A Longitudinal, Statistical Study of Reoperation Rates in Craniosynostosis

J. Kerwin Williams, M.D., Steven R. Cohen, M.D., Fernando D. Burstein, M.D., Roger Hudgins, M.D., William Boydston, M.D., and Catherine Simms, R.N.

Atlanta, Ga.

A prospective, statistical study of reoperation rates was done in the treatment of 167 consecutive children with nonsyndromic and syndromic craniosynostosis over a 6-year period at Scottish Rite Children's Medical Center in Atlanta, Georgia. Mean length of follow-up was 2.8 years, with a range of 3 months to 6 years. Reoperation equal to or exceeding the magnitude of the original procedure occurred in 7 percent of cases. Multiple regression analysis revealed several factors associated with reoperation: Females and children with syndromic synostoses were more likely to require reoperation. Total reoperation rates for syndromic and nonsyndromic synostoses were 27.3 and 5.9 percent, respectively. Age at initial surgery, length of operation, and estimated blood loss did not predict a higher reoperation rate. (*Plast. Reconstr. Surg.* 100: 305, 1997.)

The rate of reoperation is an important outcome variable in the surgical treatment of craniosynostosis. Although quantitative changes in craniofacial remodeling are critical to understanding operative results, the decision to reoperate on a particular child is determined primarily from subjective measures of outcome, most commonly aesthetic appearance. Longitudinal studies of reoperation rates from a variety of centers are beginning to appear in the literature.[1–5] Herein, a prospective 6-year study of reoperation rates in the treatment of 167 children with nonsyndromic and syndromic craniosynostosis is presented. Preoperative, operative, and postoperative variables are analyzed to determine if clinical factors associated with reoperation can be identified.

Materials and Methods

From January of 1989 to January of 1995, 167 patients with craniosynostosis were managed surgically at the Center for Craniofacial Surgery at the Scottish Rite Children's Medical Center in Atlanta, Georgia. All children were seen by a multidisciplinary group and operated on by a team of craniofacial and neurosurgeons. Our protocols for management of nonsyndromic and syndromic patients are shown in Tables I and II. Sixty-one children were females and 106 were males, whose ages at the initial operation ranged from 2 weeks to 6 years (mean 1 year). Because of the recent controversy regarding diagnosis and treatment of posterior skull deformities, a review of patients with a diagnosis of lambdoidal synostosis is currently underway at our institution. Therefore, this group was excluded from the study. There were 12 children with bicoronal synostosis (7.2 percent), 39 with metopic synostosis (23.4 percent), 18 with unicoronal synostosis (10.8 percent), 46 with sagittal synostosis who had strip craniectomies (27.5 percent), 31 with sagittal synostosis undergoing total cranial vault reconstruction (18.6 percent), 9 with multiple synostoses (5.4 percent), and 12 with syndromic synostoses (7.2 percent) (Fig. 1). Only the neurosurgeon was involved if a strip craniectomy was carried out, but for the remaining patients, four combinations of teams conducted the operation. The length of operation (total anesthesia time) ranged from 81 to 570 minutes (mean 245 minutes). The mean estimated blood loss was 203 ml. In all, 23 percent of patients required no transfusion, 16 percent required less than 100 ml, and 61 percent required more than 100 ml. Thirty-four percent of patients were sent to the intensive

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TABLE I
Treatment of Nonsyndromic Synostosis

Sagittal synostosis (<7 weeks, mild to moderate deformity): Strip craniectomy
Sagittal synostosis (>7 weeks, severe deformity): Total cranial vault reconstruction at presentation
Unicoronal, bicoronal, metopic synostosis: Fronto-orbital remodeling, floating forehead at 4 to 6 months of age

care unit after surgery, while 67 percent were transferred to the floor. Mean length of hospital stay was 4.67 days. The children were followed either directly through clinic visits or indirectly through personal phone communication. No patients were lost to follow-up.

Reoperation was defined as total if the reoperation equaled or exceeded the magnitude of the original procedure and partial if it did not (Table III). Partial reoperations were almost always for recontouring with or without hardware removal and were excluded from this review. Hardware removal was recorded as a separate partial reoperation.

Statistical Analysis

Crude statistical analysis of reoperation rates following primary repair of craniosynostosis was carried out using Fisher's exact tests or generalized Fisher's exact tests because of the relatively small number of reoperations (7 percent).[6]

Interval variables such as operating times in minutes or length of hospital stay were analyzed with *t* tests. In some cases, Wilcoxon rank-sum tests appeared more valid given the skewed distributions of the interval variables.

TABLE II
Complications Requiring Reoperation

Sagittal		
Early strip craniectomy	(<7 mos)—None	
Late strip craniectomy	(>7 mos)—None	
Early vault remodeling	(<7 mos)—None	
Late vault remodeling	(>7 mos)—Significant relapse	
Metopic		
Suboptimal cranial contouring		
Bicoronal		
Suboptimal cranial contouring		×2
Significant relapse		×2
Unicoronal		
Residual plagiocephaly		
Suboptimal cranial contouring		
Multiple		
Significant relapse		
Syndromic		
Marked brachioturricephaly		
Significant relapse		
Significant relapse		

Options for multiple logistic regression analysis of total reoperation rates using some of the variables that appeared significant on crude univariate analysis were limited in this study. The rule of thumb is that the total number of variables in the logistic regression should be no greater than the smaller of 10 percent of the number of reoperations ($n = 12$) or nonreoperations ($n = 149$). This suggests that multivariable analysis is not possible. This criterion can be stretched in order to identify important relationships among the variables, but the results must be interpreted cautiously. Also, the power of the statistical test is not high due to the limited number of operations.

Results

Twelve of the 167 patients required a total reoperation (Table IV), for a reoperation rate of 7 percent (see Fig. 1). The mean length of follow-up was 2.8 years, with a range of 3 months to 6 years. When compared individually, there was no statistically significant difference in reoperation between the synostoses. However, when reoperation rates in syndromic patients (27 percent) were compared with those in nonsyndromic patients (6 percent), a statistical difference was found ($p = 0.037$, Fisher's exact test, two-tailed).

Five of the 12 reoperative patients (41.7 percent) were done for significant relapse, as demonstrated clinically and radiographically (Fig. 2). Neither early nor late sagittal strip craniectomies required reoperations; only one patient in the late cranial vault remodeling group for sagittal synostosis (>7 months) demonstrated relapse and reoperation. Relapse was seen in two patients with bicoronal synostosis requiring reoperation and two more patients in this group underwent a second procedure for suboptimal cranial contouring. Three patients with syndromic craniosynostosis required reoperation, two for relapse and the third for marked brachiturricephaly.

The rates of total reoperation significantly differed by gender (Fisher's exact test, $p = 0.029$). Of the female patients, 13.1 percent required reoperation, compared with 3.8 percent of the males. Other variables that initially appeared to be associated with a significantly increased risk of reoperation included the operating surgeon, but this trend did not persist with multiple variable analysis.

Descriptive analysis for the interval variables

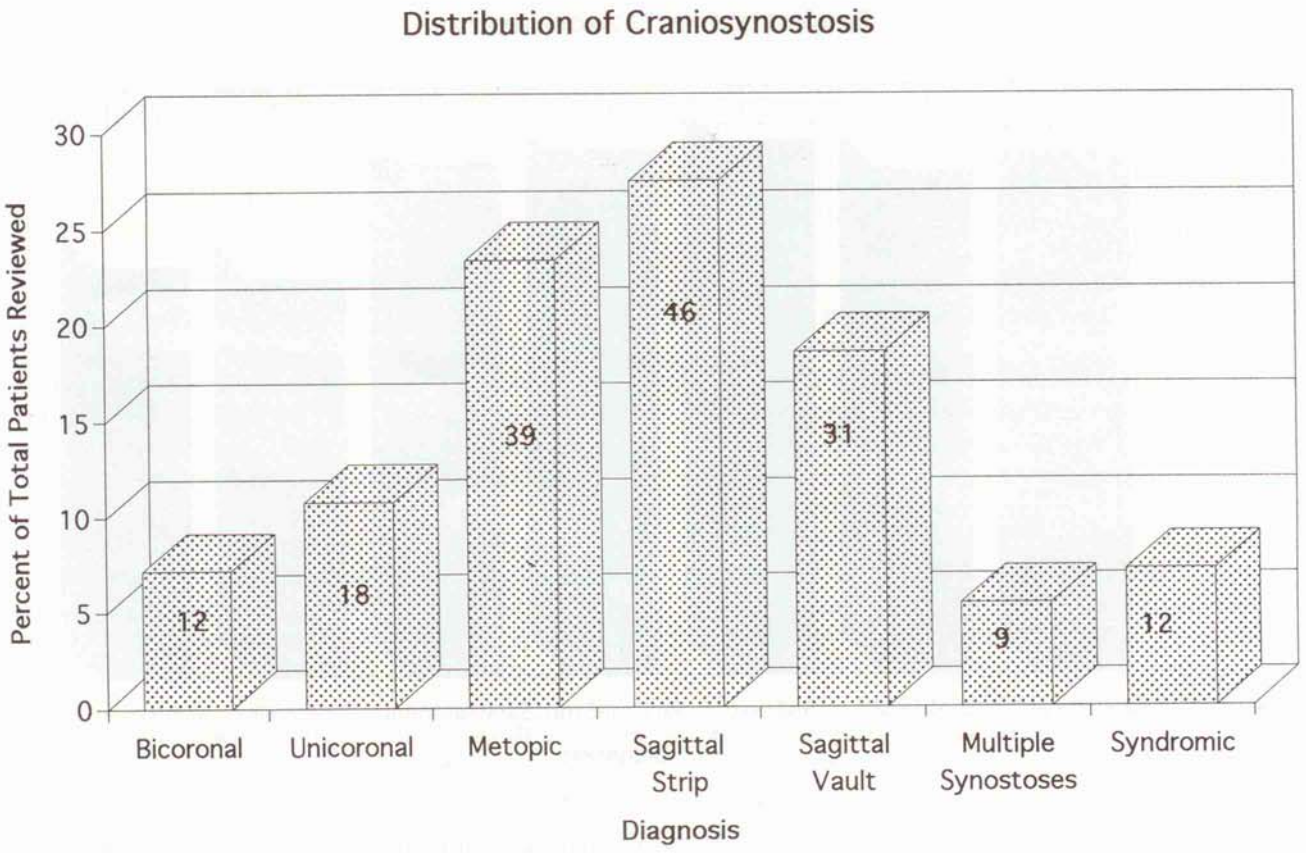

FIG. 1. The distribution of the various synostoses reviewed in this study.

also revealed several statistically significant indicators of reoperation. We found that the average length of hospital stay was longer in those patients who required a reoperation (Wilcoxon rank sum test, $p = 0.018$). Similarly, the median surgical minutes (total anesthesia time) in those requiring and not requiring reoperation were 298 and 242 minutes, respectively (Wilcoxon rank sum test, $p = 0.052$).

To date, 12 of the 167 patients (7 percent) have undergone bony recontouring with hardware removal, while 3 (2 percent) have had hardware removal only. These were not included in the total reoperative patient group.

TABLE III

Treatment of Syndromic Craniosynostosis

Fronto-orbital advancement, cranial reshaping at 4 to 6 months of age; earlier if increased intracranial pressure present
Redo fronto-orbital advancement, cranial reshaping as required at approximately 2 years of age*
Monoblock or Le Fort III with or without bipartition at 4 to 7 years of age
Orthognathic surgery at adolescence (after growth period)

* Reoperations evaluated in this study include this procedure.

Multivariable Analysis of Total Reoperation Rates

To implement a multiple regression analysis, we compared variables using three groups: syndromic, sagittal strip (plus vault reconstruction), and nonsyndromic. One control variable (i.e., diagnosis, gender, age at operation, estimated blood loss, transfusion, minutes of surgery, intensive care unit stay, length of hospital stay, complication, and length of follow-up) was added at a time. This permitted investigation into the joint effects of variables, demonstrating the degree to which specific findings did or did not change when controlling for one factor at a time.

Total reoperation rates for syndromic, sagittal strip (plus vault reconstruction), and nonsyndromic patients were 27.3, 6.5, and 5.9 percent, respectively (Table V). Generalized

TABLE IV

Indications for Reoperation (Total)

Aesthetic deformity
Increased intracranial pressure
Slit ventricle syndrome

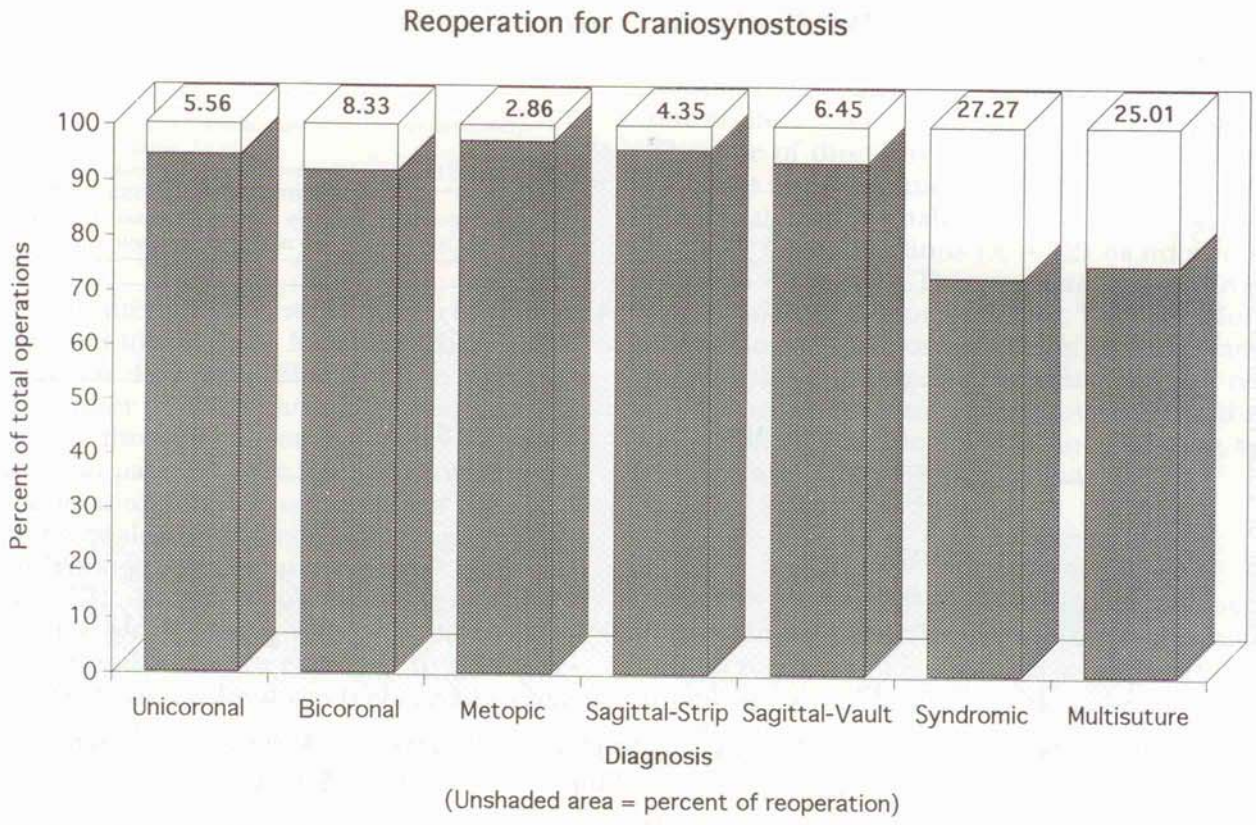

FIG. 2. The percentage of the total number of patients for a given diagnosis that underwent reoperation.

Fisher's exact test indicated that the reoperation rates differed in a statistically significant fashion ($p = 0.05$). Using odds ratios, we estimate that the odds of having a total reoperation were six times larger in the syndromic patients compared with the other groups.

TABLE V

Multivariable Analysis of Total Reoperation Rates*

Control Variable	Syndromic versus Nonsyndromic	Sagittal Vault versus Other	Only Control Variable (*p* Value)
None	6.0	1.1	—
Female gender	5.9	1.3	3.9 (0.04)
Age at surgery (1 year)	9.7	0.7	0.6 (0.19)
Blood loss (each 100 units)	6.4	0.4	1.1 (0.31)
Length of stay (days)	1.3	0.5	1.2 (0.07)
Length of surgery (each 100 minutes)	5.2	0.5	1.3 (0.53)
Months of follow-up	5.7	1.1	1.1 (0.74)
Any ICU stay	9.1	1.7	0.6 (0.59)
Any transfusion	6.3	0.5	2.3 (0.46)
Any complications	4.2	0.9	5.7
Early complications	4.4	0.8	2.4
Late complications	5.0	1.4	6.2

* The odds ratio for each variable is given independent of other variables and controlling for diagnostic group. For example, the risk of total reoperation for a female patient is 3.9 times higher than for a male patient. The variable is independent of the diagnosis (6.0 versus 5.9). On the contrary, the risk of total reoperation as the length of stay increases is marginal (1.1) but is directly related to the diagnosis (6.0 versus 1.3).

The effect of female gender on increasing the risk of total reoperation is statistically significant even after controlling for diagnostic group ($p = 0.04$). Using the adjusted odds ratio, females were 3.9 times more likely to require total reoperation than males. The multivariable analysis also indicates that gender and diagnostic group are both independent variables influencing reoperation rates. In other words, there were not more females in the syndromic group, negating the significance of the diagnostic category.

Age did not appear to have an effect on reoperation rates (Table VI). A 1-year increase in age at operation was not statistically significant after controlling for diagnostic group. The effect on reoperation rate of a 100-ml

TABLE VI

Age-Related Reoperation

	Total Reoperations	
	Yes	No
Number of patients	11	144
Mean age of initial operation	0.57 year	1.0 year
Standard deviation	0.52 year	1.27 years
Standard error	0.16 year	0.11 year

Note: $p = 0.03$.

increase in estimated blood loss was not significant after controlling for diagnostic group. Similarly, length of hospital stay, length of surgery, intensive care unit admission, and the amount of transfusion were not statistically significant after controlling for diagnostic category.

DISCUSSION

Outcome analysis functions to determine the efficacy and reasonability of a service or a product. This model is complicated in health care by the balance of cost containment with patient satisfaction and quality. Even so, application of outcome analysis provides the medical community with a method of comparing and adjusting practice modalities to meet specific demands. It also can provide a means of establishing and communicating standard of care levels to those involved in the health care industry.

This study was completed to evaluate the effectiveness of current treatment methods for craniosynostosis at our institution. It also provided additional information to an increasing amount of data regarding the reasonable expectation for reoperation as it relates to the nature of the deformity and characteristics of the patient. Analysis was limited to clinical outcomes; cost analysis was not included.

Effective use of outcome analysis within and between various centers requires well-defined, comparable treatment modalities. At our institution, fronto-orbital remodeling with a floating forehead was completed at 4 to 6 months of age for nonsyndromic synostosis other than sagittal synostosis[7,8] (see Table I). This approach is similar to treatment of isolated synostosis in several centers.[1,9,10] Bilateral fronto-orbital remodeling has been shown to be comparable with unilateral remodeling and was done in all cases.[2,8] Strip craniectomies were limited to sagittal synostosis with mild to moderate deformities. Total cranial vault remodeling was completed for severe deformities if greater than 7 weeks old.

Patients with syndromic craniosynostosis underwent fronto-orbital advancement and cranial reshaping at 4 to 6 months unless increased cranial pressure required decompression (see Table II). In this review, only frontal bone and skull deformities requiring reoperations were reviewed. Monoblock or Le Fort III advancements were done at 4 to 7 years old. Orthognathic surgery was then completed in adolescence. Again, reoperations for midface deformities were not included in this review.

Whitaker's classification of clinical results after a craniofacial procedure includes category III (C-III), requiring major bone grafting or other osteotomies, and category IV (C-IV), requiring duplication of the previous craniofacial procedure.[2] Total reoperations in our review were classified into the latter group. The increase in reoperation rates of syndromic patients was consistent with previous reviews. Whitaker et al.[2] showed a C-IV reoperation rate of 3 percent for asymmetrical lesions (isolated synostosis) and 64 percent for the symmetrical lesions (95 percent in Apert syndrome). Excluding strip craniectomies, McCarthy had a 6.7 percent reoperation rate for isolated synostosis and 28.3 percent for syndromic deformities.[7,8] Again, the highest reoperation rate was found in Apert syndrome (37.5 percent). Finally, Wall et al.[1] demonstrated a reoperation rate of 5.1 percent for single-suture synostosis and 10.8 percent for syndromic patients. Surgical approaches similar to ours were utilized in each of the aforementioned studies. Other studies demonstrated similar differences in the reoperation rate between the two groups but were not comparable in surgical technique.[5,10]

In most studies, no differences were seen in reoperative rates for treatment of single-suture stenosis as related to age; recommendations for primary intervention ranged from 2 to 18 months.[2,4,10] High reoperative rates in symmetrical deformities led Whitaker et al.[2] to recommend late surgery unless psychosocial issues demanded earlier intervention. Wall et al.[1] showed an increased reoperation rate of 20 percent in nonsyndromic synostosis when primary treatment was at less than 6 months of age compared with 5.6 percent in patients greater than 6 months old. In syndromic disorders, patients less than 6 months old had a 30.2 percent reoperation rate, compared with 9.1 percent when greater than 6 months old (40.9 months of follow-up). Other reviews have shown no relationship between age and reoperative rates.[11,12] In our study, multivariate analysis demonstrated no relationship between age at initial treatment and need for reoperation in either group (see Table IV). The median number of months from the time of the initial surgery to the reoperative date was 9.9 months. We agree that parents should be advised of the possibility of reoperation for any remodeling procedure.

The highest reoperative rate in nonsyn-

dromic children was found in bicoronal synostosis. Of children with single-suture synostosis, reoperative rates were highest with sagittal fusion requiring total vault remodeling (6.45 percent). The technical aspects of total vault remodeling used for severe sagittal synostosis have been described previously by us.[13] Average follow-up was 36 months. Reoperative rates in metopic fusion was decreased from 8.7 percent reported previously to 2.86 percent in this study, with an average follow-up of 42 months.[14] No statistical significance was found in reoperative rates for the various single-suture synostoses.

Though descriptive indicators of reoperation were identified with univariate analysis (length of hospital stay, surgical time, complication rates), these indicators were not significant when scrutinized under multivariate analysis. Only diagnostic category and gender (females over males) were found to be independent predictors of increased reoperation rates. The reason for the increased odds ratio associated with females is unknown. Since multivariate analysis has not been done for this variable in other studies, comparisons cannot be made.

Finally, there did not appear to be an increase in reoperation rates over longer periods of follow-up. Although this number may change as the mean length of follow-up increases, it is conceivable that only short follow-up times are necessary to reveal a very important outcome measurement—reoperation.

Outcome analysis of craniofacial procedures is an important tool for establishing standards of care, comparing results between centers, and allowing effective interaction with third-party payers. We found the probability of reoperation in the treatment of isolated synostosis to be 6 percent, and this was unaffected by the age at treatment. Syndromal synostosis increased the chance of reoperation sixfold. Further stratification of severity in syndromal craniosynostosis is required to predict more accurate reoperative outcomes for the various disorders.

Steven R. Cohen, M.D.
Center for Craniofacial Disorders
Suite 500, 975 Johnson Ferry Road
Atlanta, Ga. 30342

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