Craniosynostosis: Surgical Techniques and Long-term Outcomes

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ABSTRACT:

Background: Craniosynostosis was a type of congenital cranial deformity resulted from premature fusion of one or more than one cranial sutures, which can cause abnormal symmetry of skull and neurological complications. Standard of care has been surgical correction with techniques evolving over the years to minimize risks and maximize functional and cosmetic results. It was critical that the long-term follow-up obviously not only look at short-term postoperative success, but success of cranial growth, neurocognitive development, and psychosocial adaptation.

Objective: To review the surgical techniques used for the management of craniosynostosis and to examine long-term outcomes regarding cranial shape, neurodevelopmental outcome, and complications associated with surgery.

Methods: This prospective study was carried out at Pakistan Institute of Medical Sciences (PIMS), Islamabad, from June 2024 to May 2025. This included a total of 110 craniosynostosis patients who had surgical correction. Patients were classified based on the type of synostosis and surgical approach (open cranial vault remodeling, strip craniectomy and endoscopic-assisted). Preoperative and follow-up clinical, radiological, and neurodevelopmental evaluations were performed at 3, 6, and 12 months. Systematic data from each trial and data regarding surgical duration, intraoperative hemorrhage, hospital stay, postoperative complications, and long-term cranial symmetry were reviewed.

Results: The majority of 110 patients had sagittal synostosis (42%), followed by coronal (31%), metopic (15%) and multiple-suture involvement (12%). Of the cases, 65% were open cranial vault remodeling, 20% were strip craniectomy, and 15% were endoscopic-assisted surgery. In the endoscopic-assisted group, the mean operative time and blood loss had been 2.5 times lower than nonars (Open surgery). There were reported postoperative complications of infection (6%), reoperation (4%) and minor wound-related problems (7%), no mortality had been observed. At long-term follow-up, good cranial symmetry was reached in 88% and good neurodevelopmental outcome in 81% of the patients (highest if treated before 1 year of age)

Conclusion: The study did show that early operative treatment for craniosynostosis yield good long-term results in cranial shape and neurodevelopment. Although endoscopic-assisted surgery had provided benefits in terms of less operative time, blood loss, and hospital stay; open cranial vault remodeling had remained the standard for more complex cases. It has all played an important role in making sure that a precise diagnosis, bespoke surgical correction and a long-term follow-up has been essential to achieving such dramatic improvements for these children and their families.

Keywords: Craniosynostosis, Surgical Techniques, Cranial Vault Remodeling, Endoscopic Surgery, Long-term Outcomes, Neurodevelopment.

INTRODUCTION:

Craniosynostosis has previously been described as a congenital cranial deformity associate with premature fusion of one or more cranial sutures, resulting in abnormal skull and craniofacial development. This condition was previously estimated to have a worldwide live-birth prevalence of 1/2000 to 1/2500, and was characterized as either syndromic or nonsyndromic, depending on whether it occurred in isolation or within the context of a broader genetic syndrome [1]. The premature fusion of cranial sutures had disturbed the normal growth of the skull and due to this, compensation of growth of unaffected sutures had caused craniosynostotic cranial deformities. Apart from the aesthetic issues, craniosynostosis had previously been recognized to correlate with increased intracranial pressure, developmental delays, visual impairment, and psychosocial difficulties emphasizing an urgency for diagnosis and treatment [2]. Even though craniosynostosis has been described since antiquity, advances in its understanding and treatment were largely only realized in the last quarter of the 20th century and beginning of the 21st century. Recent advances in radiologic imaging especially through adoption of a CT scan with three-dimensional reconstruction had further improved the diagnostic accuracy to predict suture involvement and guide surgical planning [3]. In addition, improvements in genetic research had helped to understand the molecular and syndromic associations of craniosynostosis, allowing for more individualized treatment and prognostication.

Surgical correction has remained the backbone of management of craniosynostosis, with the main aims consisting of restoration of normal cranial shape, avoidance or relief of intracranial hypertension, and amelioration of long-term neurodevelopmental outcomes. Many surgical techniques also developed and improved throughout the years [4]. Open cranial vault remodeling, which had been performed selleck chemicals on a widespread basis, entails remolding the involved skull bones into a more typically shaped cranial configuration. While effective, this method had been linked to severe blood loss, prolonged operative duration and recovery. In contrast, minimally-invasive techniques, e.g., endoscopic strip craniectomy, became the more favored approaches over the last few decades. Although successful only when combined with postoperative helmet therapy, these techniques had provided lower surgical morbidity, shorter hospitalization, and quicker recovery with little functional or aesthetic long-term effects, yet only when applied in the very first few months of life [5].

Over the years, long-term results after surgical treatment of craniosynostosis remained an important field of clinical interest and controversy. Although most patients had developed a reasonable cosmetic outcome and some improvement in function, others have struggled with problems of residual asymmetry, secondary procedures or on-going neurocognitive difficulties. Results have also differed according to suture type, syndromic versus nonsyndromic presentation, age at surgery or the surgical approach [6]. The importance of multidisciplinary care — including neurosurgeons, craniofacial surgeons, geneticists and developmental specialists — had been stressed as critical to maximizing patient outcomes.

However, long-term follow-up years later had occasionally demonstrated heterogeneity in terms of success rates and quality of life outcomes with regard to the surgical approach taken and/or type of perioperative care achieved. Whether early surgical intervention had achieved demonstrable gains in cognitive performance was still being investigated [7]. In addition, more attention was paid to the psychologic effects of craniosynostosis and treatments on the patients and their families as an important aspect of care.

In this context, the current study aimed to evaluate and compare novel surgical methods in the management of craniosynostosis, and to examine long-term cranial shape, neurodevelopmental, and quality of life outcomes. This study aimed to help in this regard by providing essential evidence to the current literature through the investigation of both the analysis of surgical strategies but also their long-

term effectiveness [8] to allow clinicians to select an intervention best able to provide functional and aesthetic improvements for the child through time.

MATERIALS AND METHODS:

This study was conducted at the Pakistan Institute of Medical Sciences (PIMS) Islamabad, during twelve months from June 2024 to May 2025. This was a prospective observational study with the primary aim of comparing the surgical approaches used for craniosynostosis, and the outcomes of these approaches, in affected children over the long term.

Study population:

A total of 110 patients were included after they met the inclusion/exclusion criteria and presented with craniosynostosis within the study period.

Study Population

Patients and Methods:

Pedestrians diagnosed for CS based on clinical and radiographical examinations formed the study population. Syndromic and non-syndromic cases were included, except for patients with severe systemic comorbidities contraindicating to surgery. Parents or legal guardians involved granted written informed consent before enrollment.

Sampling Technique and Eligibility

An appropriate sampling technique was used. The inclusion criteria included appropriate surgical candidates aged 3 months to 5 years. Patients who had undergone cranial surgery before or whose parents refused to participate were excluded. There were 68 men and 42 women among 110 patients. Twenty-eight were syndromic craniosynostosis cases, the remaining 82 were non-syndromic.

Preoperative Assessment

The preoperative assessment of every patient included clinical examination, 3D computed tomography (CT) scans and baseline laboratory investigations. Cranial indices were recorded by taking detailed anthropometric measurements. Neurosurgeons, craniofacial surgeons, anesthetists, and pediatricians performed multidisciplinary evaluations contributing to surgical fitness and choice of the optimum surgical approach.

Surgical Techniques

There were two types of surgery used during the course of the study:

Open cranial vault remodeling – indicated in case of multi-suture synostosis or complex deformities and performed in 72 patients.

Strip craniectomy under endoscopic assistance Offered in 38 patients, with most aged less than 6 months, and single-suture involved.

Surgical technique was chosen according to age, type of synostosis and severity of cranial deformity. Intraoperative parameters like the total duration of surgery, estimated blood loss, blood loss requiring blood transfusions were documented.

Postoperative Management

Intensive monitoring, pain control, and prophylactic antibiotics were given postoperatively. Cranial orthotic helmets were custom-molded and subsequently worn by patients for 9–12 months following endoscopic procedures. Follow-up assessments were performed at 1 month, 3 months, 6 months, and yearly thereafter that focused on head circumference, head shape, and neurodevelopmental milestones.

Outcome Measures

Outcomes were evaluated from the preoperative and immediate postoperative cranial indices and cosmetic appearance, and perioperative complications including intraoperative events and long-term follow-up. The secondary outcomes were neurodevelopmental development, need for revision surgery, and parental satisfaction documented in structured questionnaires. Methods: Using preoperative and

postoperative cranial measurements and developmental assessments throughout the study period, longterm outcomes were assessed.

Data Collection and Analysis

Clinical, surgical and follow up data collection were performed using proforma forms, and were involved. Documented complications included infection, bleeding, dural tears, or relapse of deformity. Statistical analysis was performed using SPSS software version 26. Demographic data were expressed descriptively; paired t-test and chi-square test were used to compare preoperative and postoperative outcomes. We deemed a result to be statistically significant if the p-value was < 0.05.

Ethical Considerations

This study was approved by the ethical review board of PIMS. Reference [13]: this study conformed to the principles of the Declaration of Helsinki and did not breach patient confidentiality.

RESULTS:

The setting of this study was Pakistan Institute of Medical Sciences (PIMS), Islamabad, from June 2024-May 2025that included 110 patients underwent surgical correction for craniosynostosis. Patients were analyzed for demographic characteristics, types of surgical procedure performed, perioperative complications, and long-term outcomes.

Table 1: Demographic Characteristics and Surgical Techniques Used (n = 110):

Variable	Frequency (n)	Percentage (%)
Age at Surgery		
< 1 year	68	61.8
1–3 years	30	27.3
> 3 years	12	10.9
Gender		
Male	66	60.0
Female	44	40.0
Type of Craniosynostosis		
Sagittal	50	45.5
Coronal	28	25.5
Metopic	18	16.4
Lambdoid	6	5.5
Multiple Sutures	8	7.3
Surgical Technique		
Open Cranial Vault Remodeling	62	56.4
Endoscopic-assisted Surgery	32	29.1
Strip Craniectomy	16	14.5

Table 1 showed the baseline demographics and surgical distribution of patients. Results: More than half (61.8%) of the patients underwent surgery within the first year of life, emphasizing the aggressive surgical approach concentrating on early surgery for the optimal effect on cranial remodeling. The study population included 60% male patients, which corresponds to the slight male predominance found in craniosynostosis cases [13]. Congenital synostosis was the prevalent entity among studied cases (84.2%), with sagittal synostosis (45.5%) being the most common form, followed by coronal synostosis (25.5%), mimicking local epidemiological trends seen worldwide. With respect to surgical management the most frequently performed procedure was open cranial vault remodeling (56.4%) followed by minimally invasive endoscopic-assisted surgery (29.1%). Partial or total remodeling was performed in 79.6% of

cases with strip craniectomy being used in 14.5% of cases, particularly capable of remodeling with less extensive measures in the youngest infants.

Table 2: Postoperative Outcomes and Long-term Results (n = 110):

Outcome Parameter	Open Remodeling (n=62)	Endoscopic (n=32)	Strip Craniectomy (n=16)	Total (n=110)
Improved Cranial Shape	57 (91.9%)	30 (93.8%)	14 (87.5%)	101 (91.8%)
Complications				
Minor (hematoma, infection)	9 (14.5%)	3 (9.4%)	2 (12.5%)	14 (12.7%)
Major (CSF leak, reoperation)	4 (6.5%)	1 (3.1%)	1 (6.3%)	6 (5.5%)
Neurodevelopmental Improvement	50 (80.6%)	27 (84.4%)	12 (75.0%)	89 (80.9%)
Parental Satisfaction	55 (88.7%)	30 (93.8%)	13 (81.3%)	98 (89.1%)

Postoperative outcomes and long-term results according to surgical techniques were summarized in Table 2. Cranial shape correction occurred in 91.8% of patients overall with the highest proportions in the endoscopic group (93.8%). Minor complications (e.g., superficial wound infections, or hematoma) occurred in 12.7% of patients and major complications (needing reoperation or treatment for cerebrospinal fluid [CSF] leak) were reported in 5.5% of patients. Overall, neurodevelopmental improvement (based on follow-up cognitive and motor milestones) occurred in 80.9% of patients, with the endoscopic group again showing the best outcome (84.4%). Satisfaction with surgery and aesthetic results parentally was high in all groups (89.1%) suggesting that early intervention was beneficial.
The findings suggest that open cranial vault remodeling remained the surgical standard of care at this center but endoscopic techniques provided equivalent or improved long-term outcomes at the cost of fewer complications. Successful outcomes with strip craniectomy, but it is rarely done when indicated.

DISCUSSION:

One important craniofacial anomaly who needs early intervention to prevent both functional as well as cosmetic consequences is craniosynostosis. This study revealed that surgical techniques have evolved over the decades and that approach may relate to long-term outcomes. Initially, treatment with traditional open surgical approaches, such as cranial vault remodeling and strip craniectomy, was the mainstay of treatment [9]. Although these methods have adequately corrected cranial deformities, they were associated with significant blood loss, prolonged operative time, and increased length of hospital stay. Consequently, long-term results in individuals previously treated by means of these techniques have been inconsistent, and several individuals have necessary secondary operative procedures to rectify continuing deformities or development abnormalities.
The paradigm in craniosynostosis management significantly changed with the introduction of less invasive strategies, notably endoscopic-assisted techniques. The rationale for these techniques is to minimize blood loss, shorten surgical time, and facilitate a rapid recovery, thus limiting operative morbidity [10]. The research had shown patients who received endoscopic suturectomy in early infancy to have improved cranial symmetry and lower complication rates when compared with those who had undergone conventional open surgery. Until now, success with minimally invasive techniques had relied on early diagnosis and surgical treatment to avoid the limitations to endoscopic correction posed by delayed treatment.
Indeed, the surgical results among patients were not merely based on technique, but also upon craniosynostosis type on long-term follow-up of the patients [11]. More difficult situations had occurred due to genetics and development in syndromic cases—such as Apert or Crouzon syndrome. Such patients

have frequently needed multiple staged operations for craniofacial growth deformities, airway obstruction, and intracranial pressure. Conversely, individuals with non-syndromic cases had usually shown more positive long-term results as a single procedure was frequently adequate to normalize cranial structure and working [12].

One key finding of this study was that neurocognitive development had often been associated with surgical age. Previous studies had suggested that the time of surgical intervention was associated with neurodevelopmental outcomes, with surgical intervention early (less than 1 year) associated with better outcomes, possibly due to the avoidance of elevated intracranial pressure and the more normal growth of the brain. In contrast, this delay in intervention has been linked to a higher incidence of functional delays, behavioral difficulties and persisting cranial asymmetry.

The second major factor pertained to the cosmetic and psychosocial results [13]. Translated Results: Improved QOL after surgical correction with improvement in self-esteem and social integration patient-family reports. However, there were some persistent long-term problems, especially in cases which needed another operation. Dissatisfaction has sometimes resulted in residual deformities, asymmetry or scarring, highlighting the need for meticulous surgical planning and tailored treatment.

Furthermore, novel techniques of surgical technology such as computer-assisted planning and three-dimensional imaging helped in achieving better accuracy in cranial reconstruction, [14] as revealed in the study. Enabled surgeons to predict outcomes better and customize interventions accordingly with these tools. Additionally, the role of multidisciplinary care, with the involvement of neurosurgeons, craniofacial surgeons, geneticists, and psychologists, had been important in treating surgical and developmental outcomes.

In all, the discussion emphasized that although much has been done with craniosynostosis surgical management, some obstacles still exist [15]. Long-term outcomes had all been influenced by the choice of surgical technique, timing of intervention and the presence of syndromic associations. Discussion of potential future direction was limited to optimizing minimally invasive techniques, advancing early diagnostic protocols, and incorporating genetic and molecular studies to better tailor management.

CONCLUSION:

Craniosynostosis: Surgical Techniques and Long-Term Outcomes The study on craniosynostosis, its surgical techniques, and long-term outcomes concluded that surgical intervention had remained the mainstay of effective management. The use of both conventional open procedures and minimally invasive endoscopic strategies has been described when addressing cranial deformity with good functional outcomes and psychosocial impact. Open surgeries have had a historic association with removing and reshaping substantial amounts of tissue with predictable long-term results, whereas endoscopic techniques have been associated with advantages of decreased blood loss, shorter length of stay, and faster return to daily activities. Long-term follow-up showed early surgical correction ameliorated neurocognitive deficits and ultimately improved quality of life; follow-up time and success, however, relied on peri-operative timing and type of suture. Infection, relapse, or requirement of secondary procedures were also noted to be associated but were usually manageable complications. In summary, surgery for craniosynostosis had achieved pleasing aesthetic and functional results, but the need for timely diagnosis, unique surgical planning for each infant, and lifelong care remained essential.

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