The soft tissue over the cranium consists of five layers: skin; subcutaneous tissue; the occipitofrontalis muscle (epicranius); the galea aponeurotica (a lax layer of subaponeurotic fibroareolar tissue); and the pericranium. From a surgical standpoint the first three strata are considered as forming the scalp proper, since they are intimately connected and are not easily separated.

The skin of the scalp is very thick and is attached by tough, fibrous septa to the underlying galea. It has an abundant blood and lymphatic supply and numerous sweat and sebaceous glands.

The subcutaneous tissue, because of its fibrous septa, forms an inelastic but firm layer containing the blood vessels. The blood vessels embedded in the unyielding tissue bleed freely when divided because they cannot contract. Because of the abundant anastomoses of the temporal, supraorbital, supratrochlear, posterior auricular, and occipital vessels, scalp flaps with only a small pedicle usually survive and large flaps heal uneventfully. Infection is prone to remain localized because of the fibrous septa, but purulent collections are painful because the nerves are compressed within enclosed compartments.

The paired occipitofrontal muscles (epicranius) and their galeal aponeuroses, which join them across the vertex of the cranium, are attached posteriorly to the external occipital protuberance and the superior nuchal line of the occipital bone. They fuse laterally with the temporal fascia and attach through the substance of the frontalis muscle to the supraorbital ridges and adjacent soft tissues.

The subepicranial space lies between the epicranius muscle and the pericranium. This potential space is traversed by small arteries which supply the pericranium and by the emissary veins connecting the intracranial venous sinuses with the superficial veins of the scalp. This space is considered the danger zone of the scalp because hematoma and infection can spread easily through it, and thrombosis of the emissary veins may extend to the dural sinuses. Pus trapped in this space may destroy the pericranium and cause necrosis of the skull, and can even spread intracranially.

The periosteum overlying the cranium is known as the pericranium. In the neonatal skull, the fontanels are bridged by pericranium externally and dura mater internally. When the fontanels are obliterated, the dura mater and pericranium are bound closely to the suture line. Spreading infection and hematoma are thus usually limited to the confines of a single bone. The blood vessels that traverse the pericranium and the small vessels in the outer table of the cranium may afford pathways along which infection extends to the diploë and causes osteomyelitis. When the sutures are obliterated, the pericranium extends from one bone to another without deep sutural attachment.
Phylogeny

In describing the development of the cranium it is well to consider first its basic neural and visceral (branchial) components. The neural portion supports and protects the brain and sense organs. Phylogenetically, this part of the skull is a composite consisting of an old cranial base with which are associated the capsular investments of the sense organs. To this has been added more recently the facial skeleton plus a vaulted cranial roof. Thus the skull eventually consists of two components: cranial and facial. Phylogenetically, man inherited only two of the original five bones that protect the eye. They are the lacrimal and the malar bones. The decrease in the number of bones accompanying the movement forward of the orbits from their more lateral position allows for binocular vision. The progressive decrease in the number of bones in the skull as one passes from fish to man is known as "Williston's law". In general the older basal portion is preformed in cartilage, whereas the new facial and roofing bones are formed in membrane. There is, however, so much fusion and overlapping that it is unwise to try to draw too sharp a line of distinction.

The visceral (branchial) portion of the skull consists of reduced and modified remains of the gill arches, which played such an important role in food seizure (jaws) and respiration (gill arches) in our aquatic ancestors. It is of interest that most of the parts retained are still concerned with the same functions, although they have been utilized under different conditions since lung respiration replaced the gill mechanism.

Under air living conditions, the sound receiving mechanism evolves into a more elaborate form with the conversion of the obsolescent proximal ends of the first two visceral arches into the auditory ossicles. The inner aspect of the first branchial pouch becomes the eustachian tube, while the external portion forms the external auditory canal. Around the external auditory orifice, budlike proliferations form as the anlagen of the external ear. The remaining portion of the first branchial arch (Meckel's cartilage) continues forward and becomes the anlage around which two membrane bones are later laid down to form the mandible. The second branchial arch is represented by the stylohyoid ligament and the upper portion of the hyoid bone. The third arch is represented by the lower portion of the hyoid bone, and the thyroid cartilage is formed by the fourth. In the developing embryo the muscles of the face and neck are formed by mesenchymal migration carrying along the original nerve innervation and blood supply from each visceral arch. Deficiency of the mesenchyma results in various hypoplastic syndromes involving the middle and lower third of the face with deformities of the ear and rarely of the eye.

Growth of the Cranial Bones and Facial Skeleton

Congenital deformities of the cranial and facial bones are best understood by studying normal growth. The cranial base is first laid down in cartilage, and this model is gradually replaced with chondral bone in the developing infant. In contrast, the calvaria is formed by the ossification of the preexisting condensed mesenchyma (desmocranium) and by the periosteum, respectively. The preexisting fibrous structures are incorporated with a large number of newly formed fibers in the new bone matrix. Likewise with the maxilla and mandible, the first bone appears in an area of mesenchyma in which definitive collagen fibers are not present until immediately before ossification. In a third type of formation, bone
appears among the dense fibers of preexisting fascia, aponeurosis, tendon, ligament, or cartilage, eg, Meckel's cartilage.

As is well known, the brain grows rapidly; consequently, the cranium triples in volume in the first two years of life, except in premature cranial synostosis (craniostenosis). Growth of the cranium continues but at a slower rate until the seventh year, at which time it has attained 90 per cent of its adult size. Thereafter, the annual increment in growth is almost negligible.

The facial bones do not keep up with the rapid pace of the cranium. After the first year the facial skeleton grows faster and continues to grow over a much longer period.

**Congenital Defects of the Cranium and Scalp**

Congenital defects of the cranium and scalp are rare, only 76 cases having been reported up to 1930. The first patient reported by Campbell (1826) died of hemorrhage from the exposed superior sagittal sinus. This occurred also in patients whose histories were reported by Heidler (1924), Pincherle (1938), and Peer and Van Duytn (1948). According to Ingalls (1933) there were associated defects in other areas of the body in 8 per cent of the cases. Ingalls found an overall mortality of 20 per cent due to hemorrhage and infection. He also found thin-walled blebs in the midline of the head of several embryos as early as the tenth week; he thought that these blebs later ulcerated and produced the defect in the full term infant. The defect has also been attributed to failure of closure of the midline structures; 20 per cent of scalp defects, however, do not occur in the midline. It is now generally accepted that the growth and differentiation of the bones of the vault of the skull are dependent on the growth of the underlying brain. According to Snell (1961) an abnormality in the formation of the underlying brain could be connected with the development of the overlying skin, as both are derived from the adjacent ectoderm.

In the newborn the treatment is conservative, and the patient is placed under continued observation. The indications for operation in the larger lesions overlying the superior sagittal sinus have been stressed by peer and Van Duytn (1948) and Kahn and Olmedo (1950). These authors point out that if the lesion is more than 1 to 2 cm in width it may become necrotic. Reconstruction with a scalp flap is recommended. In the larger lesions, the skull defect does not close spontaneously, and grafting with bone (split rib grafts) or cartilage is necessary at a later stage to provide adequate protection for the brain. O'Brien and Drake (1961) have surveyed the literature and reported five cases.

**Craniopagus.** Symmetrical conjoined twins are unusual (one case in 60,000 births) in spite of the fact that the intrinsic conditions capable of giving rise to double monsters exist in all fertilized eggs. According to Stockard (1920-21), if differentiation is interrupted just before the differentiation of the embryonic axis, the resumption of growth may be followed by the establishment of two centers of growth, neither of which is capable of growing at a rate sufficient to inhibit development of the other. When the duplicated parts are of equal size, they are as strongly inclined to be as normal as they are in single individuals.

The treatment of craniopagus twins was reported by Grossman and coworkers (1953), Jayes (1964) and Laskowski and Baldwin (1962).
In the case of the craniopagus twins reported by Grossman, Sugar, Greeley, and Sadove in 1953, the problem was whether a surgical separation could be attempted. Unfortunately there was little information in the literature that was of any pertinent value; the few previous attempts at separation of other craniopagus twins had failed. Pneumoencephalography disclosed two separate arachnoid spaces and indicated a dural septum between the two brains. Attempts to obtain contrast visualization of the dural venous sinuses failed.

If separation was to be accomplished, an adequate covering for the exposed intracranial structures would be required. Greeley delayed two scalp flaps 35 cm long and 7.5 cm wide. After three stages, the scalp flaps were completely divided around their periphery. During the first attempt at separation, at 14 months of age, the flaps were elevated from their beds. The final separation was made three weeks later. Since there was a common dural sinus, all of the veins from the one twin had to be clipped and divided. The one twin devoid of a dural sinus never regained consciousness and died 34 days later. The other twin, with the complete dural sinus, cried immediately and moved all extremities. Repair was later done in stages as indicated. The patient is shown as he was nine years after the separation. It was impossible to place bone grafts into the defect because of a residual cyst that collected fluid and required repeated aspiration. The patient died suddenly at the age of 11.5 years.

Jayes (1964) has successfully repaired the soft tissue defects in three surviving twins who had been separated from their counterparts (who later died). He has reported that all three are alive; one twin has developed epilepsy, is mentally retarded, and has hemiplegia. Another is physically normal but mentally retarded. The third child is making excellent progress and shows every sign of undergoing normal development. Jayes planned to utilize split rib grafts at a later date to fill the cranial defects. Laskowski and Baldwin (1962) reported the successful separation of craniopagus twins joined at the forehead with their separate brains fused for 2 cm. There was only one artery and not the single venous sinus which had been found in the previously reported cases. Today both girls are bright, alert, and active individuals.

**Congenital Aplasia of the Scalp (Aplasia Cutis Congenita).** This congenital anomaly, which was described by Campbell in 1826, varies in its extent. It may involve the scalp only, or the scalp and the underlying bone, as in the patient whose case history follows. The malformation may be so extensive as to involve the scalp, cranial vault, and dura.

Aplasia cutis congenita defects are usually less than 2 cm in diameter and often heal spontaneously. Larger defects require surgical closure. The literature has been extensively reviewed by Dingman, Weintraum and Wilensky (1976).

Aplasia cutis congenita is a rare anomaly with little known of the etiology. There have been scattered reports of sequential cases in the same family, leading to the conclusion that there is a recessive genetic factor involved (Greig, 1931; Kahn and Olmedo, 1950; Savage, 1956; Farmer and Kaxmen, 1960; Rauschkolb and Enriquez, 1962; Hodgman, Mathres and Levan, 1965).

Other theories postulated to explain this defect include vascular accidents, direct trauma or pressure, syphilis, and amniotic adhesions as well as chromosomal abnormalities.
None of these can fully explain the condition. The scalp or skull defects occur most frequently in the first-born female children. The defects are generally less than 2 cm in diameter and may be symmetrical or stellate in configuration. Most often they are in the midline in the region of the posterior fontanelle. Two or more lesions have been reported in 25 per cent of the cases, and this same group often exhibits symmetrical linear trunk defects. There is never any hair over the defects.

The defect is generally irregular, involving only the epidermis, and heals spontaneously. Absence of the underlying cranial bone is seen in only 20 per cent of the cases (Lynch, and Kahn, 1970). Associated anomalies include hydrocephalus, myelomeningocele, cheiloschisis and palatoschisis, cleft lip, cleft palate, and deformities of the fingers.

Biopsies of the edges of the lesions show no inflammatory reaction. The epidermis is thinned or absent with an atrophic corium. The collagen is compact, with little adipose tissue present. Sweat and sebaceous glands as well as the elastic fibers are absent. The membrane covering the brain consists of a very thin, flattened layer of cuboidal nucleated cells set in a regular manner in a single layer (Montgomery, 1967).

**Congenital Absence of the Scalp and Cranial Vault.** A full term infant, S.H., was born with two large defects of the scalp, 2x3 cm on either side of the sagittal sinus in the posterior fontanel area. On radiologic examination there was an underlying defect of the cranium measuring 4x5 cm. Over a period of 24 hours, the exposed dura became necrotic, and the child was transferred to the hospital.

Under local anesthesia excision of the necrotic area was performed, sparing the inner layer of the dura and the pia arachnoid. There was no leakage of spinal fluid, but, as debridement was performed on the right side, there was sudden bleeding from one of the emissary veins into the sagittal sinus. This was controlled by Gelfoam, topical thrombin, and digital pressure. The defects were then closed by large rotation flaps. One flap was rotated anteriorly and the other posteriorly. A collodion splint dressing was applied.

The head of the infant was elevated in order to reduce the pressure in the sagittal sinus, and the wound healed uneventfully. Subsequent studies showed that the child had hyperthyroidism and a moderate degree of gargoylism.

**Congenital Absence of the Scalp, Cranial Vault, and Dura.** Congenital absence of scalp, skull, and dura in a neurologically intact newborn is rare. It has been termed a variant of aplasia cutis congenita, which is usually defined as congenital absence of skin but which occasionally may involve simultaneous loss of scalp, skin, and dura. The surgical treatment of a newborn with a ruptured omphalocele and an extensive area of exposed brain provides a dilemma of priorities and management and is the basis of the following report (Dingman, Weintraub and Wilensky, 1976).

A female infant was transferred to the Pediatric Surgical Service at the University of Michigan Medical Center at six hours of age with a ruptured omphalocele and a large cranial defect. The child was the product of a precipitous delivery following an uncomplicated 36 weeks of gestation. Birth weight was 2.6 kg. The parents were both 26 years of age and were in good health. The mother took vitamins and iron throughout her pregnancy and denied any
other drug ingestion. The mother had previously delivered a four-month hydatidiform mole and a full-term healthy male. There was no family history of a similar skull or cutaneous defect, syphilis, tuberculosis, or exposure to communicable diseases. At birth the Apgar scores were 2 and 2, the blood pressure 56/34, pulse 156, and temperature 96.8. The child appeared dehydrated and lethargic.

The child had a 7.5 x 5 cm defect involving the skull, scalp, and dura. This formed a clean, punched-out midline defect over the junction of the sagittal and arachnoid sinuses so that the brain, in fact, was covered by only the thin, transparent pia. The white blood cell count was 21,000, platelet count 123,000, and mixed capillary pH 7.18. Chest roentgenograms showed a pneumomediastinum without an accompanying pneumothorax. The child voided spontaneously. The child was resuscitated and started on antibiotics prior to transfer to the operating room.

The patient's clinical problems required priority decisions. There was only pia covering the child's brain, and thus the risk of hemorrhage, thrombosis, or meningitis was high. On the other hand, the ruptured omphalocele had to be dealt with, despite the fact that most authors advocated the mandatory nature of early scalp closure. It was elected to repair the omphalocele first and place cadaver skin allografts over the cranial defect. Autografted skin would offer the advantage of permanent survival, but such a graft would be almost impossible to remove safely when more definitive bony coverage would be necessary.

The omphalocele was repaired primarily without undue abdominal tension. The patient was returned to the neonatal intensive care ward, where the pneumomediastinum resolved. Six hours later the baby had a grand mal seizure. At this time the sodium was 125, potassium 4.6, chloride 86, and CO₂ 20; arterial blood gases were normal. Glucose was 40 mg per 100 mL, and calcium was 7.1. Simultaneously the child developed apneic spells and was intubated, placed on a respirator, and given phenobarbital and diphenylhydantoin. Sodium, calcium, and dextrose were administered, and the child's condition was rapidly stabilized. Over the ensuing 18 hours, the child was weaned from the respirator and extubated. The following morning oral feedings were started and she was stooling within 24 hours. The allograft skin did not take well and by the third day was removed. The child was fitted with a tube gauze headress, which was kept moist by a continuous drip of normal saline solution. By day four, the child was gaining weight on oral feedings and the serum electrolytes had returned to the normal range. Her head circumference, which was 31 cm at birth (less than the third percentile), grew 1.5 cm at the end of 7 days, and concomitantly the defect increased in size to 9.5 x 7.5 cm. On the eleventh day of life she was returned to the operating room, where bilateral scalp flaps were outlined and delayed after intravenous fluorescein testing demonstrated nonperfusion of the distal 4 to 5 cm of the flaps. Allograft skin was again used to cover the defect, and the tube gauze cap with constant irrigation was replaced. Eight days later the flaps were divided and again delayed after fluorescein demonstrated adequate perfusion of all but the distal 2-mm margin of the right scalp flap. The flaps were then transposed two days later and split-thickness skin autografts were applied to the resulting donor defects. An additional application of a small split-thickness skin graft to the flap donor area was necessary ten days later. The child did well postoperatively except for one period of seizures; these were felt to be secondary to a tight-fitting head dressing. Treatment included phenobarbital and diphenylhydantoin and replacement of the dressing. No seizure activity has been noted since that time. The patient is currently 12 months old and, although she continues to grow and
develop normally, there is no evidence of spontaneous closing of the bony defect as has been reported (Matson, 1957).

Full-thickness flap coverage of the defect was critical, and skin allograft application allowed adequate time to plan and delay the flaps. Fluorescein was used to evaluate flap viability and was definitely helpful, since it predicted loss of the flap in a location that would have recreated the original lesion. At the third scalp flap delay procedure, fluorescein demonstrated full viability and the flaps were successfully rotated.

In the future, consideration will be given to the insertion of split-rib grafts for cranial coverage. It is hoped that some skull growth might occur prior to this. She wears a specially designed plastic helmet, and to date the child is passing growth and mental milestones normally.

**Premature Synostosis of the Cranial Sutures.** The shape of the head may be severely altered by premature closure of one or more of the cranial sutures (see Chapter 56). Though the synostosis may be present before birth, the abnormality of shape may not be noticed at birth, or may not be appreciated until some time after birth. Whether the brain is involved depends on the extent of the premature closure of the suture lines. When closure of the sutures prevents enlargement of the brain, mental retardation and blindness result. The shape of the head depends upon the sutures involved, the limitation of growth being at right angles to the line of the involved sutures.

Symmetrical premature closure of the coronal sutures leads to a condition called *acrocephaly, oxycephaly, or turret skull*. Björk (1959) inserted pins into various bones of the skull and observed growth to maturity with roentgen cephalometry and presented evidence that premature closure and fusion of the cranial base likewise plays a role. The head is flattened posteriorly and protrudes anteriorly. The facial expression becomes adenoid, and the eyes protrude from widely separated eyelids which tilt downward and outward. The base of the skull is diminished and the cranium bulges in the place where the frontal bossae normally appear. The absence of the occipital bulge is partly responsible for the characteristic appearance. When associated with syndactyly of the hands and occasional polydactyly of the feet, the condition is known as *acrocephalosyndactyly or syndrome of Apert*. The appearance of the afflicted patients being similar, it appears as if they all belonged to one family (see Chapter 56).

*Craniofacial dysostosis,* as first described by Crouzon (1912), is a hereditary synostosis. It consists of acrocephaly, a beaklike nose, a triangular mouth with a short upper lip and protruding lower lip, proptosis of the eyes, and exotropia. The syndromes and their treatment are discussed extensively in Chapter 56.

**Traumatic Defects of the Cranium and Scalp**

**Scalp Avulsion**

The seriousness of avulsion of the integument over the calvarium and the need to provide cover for the exposed bone were noted by the Egyptians as early as 3000 BC. Later
the famous surgeon Ambroise Paré noted the difficulty in trephining the eburnated exposed calvarium and utilized cautery to aid in sequestration of the dead outer table.

One of the earliest references in the American literature has been contributed by Douglas (1962), as follows:

The orderly book of "Camp Lady Ambler", October 20, 1776, states "Patrick Vance appointed third surgeon with pay of assistant".

Surgery and surgical instruments were of the most primitive kind on the early frontier. During the Christmas campaign, while the men were quartered at Long Island, the above-mentioned Dr. Vance discovered a treatment for scalped persons. He bored holes in the skull in order to create a new flesh covering for the exposed bone. On being called away he taught James Robertson how to perform the operation.

Frederick Caloit, a scalped patient, was brought in and Robertson had a chance to practice upon him. "He (Vance) bored a few holes himself, to show the manner of doing it". (Vance) further declared, "I have found that a flat pointed straight awl is the best instrument to bore with as the skull is thick and somewhat difficult to penetrate. When the awl is nearly through, the instrument should be borne more lightly upon. The time to quit boring is when a reddish fluid appears on the point of the awl. I bore at first about one inch apart and as the flesh appears to rise in these holes, I bore a number more... The scalped head cures slowly. It skins remarkably slow, generally taking two years".

With the advent of the industrial revolution there were many victims of scalping as the long hair of the women workers was caught in the unprotected belts and gears of the machines driven by water and steam power. Review of the early literature indicates that many of these unfortunate patients were doomed to die from prolonged infection or intracranial complications. Sequestration of denuded bone and resultant extensive defects surrounded by dense scar were the sequelae in those who survived. Subsequent recurrent breakdown with repeated ulceration frequently terminated in carcinoma.

As early as 1911, Davis reported 81 cases of industrial scalping. In 21 cases the scalp had been replaced only to mummify. In 1924, McWilliams stated that 173 cases had been reported and the scalp replaced in 40, again with no success. During World War I, Cushing (1918) again pointed out the importance of early scalp closure. This was also reemphasized and illustrated by Gillies (1944) during World War II.

**Treatment.** The immediate surgical care is similar to the supportive care given to any patient who has suffered from trauma, hemorrhage, and shock accompanying an extensive wound. Blood transfusion is frequently indicated to correct the blood loss and secondary hypovolemia. After the patient is prepared under general anesthesia, the wounds are thoroughly cleansed and lightly debrided. The denuded areas should then be converted into closed ones as soon as possible. The therapy applied depends on whether or not the periosteum is present.

**Treatment When Periosteum is Present.** The early conversion of the extensive open wound to a closed one with autogenous skin grafting remains the method of choice. The
ability of the intact periosteum to support and nourish a skin graft has been well established (Kazanjian and Webster, 1946; Converse, 1955; Kazanjian and Converse, 1959). Thick split-thickness skin grafts provide a much more stable covering than the thin Thiersch graft but require careful suturing and adequate fixation.

Repeated attempts to utilize the full-thickness scalp have generally met with failure. Kazanjian and Webster (1946) pointed out that, even though the subcutaneous fat is removed, including most of the hair follicles, the skin of the scalp is so thick that it is far less likely to survive than are the split-thickness grafts.

Osborne (1950) reported a case in which thick split-thickness grafts from the avulsed scalp were applied to the pericranium with success. Meister (1955) used "deep" scalp grafts in two cases but obtained no hair growth, even though epithelization was attained. Delak (1955) reported one successful take of a thinned scalp graft with some fuzz three months later. According to Robinson (1952) replacement even after laborious thinning down to a full-thickness skin graft is not to be recommended. Robinson further suggested that, until further research has been undertaken on the split scalp graft, immediate coverage with split-thickness skin grafts of the areas with a pericranial base remains the method of choice.

A notable exception is a case reported by Lu (1969), in which he reported an unexpectedly successful result in a 7 year old patient with a subtotal avulsion of the scalp. The avulsed scalp was replaced in toto and was revascularized.

Miller, Anstee and Snell (1976) were successful in replanting a totally avulsed scalp by microvascular anastomoses. The procedure was successful because the detached scalp was not unduly damaged and suitable recipient vessels were available in the superficial temporal region.

**Treatment When Periosteum is Destroyed.** The outer table of the calvarium receives its blood supply from the scalp through the periosteum. Hence, when the bone is exposed by avulsion, it must be immediately covered, either by a local flap in moderate and even large sized defects or by a flap from a distance. A description of the closure of these defects is given by Converse (1954b, 1955). In the scalp all the arteries extend to the vertex, anastomose freely, and form a rich network. The mobility and abundant blood supply of the scalp permit the closure of large areas with hair-bearing scalp by transposing large and long flaps on a narrow pedicle. The closure of defects by mobilization, rotation, and advancement of local flaps is the method of choice. The nonstretchable scalp can be made to cover a large area by multiple incisions through the galea according to the technique of Kazanjian and Converse. The surrounding tissues are stretched after undermining the plane between the galea and pericranium, raising the flaps, and making a number of vertical incisions through the non-stretchable galea. These may be crisscrossed with similar horizontal incisions to relieve the tension and permit return of the flaps to their original position without compromising the blood supply.

Orticochea (1971) has devised an ingenious three-flap technique for the closure of moderate size and large defects with variations. A four-flap technique is also feasible (Orticochea, 1967). Because of the vascularity of scalp flaps, they remain viable when the base of the flap is at the periphery, where it receives the nutrient vessels of the scalp.
If soft tissue coverage is not provided, the outer table of the cranial bone undergoes necrosis and is eventually extruded. Exfoliation may be accelerated by drilling a series of burr holes through the outer table of the cranium. Granulations growing up from the diploë eventually join and provide a base of granulation tissue which will accept a skin graft. A more rapid method is to remove the eburnated dead bone with an osteotome down to bleeding bone. In a week to ten days, granulations cover the area and will accept a thick split-thickness skin graft.

For smaller scalp defects which are not amenable to coverage by means of local flaps, the outer table can be burred down until pin-point bleeding is noted. A split-thickness skin graft can be successfully applied on such a bed without any delay.

Large losses of the scalp and cranium secondary to burns cannot be repaired with local scalp flaps if the surrounding tissue is subject to circulatory and dystrophic alterations. Such a condition is often seen in recurrent carcinoma treated by irradiation. These defects are best repaired with an abdominal jump flap or a tube flap transferred to the arm as an intermediate carrier. It is necessary to remove all the necrotic bone, repair the defect with a flap transferred from a distance, and at a later date provide bony protection to the underlying brain with split-rib bone grafts inserted under the flap.

McLean and Buncke (1972), employing microsurgical revascularization techniques (see Chapter 14), covered a bare cranial defect with a free omental transplant anastomosed to the superficial temporal artery and vein; the omentum, in turn, was covered with a skin graft.

Baudet, Molenaar and Montandon (1976) have successfully closed a full-thickness defect of the scalp and cranium in a 35 year old female by a combined procedure consisting of bone grafting the defect by split-rib grafts and providing soft tissue coverage, in the same stage, with a microvascular free groin flap. The circular defect was 11.25 cm in diameter and resulted from the resection of a recurrent irradiated sarcoma.

**Defects of the Cranium**

**Historical Review.** In 1889, Seydel, in repairing a defect of the skull, grafted an osteoperiosteal graft from the tibia, which he reduced to small pieces, to repair a cranial defect. Müller (1890) and König (1890) used a flap of scalp with a portion of the outer table attached. Von Hacker (1903) transplanted a single osteoperiosteal graft from the tibia as a cranial graft. Keen (1909) filled defects from chips removed by drilling the outer table of the skull, anticipating the chip-bone grafting technique of Mowlem (1944) during World War II. During a six-year period Delagenière and Lewin (1920) reported 104 cases of tibial osteoperiosteal grafts with only two failures. Kazanjian and Converse (1940) reported 18 successful cranioplasties using osteoperiosteal grafts removed from the tibia.

In 1915, Kappis employed the full thickness of the twelfth rib with periosteum to cover a dural and skull defect. Weber (1916) and Schmidt (1916) reported the use of rib grafts. In 1917, R. C. Brown of Australia suggested splitting the rib, leaving the inner half as protection for the thoracic cavity. In 1921, Ballin suggested repairing a dural defect with fascia and laying the split ribs "cut" face down on the fascia. Fagarasanu (1937) split the rib in order to gain more substance.
Morestin in 1915 advocated costal cartilage. Westermann in 1916 transplanted a graft from the sternum, and in 1920 MacLennan used scapula. Mauclaire (1908) and Phemister (1914) employed iliac bone for the repair of cranial defects, and Phemister (1914) used the outer iliac crest. Pickerill in 1931 employed the inner table of the ilium for cranial defects and later in 1947, in a long-range follow-up, concluded there was no doubt that surgically, anatomically, and psychologically the patient's own tissues provide the best means of reconstruction.

In 1928, Brown presented a ten-year postal card follow-up of his split-rib cases. Mowlem (1944) advocated the merits of cancellous bone. Macomber (1949) used cancellous iliac bone for defects of the forehead, nose, and chin. Sodeberg and Mulvey (1947) also claimed that cancellous bone had superior osteogenic properties. McClintock and Dingman (1951) reported the successful use of autogenous iliac bone in 14 cranioplasties. Kiehn and Grino (1953) reported the relief of symptoms following removal of a tantalum plate in three cases and reconstruction with flaps and iliac bone.

In a monograph on cranioplasty, Wolff and Walker (1945) stated that for defects up to 8 cm, autogenous bone was the choice; but for larger defects inorganic materials should be used.

It is of interest that a hammered gold plate was used, before the dawn of history, to repair a frontal defect of the skull in a Neolithic Peruvian chieftain. The same type of gold plate was suggested by Fallopio, but later decried by Paré. Gold was utilized by the French (Estor, 1917) during World War I, but it was found to be too soft and expensive. Lead plates were used Mauclaire (1908) but produced acute lead poisoning, and silver was utilized by Savariaud (1912), resulting in localized argyria.

Subsequently tantalum (Pudenz and Odom, 1942), vitallium (Geib, 1941), and stainless steel (Scott and Wycis, 1946) have been extensively utilized but have the following disadvantages. They are radiopaque, conduct heat and cold, and produce varying degrees of local reaction at the time of implantation. The incidence of infection and subsequent extrusion is fairly high. White (1948), in an extensive follow-up of patients operated upon during the period between 1943 and 1946, found that the complications amounted to 10.6 per cent in 66 cranioplasties performed with lucite and 12.3 per cent in 130 after plating with tantalum. He found that the scarred scalp is likely to break down under a plate and that plates over the mastoid, frontal, and supraorbital areas tend to loosen and perforate the soft tissues. The danger with short wave diathermy in patients with metals embedded in their tissues must be seriously considered.

Small and Graham (1945-1946) pointed out the high incidence of epilepsy resulting from the intense fibrosis set up by the foreign body reaction. Newer inorganic materials have been employed more recently for large frontal bone defects. These have been cast from impressions taken of the defect; complications, including fluid collection, infection, and eventual extrusion, have occurred. It must be further borne in mind that inorganic substances have no growth potential and hence should not be utilized in the growing child. Grotesque malformations of the skull and skeleton have followed the early repair of cranial defects with fixed metallic plates and mesh. These complications contrast with the relatively uncomplicated
Conditions for Success in Bone Grafting. As previously emphasized in Chapter 13, a covering of well-vascularized soft tissue is an essential condition for success. Local or distant flaps must resurface the area to be bone-grafted if soft tissue over the cranial defect has been destroyed or is inadequately vascularized. Bone to bone contact between the graft and host bone is essential. Absence of infection is self-evident.

Split-Rib Grafts. Much has been written about cartilage, skin, and bone banks. The bank of autogenous bone (the ribs) within each individual possesses the ability to redeposit itself repeatedly, if care is taken not to destroy the periosteum of the rib bed (Longacre, 1955; Longacre and de Stefano, 1957a, b, c; Longacre and coworkers, 1959; Holmstrand and coworkers, 1960). The supply of bone is almost unlimited and can be removed without producing respiratory distress or ensuing deformity if it is done at intervals. It is a well-known fact that rib fractures in the aged and cachectic heal. It has been pointed out by Albright and Forbes (1957) that, when multiple pathologic fractures occur in certain syndromes, the only ones that heal are rib fractures. The ribs possess an inherent ability for osteogenesis. Within a few weeks after total removal of a rib, there is evidence of calcification, and within a short time a complete new rib has re-formed. Roentgenograms taken years later show no deformity of the thoracic cage. Only very careful examination will indicate which ribs have been utilized. In a patient with Romberg’s hemifacial atrophy, we have used a rib regenerated from the same rib bed as often as five times.

Clinical experience shows the low morbidity after rib resection, as compared to that after the resection of a similar amount of bone from the ilium or tibia. In addition, the ilium should not be utilized in a growing patient because of the danger of disturbing the growth center of the cartilaginous crest. However, Crockford and Converse (1972) have reported a technique of harvesting bone grafts from the ilium without disturbing the secondary centers of ossification (see Chapter 13). This technique is indicated only in small cranial defects. With regard to the amount of bone obtainable, we have resected eight full length ribs (four alternate ribs from each side of the thoracic cage) in a child within a period of two weeks without producing any cardiorespiratory embarrassment.

Technique. In this age of speed and power with its associated increase in head injuries, more patients as the result of improved care are surviving severe and mutilating trauma to the skull and facial skeleton. The resection of tumors and osteomyelitic areas produces extensive defects. As the result of intensive irradiation therapy and radical ablation of recurrent carcinoma, large defects of the cranium are produced. The radical unroofing of the calvarium as a life-saving measure in the treatment of acute lead encephalitis (McLaurin and Nichols, 1957) accounted for extensive defects (75 to 90 per cent of the calvarium).

Defects of the cranium have presented a problem since the earliest records of man (eg, the Edwin Smith Papyrus) and are seen in the remains of the trephined skulls of Peruvian Neolithic man. Rarely does the calvarium regenerate, and then only in very young children after a portion of it has been removed for craniosynostosis or osteomyelitis. It is well known that the ossification of a linear fracture of the skull requires months in children, while in an adult it will require years. In contrast, a fracture through the base ossifies after a relatively
short time. This difference in healing may be explained by the fact that the calvarium originates from membranous bone, while the base originates from cartilage (chondrocranium).

An 18 month old child had survived 40 per cent total destruction of the skull and its coverings with the exposure of the anterior, middle, and posterior cranial fossae. After the infection had been cleared up, the area was covered with postage stamp skin grafts. Since the area still remained soft, it was decided to prepare a delayed flap of the remaining scalp and rotate it over the defect, after having excised the previously grafted area. Despite the improvement in the blood supply, there was still no evidence of regeneration of the bone one year after the original injury. The diameter of the defect had increased from 13.5 cm to 15 cm during the interval. It was felt that four full length rib grafts (if taken singly in four separate operations) would not disturb the cardiorespiratory mechanism of the child and still would provide sufficient autogenous bone. The bone grafting was done in stages; after two operations there was some purulent drainage due to reactivation of infection. The wounds healed, however, without the extrusion of a single fragment. Within one year there was osteogenesis extending from the edge of the skull to the split-rib grafts and between the widely separated grafts themselves. It has now been 17 years since the reconstruction was completed. The long-term result is shown in the figure. The defect is now reconstructed with a plaque of solid bone, except in the posterior fossa where no split-rib grafts were placed. In these plaques are to be found vestiges of the original rib grafts. It is of interest that the circumference of the skull measured 53 cm at the age of nine years. The boy was active and alert and led a normal life. A six-year biopsy was taken which showed complete restoration of the defect, with the formation of an inner and outer table. At age 18 years, the patient is fully grown. Note the symmetry of skull.

Another example is that of a 4 year old child with extensive defects measuring 14 x 16 cm on either side of his skull. Two years previously he had been admitted in a moribund state with acute lead encephalitis. As the result of an extensive unroofing of the skull with radical incision of the dura, the child survived, and two years later he had a residual IQ of 90. One of the resected cranial segments, which had been removed and kept under sterile conditions in the bone bank, had later been used to reconstruct one side of this "satchel handle" defect. Osteomyelitis ensued, and the refrigerated autogenous graft was removed. Two years later there was very little evidence of bone regeneration, and he was forced to wear a special helmet to protect the brain. The eighth and tenth ribs were resected at one procedure, and part of the defect on the left side was reconstructed. After an interval of 24 days the sixth, eighth, and tenth ribs were removed from the right side and the costal beds closed carefully with a running suture of 3-0 chromic catgut. The ribs were then split lengthwise to provide sufficient bone to reconstruct the entire defect on the right side of the skull. Ten days later the seventh rib was removed from the left side of the thorax and split lengthwise in three separate grafts. There was evidence of almost complete regeneration of the eighth and tenth ribs at this time. The split-rib grafts transplanted 34 days before were found to be solidly incorporated between the dura and the scalp and appeared on gross examination to be well vascularized. The figure shows the progressive thickening of the reconstructed skull, with the formation of an inner and outer table.

Clinically it has been noted that the skulls of these children develop at a normal rate, even in a child of 18 months in whom all the growth centers on one side of the skull had been destroyed. Over a period of 16 years of observation following repair, there has been no
apparent difference in growth between the unaffected and the reconstructed sides (even though 90 per cent of the growth of the calvarium is completed by the age of eight). In other children in whom a growth center was destroyed and the defect bridged with an inorganic implant, growth failed to occur, resulting in an asymmetry between the two sides of the cranium.

**Longitudinal Studies**

Upon analysis of our results (Longacre and de Stefano, 1957b) with 146 autogenous bone and cartilage grafts to the head and face, we were impressed with the permanence of the autogenous osseous transplant and the manner in which it would stand up under reactivated infection. In addition, there was direct evidence in measurements and moulages of the continuous growth of these grafts in young patients observed over a period of six to 18 years.

The literature is filled with preliminary and so-called long-term follow-up of a mere two or three years. Results which first appeared as excellent during this short time may not be as good when followed over a more extended period. This is particularly true when the factor of growth and development is considered in the reconstruction of extensive defects of the cranial bones and facial skeleton in the developing child.

Longacre has performed more than 700 operations on humans utilizing split-rib grafts during the past 20 years. In addition, long-range experimental observations have been made in several large series of macaque rhesus monkeys. Our clinical findings in humans have closely paralleled the more detailed experimental observations in the monkeys (for details see Chapter 13).

**Iliac Bone Grafts.** Iliac bone may be utilized in frontal and other cranial defects measuring up to 10 cm in diameter. Iliac bone grafts are particularly indicated in frontal defects, as they provide a smooth contour.

**Repair of Full-Thickness Defects of the Frontal Bone**

A preferred technique for wide exposure of the frontal bone is the raising of a bifrontal or coronal scalp flap. This type of exposure is preferable to exposure through residual scars, unless they are conspicuous and require repair; usually the scars are not conspicuous by the time bone repair is being considered.

The incision through the scalp extends downwards on each side between both preauricular areas. The flap is raised through the fibroareolar tissue between the galea aponeurotica and the pericranium, and, as the dissection is continued downward, it reaches the frontalis muscle, which is raised from the periosteum of the frontal bone to the level of the supraorbital arches. In defects involving the lower portion of the frontal bone, the periosteum is incised, the supraorbital nerve is liberated from its canal (see Chapter 56) and the periorbita is raised from the anterior portion of the roof of the orbit when the defect involves the supraorbital rim.

As the raising of the flap reaches the bony defect, careful dissection is required because of the adherence of the dura to the periosteum and the flap; in many cases the tissues may be adherent and dense scar tissue present.
The extent of the bony defect is outlined. The periostium is incised around the periphery of the defect, a periosteal elevator raises the periosteal cuff thus formed around the defect, and the cuff is folded into the defect.

The periosteum around the periphery of the defect is elevated, as the iliac bone graft will be placed under it after bridging the bony defect. The iliac bone taken from the inner table of the ilium has a curvature favorable to the restoration of contour of most cranial and lateral frontal defects. The shape of the graft and size of the graft are determined by a template of malleable Asche metal. The cortex of the graft from the inner table of the ilium is placed toward the dura and the cancellous portion under the soft tissues. A central frontal defect may require a graft without the curvature. The curvature of the graft can be modified by bending the graft after weakening the cortex by a number of parallel cuts through the partial thickness of the cortex; in young patients the bone is malleable, and adequate curvature can be obtained by bending it into the suitable contour. In small and moderate sized defects, a single onlay graft is adequate. The overlapping edges of the graft, which are placed between the surrounding bone and the periosteum, are thinned and beveled by means of an air-turbine drill activating a large oval-shaped or Lindemann spiral burr. This precaution is essential to prevent the edge of the graft from forming a conspicuous peripheral ridge. A mosaic of corticocancellous and cancellous grafts is then built up to complete the coverage of the defect and to provide adequate contour when necessary.

Usually the dura is covered with scar tissue, but under the bone overlay a dead space, which will fill with blood and serum, should be obliterated with cancellous bone chips packed into the cavity.

Fixation of the bone graft is optional. The flap is replaced, sutured, and a pressure dressing applied for seven days.

Patients who have undergone reconstruction of frontal bone defects by this technique are shown in the figures.

In large cranial and frontal bone defects, the problem of obtaining sufficient bone becomes more complex. It is in these large defects that sequential split-rib grafting is indicated. The contour can be improved in large frontal bone defects by the addition of flat pieces of iliac bone, consisting mostly of cancellous bone, which straddle the split rib grafts.

**The Frontal Sinus in Frontal Bone Defects.** Radical operations for frontal sinusitis, complicated by spreading osteomyelitis, may necessitate the resection of the full thickness of the frontal bone, the anterior and posterior walls of the frontal sinuses, and adjacent supraorbital and nasal bone. Reconstruction is then required after a suitable time interval. The advent of antibiotics has made possible the control of spreading osteomyelitis and obviated the need for radical surgery.

Less radical operations are still performed for the cure of frontal sinusitis, leaving in their wake a deformity resulting from the resection of the anterior wall of the frontal sinus. Reconstruction by bone grafting is indicated.
Glabellar fractures may result in the loss of bone of the anterior wall of the frontal sinus or a depressed, malunited fracture. The treatment is similar to that illustrated in the figure.

Complications caused by repeated inflammatory episodes and suppuration have been observed because of the failure to eliminate the mucous membrane-lined cavities of the frontal sinuses. Large frontal sinuses extend far laterally, and the remainder of the sinus may be overlooked. The roentgenogram usually shows the size and position of the frontal sinus. In unusual cases, it will show the presence of the frontoethmoidal cell between the frontal sinus and the roof of the orbit. The bony defect involving the anterior wall of the frontal sinuses may not extend over the entire height and width of the frontal sinuses. The lateral portions of each sinus should be identified. All of the mucous membrane should be removed with a large size curette. "Nature abhors a vacuum", and the sinus cavity must be eliminated. The cavity is filled with corticocancellous bone chips. The frontal duct is curetted, thus removing the lining mucous membrane, and a bone chip is plugged into the duct. A bone graft overlay is then placed over the defect.

**Respective Indications and Variations in Technique.** The iliac bone graft, whether wired into the defect or employed as an overlay in conjunction with smaller grafts, has the advantage of smoothness, an important consideration in a conspicuous area of the body. Large defects can be repaired by this technique, the limit in size being the surface of bone that can be removed from the medial aspect of the ilium.

In large defects of the calvarium too extensive for iliac bone grafting, the split-rib technique performed in stages is the only feasible technique and is of particular value in the child. A disadvantage of the split-rib technique is the slightly irregular surface provided by the juxtaposed grafts. While this inconvenience is of minor importance over the hair-bearing portion of the cranium, it has an esthetic disadvantage in the repair of defects of the frontal bone. Kòrlòff, Nylén, and Rietz (1973) have achieved good results in a series of frontal bone defects by split-rib bone grafting in two stages: a first layer of split-rib grafts is placed under the edges of the defect over the dura; ten months later, a second layer of grafts is wedged into the defect at right angles to the first layer of grafts.

Another technique (Marchac, 1974) splices a single layer of split-ribs into the diploë of the bone surrounding the defect for better fixation.

In order to avoid the irregular surface that may result from reconstruction of a frontal bone defect by split-rib grafting, slabs of cancellous iliac bone grafts may be laid, mosaic fashion, over the split-ribs.

**Contour Restoration of the Frontal Bone.** With a depressed fracture of the anterior wall of the frontal sinus or a sloped forehead, as occurs in patients with craniofacial dysostosis (see Chapter 56), the full thickness of the bone is not involved.

Exposure by raising the bifrontal scalp flap, described in the preceding pages, exposes the depressed area. Onlay bone grafts contoured to shape must be placed under the periosteeum of the frontal bone in close contact with the bone. Iliac bone grafts and split-rib grafts will restore contour. When split-ribs are employed, they are placed side by side, split surface and
cortical surface altering. Slivers of the bone may be placed in the intervals between the surface of the grafts to obtain a smooth contour.

Costal cartilage grafts have provided a satisfactory means of restoring supraorbital arch depression and are an alternative source of grafting material. As stated earlier in this chapter, autografts are preferred to all other transplants or implants.