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Pediatric/Craniofacial

Calculated Blood Loss and Transfusion Requirements in Primary Open Repair of Craniosynostosis

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Background: Open surgical correction is effective in the treatment of craniosynostosis but may result in significant blood loss and transfusions. This study seeks to compare surgeon estimated blood loss with calculated blood loss and provide contemporary data that objectively quantify blood loss and transfusion rate associated with open repair of craniosynostosis.

Methods: A retrospective review of patients undergoing primary open repair of craniosynostosis between May 2011 and November 2016 was performed. The medical records of 43 patients were reviewed to obtain the operative age, weight, affected suture, pre- and postoperative hematocrit, blood transfusion volume, estimated blood loss, and syndromic status. Estimated blood volume (EBV) and red cell mass were calculated for analysis.

Results: The median age and weight at the time of surgery were 9 months and 8.6 kg, respectively. Mean surgeon estimated blood loss was 207.4 mL (28.1% of EBV). Mean calculated blood loss was 318 mL (44.3% of EBV). The mean transfusion volume was 188 mL (26.5% of EBV). The mean transfusion as a percent of estimated red cell mass was 59.1%. Fourteen percent of patients did not require any transfusion.

Conclusions: We report intraoperative blood losses and transfusion requirements that are lower than those of many previous studies of open repair of craniosynostosis. Additionally, we found that calculated blood loss estimates may be more reliable than surgeon-derived estimated blood loss. We hope that these updated, objective data will be useful in comparisons of open repair to minimally invasive surgery or to new blood loss reducing procedures. *(Plast Reconstr Surg Glob Open 2019;7:e2112; doi: 10.1097/GOX.0000000000002112; Published online 8 February 2019.)*

INTRODUCTION

As first described by Virchow in 1851, craniosynostosis refers to premature closure of ≥1 cranial sutures.[1] This premature closure alters the growth ability of the cranium leading to a dysmorphic cranial vault, facial asymmetry, and potentially increased intracranial pressure.[2] Craniosynostosis is associated with over 100 congenital syndromes, although it most commonly occurs in isolation.[2] It is estimated that craniosynostosis affects 1 in 1,700–1,900 live births worldwide.[3]

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Treatment of craniosynostosis requires surgical intervention. Traditionally, this was accomplished with open cranial vault remodeling within the first year of life. Although open surgical repair of the cranium effectively treats craniosynostosis, extensive blood loss often requiring ≥1 transfusions has been listed as the most significant risk of this surgery.[4] Because of the relatively limited red blood cell mass in these young patients, small volumes of blood loss represent significant losses in relation to total blood volume.[5] Since the 1960s, blood loss estimates for open repair of craniosynostosis have ranged from 25% to 500% of estimated blood volume (EBV).[6] This large blood loss has led many to attempt to find ways to decrease blood loss and transfusion requirements.[7–11] Recently, minimally invasive surgery has been reported as an alternative method of surgical craniosynostosis treatment. The purported advantages of endoscopic repair include reduced blood loss, decreased transfusion requirements, and shorter length of stay.[12,13] In 2012, Jimenez and Barone[12] reported

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16 years of safe and efficacious treatment of sagittal synostosis using an endoscopic technique followed by up to 12 months of wearing a postoperative cranial molding orthotic. The inconvenience of long-term orthotic use and concerns regarding the appropriate patient selection have limited the use of endoscopic repair of craniosynostosis.[12] Currently, the optimum approach to craniosynostosis repair is debated.

Although significant work has been done to study the blood loss and transfusion requirements during open repair of craniosynostosis, much of this work was completed before 2010 and relied on surgeon estimated blood loss (EBL) numbers. Updated, objective measures of blood loss and transfusion requirements during open repair of craniosynostosis are critical to reliable comparisons of open repair to minimally invasive surgery or to new blood loss reducing procedures. This study seeks to provide contemporary data that objectively quantify intraoperative blood loss and transfusion rate associated with open repair of craniosynostosis.

METHODS

This study received institutional review board approval from both Columbia University Medical Center and Weill Cornell Medical Center. Afterward, the medical records of 43 consecutive patients who underwent primary open repair of craniosynostosis with the senior author (J.A.A.) between May 2011 and November 2016 were reviewed. The electronic medical record was used to obtain the operative age, weight, affected suture, pre- and postoperative hematocrit, blood transfusion volume, surgeon EBL, syndromic status, and length of stay.

To normalize the blood loss and to compare with previous studies, the total EBV of each patient was calculated. The approximation of 80 mL blood/kg and the patient's operative weight were used. Transfusion volume was then analyzed as a percent of the EBV using the following formula:

$$\text{Transfusion}(\%\text{EBV}) = \frac{\text{Transfusion volume}(\text{mL})}{\frac{80\ \text{mL}}{\text{kg}} \times \text{Patient's weight}(\text{kg})} \times 100$$

For the 37 patients whose preoperative hematocrit was available, the blood transfusion volume was analyzed as a percent of the estimated red blood cell mass (ERCM) using the equations described by Eaton et al.[14] In their study, they assumed a packed red blood cells (pRBC) hematocrit of 75%, but for this study, a pRBC hematocrit of 60% was used to match the estimate of 55%–65% reported by the American Society of Hematology.[15] The % ERCM formulas are as follows:

$$\%\ \text{ERCM transfused} = \frac{\text{ERCM}_{\text{transfused}}\ (\text{mL})}{\text{ERCM}_{\text{preoperative}}\ (\text{mL})} \times 100$$

where

$$\text{ERCM}_{\text{preoperative}} = \frac{80\ \text{mL}}{\text{kg}} \times \text{Patient's weight}(\text{kg}) \times \frac{\text{Hct}_{\text{preoperative}}}{100}$$

and $\text{ERCM}_{\text{transfused}} = \text{Volume pRBCs transfused} \times 0.60$

For these same 37 patients, a calculated blood loss (CBL) as a percent of EBV was also determined as follows:

$$\text{CBL}(\%) = \frac{\text{ERCM}_{\text{deficit}}}{\text{ERCM}_{\text{preoperative}}}$$

$$\text{ERCM}_{\text{deficit}} = \text{ERCM}_{\text{preoperative}} + \text{ERCM}_{\text{transfused}} - \text{ERCM}_{\text{postoperative}}$$

$$\text{ERCM}_{\text{postoperative}} = \frac{80\ \text{mL}}{\text{kg}} \times \text{Patient's weight}(\text{kg}) \times \frac{\text{Hct}_{\text{postoperative}}}{100}$$

The calculated blood loss (CBL) in milliliters could then be derived by multiplying the CBL% by the blood volume (EBV).

Data were analyzed using Excel (Microsoft Corp, Redmond, WA). The Pearson correlation coefficient was used to evaluate the correlation among surgeon-reported blood loss, CBL, and transfusion requirements as a percent of total blood volume.

RESULTS

Forty-three patients underwent primary repair of craniosynostosis. The mean age of the patients at the time of surgery was 17.7 months (median, 9.0 months) (Fig. 1). The average weight at the time of surgery was 10.0 kg (median, 8.6). Of the 43 patients, 14 underwent repair for metopic synostosis, 9 for sagittal, 8 for unicoronal, 2 for bicoronal, 1 for lambdoid, and 9 for multiple sutures (Table 1). There were 2 syndromic children included in this study, one with Crouzon syndrome and the other with Beare–Stevenson syndrome. The mean length of stay was 3.7 ± 1.2 days. Table 2 summarizes the demographic, blood loss, and transfusion results.

Blood loss values were obtained from surgeon-recorded EBL. The mean EBL for all patients in the study was 207.4 ± 138.9 mL (median, 150 mL) with a range from 20

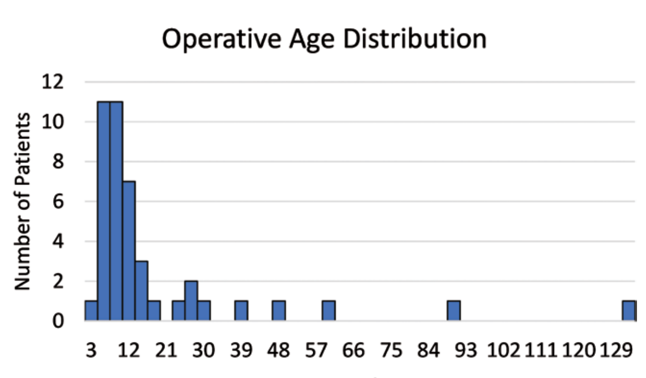

Fig. 1. Histogram of patient age at the time of surgery.

Table 1. Calculated Blood Loss Reported in Milliliters and as a Percent of Total Blood Volume for Each Suture Type

Suture	Patients (#)	CBL (mL)	CBL(%)
Metopic	11	262	37
Sagittal	8	284	38
Bicoronal	2	364	67
Unicoronal	7	276	36
Lambdoid	1	89	15
Multiple	8	488	67

to 625 mL. These values were normalized by the patient weight to account for age-related differences in preoperative blood volumes. They are reported as a percent of the EBV. The mean estimated blood loss (EBL) as a percent of EBV was 28.1% (median, 25.0%) with a range of 3.5%–95.3%. The EBL% was also calculated based on suture type as seen in Table 1.

For 37 patients, blood loss was calculated (CBL) from the patient's weight and hematocrit values as previously detailed (Table 3). The mean CBL as a percent of the patient's total blood volume was 44.3% (median, 33.8%) with a range of 2.0%–172.3%. The mean volume in milliliters of CBL was 318.0 ± 257.9 mL.

All patients requiring a transfusion received packed red blood cells. This is reported both in terms of the number of donors to which the patients were exposed, and the volume transfused. In our study, 6 patients did not receive a transfusion (14.0%), 30 patients received 1 unit of pRBCs (69.8%), and 7 patients received ≥2 units of pRBCs (16.3%). The mean transfusion volume was 188.0 ± 125.4 mL (median, 160 mL) with a range of 0–495 mL. Similar to the blood loss figures, the transfusion volumes were normalized for patient weight. The mean transfusion as a percent of EBV was 26.5% with a range of 0%–75.5%. To compare data to previously done studies, the transfusion volumes were also converted to reflect the percent of the estimated red cell mass (ERCM) received by the patient for the 37 patients with preoperative hematocrit values. The mean transfusion as a percent of ERCM was 59.1% (median, 49.6%) with a range of 0%–181.1%.

The correlation of estimated and CBL values with the transfusion volume was evaluated using the Pearson correlation coefficient. The Pearson correlation coefficient for surgeon EBL [percent of EBV (%EBV)] and the transfusion volume (%EBV) was 0.73. The Pearson correlation coefficient for CBL (%EBV) and the transfusion volume (%EBV) was 0.82 (Fig. 2).

DISCUSSION

Blood loss during open repair of craniosynostosis is a significant risk of the procedure. Accurate and up-to-date information regarding the extent of blood loss is necessary to inform surgeon and patient decisions. EBL is limited by its subjectivity. For this reason, we calculated the blood loss by using weight, pre- and postoperative hematocrit, and the hematocrit transfused during the surgery for the 37 of 43 patients for whom this information was available in the medical record.

In this 37 patient subset, the CBL was 318.0 mL compared with a surgeon EBL of 218.9 mL. The CBL was 45% higher than the EBL which is consistent with other comparisons reported in the literature.[5] Faberowski et al.[5] in 1999 reported a CBL values on a series of 80 patients and reported blood loss by suture type, reporting a CBL of 430 mL for metopic, 210 mL for lambdoidal, and 359 mL for complex sagittal synostosis repairs. By comparison, our study found CBL of 262 mL for metopic, 89 mL for lambdoidal, and 284 mL for sagittal synostosis repair (Table 1). In 1989, Kearney et al.[4] reported CBL as a percent of total blood volume for 76 patients as 24% for sagittal craniectomy, 42% for metopic, and 62% for multiple sutures. In our study, CBL as a percent of total blood volume was 38% for sagittal, 37% for metopic, and 67% for multiple sutures (Table 1). Howe and Cooper[16] reported a median CBL as a percentage of EBV of 88% for fronto-orbital advancement and 92% for cranial vault surgery. By comparison, our median CBL as a percent of EBV was 41.9% for all procedures. Although not objective measurements, surgeon EBL values have been primarily reported in the literature. Tunçbilek et al.,[17] in a 2005 retrospective chart review of 30 patients undergoing craniosynostosis repair, reported a mean EBL of 566.8 mL. More recently, Shah et al.[13] reported a mean EBL of 218 mL in patients undergoing isolated sagittal synostosis repair. Our mean EBL of 207.4 mL overall and 171.1 mL for patients undergoing isolated sagittal synostosis repair compares favorably with these numbers.

Because these surgeries are typically done during the first year of life on children with variable total blood volumes, the absolute volume of blood lost does not fully characterize the effect of lost blood volume on the patient. For this reason, many studies have chosen to normalize the blood loss values by comparing the absolute volume of surgeon EBL to a weight-based estimate of total body blood volume. Seruya et al.[6] in 2011 reported a mean EBL of 33.4% of EBV, compared with the 28.1% reported in our study. Our blood loss numbers are similar to those found by Fearon[7] who reported a blood loss of 28.5% of EBV.

Closely tied with blood loss values, transfusion requirements are important to quantify when discussing open repair of craniosynostosis. In our study, the mean transfusion volume was 188.0 mL which corresponds to

Table 2. Demographic Data and Summary of Blood Loss and Transfusion Requirement Data

	Age at op (mo)	Wt (kg)	EBL (mL)	EBL %	Transfusion (mL)	Transfusion (% of EBV)	HCT_{post}	LOS
Mean	17.7	10.0	207.4	28.1	188.0	26.5	32.3	3.7
Median	9.0	8.6	150.0	25.0	160.0	23.0	33.0	4.0
SD	24.3	4.6	138.9	20.2	125.4	18.5	5.5	1.2

HCT_{post}, postoperative hematocrit; LOS, length of stay; Wt = weight.

Table 3. Comparison of Surgeon Estimated Blood Loss and Calculated Blood Loss for the Subset of Patients Whose Preoperative Hematocrit Values Were Available

	Surgeon EBL (mL)	CBL (mL)	Surgeon EBL (%)	CBL (%)
Mean	218.9	318.0	28.1	44.3
Median	200.0	282.6	25.0	34.2

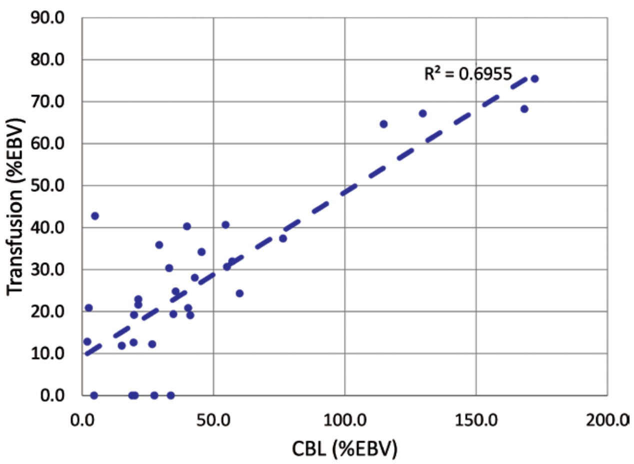

Fig. 2. Plot comparing the transfusion volume as a %EBV to the calculated blood loss as a %EBV. %EBV indicates percent of estimated blood volume.

approximately 26.5% of the patient's EBV. Tunçbilek et al.[17] reported a mean total transfusion volume of 505 mL. A mean red blood cell (RBC) transfusion of 34.4% of EBV was reported in a study by Seruya et al.[6] In both instances, our data would suggest a lower volume of transfusion was required.

Estimated red cell mass has also been used to normalize the transfusion volumes. Our calculated mean transfusion as a percent of ERCM was 56.6%. In a 1995 retrospective review of 73 patients, Eaton et al.[14] report a mean transfusion of 72.1% of ERCM. Transfusion practices may also be interpreted based on the number of patients who require transfusions. Previous studies report anywhere from 83% to 96.3% of patients requiring at least 1 transfusion.[5,14,16] Our study is on the lower end of this spectrum with 86% of patients receiving pRBCs. Regardless of the method used to analyze the transfusion data, the patients in our study had lower transfusion volume requirements as detailed above than what has been previously reported in the literature. It is also interesting to note that the CBL correlated more strongly with transfusion requirements than EBL (Pearson correlation coefficient of 0.82 vs 0.73).

In any study, there are inherent limitations. For our study, our sample size of 43 patients was not adequate to allow for a powerful subgroup analysis by suture type. We were only able to obtain the preoperative hematocrit values for 37 of the 43 patients. Also, the preoperative hematocrit values were taken with epoc blood analysis systems (Epocal Inc., Ottawa, ON, Canada) used by anesthesia immediately preoperative. A 2016 study comparing epoc systems to laboratory obtained values reported a bias of 2.78%.[18] Although the epoc system may introduce a small amount of error into our measurements, we believe that this is outweighed by the ability to account for the dilutional effect of preoperative fluid administration on hematocrit values. The ERCM equation does not account for hemodilution that occurs due to fluid administration in between the pre- and postoperative hematocrit values. This study was also limited by its retrospective nature. No new interventions were made to minimize blood loss. Future work would benefit from a prospective design in which blood loss measurement is attempted in a systematic fashion and compared with calculated values that account for hemodilution.

Our comparison of surgeon EBL with CBL suggests the need for a standardized, objective method of reporting blood loss figures. Future studies on repair of craniosynostosis would benefit from using CBL values as opposed to surgeon EBL. Additionally, improved blood loss data could inform anesthesia's decisions regarding the need for transfusion. As seen in Figure 3, the majority of patients' postoperative hematocrit values were >35%, which is higher than most preoperative hematocrits. Objective blood loss data could more precisely determine the need for transfusion, particularly postoperatively.

CONCLUSIONS

Blood loss and transfusion requirements during open primary repair of craniosynostosis have been cited as significant risks of surgery. There is a relative lack of objective, contemporary data characterizing blood loss and transfu-

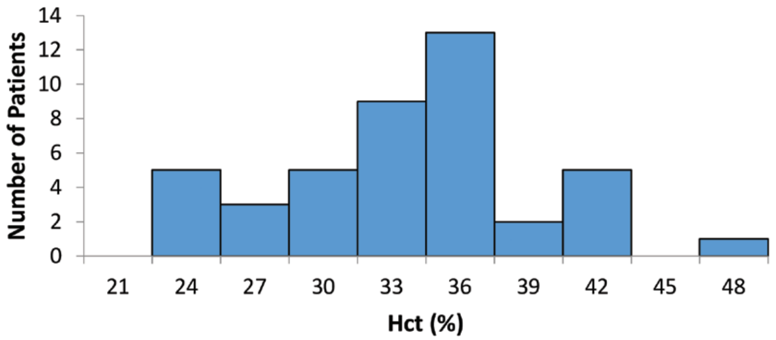

Fig. 3. Histogram of the patients' Hcts after surgery. Hct indicates hematocrit.

sion patterns. We report intraoperative blood losses and transfusion requirements that are lower than many previous studies of open repair of craniosynostosis. Additionally, we found that CBL estimates may be more reliable than surgeon-derived EBL. We hope that these updated data will be useful in the comparison of minimally invasive treatments to standard open repair of craniosynostosis.

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