Surgical Management of Craniosynostosis

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Abstract

Background: Craniosynostosis affects approximately one in 2500 live births worldwide. Sagittal synostosis is the most common type. Metopic synostosis is the second most common, followed by coronal synostosis; lambdoid synostosis is rare. More than one suture is affected in 5 to 15 percent of cases. Craniosynostosis can be divided into simple and complex. Only one suture is involved in simple craniosynostosis. By contrast, in complex craniosynostosis two or more sutures close. Clinical diagnosis of craniosynostosis is not imminent in the neonatal period. it is difficult to ascertain whether it is deformational or true craniosynostosis. Plain radiographs can show either the fused suture, the concomitant stenotic ridge and exaggerated digital impressions, suggesting increased ICP. Surgery is indicated to prevent raised intracranial pressure and mental retardation and to reduce the impact of dysmorphisms on psychological behavior. The ideal timing window remains an issue of debate regarding concerns of patient stability during surgery due to blood loss, surgical complexity, and postoperative complications. Early surgery before 6 months prevents the dysmorphism from worsening, might benefit from passive postoperative remodelling due to the rapid growth of the brain in the first 6 months of life and malleability of calvarial bone. This malleability also facilitates intraoperative bone reshaping.But, Increased surgical and anesthetic risk in young infants is a common rational for the delay of craniosynostosis repair .many concerns regarding the surgical and anesthetic safety of open repair on infants under 6 months of age are related to hemodynamic instability. The optimal timing for primary cranial vault reconstruction in nonsyndromic craniosynostosis.

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Introduction

Craniosynostosis can occur not only in mammals, but also in other species even in fish. Craniosynostosis affects approximately one in 2500 live births worldwide. Sagittal synostosis is the most common type. Metopic synostosis is the second most common, followed by coronal synostosis; lambdoid synostosis is rare. More than one suture is affected in 5 to 15 percent of cases **(1).**

After **Virchow**'s law has been popularized, distinct morphologic characteristics of affected skulls give information about which sutures are fused. **Virchow** predicted that when a suture fuses prematurely, growth perpendicular to the affected suture is inhibited and compensatory growth of the skull progresses parallel to the affected suture **(2).**

The etiology of nonsyndromic craniosynostosis is unknown, and the condition is sporadic in most cases. van Cruchten, C , et al, 2021. Potential risk factors identified from previous studies include white maternal race, advanced maternal age, male infant sex, maternal smoking, maternal residence at high altitude, certain paternal occupations (e.g., agriculture and forestry, mechanics, repairmen), genetic mutations, exposure to

teratogens such as retinoic acid, nitrosatable drug, diphenylhydantoin, valproic acid, aminopterin, retinoic acid, and fluconazole Natrium valproate., mechanical stress, or result from certain metabolic disorders such as hyperthyroidism Higashino, T., & Hirabayashi, S. (2013)., or haematologic disorders and fertility treatments. Compression of the fetal skull by fetal positioning or by extrinsic compressive forces, such as uterine anatomy or a twin can result in closure along a specific suture**.** It can occur when brain growth fails, as occurs in extreme microcephaly and over-shunted hydrocephalus **(3)**

Familial nonsyndromic craniosynostosis, which affects 2 to 6 percent of infants with sagittal synostosis and 8 to 14 percent of infants with coronal synostosis, is transmitted as an autosomal dominant disorder **(4).**

Complex craniosynostosis includes the genetic syndromes such as Crouzon syndrome, Apert syndrome, Pfeiffer syndrome, Saethre–Chotzen syndrome , Carpenter syndrome and many other syndromes. The cranial suture complex is thought to be composed of the dura mater underlying the suture, the osteogenic fronts of the calvarial bone plates, the intervening cranial suture mesenchyme, and the overlying pericranium. Studies have shown the potential influence of dura mater on cranial sutures as the dura releases soluble factors that play an important role in maintaining normal suture patency and in guiding normal and pathologic suture fusion. Disturbance of the pressure that is exerted on that dura by growing brain and cerebrospinal fluid leads to disturbance in the balance between proliferation, differentiation , apoptosis and thus premature ossification within the suture **(5).**

Caniosynostosis can be divided into simple and complex. Only one suture is involved in simple craniosynostosis. By contrast, in complex craniosynostosis two or more sutures close **(2).**

Based on aetiology, craniosynostosis can be either primary or secondary. Primary craniosynostosis, the most common type, occurs in isolation. On the contrast, secondary craniosynostosis is associated with another disorder such as thalassemia, hyperthyroidism, haematologic and metabolic disorders as mentioned before **(6).**

Finally, craniosynostosis can be either nonsyndromic (isolated) or syndromic. In nonsyndromic or isolated craniosynostosis, there are no other evident abnormalities other than those associated with early sutural fusion, such as neurological , ophthalmologic or limb anomalies **(1).**

- **Primary (isolated, nonsyndromic) craniosynostosis**

1. **Scaphocephaly (sagital suture synostosis)**

Scaphocephaly , a Greek word for boat skull, describes the head shape that results from fusion of the sagittal suture. Scaphocephaly is the most frequent type of craniosynostosis. It has a strong male preponderance. Familial cases occur in up to 6%**.** Genetic disorders are seldom found **(7).**

The impaired growth of the skull width is compensated by excessive skull length.so the skull becomes long and narrow. Frontal bossing is a common sign, which tends to progress during the first year of life**.** Occipital bossing or cupping, also called the bullet, is less frequent and may be more pronounced in cases where fusion starts at the posterior end of the suture.A ridge can be palpated at the site of the sagittal suture. Signs of raised ICP are rare and occur in older children **(7).**

2. **Unilateral coronal suture synostosis(anterior plagiocephaly)**

Plagiocephaly literally means twisted head .Unilateral coronal synostosis is the third most frequently occurring single suture synostosis. The dominance of females over males is 69%. The right coronal suture is more affected than the left **(8).**

Coronal synostosis can present as an isolated sporadic form, as part of a syndrome or as a familial inherited condition. Familial cases range from 8.4 to 9.5% **(5).** In some of these families, unilateral coronal as well as bilateral coronal synostosis is observed. Gene mutations can be found in up to 20% of patients, including changes in FGFR2, FGFR3 And TWIST **(9).**

Unicoronal synostosis, or anterior plagiocephaly, is characterized by vertical dystopia, nasional deviation to the ipsilateral (affected or same) side, flattening of the frontal bone on the ipsilateral side and bulging of the frontal bone on the contralateral (opposite) side. Strabismus from ipsilateral superior oblique paresis and compensatory contralateral head tilt is present in 50–65% of cases of unilateral coronal synostosis **.** The upper margin is moved upwards and outwards with upward displacement of the sphenoid wing, which results in a "harlequin" or "Mephistophelean" look of the orbits**. (10).**

It has to be differentiated from postural plagiocephaly and from synostosis of the frontosphenoidal suture **(11).**

Bicoronal suture synostosis (Brachycephaly)

Brachycephaly, or "short head", results from synostosis of both coronal sutures. It occurs more often in the context of a syndrome but can also occur isolated. It is more common in females (66–79%) **(12).**

. A frequently identified genetic disorder is the FGFR3 mutation or Lajeunie-Muenke type craniosynostosis. Additional disorders may be identified in some of these patients, including brachydactyly, abnormalities on radiographs of hands and feet, sensorineural hearing loss and developmental delay. The skull is short, high and broad. The forehead is retruded and flattened or even concave in the inferior part; the superior part is bossing or growing vertically (turricephaly). The supraorbital rim is retruded. The infraorbital rim is normal, unlike in syndromic cases with midface hypoplasia. The nasal dorsum is low. Hypertelorism may be present. Especially in Lajeunie Muenke type craniosynostosis, temporal bossing may be prominent **(13).**

4. Metopic Synostosis (Trigonocephaly)

Metopic synostosis shows a male predominance of 75%; 2–6% of cases are familially, and some cases are syndromic. It is easily recognized by the triangular shape of the forehead (trigonocephaly) when viewed from above. The forehead is narrow and keel shaped. Ridging of the metopic suture can be seen and palpable. Hypotelorism, recessed lateral orbital rims and a diminished bi-temporal distance are additional findings**.** The upper margin of the orbit is moved upwards and inwards, giving the orbits the aspect of a "surprised racoon" **(14).**

5. Lambdoid Synostosis:

Lambdoid synostosis is characterized by an obliterated ipsilateral lambdoid suture that reduces the anteroposterior dimension of the posterior cranial fossa. The protruding contralateral suture and bulging ipsilateral mastoid process are distinguishing characteristics of lambdoid synostosis**.** The posterior cranial base will deviate to the ipsilateral side , whereas the anterior base is unaffected **(14).**

The greatest difficulty lies in differentiating between deformational plagiocephaly (plagiocephaly without synostosis) and lambdoid synostosis. Synostosis simply restricts growth on the ipsilateral side, but deformational plagiocephaly deforms by exerting force in a ventral direction. Thus, lambdoid synostosis involves the petrous portion of the temporal bone being pulled toward the closed lambdoid suture. Correspondingly, the external auditory canal is also pulled toward the fused suture. In contrast, both the petrous portion of the temporal bone and the external auditory canal are pushed anteriorly in deformational plagiocephaly. Ipsilateral frontal bossing occurs regularly in deformational plagiocephaly, but almost never in lambdoid synostosis **(16).**

Deformational forces, such as the prenatal head on the mother's pelvic bone or the birth process itself, can affect the shape of the skull. The infant brain grows rapidly during the first several months after birth and this growth expands the skull into its normocephalic shape and corrects the deformity. Infant head circumference increases 9 cm during the first 6 months and grows approximately 12 cm during the 1st year. The skulls of babies may become progressively more misshapen during the first several weeks after birth because of deformities from unrelieved pressure on the occipital bone. The infant spend approximately 700 hour sleeping in the first two months of his life. If the baby lies supine with his head turned to one side, either from preference or the head is not rotated to redistribute the deformational forces of gravity, positional plagiocephaly can result which can be further aggravated by torticollis **(16)**

- Multiple Sutures.

Multiple-suture synostosis is most commonly associated with syndromic cases but may occur as an isolated form. Different combinations of affected sutures give rise to different skull shapes. Oxycephaly occurs with coronal and sagittal synostosis. Pansynostosis refers to fusion of all sutures. However, when pansynostosis is accompanied by a microcephaly, there is no indication for surgery **(17).**

3. Syndromic craniosynostosis

Syndromic craniosynostosis is characterized by multiple suture synostoses involving both the neurocranium (calvarium and skull base) and the viscerocranium (orbital and midfacial skeleton), accompanied by other body deformities especially the limbs, cardiac, genitourinary and musculoskeletal. The cranial base

abnormalities are manifested by hypoplasia of the midface and maxilla. These children often have hypertelorism, exorbitism, syndactyly, cleft palate, cardiac anomalies, and eye muscle abnormalities (e.g., strabismus). Depending on the degree of severity, there are frequently associated medical problems, including: hydrocephalus, papilledema, respiratory distress, and failure to thrive.

An associated developmental failure of the middle third of the face in many of these conditions results in ocular proptosis with the risk of corneal damage following even trivial traumas, papilledema , optic atrophy. Furthermore, the underdevelopment of the airways may lead to alterations of respiratory function up to the most dreadful nocturnal apneas **(18).**

Although their etiology is not totally clear and the majority of the reported cases are sporadic, it is known that they have an autosomal dominant mode of inheritance. An affected individual always has a 50% chance of parenting a child who will be born with the same condition. Mutations in specific (FGFR) gene types for these syndromes have been identified **(19).**

1- Crouzon Syndrome (Craniofacial Dysostosis)

Crouzon syndrome is an autosomal dominant syndrome first described by Crouzon in 1912. Crouzon syndrome represents approximately 4.8% of cases of craniosynostosis at birth. The birth prevalence has been estimated to be 1:25,000 births **(20).**

In most of the cases, both coronal sutures are involved. The facial phenotype is characteristic and includes a hypertelorism with exorbitism, a short upper lip and a relative mandibular prognathism with an inverted bite. Ventriculomegaly is common and sometimes progressive. Chiari malformation is also quite common in this syndrome, found in approximately 70% of the cases. They may also have a conductive hearing loss. In general, these children do not have anomalies of the hands or feet **(20).**

2- Apert Syndrome (Acrocephalosyndactyly type I)

Apert syndrome is the most complex of the craniosynostosis syndromes**.** The incidence of this autosomal dominant condition is reported as 1/50,000 to 1/160,000 (**21).**

. Infants with Apert syndrome also characteristically have multiple-suture craniosynostosis. Their skulls are often very tall and turricephalic (tower-like). The forehead is extremely flat and elongated with bitemporal widening, bilateral flattening of the occiput and a "beaked" appearance of the nose. The classic distinguishing finding in infants with Apert syndrome is syndactly of the digits of the hands and feet. There may be shortening of the upper extremities, dental abnormalities (e.g., anterior open bite), cleft palate (they almost always have a very high arched palate), conductive hearing loss, cardiac anomalies and chronic acne (first noted in infancy)**.** Developmental delay and learning disabilities are higher in this group than in children with Crouzon syndrome **(22).**

3- Pfeiffer Syndrome (Acrocephalosyndactyly type V)

This syndrome, also autosomal dominant, has an incidence of approximately 1 in 200,000 and characterized by multiple-suture craniosynostosis, varying degrees of developmental delay, midface hypoplasia, and upper airway anomalies . These children commonly have very broad thumbs and great toes, and sometimes have syndactyly. **(23).**

4-Saethere-Chotzen Syndrome (Acrocephalosyndactyly type III)

This syndrome was first described by Saethre in 1931 and by Chotzen in 1932. The predominant features include a brachycephalic skull, a low-set frontal hairline, and facial asymmetry with ptosis of the eyelids. The mode of inheritance is autosomal dominant with wide variability in expression. The facial asymmetry is often accompanied by deviation of the nasal septum and maxillary hypoplasia with a narrow palate. Intelligence is usually normal. A partial syndactyly involving the second and third digits are often observed, and short stature is also a frequent finding **(24).**

5- Carpenter Syndrome

This is a rare genetic disorder characterized by a craniosynostosis of various sutures, leading to an asymmetric head, partial syndactyly of the digits usually involves the third and fourth digits, and preaxial polysyndactyly of the feet**.** The syndrome was first described by Carpenter in 1901. It is autosomal recessive . Low-set ears

and lateral displacement of the inner canthi are also prominent features. Mental deficiency has been reported, and congenital heart defects have been reported in as many as 33% of cases. (**25).**

Other Syndromes

There are several less commonly occurring craniosynostosis syndromes, including: craniofrontonasal dysplasia, Antley-Bixler and Jackson-Weiss Syndromes. In addition, there are almost 100 other "noncraniosynostosis" syndromes in which craniosynostosis may be a finding. Two common examples are Treacher Collins syndrome and craniofacial microsomia (**26).**

Treatment

Surgery is indicated to prevent raised intracranial pressure and mental retardation and to reduce the impact of dysmorphisms on psychological behaviour.

The ideal timing window remains an issue of debate regarding concerns of patient stability during surgery due to blood loss, surgical complexity, and postoperative complications .. Evaluation of Complications and Outcomes in Craniosynostosis by Age of Operation. Early surgery before 6 months prevents the dysmorphism from worsening, might benefit from passive postoperative remodelling due to the rapid growth of the brain in the first 6 months of life and malleability of calvarial bone. This malleability also facilitates intraoperative bone reshaping.But, Increased surgical and anesthetic risk in young infants is a common rational for the delay of craniosynostosis repair .many concerns regarding the surgical and anesthetic safety of open repair on infants under 6 months of age are related to hemodynamic instable. In cases of severe and symptomatic craniosynostosis, early CVR may offer patients a stopgap to allow for symptom resolution until the patient is stable enough for definitive or esthetic procedures. But, physiologic anemia in infancy, which reaches a hematopoietic nadir in the first few months of life exacerbates the morbidity of high blood loss in this young age group. 50% of children with cranial remodeling procedures before 6 months of age required subsequent major reoperation thus increases costs **(14).**

After 9 months of age, the definite skull shape can be obtained, the chances of regrowth and renewed constriction are smaller **(14).**

Children older than 3 years of age have harder, more brittle bone, and reconstruction requires larger scale bone removal with segmentation and rigid fixation to achieve adequate remodelling. In general, as the child get older , more extensive procedures, larger amounts of blood loss can be tolerated **(14).**

Interventions include simple strip craniectomies or extended strip craniectomies then relying on future cranial vault remodelling with brain growth or with the help of helmet therapy. This procedure can be done either open or by endoscope, a less extensive procedure with less blood loss but with high recurrence rate **(14).**

Strip craniectomies combined with use of springs prevents excessive blood loss. But, the rate of distraction might be variable and unpredictable. It also requires a second intervention to remove the springs(**26)**.

Distraction techniques are very useful in syndromic cases especially for mid face advancement which decrease the complications of blood loss, making the procedure more common in childhood. But like springs, need another session for removal. **(27).**

Calvarial reconstruction, total or subtotal, as a single stage or in two stages and are frequently used techniques an remains the gold standard method for correction of deformities of craniosynostosis. But , have the risk of more blood loss which mandates delay intervention till the patient can withstand the risk. Fixation can be done by sutures and plates either resorbable or temporary non resorbable, wires or a bone graft

Metopic Synostosis:

The goal of surgery is to eliminate the frontal keel, and to advance and widen the forehead. This can be achieved by burring down the keel only in very mild cases without significant temporal narrowing **(28).**

In severe cases, a bifrontal and bilateral orbital osteotomies is performed, followed by remodeling of the supraorbital rim and the frontal bone to a more normal orientation. flattening of the midline angle of the orbital rim is done either by breaking or by sectioning and refixing the midline. Lastly, the bilateral squamous temporal bones are outfractured **(14).**

. The lateral parts of the forehead have to be reconstructed in such way that the bi-temporal diameter is enlarged and even overcorrected. the temporalis muscle should be reinserted meticulously in order to prevent the temporal depressions so often seen after correction of trigonocephaly **(28).**

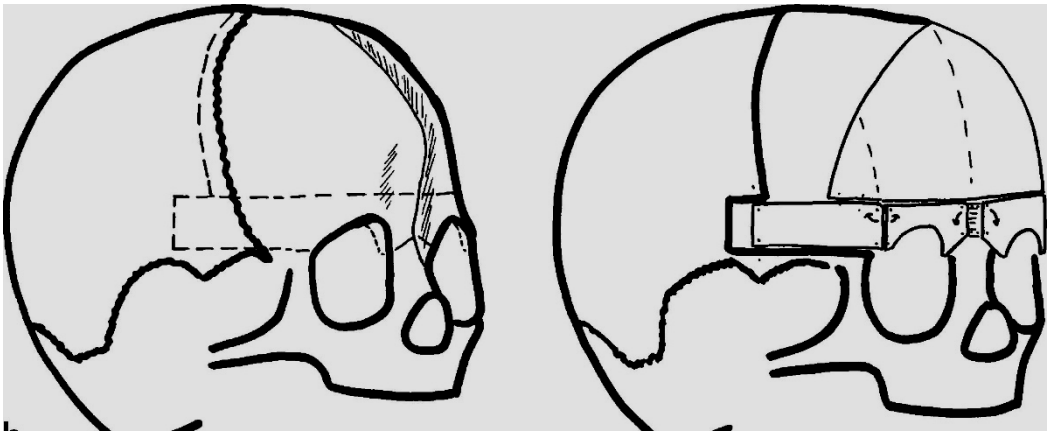


Diagram demonstrating Operating technique for metopic synostosis **(28).**

An isolated frontal ridge without the accompanying dysmorphisms of the orbit and temporal bone should not be considered for surgery; those ridges will remodel spontaneously during the first years of life

Unilateral coronal Synostosis:

The goal of surgery is to achieve forehead and orbital symmetry **(10).**

Significant contralateral compensatory deformity requires a bifrontal craniotomy, coupled with an extended unilateral or more often bilateral orbital roof osteotomy, with lateral cuts at the fronozygomatic sutures **(11).** Symmetry of the orbital rim and frontal bone is achieved by reducing the projection of the bulging side and increasing the projection on the flattened side. The frontal bone reconstruction may require osteotomies to achieve appropriate contouring **(8).**

Bilateral coronal synostosis:

Bilateral coronal synostosis is challenging to treat, mainly owing to the difficulty of reducing the height of the cranial vault **(12).**

Some surgeons prefer to perform staged anterior and posterior procedures, rather than a total calvarial reconstruction, although correction of the turricephaly may be easier to accomplish as a single procedure. Care is taken to minimize excessive blood loss and avoid unintended ICP elevations with the height-reduction step (**28)**

Postoperative Management:

Patients are observed clinically and neurologically in a high care or intensive care unit for 24 hours after surgery. Several independent risk factors for ICU admission have been identified by Goobie et al (31) :weight <10 kgs, ASA class 3 , red blood cell transfusion >60 ml /kg,intraoperative complication or use of hemostatic products(plasma, cryoprecipitate or platelets

Blood haemoglobin and haematocrit should be followed closely as blood loss may continue after the intervention. Fever is expected following the first days after surgery. If surgery involves reconstruction of the forehead and superior orbital rim, the eyes will be oedematous and difficult to open for the first two days. **(25).**

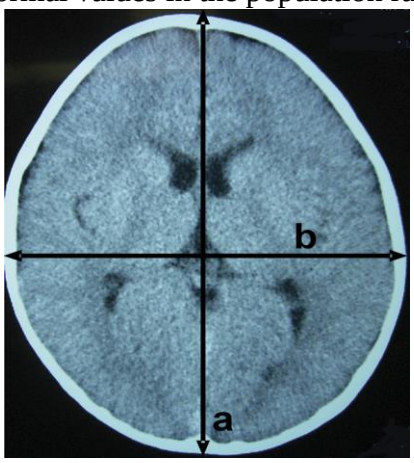
Successful correction of craniosynostosis can be measured in various ways, and long-term esthetic stability is the desired outcome. It was devised that the following classification system:

Category I— is defined as those patients in whom no refinements or surgical revision was advised or necessary per the patient or the surgeon

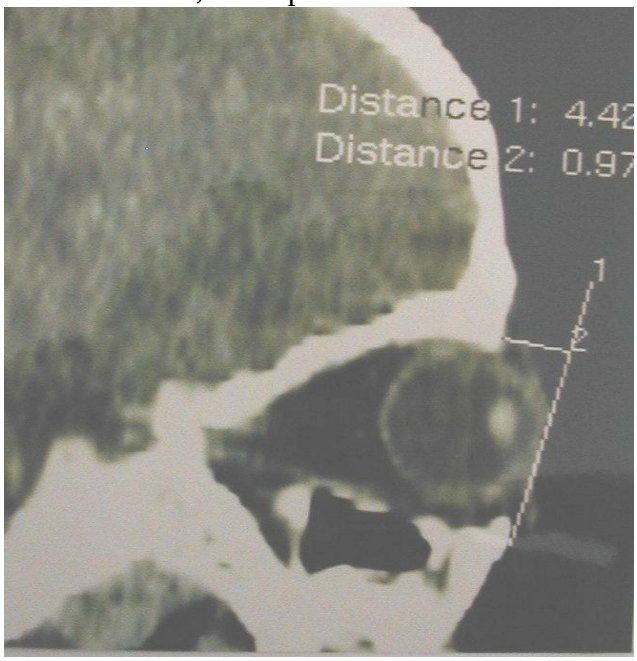
Category II— soft tissue or lesser bone contouring revisions were desired, regardless if performed or not.

Category III— major alternative osteotomies or bone grafting procedures were needed or performed, yet these procedures were not as extensive as the original procedure.

Category IV— a major craniofacial procedure was again or will be required, and the procedure will be either as great as or greater in magnitude than that of the original surgery.
Those in category I and II are considered to have at least satisfactory craniofacial form **(29).**
There are many objective ways of measuring the postoperative change that occur in the cranial bones following corrective surgery, including the cranial index , supraorbital projection. The cranial index is a ratio of the maximum cranial width over the maximum cranial length, clinically measured using cephalometric radiographs or better CT films. The normal values in the population range from 75% to 84% **(30).**

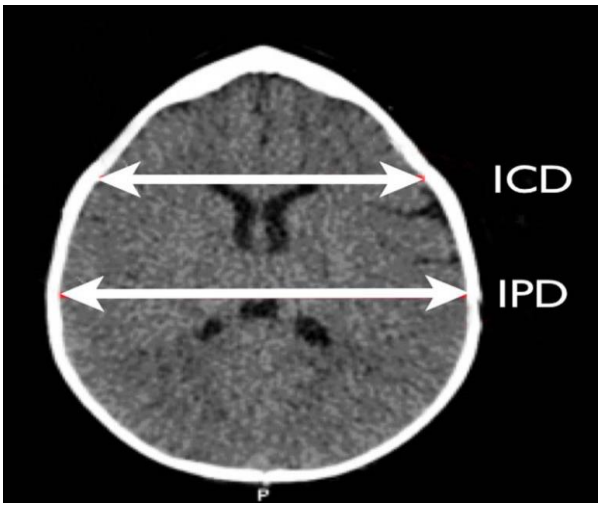


CT image showed the method used for measurement of the cranial index **(30).**
The supra-orbital rim projection can be measured from the longitudinal orbital projection by making a line extending from the midpoint of the inferior orbital rim tangent to the corneal surface upward..This line should pass through the supraorbital rim. Otherwise, the supraorbital rim is considered either retruded or ptotruded.



CT image demonstrates the supra orbital rim recession measurement of one of our patients

The severity of the metopic craniosynostosis can be assessed by measuring the interparietal distance IPD, between the outer skull tables at the widest points of the skull, and intercoronal distance ICD, between the outer skull tables at the level of the anterolateral corners of the lateral ventricles. It was determined that the IPD/ICD to be 1.21 in normal children.



Complications of surgery

The most common intraoperative complication is a dural tear.Infections which increases with the duration of surgery, the combination of intracranial and extracranial intervention, age of the child, redo cases and number of surgeons present in the operation theatre. Postoperative infection is associated with bone reabsorption and persistent defects…. Evaluation of Complications and Outcomes in Craniosynostosis by Age of Operation: Analysis of the National Surgical Quality Improvement. Cranial defects persist more frequently if surgery is performed after the age of 1 year **(30).**

Blood loss which may be life threatening as loss of even small amounts of blood in those young fragile kids can represent a large volume .So , it is advised to be meticulous regarding this issue not only to improve outcomes, but also to keep the life of those patients and avoid mortality resulting from the extensive surgical procedure. Calculated blood loss and transfusion requirements in primary open repair ofcraniosynostosis. Plast Reconstr Surg Glob Open 2019;7:e2112

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