Chapter 9
Metopism: Anatomical, Clinical and Surgical Aspects

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9.1 Introduction and Terminology

The flexible fibrous joints (*sutures*) located between the bones of the skull that surround the brain have two major functions during and after birth. First, during childbirth, they allow the bones in the calvarial roof to cross over each other, except for the bones around the synchondrotic type joints in the skull base, and this helps delivery by reducing the head circumference. Secondly, they allow the skull to grow as the brain increases in volume postpartum. These sutures slowly close at different times after birth. During infancy, the *metopic suture* closes first and disappears naturally; other sutures close much later. However, the metopic suture sometimes does not close during infancy and continues to the sagittal midline, like a joint separating the frontal bone into two symmetrical halves. The presence of the metopic suture in an adult cranium is commonly known as a '*persistent metopic suture'* or '*median frontal suture'* and is considered a normal variant. It can be found as an incomplete (partial) or a complete type. The presence of a complete metopic suture in the adult cranium is called '*metopism*' (Fig. 9.1). Crania with metopic sutures are also referred to as '*crania metopica'* or '*crania bifida'* [1]. The term '*metopic'* means *'in the middle of the face',* from the Greek; *'metopon'* means *'forehead'* [2, 3]. Metopism has anthropological, developmental, and clinical significance [1, 3].

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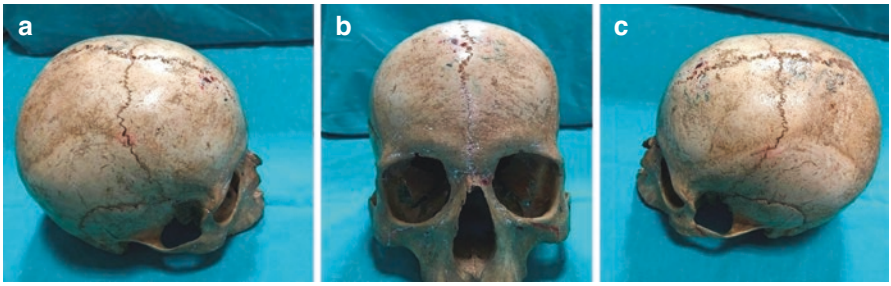

Fig. 9.1 Metopism, persistent complet type metopic suture in an adult skull. In complete type metopic suture, the suture extends from the bregma to the nasion. Right lateral (**a**), frontal (**b**) and left lateral (**c**) views

9.2 Epidemiology

The frequency of metopism differs among geographic populations and between the sexes. Its prevalence is 0.12% in the Malawian skull and 12.8% in the Medieval Oslo skull [1, 4]. Its frequency is reported as 7–10% in Europeans, 4–5% in Asians, 1% in Africans, and 1% in Australians, but some recent studies show the upper and lower limits differ when populations are evaluated individually [5, 6]. For instance, while the frequency of metopism among European populations is given as 7–8%, it is 14.9% in French and Swiss populations and 10.70% among Italians; it is given as 4–5% among Asians, it is 9.1% in the Japanese [7]. These results fall outside the given intervals. Indeed, there can be differences even within the same nation; for example, while the frequency of metopism in Brazil was found to be 2.75%, it was 7.04% among South Brazilians [8]. Researchers attribute this difference to the migration of a large group of Europeans to the south of Brazil. On this basis, it appears that genes are important for the frequencies of metopism among different populations.

Eroğlu et al. [5] examined 487 adult crania aged between 16.5 and 65 years. The skeletons belonged to individuals from twelve different Anatolian populations. They lived in different areas in Anatolia during different historical periods from the Neolithic to the first quarter of the twentieth century. Metopism was not related to cranial form or sex in those populations. In her study, the frequency of metopism in ancient Anatolia ranged from 3.3% to 14.9%, and she commented that this range shows that the inhabitants of Anatolia have been open to gene flow in both the past and the present.

The frequency of metopism differs between the sexes according to the literature. Its prevalance has been reported as between 0.32% and 23.6% in females and between 1.56% and 17.8% in males. da Silva et al. [9] examined 134 skulls, 13 of which had persistent metopic sutures; 61.5% were male and 38.5% female. In some studies, females had significantly higher frequencies of metopism. In contrast, in the Marciniak and Nizankowsky's study, the frequency of metopism was significantly higher in Polish men than women [10]. When all populations are considered

together, the frequency of metopism is 2% higher among females, but this is not statistically significant [5].

9.3 Etiology

All questions regarding metopism focus on why the two halves of the frontal bone do not merge [5]. According to Scheuer et al., the question is: why does the interfrontal suture not merge in a small group of people while it happens in the vast majority of individuals at an early age [11]? Researchers think that the frontal bone is very important for connecting the facial bones to the neurocranial skeleton owing to its morphology and position; therefore, they suggest that the early closing of the metopic sutures, as a result of the finalization of growth in the ethmoid centers, serves to provide maximum stability in the fronto-ethmoidal-nasal suture system [5]. Nevertheless, early closure of the metopic suture (metopic synostosis) can result in serious deformity of the orbital walls and other cranial areas, but metopism is not associated with such deformities.

Vinchon [12] claims on the basis of data from comparative anatomy and paleoanthropology that postnatal persistence of the metopic suture in early hominid species resulted from the risk of dystocia caused by the closed pelvis associated with bipedalism. The predisposing factors for metopism include abnormal growth of the cranial bones, growth retardation, hydrocephalus, heredity and heredo-specific factors, sexual influence, plagiocephaly, stenocrotaphia, scaphocephaly, mechanical causes and hormonal dyfunction [6, 13–15].

The mechanism or etiology of metopic synostosis is still uncertain. However, studies indicate a multifactorial etiology; genetic abnormalities combine with various epigenetic and environmental factors to affect suture development. According to the current literature, several main mechanisms such as bone malformation, brain malformation, obstetric issues causing cranial compression, and fetal head immobilization during late stage pregnancy can change suture biology and fusion development and could also cause metopic synostosis. Many researchers have studied the cellular mechanisms related to sutural growth and fusion. Recent studies show that particular proteins and transcription factors are related to the development of metopic craniosynostosis, including FGFR2, TGBF, RUNX2 and BMP [15].

Manzanares and colleagues found two distinct tissue types along the edges of the metopic suture: secondary cartilage and chondroid tissue [16]. The secondary cartilage appears after the chondrocranium, which is accepted as primary cartilage. It undergoes endochondral ossification with no evidence of direct transformation into chondroid bone and it is not involved in sutural fusion. Manzanares et al. also showed that the edges of the metopic suture are composed of chondroid tissue throughout the period of sutural development [16]. The secondary cartilage in the sutural area allows for passive growth of the frontal bones and is not involved in sutural fusion; it is eliminated by endochondral ossification. The chondroid tissue is responsible for the growth of the frontal bones toward each other and for the first

bridge uniting them. The trabeculae of the chondroid tissue are replaced by lamellar bone as the metopic suture is almost closed. At this stage, continued resorption of new bone along the edges can keep the suture open. Manzanares et al. [16] claimed that this active resorbtion continues from birth to the 17th month of neonatal life in the metopic suture, but Weinzweig et al. [17] reported that it finishes much earlier, enabling the metopic suture to fuse normally by 6–8 months of age. Chaoui et al. examined second and third trimester fetuses by three-dimensional sonography and reported pathological changes in the metopic sutures of 11 fetuses at 17–32 weeks [18]. In those fetuses with abnormal metopic sutures there were other midline abnormalities such as holoprosencephaly, abnormal corpus callosum, or Dandy-Walker malformation.

The metopic suture is reported to remain a suture throughout life in certain circumstances. According to the literature, it persists in adult skulls because of genetic influences. It is not an abnormality, but a consequence of the brachycephalization process, i.e. shortening of the skull. This process has continued from paleolithic times to the present [14].

9.3.1 Anatomical Aspects

The frontal bone is a median and symmetrical bone that occupies the most anterior part of the cranium, forming the forehead (Fig. 9.2). It forms joints with the parietal, ethmoid, sphenoid, nasal, zygomatic, lacrimal, and maxillary bones, thus contributing towards uniting the neurocranium and viscerocranium. The first ossification

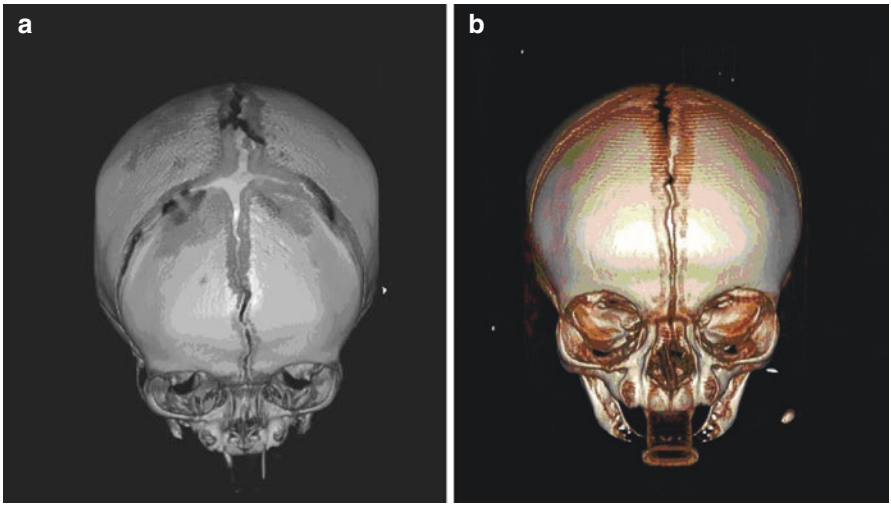

Fig. 9.2 The 3D cranial CT images of a 2-month-old female with a suspicion of premature closure in sutures (**a**) and a 6-month-old female with a head injury (**b**). Metopic sutures that are not fully closed are clear in both cases

centers appear between the sixth and seventh weeks of intrauterine life, and from these the frontal bone begins to grow and develop. In three-dimensional sonography of normal fetal frontal bones and the metopic suture, Faro et al. [19] reported that radial bone expansion begins during the second trimester and the metopic suture starts to close from the glabella to the anterior fontanel during the third trimester.

The metopic suture is a dentate type and leads from nasion to bregma. It normally begins to fuse from the nasion, progressing towards the superior end on the anterior fontanel (Fig. 9.3). Nevertheless, it begins to disappear on the frontal tuber and progresses in both directions. The suture is located almost in the middle of the two frontal bones. It first becomes apparent at the end of the second month of fetal life. It usually closes during the first or second year of life, but the literature reports cases that do not close until 8 years old. There are disagreements among studies about the closure time of the metopic suture. Vu et al. [20] found that the earliest time of metopic suture closure was 3 months of age (33%; 4:12); at 5 and 7 months of age, there is closure in 59% (13:22) and 65% (15:23) of children, respectively. There is no easy way to determine the time of suture closure during neonatal life.

The metopic suture can be complete or incomplete. In the 'complete' type, the suture extends from the bregma to the nasion. If the suture does not extend over this entire distance and occupies only a small area between these two points, it is considered 'incomplete'. Incomplete metopic sutures can be divided into two subclasses: 'nasion incomplete type' and 'bregma incomplete type', depending on the site from which they arise. The nasion incomplete metopic suture type is also described as a linear type, V-shaped and U-shaped (Fig. 9.4). Singh et al. [6] examined 80 crania and found 2.5% complete type and 11.25% incomplete type metopic sutures.

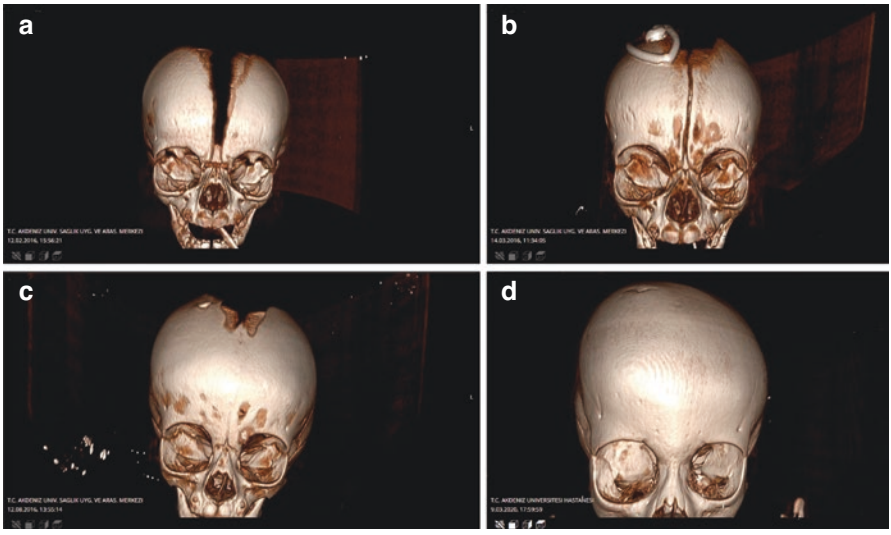

Fig. 9.3 The cranial 3D CT images of a female patient aged 2 (**a**), 3 (**b**), 6 months (**c**) and 4 years (**d**) who we followed up due to premature posthemorrhagic hydrocephalus (a permanent vp shunt performed after temporary subgaleal shunt). It can be seen that the metopic suture was mostly closed at 6 months of age and no longer remains at the age of 4

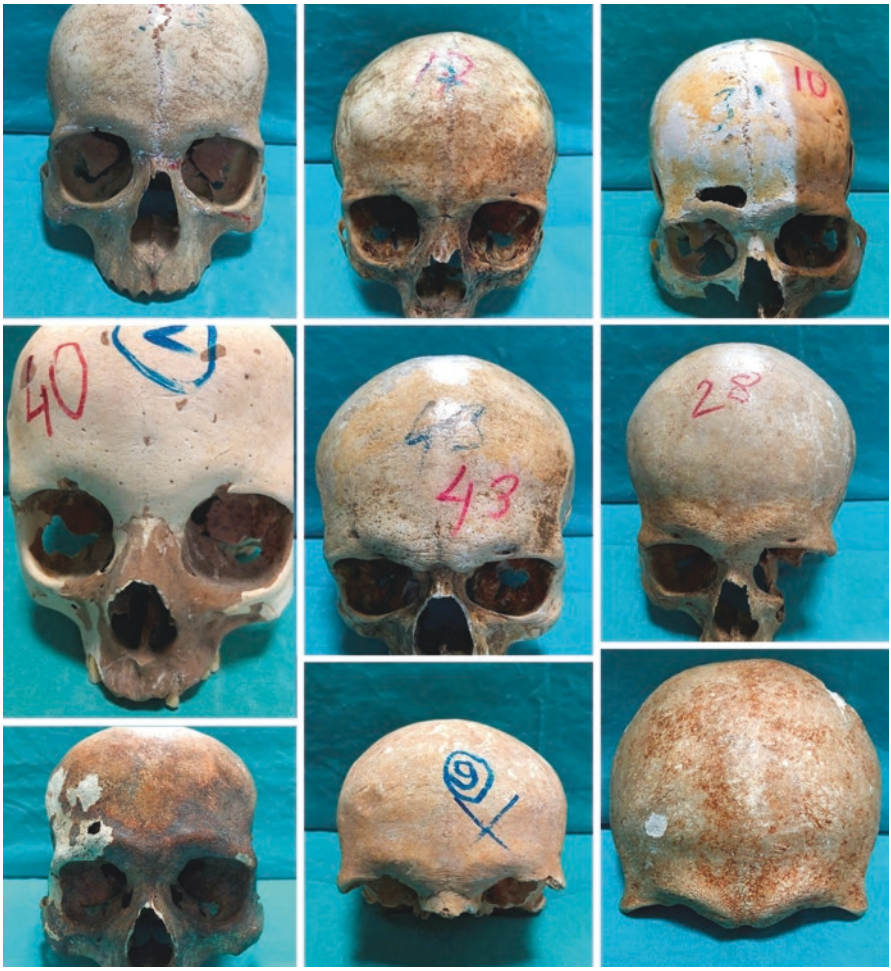

Fig. 9.4 Skulls showing different types of metopic suture

9.4 Relationship Between Metopism and the Frontal Sinus

The frontal bone is described as pneumatic because it has a cavity called the frontal sinus. This cavity is usually radiologically invisble during the first year of life. During childhood, the development of the frontal sinus is influenced by osteoclastic activity in the region of the ethmoidal cells, the two sides developing independently. The morphology of the frontal sinus differs among individuals (Fig. 9.5). During adolescence or early adulthood, the frontal sinuses are fully mature and their sizes and contours remain constant thereafter. Since the radiographic morphology of the frontal sinus is highly distinctive, it is very useful for human identification in complex cases [10, 13, 21, 22].

Studies show that persistence of the metopic suture can prevent frontal sinus development. This is based on the fact that frontal bone growth is necessary for frontal sinus development; it is probably a feedback mechanism. If the frontal bones fail to connect, the metopic suture could become permanent, and the frontal sinuses cannot develop or they develop late. Some studies have confirmed this hypothesis. While the frontal bones and metopic suture develop during intrauterine life, the frontal sinuses appear during the fifth or sixth years postnatally. In view of this time line, it is interesting that there is a connection between these two anatomical

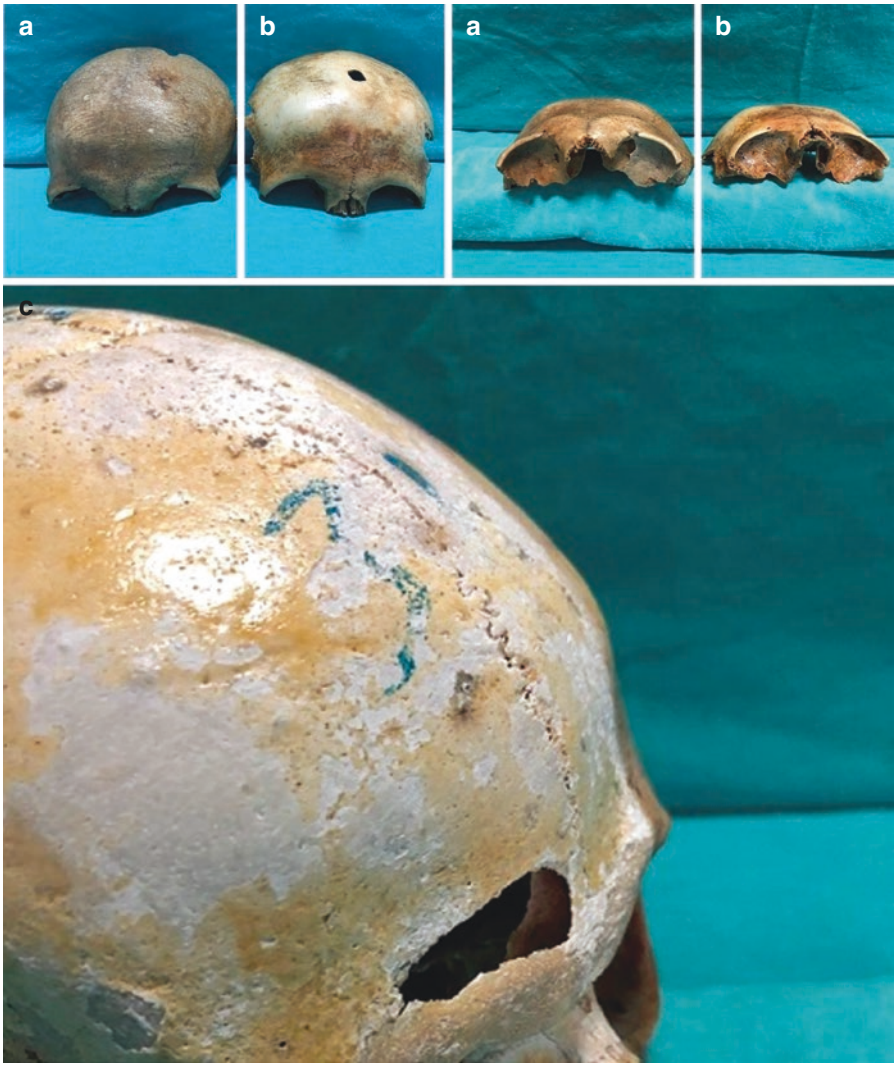

Fig. 9.5 Samples showing the relationship between the metopic suture and frontal sinus. Normal (**a**) and hypoplastic (**b**). Frontal sinuses are seen in the upper frontal bones with partial metopic sutures. Permanent metopic suture and large right frontal sinus on the skull (**c**)

structures. According to this hypothesis, a persistent metopic suture cannot affect frontal sinus development [10, 22] (Fig. 9.5).

However, there is still no consensus about the correlation between frontal sinus development and late closure of the metopic suture. Bilgin and colleagues examined 631 CT and MRI images of patients to evaluate persistent metopic sutures [21]. Sixty-one of the cases revealed persistent metopic sutures (9.7%), and 15 (2.4%) had a persistent metopic suture associated with an atrophied frontal sinus. Among those 15 cases, the frontal sinus atrophy was bilateral in six. There is no significant correlation between metopism and the development of the frontal sinus. Also, when a metopic suture persists, the frontal sinus develops separately on each side, not connecting on the midline, and this can be used to differentiate a persistent metopic suture from a cranial fracture. Bilgin et al. [21] and Nikolova et al. [13] reported that persistence of the metopic suture leads to dominant pneumatization of the left side of the frontal sinus and also underdevelopment or absence of the right side. This condition results in a greater risk of injury to the left sinus than the right during supraorbital craniotomy.

Phylogenetically, the frontal sinus is present only in African great apes and humans. Metopism never occurs in other primates. Thus, investigations of the prevalance of agenesis of the frontal sinus among subjects with metopic sutures have potential applications in human identification in forensic medicine. More specifically, agenesis of the frontal sinuses is important for post-mortem forensic investigations [10, 13, 22].

9.4.1 Clinical Aspects

Sutures are important for the growth of the skull and the brain within it. Persistence of the metopic suture is not necessarily pathological, but its anatomy and incidence are clinically important. Metopism is also significant for paleodemography and in forensic medicine [3].

The metopic suture can be misdiagnosed as a fracture in head injury patients [1, 23]. On X-ray, the sclerotic borders enable the distinction to be made. This helps the radiologist and neurosurgeon to diagnose and treat a head injury patient and is also helpful during frontal craniotomy surgery. This is important because such a misdiagnosis can lead to wrong therapies and unnecessary interventions. Neurosurgeons want to know all about the anatomical configurations of the skull before cranial surgery. A persistent metopic suture should be revealed prior to a frontal craniotomy. Sometimes, X-rays can show a linear fracture better than other tests, so meticulous radiographic examinations including X-rays and 3-dimensional CT should be performed to ensure the correct diagnosis. Some clinical situations can coexist with metopic sutures: visceral inversion, cleft lip, cleft palate, frontal sinus variation, cretinism, abnormal intelligence, and wormian bones [1]. The sutures can be prominent in such diseases as hydrocephalus, cerebritis, brain neoplasms, metastases, leukemia, lymphoma, and increased intracranial pressure. There is no significant relationship between metopic sutures and frontal sinusitis or other frontal sinus pathologies in the literature [21].

Metopic synostosis is the second most common type of craniosynostosis. It can be part of a syndrome such as Crouzon or Saethre-Chotzen, or it can occur nonsyndromically [15, 24–26]. A diagnosis of metopic synostosis is suspected by physical examination and confirmed by radiography. Metopic synostosis is characterized by restricted growth of the frontal bones, resulting in a prominent midline ridge with a triangular forehead and bitemporal narrowing and occipitopariteal widening, the condition described as '*trigonocephaly*' [24, 26]. The calvaria try to compensate for metopic synostosis, resulting in characteristic orbital dysmorphology, with depression of the superolateral orbital rims and ethmoidal hypoplasia; this is called *orbital hypotelorism* (Fig. 9.6).

Trigonocephaly has become more prevalent during recent years. Researchers say that this malformation is the second most frequent isolated craniosynostosis, with an incidence approaching one per 5000 live births [25]. The female to male ratio is 1:3.

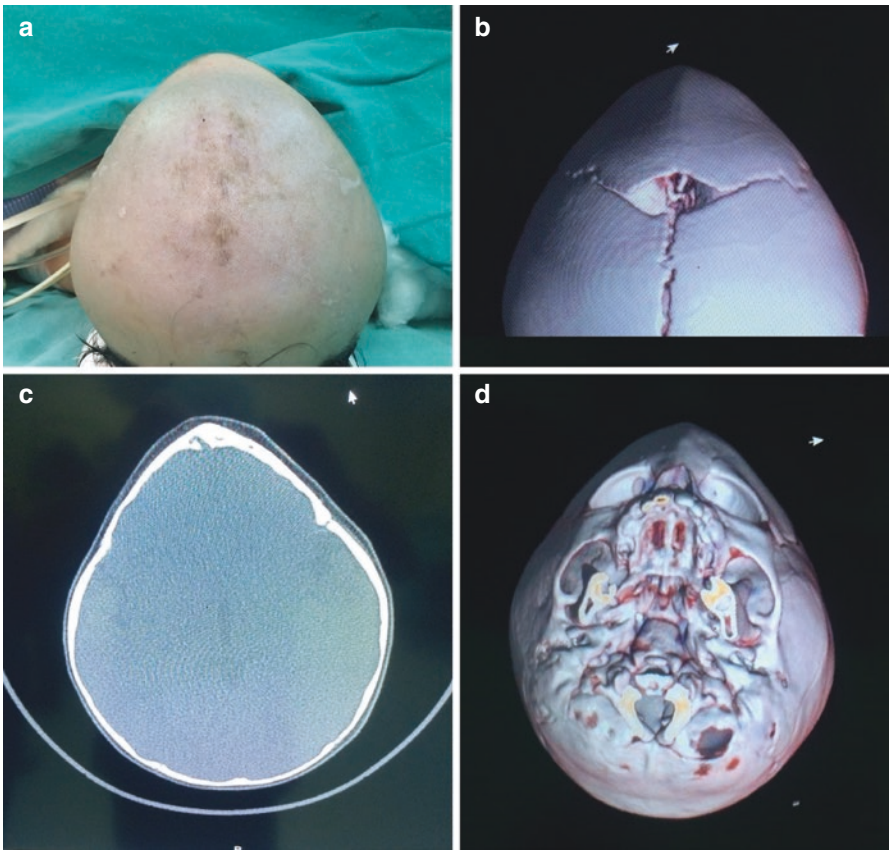

Fig. 9.6 Intraoperative view, demonstrating the characteristic features of a patient with metopic craniosynostosis (**a**). 3D CT reconstruction from the top, demonstrating the characteristic features of a patient with metopic craniosynostosis (**b**). Axial CT slice, demostrating a patient with a prominent metopic ridge and bitemporal narrowing (**c**) 3 D CT reconstruction of the same case demonstrating orbital hypotelorism with a prominent metopic ridge from the ventral view (**d**)

A positive family history is found in 6.8% of patients. The pan-European study in 1997–2006 in which 3240 patients were operated on in seven craniofacial centers revealed that the incidence of isolated suture craniosynostosis was 23%, but other publications from North America reported incidences as high as 27% and 31%. There are multiple explanations for the etiology of trigonocephaly, including increasing maternal and paternal age, changes in prenatal folic acid intake, an increase in syndrome-associated subtypes, and a possible correlation with small uterine anatomy and other deformations. Subjective assessment of moderate and mild subtypes can be related to over-diagnosis and over-treatment for trigonocephaly. Unlike metopic synostosis, trigonocephaly is associated with a high incidence of neurodevelopmental problems. Children with this condition show delayed speech and language development, and cerebral function disorders associated with frontal lobe dysfunction [27]. MRI reveals both cortical and subcortical brain dysmorphology that cannot be completely explained by the abnormal cranial shape (Fig. 9.7).

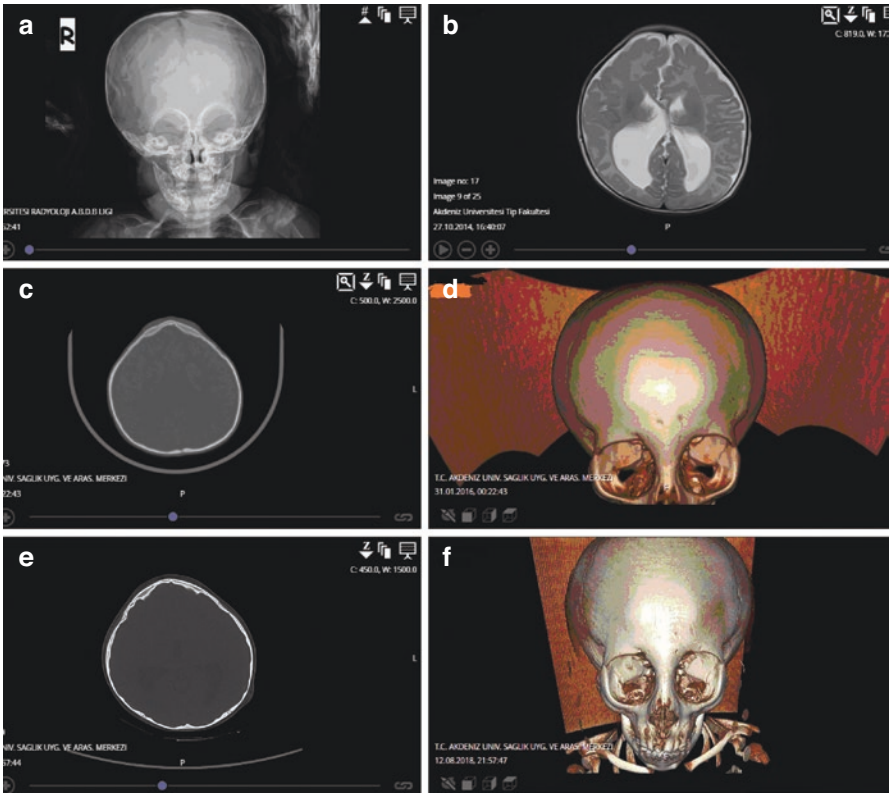

Fig. 9.7 The mild trigonocephalic appearance was present in the physical examination of the case, who was diagnosed with hydrocephalus in the intrauterine period and was born with C/S. There was no clinical or radiological findings about high intracranial pressure. Hypotelorism was prominent on the AP cranial radiography (**a**). There was corpus callosum dysgenesia, colpocephaly and ventricular deformation in cranial MRI (**b**). The cranial axial and 3D CT images of 3 month of age case who we did not performed surgery (**c**, **d**). The cranial axial and 3D CT images of 4 years old case who we did not performed surgery (**e**, **f**)

Small frontal lobes, widened precentral sulcus, frontal subdural space, ventriculomegaly and corpus callosum and cerebellar dysmetria are other structural abnormalities. The pre- and post-operative brain volumes of metopic synostosis patients show no change: gray matter, white matter, and regional and total volume remain similar [15, 24–26].

In clinical practice, besides metopic synostosis, there is a group of children with only a metopic ridge in the frontal midline [2, 28–30]. This can be palpated during examination. The ridge starts from the nasofrontal suture and extends towards the anterior fontanel. Children with a metopic ridge have no features characteristic of trigonocephaly such as hypotelorism or orbital dismorfism (Fig. 9.8). According to Hopper and colleagues [31], metopic ridging is a variant of the metopic suture. Birgfeld et al. [24] reported that the palpable ridge forms physiologically during metopic suture closure and is often confused with premature closure of the metopic synostosis. In the relevant literature, there is no clear definition of metopic suture pathologies.

It is reported that metopic synostosis can be a familial and inherited facial morphology, with no clinical significance in its mildest form. Metopic synostosis and trigonocephaly are not similar clinical entities; the former is a prominent ridging of the metopic suture without features of trigonocephaly. It is a nonsurgical metopic ridge. The definition of trigonocephaly is a surgical form of metopic synostosis. Metopic synostosis is a suture pathology, but trigonocephaly is a clinical problem (Fig. 9.9). Weinzweig et al. [17] reported that an endocranial ridge was rare in synostotic patients, but a 'metopic notch' was diagnostic of premature suture fusion; it was seen in 93% of synostotic patients but in no nonsynostotic patients. In addition to the typical clinical and radiological findings, this radiological finding could help in the differential diagnosis between metopic synostosis and metopic ridge. Corrective surgical intervention is not applicable to simple metopic synostosis children without the typical clinical or radiological features of trigonocephaly.

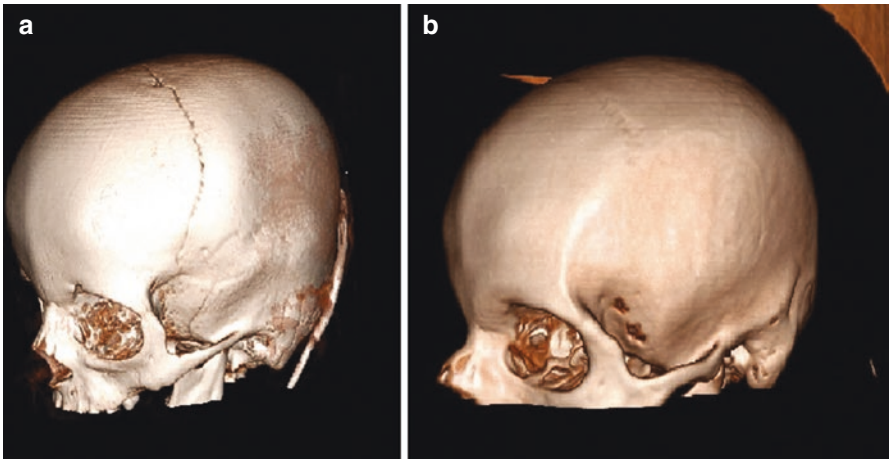

Fig. 9.8 Metopic ridge. 3 years old male case (left sided vp shunt). Partially closed metopic suture and metopic ridge (**a**). 23 year old female case. The metopic ridge in posttraumatic 3D cranial CT reconstruction (**b**)

Fig. 9.9 8 years old male case. An unoperated patient. Mild trigonocephalic appearance on physical examination

9.4.2 Surgical Aspects: Metopic Synostosis—Trigonocephaly

Normally, the metopic suture closes in children during their first year of life, but there are a few exceptions. It is very important to determine whether surgical intervention is necessary in early stage or suspected trigonocephaly cases. Overgrowth of the posterior biparietal bones and perisutural region (bifrontal narrowing) can be a compensatory mechanism and also an early warning sign for trigonocephaly. Unfortunately, there are no subjective analyses or objective measurements for the severity of trigonocephaly [32]. Indications for surgery for craniosynostosis include esthetic reasons and making adequate space for normal brain growth; these indications also cover trigonocephaly. The aim of esthetic correction is social and psychological improvement in the child's life. Increased intracranial pressure (ICP) is an absolute indication for craniosynostosis surgery. However, the risk for increased ICP is very low in metopic synostosis. Surgical methods and techniques for correcting craniosynostosis-related skull deformities have evolved, but there is no consensus about which surgical technique is best. At the moment, the most popular surgical techniques are fronto-orbital advancement with anterior cranial wall reconstruction, or minimally invasive anterior wall recontruction using endoscopy combined with cranial orthotic therapy. The aims of surgery are to correct hypotelorism and the trigonocephalic deformity, and also to regulate pterional and frontozygomatic connections, and to improve lateral and superior orbital rim projections and the forehead contour [25, 26, 33, 34].

Surgical craniosynostosis procedures are usually safe but intervention should only be undertaken if necessary. There are some arguments about the cosmetically acceptable level of craniofacial dysmorphology and who should decide it. The best way to decide the surgery is open and honest discussion between the surgeon and family regarding risks and benefits. The other indication for surgical treatment is to prevent limited neurodevelopment; but does surgical treatment of metopic synostosis affect neurodevelopment? This is not clear in the literature, but some researchers have said that cranial bone expansion prevents, limits, or even treats neurodevelopmental delay in patients with metopic craniosynostosis [27, 35].

The timing of the operation should also be planned carefully, as the procedures in infants tend to be less invasive. Endoscopic techniques show the best performance by 3–6 months of age [26]. Open cranial procedures are usually delayed until 6–12 months because patients undergoing operations before the age of 6 months often need revision surgery. The complication and mortality rates in trigonocephaly surgeries are very low. However, there are still complications in surgery such as subgaleal hematoma, cerebrospinal fluid leakage, infections, and dural injuries.

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