁸ reported the first strip craniectomy, which became the standard of care for several decades.⁷ During a strip craniectomy, the bony strip of fused suture is removed with the hope that the cranial deformities will correct secondarily with the expansive forces of the growing brain. However, in practice, many sutures refused, necessitating modifications to this procedure.²

Because of the limitations of the strip craniectomy, the open cranial vault remodeling procedure was introduced in the 1970s by Tessier.⁹ In the open remodeling procedure, the affected bones are removed, reshaped, and then reattached as a graft using wires and/or metallic or absorbable plates and screws. This technique provided superior aesthetic results, addressing frontal bossing and occipital protrusion more effectively than the strip craniectomy. As such, it became the standard of care for surgical correction of craniosynostosis.²

In the 1990s, Jimenez and Barone revived the strip craniectomy with the added modifications of an endoscope-assisted surgical technique, and with a postoperative molding helmet regimen.^{10–14} They have published several papers demonstrating the efficacy of the endoscope-assisted method, noting as well its relatively decreased procedural time, low estimated blood loss, shorter hospital stay, and relatively decreased complication rate. The inadequate outcomes previously encountered with open strip craniectomies were obviated via the use of the custom-tailored molding helmet postoperatively, yielding aesthetic results comparable to the open cranial vault procedure¹⁵ (Figs. 5 and 6).

To date, there are few studies corroborating the work of Jimenez and Barone, although several smaller studies have helped characterize the benefits and outcomes of the endoscope-assisted

technique.^{16–18} However, there are limitations to these studies; for example, Keshavarzi examined the open repair to the endoscope-assisted repair only in patients with metopic craniosynostosis. Nevertheless, our results corroborate those few previous studies and strengthen the notion that the endoscope-assisted technique is consistently associated with shorter operative times, decreased blood loss, and shorter hospital stays.

It must be noted that our data present relatively longer operative times and higher blood loss than Jimenez and Barone, Keshavarzi, and Clayman.^{10–14,17,18} However, to be taken in context, it must be considered that the operating room times reported here were not purely surgical times but included the time from when the patient entered the operating room, until the moment they exited the operating room. This time value was used here to demonstrate overall costs incurred and perioperative burden, as opposed to simply the procedural time. Our actual procedural times for the endoscope-assisted patients averaged 1 hour 10 minutes, which falls in line with the reported times of the aforementioned studies. Regarding blood loss in these procedures, the adjusted EBL (excluding the extreme outlier) of 62 mL is somewhat more in line with previous studies, although still remains relatively high. It should be noted that for this study, we used the anesthesiologist's estimate of EBL as opposed to the surgeon's, and the latter was generally considerably less. This could certainly have played a role in the nature of our reported data, and as we do not know how the previously reported values were calculated, it is difficult to make relevant comparisons between these data.

Our data also show that more than half (55%) of the patients undergoing the endoscope-assisted procedure received transfused pRBCs. This number is significantly higher than those reported in the Barone studies, although it is in line with the 62% transfusion rate reported by Keshavarzi.^{13,14,17,18} The decision to transfuse these patients was based either on intraoperative blood loss/clinical judgment (8 patients) or more commonly on postoperative Hct levels (12 patients). Our average postoperative Hct of 24 is slightly lower than data reported in previous studies but not so much as to be alarming, as Jimenez and Barone describe postoperative hematocrits ranging from 25 to 31.^{11,12,14} There was also a trend that we found in the data, which could potentially account for a number of transfusions, and should be noted. There were 2 endoscope-assisted cases in which the patients incurred a disproportionate amount of blood loss relative to our average, and these patients had more complicated courses in general. The several patients immediately after these complicated cases had significantly lower blood loss but received transfusions intraoperatively at a seemingly much higher than expected rate. It is conceivable that the complications that we incurred could have influenced our clinical decision making in the near term and caused us to transfuse much more readily than we otherwise would have. Nevertheless, the overall theme holds true that the endoscope-assisted cases had far less blood loss and significantly decreased transfusion rates as compared with the open cases.



FIGURE 6. Preoperative (left) and 4-year postoperative (right) photographs of a patient with right coronal synostosis that was corrected with endoscope-assisted strip craniectomy and postoperative helmet molding therapy.

One weakness of our study that must be considered when examining our data in context with previous studies is that we did not adjust hospital costs for inflation. The study by Jimenez and Barone from 2002 examined their total costs for the endoscopic procedure in context of then current dollars. This fact alone could conceivably account for the relative increase in costs seen at our institution for this treatment regimen. Their total averaged hospital charges at the time were \$14,000 for the endoscope-assisted group versus \$39,000 in averaged charges for the patients who underwent an open calvarial vault procedure.¹¹ However, it is also unclear if the total hospital costs discussed in that study included the cost of the postoperative helmet therapy, which they approximate at \$700 per helmet. In their study from 1999, the average cost for the endoscope-assisted approach, this time including the cost of helmet therapy, was \$11,671. The average cost of their open repair at that time was \$36,685.¹⁰ Additionally, as the majority of our open cases were performed earlier than the endoscope-assisted cases, adjustment for inflation would only exaggerate the difference in costs in the already more expensive open case treatment group. That being said, the trend from previous studies holds true, and the endoscope-assisted option significantly reduces the overall relative costs.

Because of the necessity of close follow-up and strict compliance to postoperative therapeutic helmet regimens, our evaluation of patients under consideration for an endoscope-assisted procedure included extensive discussions with the patient's caregivers, which emphasized the considerable commitment and time required to achieve an optimal aesthetic result. Caregivers were counseled that patients must be seen on a monthly basis after surgery for at least a year. If they were unable to accept this commitment, we did not offer the endoscope-assisted release and, instead, recommended an open cranial vault remodeling procedure. However, despite our meticulous evaluation process, we still encountered a noncompliance rate of 17%. Issues encountered centered around 3 main issues: caregiver concern that the helmet was too tight and causing discomfort, inability for the caregiver to afford to continue care appropriately or overt caregiver neglect. These issues ultimately were resolved without significant complication in a majority of cases; however, there were several patients that were lost to extended follow-up. Again, this is an important factor that must be taken into consideration when offering this procedure and can potentially add to the overall costs and complications encountered in the course of treatment.

There are few previous studies that have compared the endoscope-assisted release with postoperative helmet molding therapy to open cranial vault remodeling, indiscriminant of the type of synostosis. In this study, data are examined from patients with all types of craniosynostosis and further strengthen the argument that the endoscope-assisted approach can be used successfully for multiple types of craniosynostosis with less operative risk and minimal postoperative morbidity. Additionally, in corroborating the results of other authors, we have demonstrated that the endoscope-assisted approach with postoperative helmet remodeling therapy is significantly more cost effective than the open cranial vault procedure.

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