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Reduction of transfusion rates in the surgical correction of sagittal synostosis

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Object. As public concern about the risks of blood transfusions increased in the mid-1990s, avoidance of transfusions became a goal of surgery for sagittal synostosis. This study was performed to confirm a hypothesized reduction in transfusion rates in recent years and to identify factors associated with both the need for transfusion and low postoperative levels of hemoglobin.

Methods. Sagittal synostosis operations performed in children between 1986 and 1999 were reviewed retrospectively. Patients underwent a minimum of vertex strip craniectomy and parietal craniectomies. There were 118 patients whose median age at surgery was 4.2 months. The primary end point for analysis was defined as either the receipt of a blood transfusion or a postoperative level of hemoglobin less than 70 g/L. Forty-two percent of patients (95% confidence interval [CI] 31–52%) treated before 1996 and 11% of patients (95% CI 0–23%) treated from 1996 onward received blood. The reduction in the blood transfusion rate in later years was, in part, related to the acceptance of a lower postoperative hemoglobin level, often below 70 g/L. A univariate analysis showed that the only patient or surgical factors that correlated with reaching the primary end point in a statistically significant manner were the year of surgery and the extent of surgery. A logistic regression of the age and weight of the child, length of surgery time (from skin opening to skin closure), preoperative hemoglobin level, extent of surgery, and surgeon against the primary end point revealed that the best predictor of the need for a blood transfusion or the presence of a postoperative hemoglobin level lower than 70 g/L was the extent of surgery ($\beta = 1.4$, standard error of the β statistic = 0.44). Once the extent of surgery was accounted for in the model, no other covariates significantly improved the model.

Techniques implemented to minimize blood loss since 1995 included the following: use of the Colorado needle for scalp incision, selection of the Midas Rex craniotome for cranial cuts, and application of microfibrillar collagen. Postoperative hemoglobin was allowed to decrease to 60 g/L if the child was stable hemodynamically, before blood was administered. There were no cardiovascular, wound healing, or infectious complications, and no surgeries were repeated for cosmetic reasons.

Conclusions. Low blood transfusion rates were achieved using simple intraoperative techniques and by accepting a low level of postoperative hemoglobin.

Key Words • sagittal craniosynostosis • blood transfusion • craniectomy

Numerous surgical procedures are used in the treatment of sagittal synostosis, ranging from simple strip craniectomy to total calvarial reconstruction, and are associated with different results, complications, and utilization of resources.[3,6,8,10,13–16,23–25] It is generally recommended that surgery be performed when the infant is younger than 6 months of age to achieve the best results.[2,21,22,24,27] Whatever the procedure or the patient's age when surgery is performed, significant blood loss is expected, and there is the possibility that a blood transfusion will be required either intraoperatively or during the early postoperative period.

Public understanding of and concern about the risks of allogenic blood transfusion have increased during the last decade, and avoidance of blood transfusion during surgical procedures has become more important. In surgery for sagittal synostosis a number of methods have been described to reduce the need for allogenic blood transfusions. These techniques include autologous blood transfusions,[17,30] intraoperative blood salvage,[17,30] use of microcautery tips, and other elaborate protocols.[29–31]

In Canada, public concern about the risks of blood transfusion was particularly heightened by the creation in 1993 of a special commission, headed by Justice Krever, to review how 1200 Canadians had been infected with human immunodeficiency virus through tainted blood given to them in the early 1980s. The Krever Commission held public hearings on this matter for many years and finally issued a report in November 1997.[5] During this time period (the mid-1990s), neurosurgeons at British Columbia's Children's Hospital, Vancouver, Canada, were influenced by the public's concerns and felt some pressure to minimize the use of perioperative allogenic blood transfusions. This was particularly true for operations performed for craniosynostosis, for which the indications for surgery are primarily

Abbreviation used in this paper: CI = confidence interval.

cosmetic. By the mid-1990s avoidance of allogenic blood transfusion in children undergoing surgery for craniosynostosis became one goal of surgery for all three pediatric neurosurgeons at this hospital.

It was our expectation and the hypothesis for this study that the amount of blood lost during surgery for sagittal synostosis and the rate of allogenic blood transfusions declined in the latter half of the 1990s, compared with earlier years. The purpose of this study was to confirm that transfusion rates decreased during that time period, to describe techniques used to limit intraoperative blood loss and avoid transfusions, and to determine if any factors, such as patient age and weight at surgery or extent of the surgical procedure, correlated with the transfusion rate or a low level of postoperative hemoglobin.

Clinical Material and Methods

Patient Population

A retrospective chart review was performed for patients who underwent surgery for sagittal synostosis between January 1986 and December 1999. Information regarding operative details, hemoglobin levels, perioperative blood loss, blood transfusions, and the cephalic index at presentation and at the latest follow-up examination was obtained. The cephalic index was the ratio between the maximum biparietal or bitemporal diameter and the maximum anteroposterior diameter.

One hundred eighteen patients were included in this study; the median age of these patients was 4.2 months. Two thirds of the patients were younger than 6 months of age at operation, whereas approximately 10% were older than 1 year of age.

Operative Procedure

Preoperatively, the hemoglobin level was measured in all patients. One unit of packed red blood cells, either regular blood-bank blood or donor-directed blood, was crossmatched in case it should be required perioperatively. The patients were admitted on the day before surgery in the early part of the study and on the day of surgery since 1995. Apart from three patients with iron deficiency anemia in whom the hemoglobin level was less than 100 g/L, who were treated with iron for 1 month, no patient received any treatment, such as erythropoietin, to optimize hemoglobin levels prior to surgery. No patient underwent harvesting of autologous blood.

The surgical procedures performed in patients younger than 1 year of age were fairly homogeneous during this time period and are detailed later in this paper. The techniques for children older than 1 year of age were quite variable. The anesthesiologist assigned to each case was variably selected from a group of nine pediatric anesthesiologists, and may or may not have had a special interest in neurosurgical procedures. Each operation was performed by one of three surgeons (P.S., D.D.C., and J.K.), who was usually aided by a resident assistant.

The scalp was infiltrated with a mixture of adrenaline and xylocaine. A bicoronal scalp incision was made. Before 1995, the incision was made using a scalpel and hemostatic clips were applied to the scalp. From 1995 onward, cutting needle cautery (Colorado tip; Colorado Biomedical, Evergreen, CO) was used with increasing frequency for the skin incisions, negating the need in some cases for hemostatic clips. Anterior and posterior subgaleal flaps were turned using the unipolar cautery to expose the entire cranial vertex from the coronal sutures to the inion. Bipolar coagulation of blood vessels, placement of microfibrillar collagen on the subgaleal surface of the scalp flaps, and application of bone wax to the cut edges of bone aided in hemostasis. All patients underwent a standard wide midline sagittal craniectomy measuring 4 to 6 cm, and parietal craniectomies to allow the parietal bones to move laterally readily. Depending on the shape of the cranium, anterior and/or posterior parietal wedge craniectomies were often performed to remove the most narrowed areas. In addition, barrel stave or other parietal osteotomies were usually performed. If there was significant frontal bossing or occipital protrusion, frontal or occipital craniotomies and remodeling procedures were sometimes performed to correct these defects. These additional procedures were performed more frequently during the first half of the series. For the purpose of analysis, the extent of surgery was subdivided into three categories: "basic," in which only vertex and parietal craniectomies were done; "moderate," in which either an occipital craniectomy or frontal remodeling was added; and "extensive," in which both occipital and frontal remodeling were performed. All bone cutting was performed with the aid of the Midas Rex craniotome (Medtronic Midas Rex, Fort Worth, TX). From 1996 onward, one of the surgeons indicated to families preoperatively that a planned frontal or occipital remodeling might be aborted if the child was believed to be approaching the need for blood transfusion and the remainder of the procedure had been completed.

Blood Products

The estimated blood loss was determined on the basis of the surgeon's and/or anesthesiologist's best estimate at the time of the procedure, as documented in the hospital record. Estimated blood volume was calculated on the basis of 80 ml/kg body weight.[20,29] Calculated blood loss, or CBL, was derived from the formula [$CBL = EBV \times Ln(Hb_{pre}/Hb_{post}) + \text{volume transfused}$], where EBV represents estimated blood volume; Ln, logarithm (natural form); Hb_{pre}, preoperative hemoglobin; and Hb_{post}, postoperative hemoglobin.[32]

Statistical Analysis

One end point was chosen for statistical analysis. As part of this study, we wished to examine factors related to the surgery that might have been associated with sufficient loss of blood to precipitate a blood transfusion. Because indications for blood transfusion could have varied among the different anesthesiologists and surgeons, it was believed that a better end point than blood transfusion would be a low hemoglobin level postoperatively. We chose a level of 70 g/L as the end point level; this is a level below the point at which many physicians would consider giving blood. We recognized that, in children who received a blood transfusion intraoperatively, the postoperative hemoglobin level would probably never drop to less than 70 g/L, even though an end point had clearly been reached, because enough blood had been lost to require a transfusion. We therefore

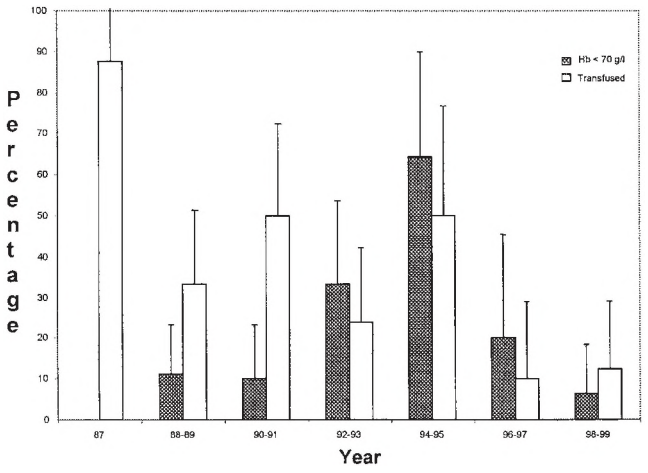

FIG. 1. Bar graph showing the percentages of patients who received transfusions and the percentage with a hemoglobin (Hb) level lower than 70 g/L from 1986 to 1999.

TABLE 1
Descriptive statistics by year of operation

Variable	1986–1995 Group 1	1996–1999 Group 2
age (mos)*	4.1 (1.9–38.6)	4.8 (2.2–81.3)
weight (kg)*	7.1 (4.8–16.1)	7.1 (5–22)
preop hemoglobin (g/L)*	113 (93–136)	116 (80–139)
duration of op (mins)†	78 (44–235)	135 (90–270)
extent of surgery‡		
basic	19 (21)	20 (74)
moderate	62 (68)	6 (22)
extensive	10 (11)	1 (4)
surgeon‡		
A	37 (41)	15 (56)
B	43 (47)	9 (33)
C	11 (12)	3 (11)

* Values are expressed as the median (range).
† Duration of operation from skin opening to skin closure (range).
‡ Values are expressed as number of patients (percentage).

decided that the primary end point should be either a transfusion of blood products or a postoperative hemoglobin level below 70 g/L, even if no blood was transfused.

The rate of blood transfusion was plotted by 2-year periods. Confidence intervals for the proportions were calculated using normal approximation. The chi-square test, the Fisher exact test, a t-test, and the Wilcoxon test were used to investigate differences between those patients who reached the primary end point and those who did not in terms of year of operation, extent of surgery, surgeon, weight of the child, duration of surgery (time from skin opening to skin closure), and preoperative hemoglobin level. All covariates, except the year in which surgery was performed, were also included in a logistic regression to explore the potential interrelationships between the surgical and patient-related factors and the primary end point. To control for multiple testing, we used a Bonferroni–corrected Type I error rate (p value) of 0.01. Analyses were conducted using commercially available statistical computer software (SPSS version 7.5; SPSS Inc., Chicago, IL).

Results

Transfusion Requirements

Forty-one (34.7%) of 118 patients in the study received blood transfusions. A decreased rate of blood transfusion was evident in later years, particularly from 1996 onward (Fig. 1). The percentage of patients with a postoperative hemoglobin level lower than 70 g/L increased from the start of the study to 1995 and then decreased thereafter (Fig. 1). Among the patients who received a blood transfusion, 26 (68%) of 38 patients who did so before 1996 and two (67%) of three patients who did so since 1996 received transfusions, even though their hemoglobin levels had not dropped below 70 g/L and there were no signs of hemodynamic instability. Among those patients with seemingly adequate hemoglobin levels, 24 (92%) of the 26 patients who received blood transfusions before 1996 and two (100%) of two patients who received blood later did so intraoperatively, presumably because the anesthesiologist or surgeon was concerned about the extent of blood loss. The other two patients in the first group received transfusions because their postoperative hemoglobin levels were believed to be unacceptably low, although not below 70 g/L.

Based on the results of the transfusion rates, and in keeping with the original hypothesis of the study, patients into two groups for analysis. Group 1 included patients who underwent surgery between January 1986 and December 1995, whereas Group 2 included patients who underwent operative intervention between January 1996 and December 1999. The demographic characteristics of the patients in the two groups were similar (Table 1); however, patients in Group 2 tended to have undergone less extensive surgery, albeit with longer operative times, than patients in Group 1.

Blood transfusions were given to 38 (41.8%) of 91 patients in Group 1 (95% CI 31–52%) and three (11.1%) of 27 patients in Group 2 (95% CI 0–23%; Table 2). The average amount of estimated blood volume transfused was lower in patients in Group 2 (2.6% compared with 10.9% in Group 1). The absolute lowest hemoglobin recorded was 50 g/L in a patient who did not receive a blood transfusion, whereas the average lowest postoperative hemoglobin level was 87 g/L overall, with similar values over both study periods. The estimated blood loss and calculated blood losses were similar throughout the study. The estimated blood loss underestimated the calculated blood loss by more than 100% (note that the formula used in this study only partially accounts for hemodilution in a standardized fashion) (Fig. 2).

The indications for transfusion were determined on the basis of individual patients, surgeons, and anesthesiologists. In general, patients received transfusions intraoperatively if the surgeon or anesthesiologist was concerned about the extent of blood loss or if the child was hemodynamically unstable. During the postoperative period, patients received transfusions either because the hemoglobin level was believed to be too low or there were signs of hypovolemia, such as tachycardia, hypotension, and tachypnea. The percentage of patients in whom the postoperative hemoglobin level reached less than 70 g/L was lower in Group 2 (Table 2 and Fig. 1), but the percentage of patients in whom the hemoglobin level reached less than 80 g/L was

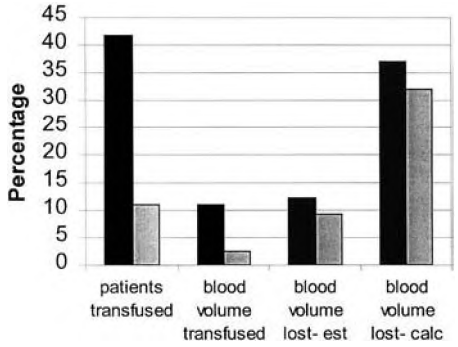

FIG. 2. Histogram showing the percentages of patients who received transfusions, the amount of blood transfused, the estimated blood loss (est), and the calculated blood loss (calc) for patients who underwent surgery between 1986 and 1995 *(black bars)* and between 1996 and 1999 *(gray bars)*. The amount of blood transfused, estimated blood loss, and calculated blood loss, are expressed as a percentage of the patient's estimated blood volume. The amount of blood transfused was lower after 1995, despite similar estimated and calculated blood losses.

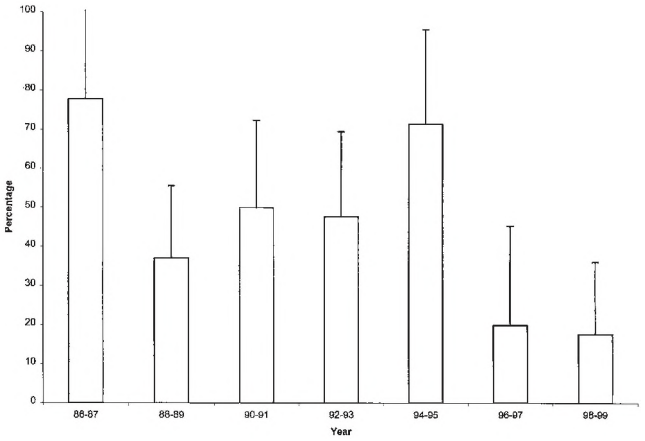

FIG. 3. Bar graph demonstrating percentages of patients who reached the primary end point from 1986 to 1999. The primary end point was defined as either receiving a blood transfusion or having a postoperative hemoglobin level lower than 70 g/L.

the same in the two groups. There were no adverse reactions to the blood transfusion. There were no cardiovascular, wound healing, or infectious complications.

For the purposes of further analysis, as explained in *Clinical Material and Methods*, the primary end point was reached when a patient received a transfusion of blood products or when the postoperative hemoglobin level was below 70 g/L, even if no blood was transfused. The rate at which patients attained the primary end point fluctuated between 35% and 75% from 1986 to 1995, but decreased to less than 20% after 1995 (Fig. 3). The relationship between individual patient and surgical factors and the attainment of the primary end point of the study was examined using univariate analyses (Tables 3 and 4). The only factors that correlated with the primary end point in a statistically significant manner were year of surgery and extent of surgery. A multivariate analysis was performed using regression to explore the potential interrelationships of different variables—the age and weight of the child, duration of surgery (time from opening the skin to closing the skin), preoperative level of hemoglobin, extent of surgery, and surgeon—with reaching the primary end point. Logistic regression revealed that, for the present data, the best predictor of a postoperative hemoglobin level lower than 70 g/L or receiving a blood transfusion (that is, reaching the primary end point) was extent of surgery ($\beta = 1.4$, standard error of the β statistic = 0.44). The odds of reaching the primary end point for extensive surgery over basic surgery was 3.98 (95% CI 1.67–9.5). Once the extent of surgery was accounted for in the model, no other covariates significantly improved the model.

TABLE 2

*Blood loss and transfusion results**

Parameter	Group 1	Group 2	Overall
% of patients who received transfusion	41.8	11.1	34.7
EBL (ml)			
mean	74	65	72
range	10–300	25–300	10–300
CBL (ml)			
mean	220	197	215
range	9–826	42–369	9–826
EBV (ml)			
mean	603	635	610
range	384–1288	400–1760	384–1760
EBL/CBL (%)			
mean	44	33	42
range	5–448	12–98	5–448
EBL as % of total			
mean	12	9	12
range	2–50	4–32	2–50
CBL as % of total			
mean	37	32	35
range	2–108	8–66	2–108
lowest hemoglobin (g/L)			
mean	88	85	87
range	51–142	50–145	50–145
% of patients w/ postop hemoglobin <70 g/L	23.1	11.1	20.3
% of patients w/ postop hemoglobin <80 g/L	37.4	37.0	37.3
BV transfused (ml)			
mean	10.8	2.6	8.2
range	0–65.2	0–30.9	0–64.8

* Group 1 includes patients treated before 1996 and Group 2 those treated from 1996 onward. Abbreviations: BV = blood volume; CBL = calculated blood loss; EBL = estimated blood loss; EBV = estimated BV.

Cosmetic Outcome. At an average follow-up period of 26.1 months, the mean increase in the cephalic index compared with that measured preoperatively was 9.9% (Table 5). Similar values for pre- and postoperative cephalic indices were obtained in Groups 1 and 2. In three patients there was a decrease (worsening) in the cephalic index postoperatively. In two of these patients the indices had been significantly improved in the early postoperative period and gradually drifted toward a more scaphocephalic ratio over a mean of 4.3 years of follow-up observation, ending up with a lower cephalic index than preoperatively. Both patients were noted to have good cosmetic results, despite the worsened cephalic index. In the third patient the preoperative ratio was 0.78 and the postoperative ratio was 0.77 1 year after surgery, despite the fact that there

TABLE 3

Results of univariate analysis of continuous variables

Variable	Primary End Point*		Statistic	p Value
	Attained	Not Attained		
age (mos)	4.3 (1.9–81.3)	4.1 (2.1–28.9)	W = 3875.5	0.78
weight (kg)	7.2 (4.8–22.0)	6.8 (5.1–14.5)	W = 3006.0	0.63
duration of op (mins)†	92 (44–270)	90 (50–235)	$t_{116} = 0.59$	0.56
preop hemoglobin	115 (94–139)	112 (80–136)	$t_{116} = 1.84$	0.07

* Values are expressed as median (range). The end point was attained in 66 patients; it was not attained in 52.

† Time was log transformed for statistical testing.

TABLE 4

Results of univariate analysis of categorical (noncontinuous) variables

Variable	No. of Ops	No. Reaching Primary End Point (%)	χ^2	p Value
yrs of study			9.3	0.002
1986–1995	91	47 (52)		
1996–1999	27	5 (19)		
extent			NA*	0.001
basic	39	9 (23)		
moderate	68	34 (50)		
extensive	11	9 (82)		
surgeon			4.5	0.11
A	52	25 (48)		
B	52	18 (35)		
C	14	9 (64)		

* The Fisher exact test was used. Abbreviation: NA = not applicable.

was much cosmetic improvement. Only one patient underwent a repeated operative procedure. This child experienced elevated intracranial pressure and underwent a cranial expansion procedure 4.4 years after the original surgery. In two additional patients the cosmetic results were believed to be unsatisfactory by the surgeon. One of these patients suffered from fetal alcohol syndrome and the associated microcephaly was believed to be the major factor responsible for the poor result. In the other patient, a repeated operation was recommended, but the patient's parents did not believe the cosmetic issue warranted repeated operation. Since 1996, a planned occipital–frontal remodeling was aborted to avoid transfusion in only one patient. In that patient, the results of the surgery were good, with pre- and postoperative cephalic indices of 0.67 and 0.73, respectively.

Discussion

Surgical Outcome

A variety of surgical procedures have been described for the treatment of sagittal synostosis. Some authors have recommended a relatively simple technique such as strip craniectomy, relying, in part, on brain growth to remodel the skull shape.[10,13,25] Others have recommended a more complicated procedure aimed at the immediate correction of skull contour.[11,14,24] Endoscopic techniques have also been described more recently.[16]

The cosmetic outcomes of these various procedures have been compared.[2,6,14,18,21,26] The procedures used in the patients described in this study are variations of an extended strip craniectomy. Authors of previous reports have suggested that more extensive procedures (such as subtotal calvariectomy and remodeling) may produce head shapes with a more normal cephalic index than those achieved using extended strip craniectomies.[2,7,18,21,26] If the goal of surgery is to produce a normal cephalic index and one is not concerned about the need for a blood transfusion or other risks associated with the more extensive surgery, the more extensive procedure may be preferable. It is our opinion, however, that the goal should not necessarily be a normal cephalic index, but simply an improvement in the shape of the cranium, such that the child's appearance is considered "normal" by members of society and, in particular, the child's peers. Furthermore, we believe that one must balance the goal of this essentially cosmetic surgery with the operative risks, including the potential risks of allogenic blood transfusion. The average postoperative cephalic index reported here is consistent with those reported by other authors who perform extended strip craniectomies.[7,18,21,26] With hair growth and further skeletal development, the appearance of someone with a postoperative cephalic index in the range achieved in this group of patients would usually allow the child to pass for what is deemed normal. The assessment of cosmetic results after surgery for sagittal synostosis is subjective, but the fact that no patient underwent a repeated operative procedure for cosmetic reasons attests to the claim that the results were, at least, acceptable.

It is difficult to argue against more extensive procedures based on the complication rate alone, because the perioperative complication rate, even for much more radical craniectomies and calvarial remodeling, is low.[1,2,11,15,19] The operative times and hospital stays, when reported, are quite similar among the various procedures, with stays generally ranging from 3 to 5 days and operative times from 1 to 2 hours.[1,10,11,25] Only procedures in children older than 1 year of age are consistently longer.[14] A significant difference noted among procedures, especially for the series reported here, however, is blood loss and the need for perioperative transfusion.

TABLE 5

Operative results

Parameter	Group 1	Group 2	Overall
preop cephalic index			
mean	0.67	0.69	0.67
range	0.58 to 0.77	0.63 to 0.78	0.58 to 0.78
postop cephalic index			
mean	0.74	0.74	0.74
range	0.65 to 0.84	0.66 to 0.86	0.65 to 0.86
% correction			
mean	10.5	7.9	9.9
range	−1.5 to 35.5	−1.5 to 25.6	−1.5 to 35.5
follow up (mos)			
mean	30.6	11.0	26.1
range	0.1 to 41.3	0.1 to 41.3	0.1 to 112.3
hospital stay (days)			
mean	3.9	3.0	3.7
range	2 to 8	2 to 4	2 to 8

Transfusion Practices

Many authors have reported transfusion rates of nearly 100% for sagittal synostosis surgery[1,3,9,11,27] and most others have reported rates significantly higher than 50%.[10,19] The known risks of blood transfusion include hemolytic reactions, graft versus host disease, allergic reactions, electrolyte abnormalities, and the more publicly realized risks of hepatitis and human immunodeficiency virus.[17,30,33] The risks of transfusion can be acutely life threatening,[4] or may not be realized until years later.[5] In the setting of surgical correction for sagittal synostosis, which is almost entirely a cosmetic matter, and in light of public concern in Canada about the safety of blood, our position is that the risk of long-term morbidity can be decreased by minimizing the use of blood products perioperatively.

Over the course of the 14 years covered by this study, the rate of blood transfusion at our institution has gradually decreased from greater than 50% before 1991 (the initial years of the study) to 11% after 1995 (the most recent years of the study). The rate at which the primary end point was reached fluctuated between 35 and 75% from 1986 to 1995, but decreased to less than 20% after 1995. In the early years of the study (1986–1991), during which more than 50% of patients received transfusions, very few patients were found to have postoperative hemoglobin levels below 70 g/L (Fig. 1) and 74% of the transfusions occurred intraoperatively. This most likely reflected the common practice of transfusing blood once blood loss had begun, in an attempt to keep ahead of the expected blood loss, as well as the unwillingness to allow the postoperative hemoglobin level to fall below 70 g/L before initiating transfusion. In the middle years of the study (1992–1995), the rate of blood transfusion decreased to between 20 and 30%, and this was associated with a 40% rise in the percentage of patients in whom the postoperative level of hemoglobin was less than 70 g/L. There was no change in the percentage of patients who reached the primary end point (Fig. 3). The percentage of transfusions started intraoperatively decreased from 74% before 1992 to 50% during the years 1992 to 1995. These results suggest that the reduction in the transfusion rate in the middle years of the study may have occurred almost completely because of the willingness to accept a lower postoperative hemoglobin level and, specifically, to allow the hemoglobin level to fall below 70 g/L without transfusing blood. In the last 4 years of the study (1996–1999), the rate at which the primary end point was reached was reduced to less than 20% and the transfusion rate was 11%. The estimated and calculated blood loss also decreased. The fact that the calculated blood loss was on average twice that estimated at the time of operation has caused us to examine and reevaluate our estimations of intraoperative blood loss. The findings suggest that these most recent low transfusion rates were achieved not only by a willingness to accept a low hemoglobin level postoperatively, but also by implementing effective surgical techniques to limit intraoperative and perioperative blood loss. Based on the findings of the multivariate analysis, the most important factor in limiting blood loss was the trend toward a less extensive surgical procedure. In all cases a minimum of a vertex craniectomy and multiple parietal osteotomies were performed, but frontal remodeling, occipital craniectomy, or both were not performed as frequently after 1995. Indeed, one of the surgeons was prepared to terminate the procedure after the vertex and parietal craniectomies, if proceeding with a planned occipital or frontal remodeling would necessitate a blood transfusion. This occurred in only one patient.

Other surgical techniques, which could not be examined in this study, may have played a role in limiting blood loss. These included the use of the Colorado needle for the skin incision, application of microfibrillar collagen to the subgaleal flaps, and, perhaps, a more meticulous approach to obtaining rapid hemostasis. It is noteworthy, in this regard, that the length of surgery after 1995 was more prolonged, despite the trend toward less extensive surgery, and this may reflect a more meticulous approach to the surgery and hemostasis. Despite the increased operative times, there were no infections in this series.

The patient's age, weight, length of surgery, preoperative hemoglobin level, and surgeon did not have a statistically significant effect on the rate at which the primary end point was attained, according to either the univariate or multivariate analysis.

To avoid allogenic blood transfusions, complicated protocols have been devised, consisting of preoperative autologous donation, hemodilution, and intraoperative and postoperative blood salvage.[30] We have developed a much simpler approach that requires significantly less resource utilization. By meticulous attention to the prevention of intraoperative blood loss and by avoiding more complicated procedures than necessary to obtain a satisfactory cosmetic outcome, it has been possible to reduce the amount of blood loss. Nonetheless, one of the most critical aspects of avoiding blood transfusions has been a willingness to accept a lower postoperative hemoglobin level than that which is usually recommended. We are prepared to allow the level of hemoglobin to decrease as low as 60 g/L, as long as the patient's cardiovascular parameters are stable. It used to be said that a hemoglobin of 100 g/L was the lowest acceptable level during the postoperative period, because of concerns about cardiovascular and wound healing complications. Nevertheless, it is likely that such complications occur at much lower levels of hemoglobin than 100 g/L,[28] and indeed, in this series there were no such complications and no infections, even in patients in whom the hemoglobin level was lower than 70 g/L. Limiting the use of transfusions and acceptance of lower hemoglobin levels has been studied in other populations of patients and has actually been shown in some cases to reduce incidences of morbidity and mortality significantly.[12]

Conclusions

We have described an approach to the surgical management of sagittal synostosis in infants that involves extended strip craniectomy; this approach has been modified first to obtain acceptable cosmetic results and second to limit the use of blood products during the perioperative period. Acceptable cosmetic results and low blood transfusion rates can be achieved using simple techniques to minimize intraoperative blood loss and operative complexity, and by accepting a low level of postoperative hemoglobin. For children, who have many years of life ahead of them, the avoidance of even potential long-term morbidity is extremely important.

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