Unreliability of intraoperative estimated blood loss in extended sagittal synostectomies

Clinical article

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Object. Intraoperative blood loss represents a significant concern during open repair of craniosynostosis, and its reliable measurement remains a serious challenge. In this study of extended sagittal synostectomies, the authors analyzed the relationship between estimated blood loss (EBL) and calculated blood loss (CBL), and investigated predictors of hemodynamic outcomes.

Methods. The authors reviewed outcomes in infants with sagittal synostosis who underwent primary extended synostectomies (the so-called Pi procedure) between 1997 and 2009. Patient demographic data, operating time, and mean arterial pressures (MAPs) were recorded. Serial MAPs were averaged for a MAP mean. The EBL was based on anesthesia records, and the CBL on pre- and postoperative hemoglobin values in concert with transfusion volumes. Factors associated with EBL, CBL, red blood cell transfusion (RBCT), and hospital length of stay (LOS) were investigated. Hemodynamic outcomes were reported as percent estimated blood volume (% EBV), and relationships were analyzed using simple and multiple linear and logistic regression models. A p value < 0.05 was considered significant.

Results. Seventy-one infants with sagittal synostosis underwent primary extended synostectomies at a mean age and weight of 4.9 months and 7.3 kg, respectively. The average operating time was 1.4 hours, and intraoperative MAP was 54.6 mm Hg (21.3% lower than preoperative baseline). There was no association between mean EBL (12.7% EBV) and mean CBL (23.6% EBV) (r = 0.059, p = 0.63). The EBL inversely correlated with the patient’s age (r = −0.07) and weight (r = −0.11) at surgery (p < 0.05 in both instances). With regard to intraoperative factors, EBL positively trended with operating time (r = 0.26, p = 0.09) and CBL inversely trended with MAP mean (r = −0.04, p = 0.10), although these relationships were only borderline significant. Intraoperative RBCT, which was required in 59.1% of patients, positively correlated with EBL (r = 1.55, p < 0.001), yet negatively trended with CBL (r = −0.40, p = 0.01). Undertransfusion was significantly more common than overtransfusion (40.8% vs 22.5%, p = 0.02, respectively). The mean hospital LOS was 2.3 days and was not significantly associated with patient demographic characteristics, intraoperative factors, blood loss, RBCT, or total fluid requirements.

Conclusions. In extended synostectomies for sagittal synostosis, EBL and CBL demonstrated a decided lack of correlation with one another. Intraoperative blood transfusion positively correlated with EBL, but inversely correlated with CBL, with a significantly higher proportion of patients undertransfused than overtransfused. These findings highlight the need for reliable, real-time monitoring of intraoperative blood loss to provide improved guidance for blood and fluid resuscitation. (DOI: 10.3171/2011.8.PEDS11180)

Key Words • sagittal synostosis • extended synostectomy • Pi procedure • calculated blood loss • estimated blood loss

Intraoperative blood loss remains one of the most significant concerns during open reconstruction for craniosynostosis. In young infants with low circulating blood volume, even relatively small amounts of blood loss can represent a large proportion of total blood volume, potentially leading to life-threatening hypotension and cardiac arrest.9

The degree of blood loss following open craniofacial repair continues to be debated, with numbers cited between 25% and 500% EBV.13 Assessment of blood loss also differs, ranging from EBL recorded by the anesthesiologist/surgeon to CBL based on hemoglobin change.
Compounding these issues, there is little agreement on the specific factors that affect blood loss, including the following: patient's age at surgery; type of synostosis; duration of surgery; and controlled systemic hypotension.10,17,18,22,32

The purpose of this study was to analyze the relationship between EBL and CBL, and to investigate predictors of hemodynamic outcomes following extended synostectomies for sagittal synostosis.

Methods

Patient Population

An Institutional Review Board–approved (#4394) retrospective review was performed in patients with sagittal synostosis who underwent extended synostectomy at Children's National Medical Center between 1997 and 2009. Patients were excluded from the study for multisutural synostosis, history of open craniofacial repair, or incomplete records.

Surgical Technique

Extended synostectomy is performed similarly to the method described by Jane et al.17 and includes perioperative antibiotics and steroids, scalp infiltration with local anesthetic (0.5% lidocaine and 1/400,000 parts epinephrine), and initiation of controlled systemic hypotension (target MAP 55–60 mm Hg). The cranial vault is accessed by a retroauricular bicoronal incision followed by a subgaleal dissection, carefully preserving the pericranium by a retroauricular bicoronal incision followed by a subgaleal dissection, carefully preserving the pericranium in the process (to limit blood loss). Subgaleal exposure is carried out to the level of the coronal and lambdoid sutures. The planned cuts for the extended synostectomy are then marked with methylene blue, in the shape of a modified Greek letter “π.” These osteotomies are approximately 1 cm lateral to the sagittal suture and extend just anterior to the lambdoid sutures and posterior to the coronal sutures. The osteotomy extends across the midline immediately behind the coronal suture and requires that a 2-cm portion be removed.

Osteotomies are made approximately 1 cm lateral to the sagittal suture, extending anterior to the lambdoid sutures and posterior to the coronal sutures. The osteotomy extends across the midline immediately behind the coronal suture and requires that a 2-cm portion be removed. This distance is subsequently narrowed, with the placement of absorbable sutures from the sagittal strip still in place to the frontal bone at the coronal suture. In the process, the parietal bone segments are displaced laterally, thus promoting a wider and more normocephalic shape. A subgaleal drain is then placed, followed by a layered soft-tissue closure.

Data Collection

Electronic medical records aided in review of patient demographic data, intraoperative factors, and hemodynamic/perioperative outcomes. Patient demographics included age and weight at operation. Anesthesia records provided data on intraoperative factors: operating time (duration from incision to closure), and intraoperative MAPs (based on systolic and diastolic blood pressures recorded every 5 minutes during the procedure). Serial MAPs were averaged for a MAPmean.

Hemodynamic and perioperative outcomes included EBL, CBL, intraoperative crystalloid, iRBCT, total intraoperative fluid requirements (sum of crystalloid, iRBCT, and other colloid products), PRBCT, total blood transfusion (sum of iRBCT and PRBCT), and hospital LOS. The EBL was assessed by the pediatric anesthesiology team and was based on the quantity of blood within suction canisters, excluding irrigation fluid, as well as visual estimation of blood within surgical sponges, drapes, and gowns. The CBL was determined using the formula developed by Gross10 and described by Faberowski et al. It corrects for the dilutional effects associated with concurrent administration of crystalloid, while simultaneously factoring iRBCTs.

This is expressed by the following formula: CBL = ((Hb0 - Hb1)/Hb0) × ABV × Wt + iRBCT, where Hb0 is baseline hemoglobin, per preoperative laboratory tests; Hb1 is immediate postoperative hemoglobin, on admission to the ICU; Hb0 = (Hb0 + Hb1)/2; ABV is the average blood volume (80 ml/kg in infants); Wt = weight in kg; and iRBCT = volume (in ml) of RBCs transfused.

Blood loss and transfusion volumes (in ml) were converted to % EBV by dividing volume (in ml) by the patient’s total estimated blood volume (ABV × Wt) and then multiplying by 100. This provided a better opportunity to observe relationships between factors and outcomes while simultaneously accounting for the effects of patient weight.

Finally, intraoperative transfusion management was assessed. This was done by calculating the change in blood volume immediately following the operation, equal to iRBCT minus CBL. Transfusions were considered appropriate for changes in blood volume within 15% of preoperative baseline.18 Overtransfusion was defined as blood volume excess > 15%. Undertransfusion was defined as blood volume deficit > 15%.

Statistical Analysis

Simple and multiple linear and logistic regression
models were used to evaluate the relationships between clinical factors and outcomes. Chi-square tests were used for contingency data. The means are expressed ± SD. A p value < 0.05 was considered significant.

**Results**

Seventy-one infants with sagittal synostosis underwent primary extended synostectomy (the so-called Pi procedure) over the 12-year study period. There were 53 male and 18 female patients, comprising 74.6% and 25.4% of the study population, respectively. The mean age at repair was 4.9 ± 1.8 months, and the mean weight was 7.3 ± 1.3 kg. The average operating time was 1.4 ± 0.4 hours and the intraoperative MAP was 54.6 ± 6.4 mm Hg; 21.3% lower than the preoperative baseline.

The mean EBL was 72.6 ± 42.6 ml (12.7% ± 7.4% EBV) and CBL was 135.8 ± 72.9 ml (23.6% ± 12.7% EBV). Comparison testing of EBL versus CBL demonstrated a distinct lack of correlation with one another (r = 0.059, p = 0.63). Bland-Altman analysis revealed that EBL more often underestimated than overestimated CBL (Fig. 2).

Associations between clinical factors and blood loss were explored (Table 1). The EBL was negatively correlated with the patient’s age (r = −0.07) and weight (r = −0.11) at surgery (p < 0.05 in both instances). The CBL was not significantly associated with patient demographic characteristics. The EBL positively correlated with operating time, although this relationship was only borderline significant (r = 0.26, p = 0.09); there was no association found between CBL and operating time. An inverse relationship was found between CBL and MAP mean (r = −0.04, p = 0.10), although it was of only borderline significance; EBL was not related to MAP mean.

Intraoperative red blood cell transfusion was administered in 42 patients (59.1%) and averaged 90.5 ± 94.3 ml (16% ± 16.7% EBV). Transfusion volumes positively correlated with EBL (Fig. 3 upper), yet inversely trended with CBL (Fig. 3 lower). Intraoperative transfusion management was further investigated by evaluating the change in blood volume versus average blood loss (average of EBL and CBL). As shown in Fig. 4, only 36.6% of patients received appropriate amounts of transfusion; patients were undertransfused significantly more often than they were overtransfused (40.8% versus 22.5%, respectively; p = 0.02). Postoperative transfusions occurred in 24 patients (33.8%) and averaged 31 ml (5.3% EBV). Over the course of the entire hospital stay, 57 patients (80.3%) required an RBCT, averaging 121.5 ± 85.9 ml (21.3% ± 15.4% EBV).

The mean hospital LOS was 2.3 ± 0.5 days. Predictors of LOS were investigated using a Cox proportional hazards model (Table 2). There were no significant associations between LOS and patient demographic characteristics, intraoperative factors, blood loss, RBCT, or total fluid requirements.

**Discussion**

Amid the growing interest in minimally invasive approaches to craniosynostosis, proponents of open craniofacial repair face the challenge of further

**TABLE 1: Blood loss versus demographic and intraoperative factors**

<table>
<thead>
<tr>
<th>Factor</th>
<th>EBL r Coefficient</th>
<th>EBL p Value</th>
<th>CBL r Coefficient</th>
<th>CBL p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>demographic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>age</td>
<td>−0.07</td>
<td>&lt;0.05</td>
<td>0.05</td>
<td>0.60</td>
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<td>&lt;0.05</td>
<td>−0.09</td>
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</tr>
<tr>
<td>intraop</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>op time</td>
<td>0.26</td>
<td>0.09</td>
<td>−0.24</td>
<td>0.53</td>
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<td>MAP</td>
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<td>0.96</td>
<td>−0.04</td>
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curtailing surgical morbidity. Blood loss remains one of the greatest concerns, occurring during extensive scalp dissection and, more importantly, at osteotomy sites. In young infants with low hemodynamic reserve, relatively small amounts of blood loss can represent a large proportion of total blood volume, and translate into life-threatening hypotension and cardiac arrest. In addition, intraoperative blood loss can result in a significant transfusion requirement, placing patients at risk for pathogen transmission, development of transfusion reactions, and other short- and long-term sequelae.

Presently, there is little consensus on the degree of blood loss following open craniofacial reconstruction for craniosynostosis, with numbers cited between 25% and 500% EBV. This disagreement may be secondary to the comparison of hemodynamic outcomes across different methods of open craniofacial repair; indeed, blood loss has been found to correlate positively with the extent of the procedure. Moreover, lack of standardization in blood loss assessment further confuses prior study results, with some reports focusing on EBL and others highlighting CBL.

Indeed, blood loss can be measured by a variety of methods, each of which can be inaccurate, cumbersome, and/or impractical to varying degrees. These include subjective estimation, gravimetric technique, colorimetric method, and radioisotope labeling. The accuracy of subjective estimation has been questioned by practitioners in other surgical specialties. Furthermore, the last two techniques each demand significant time, expense, and equipment, and do not allow for concurrent assessment of blood loss during the course of the operation.

In contrast, several hemodynamic outcomes studies in craniofacial surgery have focused on CBL, based on preoperative versus postoperative hemoglobin and volume of transfused blood. Although not conclusively the gold standard for blood loss assessment, this method has been validated in the pediatric population with large volumes of blood loss. In a study of infants and children weighing between 10 and 20 kg, with blood loss ranging from 70 to 940 ml, Ward et al. found a high correlation between calculated and actual values. The CBL measure also offers the advantages of ease, low cost, and practicality.

This retrospective study focused on a single type of open craniofacial technique (Pi procedure) for a single form of craniosynostosis (sagittal synostosis) and compared 2 methods of blood loss assessment, specifically EBL versus CBL. The average EBL was 72.6 ml or 12.7% EBV, which compared favorably to the historically reported for the Pi procedure. The mean CBL was 23.6% EBV, which was also consistent with prior hemodynamic studies on sagittal synostectomies.

On comparison of mean values, EBL was nearly one-half that of CBL, similar to other studies documenting EBL underestimated CBL by 30% to 35%. Paired testing of individual measures of EBL and CBL demonstrated a distinct lack of correlation with one another; EBL more often underestimated than overestimated CBL.

TABLE 2: Factors associated with hospital LOS

<table>
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<tr>
<th>Factor</th>
<th>HR at Discharge</th>
<th>p Value</th>
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</thead>
<tbody>
<tr>
<td>age</td>
<td>0.968</td>
<td>0.61</td>
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<tr>
<td>weight</td>
<td>0.949</td>
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</tr>
<tr>
<td>op time</td>
<td>0.774</td>
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<tr>
<td>CBL</td>
<td>0.999</td>
<td>0.97</td>
</tr>
<tr>
<td>EBL</td>
<td>0.991</td>
<td>0.58</td>
</tr>
<tr>
<td>iRBCT</td>
<td>0.997</td>
<td>0.67</td>
</tr>
<tr>
<td>total intraop fluid</td>
<td>0.999</td>
<td>0.37</td>
</tr>
<tr>
<td>total RBCT</td>
<td>0.996</td>
<td>0.60</td>
</tr>
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</table>
Blood loss and extended sagittal synostectomies

In total, these results confirmed that EBL was a poor surrogate for CBL. Indeed, blood loss estimation has also been reported to be inaccurate when done by urologists,21 otolaryngologists,3 and obstetricians,1,8,24 as well as nurses30 and emergency medical personnel.23 One explanation is that practitioners tend to gravitate toward the mean during blood loss estimation.24 This observation may also help resolve the difference in standard deviation between EBL and CBL. With measures of EBL gravitating toward the mean and CBL potentially affected by patient and/or operative factors, it is not surprising that EBL had a relatively narrower standard deviation.

One important question that arises is whether ongoing blood loss between surgical closure and the postoperative hemoglobin blood draw is responsible for EBL underestimating CBL. Indeed, sequestration of blood beneath the undermined scalp postoperatively can promote a drop in hemoglobin and potentially trigger the need for further transfusion. The methodology of this particular study, however, makes that an unlikely cause. Indeed, postoperative hemoglobin was recorded on admission to the ICU, typically 1–3 hours after open craniofacial repair. It is therefore unlikely that this short postoperative window could have provided enough time for blood sequestration to impact significantly the hemoglobin result and/or the CBL. Furthermore, nearly all 24 patients who received a pRBCT were found to have a large discrepancy between EBL and CBL, supporting blood loss underappreciation as the main reason for further resuscitation.

The impact of patient and intraoperative factors on blood loss also continues to be debated. In this study, neither was significantly related to calculated blood loss. Two explanations may account for these findings. First, the patient population was rather uniform, with a tight range of age at operation (4.9 ± 1.8 months), weight (7.3 ± 1.3 kg), and time (1.4 ± 0.4 hours). Second, this study focused on an open craniofacial repair technique involving less complex osteotomies, with less potential for extensive bleeding. Together, these conditions may have diminished the study power, thereby decreasing the likelihood for observing hemodynamic relationships. Indeed, we have recently demonstrated significant associations between patient and/or intraoperative factors and blood loss in a more heterogeneous patient group receiving more complex open craniofacial repair, specifically frontoorbital advancement for craniosynostosis.27

Interestingly, we found an inverse relationship between CBL and MAPmean. Although this only reached borderline statistical significance, it questions the benefit of controlled systemic hypotension, which is commonly practiced by most craniofacial surgeons. This finding contrasts with those from a prospective study of Diaz and Lockhart, demonstrating beneficial effects of hypotensive anesthesia on EBL during open craniectomy for craniosynostosis.7 To resolve this discrepancy and correctly interpret the inverse relationship, we must first determine whether blood pressure is affecting blood loss or vice versa. Therefore, we are currently studying the longitudinal relationships between serial intraoperative CBL and blood pressure during extended sagittal synostectomies.

Over the course of their hospital stay, 80.3% of patients in this study received a blood transfusion. This is in agreement with the 80%–91.3% quoted in the past for the Pi procedure.16,33 Our average total transfusion volume of 121.5 ml is within range of the 96 ml reported by Kanev and Lo.16

Basing hemodynamic resuscitation on EBL, which was shown to be an unreliable measure of blood loss, was not without consequence. Intraoperative transfusion volumes positively correlated with EBL, yet negatively trended with CBL. The end result was that only 36.6% of patients underwent appropriate iRBCT (Fig. 4). Indeed, patients were more often undertransfused than overtransfused, probably due to the underestimation of blood loss.

Finally, the mean LOS was 2.3 days, lower than 3.7–5.6 days historically reported for the Pi procedure.4,16 As demonstrated in Table 2, LOS was not related to patient and/or intraoperative factors or hemodynamic outcomes in our study. Similar to the logic used in blood loss analysis, we believe this may be explained by the relatively homogeneous patient population, more limited open craniofacial repair technique, and tight range of he-
modynamic and fluid resuscitation. Combined, these conditions may have decreased the overall study power and the likelihood of observing relationships. Indeed, we have recently demonstrated significant associations between hemodynamic outcomes and hospital LOS in our study of patients undergoing frontoorbital advancement for craniosynostosis between the ages of 3 and 118 months.27

Our study has several limitations, including the retrospective design, relatively low power, and the fact that it is not generalizable to other types of open craniofacial repair. To address the first two concerns, we are designing a prospective study to evaluate the efficacy of real-time, transcutaneous hemoglobin monitoring in assessing blood loss and guiding hemodynamic resuscitation. We are also exploring the same hemodynamic relationships in more complex open craniofacial repair, including frontoorbital advancement and total calvarial reconstruction. Doing so should provide a clearer picture of how these associations behave under different sets of conditions.

Conclusions

In extended synostectomies for sagittal synostosis, EBL and CBL demonstrated a decided lack of correlation with one another. Intraoperative blood transfusion positively correlated with EBL, but inversely correlated with CBL, with a significantly higher rate of undertransfusion than overtransfusion. These findings highlight the need for reliable, real-time monitoring of intraoperative blood loss to provide improved guidance of blood and fluid resuscitation.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Concepcion and design: Keating. Seruya. Acquisition of data: Seruya. Analysis and interpretation of data: Keating. Statistical analysis: Seruya. Administrative, technical/material support: Boyajian, Myseros, Yann. Study supervision: Keating, Seruya, Oh.

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