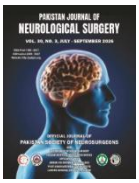

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Original Research

Surgical Outcomes of Strip Craniectomy in Metopic Craniosynostosis without Orthotic Helmet Therapy

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ABSTRACT

Objective: To evaluate the clinical and cosmetic outcomes of strip craniectomy performed without postoperative orthotic helmet therapy in infants diagnosed with trigonocephaly.

Materials and Methods: A prospective single-centre study was carried out at the Department of Pediatric Neurosurgery, The Children's Hospital Lahore, over a period spanning November 2021 to July 2023. Thirty consecutive patients under four months of age with confirmed metopic craniosynostosis were enrolled. All patients underwent strip craniectomy and were followed for twelve months postoperatively. Operative and outcome data were analyzed using SPSS version 27.

Results: The cohort comprised 30 patients with a mean age of 3.3 ± 0.8 months; 19 were male (63.3%), and 11 were female (36.7%). Mean operative duration was 58.2 ± 5.7 minutes, with an average blood loss of 30 ± 5 mL. Perioperative complications included surgical site infection in two patients and a dural laceration in one, repaired intraoperatively without sequelae. No venous sinus injuries, air embolism, seizures, intracranial hemorrhage, or neurological deficits were recorded. Mean postoperative hospital stay was 3.0 ± 0.5 days. OFC improved from a preoperative mean of 39 ± 1.5 cm to 42 ± 1.4 cm at twelve months.

Conclusion: Strip craniectomy performed without adjunctive helmet therapy is a safe and effective intervention for trigonocephaly in resource-limited environments. Operating between 3 and 6 months of age leverages the plasticity of the neonatal calvaria and rapid cerebral expansion. Future multicenter studies with larger cohorts are needed to validate these findings.

Keywords: Metopic Craniosynostosis, Trigonocephaly, Strip Craniectomy, Orthotic Helmets, Pediatric Neurosurgery.

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INTRODUCTION

Craniosynostosis (CSO) refers to the pathological premature fusion of one or more cranial sutures

during fetal or early postnatal life. When a suture ossifies prematurely, expansion of the skull perpendicular to that suture is abolished, and compensatory growth continues in a parallel direction, producing characteristic craniofacial deformity. The condition affects approximately 0.6 per 1,000 live births and may be classified as primary—either syndromic (involving multiple sutures and associated anomalies) or non-syndromic—or secondary, arising from metabolic, toxic, or hematologic disturbances.[1,2] Among non-syndromic forms, sagittal synostosis is most prevalent (40–60%), followed by coronal (20–30%) and metopic involvement (under 10%).[3,4]

Premature fusion of the metopic suture produces trigonocephaly, a condition characterized by a triangular or keel-shaped frontal contour, a palpable midline bony ridge, and bilateral restriction of frontal growth. Under normal developmental conditions, the metopic suture closes between four and nine months of age.[2,3] The reported incidence is approximately 1 per 15,000 live births, with a consistent male preponderance of roughly 75%. Recognized predisposing factors include low birth weight below 2.5 kg, maternal cigarette smoking, exposure to nitro-stable drugs, and autosomal dominant inheritance in some familial cases.[5] The phenotypic spectrum is broad and depends on when and to what degree the suture prematurely obliterates.[6]

Craniofacial features of trigonocephaly include a wedge-shaped forehead when the skull is viewed from above, reduction in anterior cranial fossa volume, anterior shift of the coronal suture, compensatory parietal-occipital bossing, and variable degrees of hypotelorism. A minority of patients (fewer than 10%) harbour chromosome 19p deletions and may exhibit intellectual impairment. Uniquely among single-suture synostoses, trigonocephaly has been consistently associated with neuropsychological sequelae and neurodevelopmental delay, making timely diagnosis and management particularly important.[6,7]

Plain skull radiography, using anteroposterior, Towne, and lateral projections, can reveal sutural obliteration, parasutural sclerosis, and narrowing. Computed tomography with three-dimensional reconstruction provides a definitive assessment of sutural anatomy and is the preferred confirmatory investigation in equivocal cases.[8]

Surgical options for metopic craniosynostosis include open strip craniectomy, endoscope-assisted craniectomy, spring-mediated cranioplasty, distraction osteogenesis, orthotic moulding, and total calvarial reconstruction. The most appropriate timing of elective correction remains debated. Operating between three and six months of age offers practical advantages: the neonatal calvaria is inherently pliable and easily reshaped, and the rapid cerebral growth at this age drives passive remodelling of the cranial vault without additional orthotic force.[9]

The classical open technique for trigonocephaly involves bifrontal craniotomy with fronto-orbital advancement, calvarial recontouring, and bone flap remodelling.[6,10] Endoscopic strip craniectomy combined with postoperative helmet therapy over 9–12 months yields favorable early outcomes; however, helmet effectiveness depends on consistent daily wear of at least 23 hours and precise, repeatedly adjusted fitting. In addition to the physical burden these places on infants and caregivers, non-compliance significantly compromises cosmetic results.[10]

In the healthcare context of Pakistan and comparable developing countries, helmet therapy presents formidable barriers: high cost, limited availability of orthotics services, frequent adjustment visits—particularly burdensome for families travelling long distances—and limited caregiver health literacy. The present study was therefore designed to determine whether strip craniectomy without postoperative helmet therapy can achieve satisfactory outcomes in infants with trigonocephaly managed in this resource-constrained setting.

MATERIALS AND METHODS

Study Design, Sampling Technique and Setting

This prospective study was conducted at the Department of Pediatric Neurosurgery, University of Child Health Sciences, The Children's Hospital, Lahore, from November 2021 to July 2023. Ethical approval was granted by the institutional review committee (Reference No. 614/CH-UCHS). Written informed consent was obtained from the parent or legal guardian of each participant. Consecutive sampling was employed.

Inclusion and Exclusion Criteria

Infants aged four months or younger presenting with trigonocephaly secondary to isolated metopic craniosynostosis were eligible for inclusion. All enrolled patients were followed for twelve months postoperatively.

Exclusion Criteria

Patients older than four months, those with multi-suture synostosis, and those with significant concurrent systemic or craniofacial anomalies were excluded from analysis.

Preoperative Assessment and Data Collection

Following referral via the outpatient clinic, each patient underwent thorough history-taking and clinical examination. Computed tomography with three-dimensional reconstruction was performed when diagnostic uncertainty existed. Standard hematological and biochemical screening was completed, and one unit of matched blood was cross-matched preoperatively. Pre- and postoperative photographs were taken of each patient with documented parental consent. Demographic, clinical, operative, and outcome data were prospectively recorded on a standardized proforma and entered into SPSS version 27 for analysis.

Statistical Analysis

Statistical analysis was done using SPSS version 27. Continuous variables—including age, operative duration, blood loss, and occipitofrontal circumference—were summarised as mean ± standard deviation with stated ranges. Categorical variables were presented as frequencies and percentages. Preoperative and postoperative occipitofrontal circumference and cephalic index were compared using the paired t-test. A two-sided p-value was considered significant.

OUTCOME MEASURES

Cranial shape was assessed using the cephalic index (CI), calculated preoperatively and during follow-up visits. Cosmetic outcomes at 12 months were graded using the Whitaker classification system. Neurodevelopment was evaluated at each follow-up using the Denver Developmental Screening Test II (DDST-II), including motor, language, and social domains. Parental satisfaction was recorded at 12 months using a 5-point Likert scale, ranging from 1 (very dissatisfied) to 5 (very satisfied).

Surgical Technique

All patients were operated under general anaesthesia in the supine position. Prophylactic cefazolin was administered intravenously at induction. Intra-arterial blood pressure monitoring was established in every case. A 2.5 cm incision was marked at the hairline and infiltrated with local anaesthetic. Following skin incision, the dura mater was carefully dissected free from the inner calvarial surface using a Penfield dissector, with careful protection of the superior sagittal sinus throughout. A paramedian burr hole was created using a craniotome or hand perforator, subsequently enlarged with a Kerrison rongeur; a bony strip measuring 12–15 mm in width was then removed along the course of the fused metopic suture, extending from the anterior fontanelle to

the fronto-nasal junction. Haemostasis over exposed dura was secured with a topical haemostatic agent. Wound closure employed 3-0 Vicryl for the galea and 3-0 Prolene for skin. Patients received parenteral analgesia postoperatively and were discharged on the first postoperative day. Suture removal was scheduled at one week. Follow-up assessments were done at quarterly intervals for twelve months to document the occipitofrontal circumference, craniofacial morphology, neurodevelopmental milestones and seizure activity.

RESULTS

Demographic and Anthropometric Characteristics

Thirty patients with metopic craniosynostosis were enrolled. Sixteen patients (53.3%) were aged 1–2 months and 14 (46.7%) were aged 3–4 months, yielding a mean age of 3.3 ± 0.8 months. Nineteen patients were male (63.3%), and 11 were female (36.7%), reflecting an approximate 2:1 male-to-female ratio. The majority of the cohort (70%, n = 21) had a body weight between 5 and 8 kg at the time of surgery; the remaining 30% (n = 9) weighed between 3.5 and 5 kg.

Table 1: *Age Distribution of Patients.*

Age (Months)	Number of Patients (%)
1–2 Months	16 (53.3%)
3–4 Months	14 (46.7%)
Total	**30 (100%)**

Clinical Presentation

All 30 patients presented with the cardinal features of metopic craniosynostosis: a palpable midline metopic ridge, a keel-shaped triangular forehead, occipital flattening, and varying degrees of hypotelorism. No patient had features of raised intracranial pressure at presentation, and none had associated syndromic findings.

Operative Data

Mean operative duration was 58.2 ± 5.7 minutes (range 50–70 minutes). Mean intraoperative blood loss was 30 ± 5 mL. All procedures were completed without intraoperative blood transfusion. The excised bony strip measured 12–15 mm in width in all cases. No postoperative orthotic helmet therapy was prescribed to any patient.

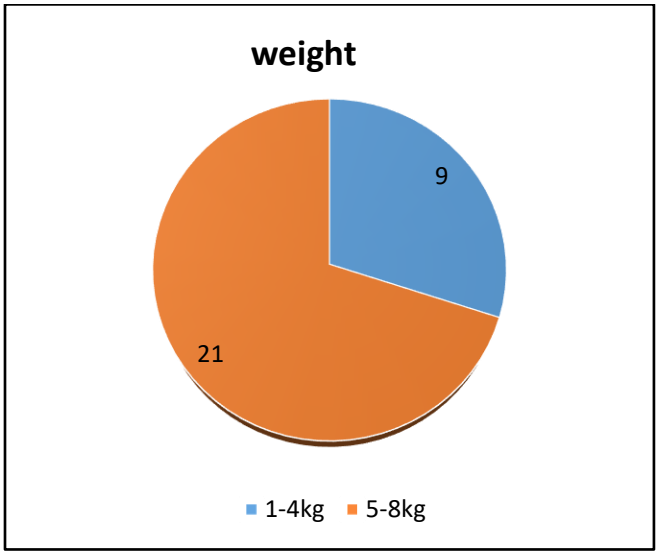

Figure 1: *Distribution of patient body weight at time of surgery. The majority (70%) weighed between 5 and 8 kg.*

(Parental written consent for clinical photograph publication was obtained for all images presented.)

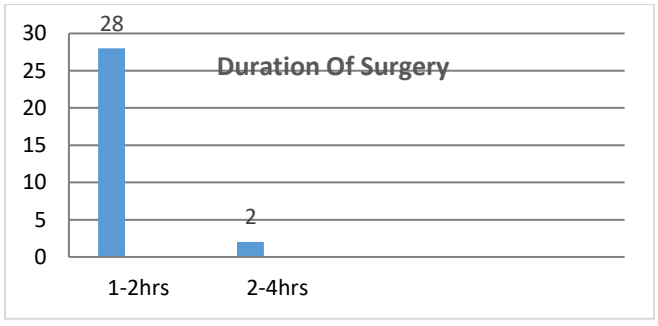

Figure 2: ***Mean operative duration across the cohort.***

Perioperative Complications

Complications occurred in three patients (10%).

Two patients developed postoperative surgical site infections that resolved with wound care and antibiotics without further surgical intervention. One patient sustained an intraoperative dural laceration that was repaired primarily without sequelae. No episodes of venous sinus injury, air embolism, new-onset seizures, intracranial haemorrhage, or postoperative neurological deficit were recorded. No patient required revision surgery.

Table 2. Perioperative Complications

Complication	n	Percentage (%)
Wound / Skin Infection	2	6.7%
Dural Tear (repaired intraoperatively)	1	3.3%
Venous Sinus Injury	0	0%
Air Embolism	0	0%
Postoperative Seizures	0	0%
Intracranial Hemorrhage	0	0%
Neurological Deficit	0	0%
Revision Surgery Required	0	0%

Postoperative Course and Length of Stay

The average postoperative length of hospital stay was 3.0 ± 0.5 days (range 2–4 days). In the majority of patients, discharge was planned on the first postoperative day; in a minority, stay was extended to two or three additional days for monitoring of wound healing and recovery observation. No intensive care unit admission was required.

Twelve-Month Outcomes

The mean preoperative occipitofrontal circumference (OFC) was 39 ± 1.5 cm (range 37–41 cm). At the twelve-month follow-up assessment, the mean OFC had increased to 42 ± 1.4 cm (range 40–44 cm), representing a mean gain of 3 cm. Serial photographic documentation confirmed appreciable improvement in cranial symmetry and correction of the triangular frontal contour in all patients. Neurodevelopmental assessment demonstrated age-appropriate milestones achieved across the entire cohort. No postoperative seizures were recorded during the follow-up period.

Cephalic Index

Before surgery, the average cephalic index was 70 ± 3 (range 67–76). This value is typical for the narrow, elongated head shape commonly seen in metopic synostosis. At the 12-month follow-up, the mean cephalic index had improved to 76 ± 2 (range 72–81). This increase was statistically significant ($p < 0.05$). The change shows a gradual return toward a more normal head shape, with better balance between the skull's width and length after the fused suture was surgically released.

Whitaker Outcome Classification

Cosmetic results were evaluated using the Whitaker classification system at 12-month follow-up. Twenty-six patients (86.7%) were rated as Category I, meaning they had excellent outcomes and required no additional surgery. Four patients (13.3%) were classified as Category II due to mild residual forehead asymmetry. No patients fell into Category III or IV. Overall, the vast majority of patients achieved good cosmetic results with surgery alone, without the need for postoperative helmets or orthotic therapy.

Neurodevelopmental Outcomes

Neurodevelopmental progress was assessed using the Denver Developmental Screening Test II at three, six, and twelve months after surgery. At the twelve-month follow-up, 27 patients (90%) showed completely normal development across all four domains: gross motor, fine motor-adaptive, language, and personal-social skills. Three patients (10%) had mild language delay noted at the six-month visit, but this had fully resolved by the

Table 3: *Summary of Operative and Outcome Data.*

Outcome Measure	Preoperative	At 12-Month Follow-Up
Mean OFC (cm)	39.0 ± 1.5 (range 37–41)	42.0 ± 1.4 (range 40–44)
Mean Operative Duration (min)	58.2 ± 5.7 (range 50–70)	—
Mean Blood Loss (mL)	30 ± 5	—
Mean Hospital Stay (days)	3.0 ± 0.5 (range 2–4)	—
Cranial Symmetry (photographic)	Triangular / wedge deformity	Marked improvement in all
Neurodevelopmental Milestones	Baseline	Age-appropriate in all patients
Seizure Activity	Absent	Absent throughout follow-up

twelve-month assessment. Importantly, no child showed any developmental regression during the follow-up period. These results support the understanding that timely surgical release in metopic craniosynostosis helps promote normal neurocognitive development.

Parental Satisfaction

At the 12-month follow-up, overall parental satisfaction was very high. Twenty-four parents (80%) rated their satisfaction as 5 (very satisfied). Six parents (19.7%) gave a score of 4 (satisfied). No parent reported being dissatisfied with the surgical outcome or with the decision to avoid postoperative helmet therapy. The mean satisfaction score was 4.77 ± 0.43.

Pre- and postoperative photographs illustrating the improvement in craniofacial morphology are presented below.

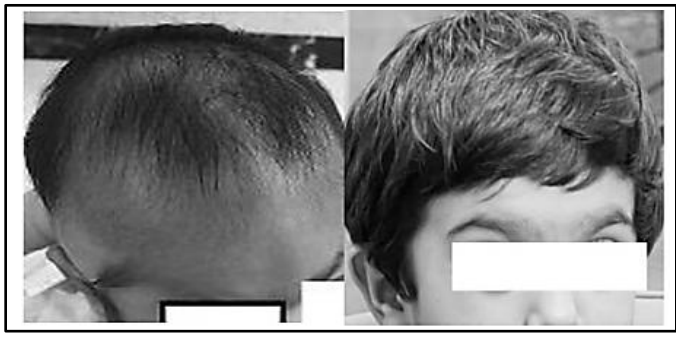

Figure 3: *Preoperative and twelve-month postoperative photographs demonstrating correction of triangular frontal deformity and improvement in cranial symmetry. Written parental consent for publication of clinical photographs was obtained before inclusion.*

DISCUSSION

In early infancy, the frontal bone consists of two lateral ossification centres separated by the unfused metopic suture, permitting biparietal expansion. When trigonocephaly develops, premature metopic obliteration arrests lateral frontal growth. Phenotypic severity varies with the extent of suture involvement: milder cases affect only the superior aspect of the suture, while more severe forms also implicate the presphenoid, mesoethmoid, and ectoethmoid components of the anterior cranial base.[6] Because anterior fossa volume is consistently reduced in this condition, surgical decompression serves a genuine neuroprotective function beyond its obvious cosmetic benefit, and is not merely a cosmetic intervention.

The optimal age for elective correction of trigonocephaly has not been definitively established. Accumulating evidence favours minimally invasive approaches over open calvarial remodelling in selected patients.[8] In our unit, strip craniectomy is offered to all patients younger than six months of age, with the preferred operative window below four months, when postoperative helmet therapy would conventionally be initiated to maximise the period of active cerebral expansion. In the present series, no patient received orthotic therapy, yet satisfactory craniofacial and neurodevelopmental outcomes were achieved across the cohort. A methodologically stronger evaluation incorporating larger patient numbers stratified by age would provide more robust statistical

validation and further define the optimal intervention timing.

Our demographic findings align well with those reported in a large multi-institutional retrospective series by Jimenez et al., which included 141 patients with isolated non-syndromic metopic craniosynostosis treated by endoscope-assisted craniectomy between 1998 and 2017.[12,13] That series documented a male-to-female ratio of approximately 3:1 (75.9% male), compared with 1.7:1 in our cohort (63.3% male); both confirm the well-established male preponderance in this condition. The mean operative age was 4.1 months in that series versus 3.3 months in ours. Mean body weight was 6.4 kg in the reference series compared with 5.4 kg in our patients, a difference likely attributable to the younger age at operation. Estimated intraoperative blood loss was comparable (33 mL versus 30 mL), as was mean operative time (56 versus 58.2 minutes). An earlier 2013 series of 16 patients documented substantially higher blood loss of 82.8 mL,[13] potentially reflecting differences in surgical technique or the older mean age of the patients operated.

Spring-assisted cranioplasty is a popular minimally invasive option for correcting trigonocephaly, especially in places where helmet therapy is not readily available. Studies show it delivers cosmetic results similar to endoscopic strip craniectomy with helmets. Its main advantage is that the springs apply continuous outward pressure without relying on patient compliance with an external device. However, it requires a second surgery to remove the springs around six months later, which adds anaesthetic risk and extra costs. In our resource-limited setting, simple strip craniectomy without helmets proved to be an effective single-stage approach. It achieved comparable early outcomes while avoiding both the compliance issues of helmets and the need for a planned second operation.

Concerning hospital stay, endoscopic series consistently report shorter admissions of approximately 1.6 days, compared with 3.0 days in our cohort, partly due to the need for preoperative admission for patient optimization and diagnostic evaluation in our low- to middle-income healthcare setting. The dimensions of the bony strip excised in comparable series (approximately 0.6 × 10 cm) were consistent with our practice of 12–15 mm width excision.

Regarding intraoperative complications, Engel et al, reported a dural laceration rate of 11.11% among patients who subsequently received helmet therapy [14,] while open surgical series have reported dural tear rates approaching 22%. Our dural tear rate of 3.3% (1/30) is considerably lower than both, likely reflecting the younger age at operation and the inherent compliance of the neonatal calvaria. Helmet-associated complications reported in other series—including contact dermatitis and pseudomeningocele formation—were expectedly absent in our helmet-free cohort.

The challenge of helmet therapy compliance has been extensively documented. Barriers include the substantial daily wear requirement, the need for repeated orthotics visits—especially burdensome for families travelling from distant regions—and the high cost of devices in lower-income settings.[15,16,17,18] Kim et al, highlighted that despite thorough preoperative counselling, compliance remained poor in a proportion of patients, contributing to inferior cosmetic outcomes.[15] In Pakistan, these barriers are compounded by limited caregiver health literacy and inconsistent follow-up. Our findings suggest that omitting helmet therapy does not necessarily compromise outcomes when strip craniectomy is performed sufficiently early to capitalise on the period of maximal brain-driven calvarial remodelling.

CONCLUSION

This study demonstrates that strip craniectomy performed without postoperative orthotic helmet

therapy is a safe, feasible, and effective treatment option for metopic craniosynostosis in young infants managed in resource-limited environments. The approach eliminates the operational and compliance burdens associated with prolonged helmet use while yielding low complication rates and satisfactory craniofacial and neurodevelopmental outcomes over twelve months of follow-up. Early surgical intervention at 3–4 months of age appears to favor the biological conditions for brain-driven calvarial remodelling, reinforcing the clinical imperative for early diagnosis and referral. The principal limitation of this study is the relatively small sample size of 30 patients; future multicenter prospective trials with larger cohorts and comparative arms are required to provide stronger evidence and more precisely define optimal operative timing.

Statement of Disclosure

The authors declare no financial relationships, competing interests, or personal affiliations that could have influenced the design, conduct, results, or interpretation of this study.

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Additional Information

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Human Subjects: Consent was obtained from all patients in this study.
Conflicts of Interest: In compliance with the ICMJE uniform disclosure form, all authors declare the following:
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Other Relationships: All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.
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AUTHORS CONTRIBUTIONS

Role	Contributing Author(s)	Role	Contributing Author(s)
Conceptualization	Jamal Nasir	Data Curation.	Rabia Saleem
Methodology	Rabia Saleem	Writing - Original Draft/Literature Review.	Rabia Saleem
Software	Jamal Nasir	Writing - Review & Editing.	Rabia Saleem
Validation	Faiq sheikh	Visualization.	Jamal Nasir
Formal analysis	Faiq sheikh	Supervision.	Faiq sheikh
Investigation	Usman Ajmal	Project administration.	Rabia Saleem
Resources	Usman Ajmal	Any other (Misc).	-