Facial injuries in children are considered separately in this text because of special problems which arise in their treatment. Children are subjected to injuries similar to those of adults. The automobile is responsible for large numbers of deaths and injuries, and children, as victims, are no exception.

Children under 5 years of age account for 2 to 3 per cent of automobile occupant deaths; children under 14 years of age account for approximately 6 per cent of automobile deaths. Of children between the ages of 5 and 14 years who were injured in automobile collisions, 56 per cent were actual occupants of automobiles (Burdi and coworkers, 1969).

These figures relate to automobile accidents; there are other causes of accidents in children extending over a wide range from a fall to a thermal burn. Athletic activities are responsible for facial injuries in the older child. The vast canine population in the United States (it is estimated there are over 65 million dogs) subjects the child to dog bites, which often result in considerable soft tissue disorganization and loss.

Soft tissue injuries and fractures may require special therapeutic techniques owing to difficulties in obtaining the cooperation of young children. Another aspect of facial injuries in children that must be considered is the effect of trauma upon facial development. A posttraumatic facial deformity in a child is the result not only of the displacement of bony structures caused by the fracture but also of faulty or arrested development resulting from the injury. Developmental malformations seen in young adolescents and adults are often secondary to early childhood injury. A statement should always be made to the parents of a child, preferably in writing, that maldevelopment in growth may occur as a result of a facial bone fracture despite adequate remedial treatment, particularly in injuries involving the nasomaxillary complex and the condylar area of the mandible. This is an essential medicolegal precaution.

The Child and the Adult: Anatomical Differences

Infants and children are not small adults. They differ structurally from adults, particularly in the relation of the head mass to the remainder of the body. The child's head is proportionally larger than that of the adult; this heavier head mass may, in part, be the basis for a high frequency of head (and face) injury.

At birth the facial portion of the head is smaller than the cranium in a 1:8 ration, as compared with the adult ratio of 1:2.5. Owing to the large size of the frontal lobes, the forehead is high and protrusive. Although half of the postnatal increase in brain volume occurs during the first year of life and the brain attains 75 per cent of its adult size by the end of the second year, disproportionate craniofacial size is noticeable even in children 7 or 8 years of age.
Vertical growth of the face progresses in spurts related to respiratory needs and tooth eruption, first during the first 6 months after birth, then during the third and fourth years, from the seventh to the eleventh years, and lastly between the sixteenth and nineteenth years.

Thus, it is obvious that during the period of growth and development the child differs structurally from the adult and that soft and hard tissue injuries consequently require special consideration.

**Prenatal and Birth Injuries**

Intrauterine compression is though to be one of the causes of prenatal deformities, although evidence of this type of injury has never been substantiated.

Birth injuries may result from prolonged labor with difficult passage through the birth canal and delivery by obstetrical forceps. Most of these injuries due to obstetrical forceps are minimal, and recovery usually takes place without residual deformities. Infant and child skulls are pliable because of the segmental arrangement, flexibility, resiliency, and relative softness of the bones. The bones develop as a loosely joined system found in the matrix surrounding the brain. They are separated by fontanelles and sutures covered by a thin fibrous sheath. These characteristics explain the malleability of the cranial and facial bones and the fact that they are subject to distortion and crushing injuries which may have subsequent developmental repercussions.

Deviation of the septum has been attributed to forced deflection during birth. More severe injuries have been attributed to forceps compression of the soft tissues and bones of the face, which may cause permanent facial scars and osseous deformities in the region of the zygomatic arch and temporomandibular joint, resulting in temporomandibular joint, resulting in temporomandibular ankylosis with subsequent developmental hypoplasia of the mandible. Because of the lack of development of the mastoid process at birth and the superficial position of the seventh cranial nerve, facial paralysis caused by injury of the nerve by delivery forceps pressure is not infrequently observed.

Injuries to the eye or its adnexa, such as damage to the extraocular musculature, may be caused by intraorbital hemorrhage. Fractures of the body of the mandible due to birth injury are rare. They are usually linear fractures with little, if any, displacement. Healing occurs in a short time without manipulative treatment.

Johnson (1962) reported the case of a newborn baby with separation of the two halves of the mandible at the symphysis following a maneuver in which the obstetrician placed his finger in the child's mouth and used forceful manipulation to deliver the baby.

**Injuries in Infants**

It has long been suspected that infants fall much more frequently than is generally known. Of 536 infants involved in a study sponsored by the National Safety Council (Kravits and coworkers, 1969), 47.5 per cent fell from a high place such as an adult bed, a crib, or an infant dressing table during their first year of life. Some of the infants in the series suffered cranial, intracranial, and facial injuries. It can be assumed that facial trauma occurring in such
falls in infants, although not often resulting in fractures because of the elasticity of the neonatal bones, may be sufficient to interfere with growth centers and may explain some of the developmental malformations of the face observed in later years.

**Soft Tissue Injuries in Infants and Children**

Soft tissue wounds in children heal rapidly and therefore require early primary suture. Fortunately, lacerations repaired at an early age tend to become less conspicuous with the passage of time. Pediatricians will often advise the parents to wait until the child has reached adolescence before effecting the repair; this is poor advice, because many scars repaired in infancy and childhood are inconspicuous if not invisible in adolescence.

Some wounds tend to heal with considerable hypertrophic scarring; discouraging results often require later repair of the scar (see Chapter 16). It is wise to mention this possibility to the parents, advising that secondary surgery may be necessary. Densely scarred areas may require reconstructive procedures, for such untreated areas may interfere with subjacent growth, particularly in the area of the mandible.

Loss of soft tissue of the face by avulsion or thermal burns is remedied by skin transplantation. Defects of the nose are adequately repaired, in many cases, by composite auricular grafts, which show a high success rate in children. While subtotal or total loss of the nose has not been observed by the authors, Lewin (1955) has described reconstruction of the nose in a 2 month old infant.

**Emergency Treatment**

Arrest of hemorrhage and provision of an adequate airway are emergency measures that are more important in the facially injured child than in the adult. The small size of the laryngotracheal airway in the child, edema of the laryngeal mucous membrane, or retroposition of the base of the tongue can contribute to sudden respiratory obstruction. Immediate relief of obstruction is obtained by means of a suture placed through the tongue for forward traction. Although humidification of the room by a vaporizer or administration of corticosteroids can relieve the symptoms of laryngeal obstruction, one should not hesitate to perform a tracheotomy in a child with a fractured mandible or maxilla who is unconscious or who is showing increasing respiratory distress. In doing a tracheotomy in a young child, one should avoid incising through the first tracheal ring because of the danger of causing tracheal stenosis. Caution must also be exercised to avoid the innominate vein in a low approach to the trachea. Expert intratracheal intubation may obviate the need for a tracheotomy.

**Fractures of the Facial Bones in Children**

**Incidence.** Fractures of the facial bones are less frequent in children than in adults. Except in large medical centers, the total experience of any surgeon in the management of facial fractures in children is limited.

During their early years children live in a protected environment under close parental supervision. The resiliency of the developing bone, the short distance of the falls, and the
thick overlying soft tissue enable the child to withstand forces that in the adult would result in extensive comminution rather than in the greenstick fractures seen most frequently in children. The tooth to bone ratio in the developing mandible is comparatively high, and the bone has a more elastic consistency. The rudimentary paranasal sinuses, the large cartilaginous growth centers, and the small volume ratio between the jaws and the cranium are all factors providing protection to the facial bone structures.

The incidence of facial bone fractures in children varies according to various reports. In a series of mandibular fractures reviewed by Kazanjian and Converse (1974), children between 4 and 11 years represented approximately 10 per cent. In a series reported by Panagopoulos (1957), fractures of all facial bones in children represented only 1.4 per cent of the entire series. Pfeifer (1966), reviewing a series of 3033 cases of facial bone fractures, noted that 4.4% per cent of these cases had occurred in children in the age group extending from birth to 10 years; in the age group extending to 14 years, the incidence was 11 per cent; in the age group from 11 to 20 years of age, the incidence was 20.6 per cent.

Rowe (1968) summarized the data by stating that 1 per cent of facial fractures occur before the sixth birthday, and a total of 5 per cent occur in children under the age of 12 years. Approximately 1 in 10 fractures in children under 12 years involves the midfacial skeleton; midfacial fractures are uncommon before the age of 8 years.

One of the principal causes for the rarity of fractures of the facial skeleton in children is the large size of the cranium in relation to the facial skeleton. McCoy, Chandler, and Crow (1966), in an analysis of 1500 cases of facial fractures, reported 86 children of whom 35 (40.8 per cent) had associated skull fractures. This finding can be explained by the protrusion of the massive brain case; the large cranium-face proportion is noticeable even up to 7 or 8 years of age.

A major portion of the cranial growth is achieved by the age of 2 years. In contrast, facial skeletal growth continues during childhood. The facial skeleton gradually becomes pneumatized by the accessory sinuses. Although the period of maximal growth of the maxilla is reached around the age of 6 years, the adult size of the orbit is attained during the seventh year. From birth until adult size is reached, the facial skeletal framework increases threefold in size compared with the cranium. The small facial skeleton, not yet weakened by the air sinuses and further protected by the soft tissues with the thick adipose layer characteristic of young children, is less subject to fracture that the dominant cranium.

**Mandibular and Facial Bone Fractures in Children: Special Aspects**

1. Predisposition to greenstick fractures in developing bone is attributed to two factors. The first, as mentioned earlier in the text, is subcutaneous tissue, mainly adipose tissue, which increases rapidly in thickness during the nine months after birth. At the age of 5 years, this subcutaneous tissue is actually only half as thick as in a 9 month old infant.

The second factor is the resiliency of the developing bone, which predisposes to the characteristic greenstick type of fracture. The line of differentiation between cortical bone and medullary bone is not sharply defined, and the resiliency of the young bone explains the higher frequency of such fractures in the child. When fractures do occur, however, fractures
involving the body of the mandible frequently show a considerable degree of displacement, and the fracture lines tend to be long and oblique, extending downward and forward from the upper border of the mandible. The obliquity of the fracture line is quite different from that observed in the adult, in whom the direction of the fracture line is usually downward and backward.

2. Prior to the eruption of the permanent (or secondary) dentition, the developing permanent teeth occupy most of the body of the mandible. This anatomical characteristic must be considered if interosseous fixation is to be employed, in order to avoid injuring the tooth buds of the permanent teeth. The wires must be placed near the lower border of the mandible. The roots of the deciduous teeth are gradually being resorbed, and between the ages of 5 and 9 years (the mixed dentition), because of the frequent absence of teeth and the poor retentive shape of the crowns of the deciduous teeth, it is often difficult to utilize the dentition for fixation.

The teeth cannot be employed for fixation in the treatment of mandibular fractures in very young infants in whom the teeth are unerupted or only partly erupted. An impression of the mandible can be taken under light anaesthesia and an acrylic splint fabricated. After realignment of the fragments, the splint is placed over the mandibular arch, lined with softened dental compound for better adjustment, and maintained in position by circumferential wiring. This type of monomaxillary fixation may be adequate. Intermaxillary fixation is obtained by circumferential wiring around the body of the mandible, and the wire is further passed into the floor of the nose and downward through the palate, thus surrounding the alveolar area of the maxilla without interfering with the tooth buds of the secondary dentition. Transalveolar wiring above the apices of the teeth can be used in the older child after the eruption of the secondary dentition. At this later age, however, the dentition may be adequate for intermaxillary dental fixation.

During the period when the deciduous dentition is being replaced by the permanent dentition, particularly in the period between the ages of 6 and 12 years, some difficulty may be experienced in obtaining interdental fixation. Acrylic splints may prove to be most useful in this age group.

In older children in whom the dentition is more retentive, various types of fixation can be employed. The cable arch wire is useful as an emergency fixation appliance. A band and arch appliance can be employed if the teeth permit retention of the appliance; circumferential wire will aid in stabilizing the mandibular appliance. Eyelet wiring may also be feasible. Direct interosseous fixation, placing the wire near the lower border of the mandible in order to avoid injuring the tooth buds, is of considerable assistance in maintaining the fixation when only deciduous teeth are present for fixation. The interosseous wires may be placed through an intraoral approach after degloving the mandible. A circumferential wire around the mandible is also a useful adjunct in reinforcing the fixation established by the arch bar fixation and can be employed after exposing the ends of the fractured bone intraorally by the degloving procedure (see Chapter 24).

When the deciduous teeth and alveolar process are avulsed the deciduous teeth are discarded, the alveolar bone is replaced, and the mucous membrane is sutured.
A severe compound fracture of the maxilla can be treated by arch bars wired to the remaining teeth. Following the interosseous fixation, intermaxillary fixation is established whenever possible.

3. Fractures of the facial bones in children must be recognized and treated early because the reparative process in children is rapid; loose, displaced fragments become adherent to one another within three or four days after injury. At this time, fragments are difficult to manipulate and must be loosened under general anaesthesia before reduction of the fracture is possible.

Minor degrees of malunion can be tolerated in the growing facial bones, as corrective adjustment will take place with the erupting teeth under normal masticatory stresses.

4. Fractures involving the body of the mandible frequently involve the permanent tooth follicles, but it is seldom necessary to remove these. Eruption of the permanent teeth may be delayed, however, and the teeth may show varying degrees of damage after consolidation of the fracture.

5. Children are usually not as cooperative as adults because of fear, apprehension, and pain. Kindness, consideration, and tact are necessary in managing the child patient. Whenever possible, the operative procedure or even minor manipulative work, such as intermaxillary wiring or the making of wire loops or buttons, should be performed under general anaesthesia.

A few children, however, if the need for treatment is carefully explained to them, become remarkably cooperative, and these procedures can then be done under sedation, which may also be required before radiographic examination.

6. Fractures or injuries to the articular surface of the temporomandibular joint should be suspected in all children who have suffered a severe blow to the chin. Radiologic studies may demonstrate fractures of one or both mandibular condyles with or without displacement. Condylar fractures and injuries (see Chapter 24) should always be viewed with concern in the young child because of the possibility of secondary growth deformities resulting from damage to the condylar growth centers. Injuries to the articular surface of the joint may result in hemarthrosis with cicatricial organization and damage to the articular surface of the joint with subsequent bony ankylosis. This potential should always be considered and discussed with the parents in injuries of this type.

Temporomandibular ankylosis may follow injury to the condyle. An example of such a complication is the following: one of our patients, a 3 year old boy, was examined after a fall on the chin. No apparent injury could be found on clinical and radiological examination. Six months later, the child had developed limitation of motion of the mandible due to partial ankylosis of the right temporomandibular joint. Resection of the head of the condyle restored mandibular function.

Topazian (1964) reported that trauma, most frequently a traumatic force applied to the point of the chin in children under 9 years of age, was responsible for approximately one-third of the cases of temporomandibular ankylosis on a personal series of 44 cases and in 185 cases surveyed in the literature.
Fractures of the condyle which involve the base of the neck of the condyle are often of the greenstick variety and are not usually accompanied by disturbance of the temporomandibular joint. Fortunately, many fractures in the condylar area of the mandible in children are not followed by ankylosis or growth disturbance.

A progressive straightening of the neck of the condyle is observed after fractures in which bony contact between the fragments has been maintained. Pfeifer (1966) noted that, in fracture-dislocation with loss of contact between the fragments, there was a shortening of the ramus on the affected side and asymmetry of the mandibular arch. In these cases, resorption of the condyle was observed, followed by the formation of a new joint. In none of these cases did ankylosis occur, although deviation upon opening of the mouth was frequent owing to the shortening of the ramus and dysfunction of the lateral pterygoid muscle.

A case referred to in Chapter 24 (Gregory, 1957) is that of a girl, aged 8 years, who sustained a subcondylar fracture of the mandible on the right side when she fell while riding on her bicycle. Roentgenographic examination showed a medial dislocation of the right condyle; the teeth were wired in occlusion by means of intermaxillary wire. Consolidation was completed with the head of the condyle at the right angles to the ramus. The patient had no trouble in masticating food, but there was a deviation of the mandible to the affected side when the mouth was opened wide, indicating dysfunction of the right lateral pterygoid muscle. She was instructed to stand before a mirror and exercise her jaw daily in order to restore lateral pterygoid muscle function. Radiographs taken three years later showed a nearly normal position of the condyle and satisfactory growth, position, and function of the mandible.

Temporomandibular ankylosis (see Chapter 31) and mandibular hypoplasia are often attributable to damage to the articular cartilage of the condyle. Varying degrees of anatomical disruption of the condylar process, overriding of fragments and comminution do not seem to be the responsible factors in causing temporomandibular ankylosis. Before the age of 5 years the condylar neck is less developed, and the bony tissues are soft and more susceptible to a "crush" type of injury; after the age of 5 years, the condyle will, in all probability, fracture at the neck. The crush type of injury may cause the condylar cartilage to sustain the main damage. Because the condylar cartilage is one of the factors in mandibular growth, mandibular hypoplasia results when it is injured. The degree of deformity seems to be inversely proportional to the age at which injury was sustained: the younger the patient at the time of injury, the more severe the deformity.

Condylar cartilage is first noted during prenatal life at the twelfth week. Blackwood (1965) has shown that large vascular channels appear during the twentieth week of fetal life and persist until the second or third year of postnatal life, when they progressively diminish in size. During this period the neck of the condyle progressively increases in length to form the long, slender condylar neck of the adult. Despite the fact that during the first three years of postnatal life the condyle is short and thick and thus less susceptible to fracture, it is also more vulnerable to a crushing injury because of its vascular trabecular structure. The crushing results in intra-articular and periarticular hemorrhage, and osteogenesis and progressive ossification results in temporomandibular ankylosis. Dufourmentel (1929) had noted that the condyle in the young child was more easily crushed than fractured.
There seems, therefore, to be a distinct difference in the results of a crushing injury in early childhood and a fracture of the neck of the condyle in later childhood. Whereas the crushing injury and the resultant damage to the condylar cartilage, as emphasized by Walker (1957), result in developmental arrest, the deformity resulting from the condylar neck fractures, when treated by simple intermaxillary fixation, is self-correcting (Gregory, 1957; Blevins and Gores, 1961; Rakower and coworkers, 1961; Kaplan and Mark, 1962; MacLennan and Simpson, 1965; Rowe and Killey, 1968; Rowe, 1969). The advisability of intermaxillary fixation in fractures of the neck of the condyle in children has been questioned by Leake, Doykos, Habal, and Murray (1971), who observed spontaneous recovery of function and form in 20 children with unilateral or bilateral condylar neck fractures treated by early motion and no immobilization.

Fractures of the Alveolus

Injuries of the Teeth. In the young child, teeth may be dislodged along with a segment of alveolar bone which is subjected to a labial, buccal, and lingual displacement. Frequently the fragments of bone can be molded into alignment, and the teeth will survive if adequately supported for several months by wiring to an arch bar, by fixation with an acrylic splint, by threading wires between the teeth and wiring the fragment to solid teeth on either side of the fragment, or by use of a cable arch wire. In the child with incompletely developed roots, teeth may regain their blood supply and survive. In some instances, after root canal therapy the tooth can be replanted with success. If the teeth are fractured and the alveolar structures are hopelessly damaged so that they cannot retain tooth structures, it is best to remove the teeth, trim the alveolar process, and suture the soft tissues over the retained but injured bone. Bone fragments should not be dissected from attached soft tissue, and alveolar bone structure that has any opportunity to survive should be retained; even loose bone fragments, if covered with soft tissue, will survive as grafts.

Fractured crowns of teeth without exposure of the pulp should be protected by dental methods, as they can usually be successfully restored. If the crown of the tooth is fractured with the dental pulp exposed, the prognosis may be good if the tooth is capped or partial pulpectomy is done. This is most successful in the tooth with an open apex, but even in the more fully developed tooth, pulpectomy and root canal treatment may be effective in saving the tooth structures. Fracture of the root near the crown of the tooth usually requires extraction. If teeth can be retained only a few months, they may be useful in maintaining space until prosthetic replacement can be provided. Damage to the permanent tooth buds may result in deformed tooth structure, faulty eruption, or irregular arrangement of erupting teeth in the dental arch.

Delayed Treatment. If reduction of a fractured mandible has been delayed and cannot be achieved through simple manipulation, the fibrous tissue which forms rapidly in children between the ends of the fragments is excised and the fragments are loosened. A stout needle or trochar establishes a hole through the alveolar process of the distal and proximal fragments. Stainless steel wire is then passed from the buccal to the lingual side across the fracture line and returned from the lingual to the buccal side. The fragments are manipulated into alignment, and the ends of the wire are twisted. The twisted ends are bent close to the alveolar process and left long enough to protrude through the gingival tissue. The wire can then be removed as early as 14 days later, as consolidation occurs rapidly in children.
Although this procedure may occasionally cause injury to unerupted teeth, little damage has occurred in our cases. Even though one or more teeth must eventually be sacrificed, less harm ensures than would occur if the jaw fragments were permitted to heal in a distorted position, which may lead to greater deformity in children than in adults.

**Fractures of the Bones of the Midfacial Skeleton**

The preceding pages have considered facial fractures in general and mandibular fractures in particular. Midfacial fractures in children up to the age of 12 years have constituted less than 0.5 per cent of all facial fractures; this figure may require revision in view of the greater number of children involved in automobile accidents. Because of the higher degree of elasticity of the facial bones in young children and the lesser degree of development of the midfacial skeleton in relation to the frontal and cranial area, middle-third facial fractures in children are less frequent than in the adult. Maxillary, naso-orbital, and orbital blowout fractures are not infrequent, and in children submitted to an unusually strong traumatic force, frontal bone and telescoping naso-orbital fractures can be associated with midfacial bone fractures.

**Fractures of the Maxilla.** The typical Le Fort lines of fracture are rarely seen in children's fractures. Low maxillary (Le Fort I) and pyramidal (Le Fort II) fractures are occasionally encountered.

Problems with fixation are similar to those encountered in the treatment of mandibular fractures because of the presence of poorly retentive teeth. In addition, alveolar fractures cause loosening, luxation, avulsion, or fracture of teeth, particularly the anterior teeth which are especially exposed to injury. A fixation appliance (cable arch, arch bar, or acrylic splint) may be attached to the remaining teeth and, in the older child, to selected erupted permanent teeth.

Internal wire fixation is an excellent means of fixation in the older child. In the young child, internal wire fixation to the frontal bone, to the orbital rim, or around the zygomatic arch may be unsatisfactory because the bone is soft and the wire, when placed under tension, tends to cut through the bone. Internal wire fixation to the edges of the pyriform aperture, which consists of thicker and stronger bone, is a preferable method.

Rapid fabrication of an acrylic splint in the operating room with quick-curing acrylic resin, while other fractures of the middle third of the face are being treated, will provide an appliance which is held by wire fixation to the edge of the pyriform aperture.

Because fractures of the facial bones in children consolidate readily and rapidly, a simple head bandage may be all that is required to provide cranial fixation of the fractured maxilla in the young child after occlusal relationships are established either with or without intermaxillary fixation.

**Nasal Skeletal Fractures and Naso-orbital Fractures.** Fractures of the nasal skeleton in children are more frequent than fractures of the maxilla or zygoma. In the early years of childhood, the nasal skeleton is proportionately more cartilaginous than bony, and diagnosis of nasal fracture is thus more difficult. The nasal bones in children are separated in the
midline by an open suture line; thus the open-book type of fracture, with overriding of the nasal bones over the frontal processes of the maxilla, is a characteristic feature of nasal fracture in the child.

As with other types of childhood facial injuries, but particularly more so in nasal injuries, the complicating factor is that growth and development may be affected even after accurate diagnosis and adequate treatment.

The first five years of postnatal life are years of rapid facial growth. After a period of moderately active growth, a second period of rapid growth occurs between the ages of 10 and 15 years. Growth of the nasomaxillary complex may be affected by trauma during the early postnatal years. The work of Kravits and his associates (1969) suggests that injuries in infants are more frequent than generally suspected. Such injuries, as well as those suffered during delivery, may explain nasal deviation and nasomaxillary hypoplasia which have no other apparent cause.

The diagnosis of nasal injury in a young child is difficult and may often require general anesthesia in order to permit careful intranasal, extranasal, and skeletal inspection and palpation. Roentgenographic examination is a requisite for diagnostic and medicolegal purposes.

The nasal bones, which are relatively small, may not be fractured. Fractures, dislocations, and hematomas may be present, however, in the cartilaginous portion of the nose, which occupies a large proportion of the surface area of the nasal pyramid in the younger child.

The nasal bones are formed on the surface of the cartilaginous nasal capsule, and there is a considerable overlap between the lateral cartilages and the nasal bones. The lateral cartilages may be detached from the undersurface of the nasal bones because of their relatively loose attachment in the child and may collapse in conjunction with a fracture of the septum. A hematoma may form in this area between the lateral cartilages and the undersurface of the nasal bones; it should be evacuated through an intercartilaginous incision. A subperichondrial blood collection may also form over the alar cartilages and should be evacuated through a transcartilaginous incision.

Fractures and dislocations of the septal cartilage are frequent attendant injuries in fractures of the nasal bones, but they may occur independently. Hematoma of the septum, a collection of blood between the cartilage and the mucoperichondrium caused by rupture of the abundant vasculature of the area, manifests itself as a bluish-red bulging in the vestibule and nasal fossa. Beware of the child who cannot breathe through his nose after a nasal injury! Septal hematoma may also be caused by a simple traumatic bending of the septal cartilage without fracture or dislocation. Hematoma of the septum is always a serious complication in children, not only because of nasal obstruction which results from fibrous tissue increasing the thickness of the septum but also because of the possibility of collapse of the dorsum and saddling, as a result of loss of septal cartilage support through pressure necrosis from hematoma or a septal abscess.
Special care should be taken to drain the septal hematoma (see Chapter 24). An L-shaped incision, extending through the mucoperiosteum over the vomer, is made along the floor of the nose and extends forward and then vertically upward through the mucoperichondrium over the septal cartilage. The flap of mucous membrane thus outlined is raised, and the hematoma is evacuated. The dependent position of the incision assures drainage and thus prevents a recurring collection of blood. When the septal framework is fractured, the hematoma may collect bilaterally on both sides of the septal cartilage (see Chapter 24). A position of the septal cartilage should be removed so that the two areas of hematoma communicate; a bilateral incision through the mucoperiosteum covering the vomer at the base of the septal framework provides dependent drainage and prevents recurrence of the hematoma.

Treatment of nasal bone fractures in children is similar to that of fractures in adults (see Chapter 24). Under general anaesthesia, an elevator is placed into the nasal fossa, and the fractured fragments of nasal bones and frontal processes of the maxilla are elevated. Further realignment is obtained by external manual palpation. The septum, if fractured, is straightened, and if it is dislocated, the lateral cartilages are realigned and repositioned. A splint of dental compound or plaster is placed over the nose for five to seven days. Intranasal packing is often necessary, in conjunction with the external splint, to assist in the realignment of the bony and cartilaginous fragments.

Naso-orbital fractures in which the bony structures of the nose are pushed backward into the interorbital space between the medial orbital walls, or lateral to the medial wall into the medial portion of the orbit, occur in automobile accidents and can be treated by the wired plate technique (see Chapter 24). The open-sky method (Converse and Hogan, 1970) provides ideal exposure (see Chapter 25). Open reduction is achieved through bilateral vertical incisions over the frontal processes of the maxilla, exposing the comminuted bones, which are realigned and maintained by subcutaneously placed transosseous wiring. An alternative approach is the bicoronal incision (Tessier and associates, 1967). This type of direct approach can prevent the subsequent sequelae of traumatic telecanthus, saddle-nose deformity, and lacrimal apparatus disturbances. Naso-orbital fractures are often associated with blowout fractures of the orbital floor.

Nasal bone fractures heal rapidly in children, frequently with overgrowth of bone and hypertrophic callus, resulting in widening of the bony dorsum of the nose. Children who have suffered comminuted nasal bone fractures may show developmental deformities years later, even though they received adequate treatment after the accident, an important consideration from a medicolegal viewpoint. The deformities are deviation and thickening of the septum, flattening of the nasal dorsum, widening of the bony skeleton by hypertrophic callus, and varying degrees of nasomaxillary hypoplasia.

One should not hesitate to realign by osteotomy the nasal pyramid or septum in children who have suffered an injury resulting in malunited fracture and nasal obstruction. The risk of impairing growth is slight, as the damage to the growth potential has already been done by the causative trauma. The deformity, characterized by depression of the dorsum with widening of the nasal bridge, may require correction for psychologic as well as for functional reasons. A costal cartilage or bone graft may be required, with the understanding that
definitive surgery will be required during adolescence. Nasomaxillary deformities are discussed in Chapter 30.

**Zygoma and Orbital Floor Fractures.** Zygoma fractures are rare in children and occur mostly in older children. Considerable force is required to fracture the resilient zygoma of the child, and the fracture usually takes the form of a fracture-dislocation. Lack of complete union at the frontozygomatic suture also explains the mechanism of this type of fracture. Treatment is similar to that of zygoma fracture in the adult (see Chapter 24).

Orbital fractures (see Chapter 25) in children are observed after automobile accidents and are often characterized by a separation of the frontozygomatic junction in the lateral orbital wall with downward displacement of the floor. This type of unilateral craniofacial detachment is more frequent in the child than the Le Fort III bilateral craniofacial disjunction. Treatment consists of direct interosseous wire fixation.

The mechanism of production of orbital blowout fractures is similar to that of fractures in adults. The authors have observed blowout fractures in children caused by the thrown snowball, another child's fist, tennis balls, and other objects. The maxillary sinus is small in the young child, and the floor of the orbit is concave, dipping downward behind the rim of the orbit, an anatomical characteristic that can mislead the surgeon into an erroneous diagnosis of orbital floor collapse. Despite the small size of the maxillary sinus, escape of orbital contents through the fractured floor occurs and may cause enophthalmos.

Restoration of the continuity of the orbital floor is the method of treatment, as it is in the adult. Comminuted fragments should be carefully preserved in children, as they consolidate very rapidly in a realigned position. The release of the entrapped orbital contents from the area of the blowout, which can then be covered by a small alloplastic implant, is followed by rapid return of ocular rotary movements. Children seem to have rapid recuperative ability after a blowout fracture, restoring the full range of extraocular muscle function, a recuperative ability which recalls that observed after flexor tendon repair in children.

**Complications of Facial Bone Fractures in Children.** Pulmonary complications were mentioned by McCoy, Chandler, and Crow (1966); aspiration of stomach contents or gastric dilatation occurred in 25.6 per cent of the children in their series. They noted that tracheostomy does not prevent this complication but suggested that a cuffed tube might prevent the problem. Early evacuation of stomach contents by nasogastric tube is indicated as a preoperative and postoperative measure.

Ocular injuries, damage to the lacrimal system, and cerebrospinal fluid rhinorrhea are observed in children and must receive the same consideration as those complications in the adult patient. Nonunion occurs infrequently. Osteomyelitis, which at one time was a serious complication in fractures, is rarely seen with modern antibiotic therapy.

Underdevelopment, maldevelopment, malocclusion, and ankylosis are all potential complications of facial bone fractures in children.
Compound, Multiple, Comminuted Fractures of the Facial Skeleton in Children

In trauma of particularly severe violence, multiple lacerations with partial avulsion of the soft tissues and multiple fractures of the facial bones require careful surgical care. The reward for adequate primary management is the prevention of severe facial disfigurement.

Partly or nearly totally avulsed flaps of soft tissue and loose comminuted bone fragments should be preserved and replaced, as the blood supply of the facial area, and particularly of the child's face, ensures survival.

The following case history (Kostecki and coworkers, 1969) is an example of the satisfactory management of such a problem and is described in some detail, as it will serve to illustrate the application of many of the principles enumerated above.

Case History

A 5 year old boy was leaning through the open doors of a garage building elevator shaft when the elevator, on its descent, struck him on the right side of the face. On arrival at the Bellevue Hospital Center, he was conscious but was in respiratory distress. His blood pressure was 100/70, respiratory rate 20, and pulse rate 100.

Clinical Examination and Diagnosis. The injuries were confined chiefly to the head and, more specifically, to the right side of the face. The most conspicuous defects were two major transverse soft tissue lacerations delimiting an area in which the soft tissues were avulsed from the bone and attached by small pedicles. One laceration extended from the midportion of the forehead to the upper pole of the right ear. The second laceration extended from the left side of the nose, across the dorsum of the nose and through the right lower eyelid, anterior to the right tragus, then downward toward the angle of the mandible. The second laceration extended into the nasal and oral cavities. There were also a laceration through the skin of the right upper eyelid and a full thickness laceration through the right portion of the upper lip, extending upward into the floor of the nose. Bilateral mandibular body fractures extending through the midportion of the body of the mandible were noted. It was necessary to maintain forward traction on the loose anterior portion of the body of the mandible in order to keep the tongue from occluding the airway. There was no injury to the ocular globes.

A transverse laceration through the right upper eyelid raised concern as to whether it extended through the levator palpebrae superior muscle or aponeurosis. Levator function of the upper eyelid seemed to be intact as far as could be determined in the presence of severe edema. Orbicularis oculi and frontalis muscle function seemed adequate, a reassuring sign that the temporofacial portion of the seventh nerve was not severed. Exploration of the badly damaged tissues of the cheek area was postponed until the patient was under anaesthesia.

An intravenous cannula was immediately inserted to facilitate fluid administration. Tetanus toxoid and antibiotics were given, and portable skull and chest roentgenograms were taken. The child was moved to the operating room where a tracheotomy was done under local anesthesia. A suitable airway was thus established, and inhalation anesthesia was administered through a cuffed endotracheal tube.
The child's face was cleansed with an antiseptic, and the injuries were evaluated by careful tissue manipulation and palpation. Examination of the soft tissues of the cheek denuded by the avulsion of the cutaneous flap showed that Stensen's duct and the buccal branches of the facial nerve had been severed as they emerged from the parotid gland. Posteriorly, the proximal stump of the severed cervicofacial branch of the facial nerve was identified; the distal end was located with the aid of a nerve stimulator. The right lower canaliculus was divided approximately 3 mm medial to the punctum.

Further examination showed a fracture of the right half of the maxilla extending through the center of the hard palate, the base of the frontal process of the maxilla, the orbital floor, and the right zygomaticomaxillary suture line. The right zygoma was mobile, being separated by fractures through the frontozygomatic suture line and also through the base of the frontal process of the maxilla. There was also a fracture through the body of the mandible on the right side.

The ocular globe moved freely, and the forced duction test was negative, the eyeball being readily rotated upward when the forceps were applied to the inferior rectus tendon through the sclera. The right infraorbital rim and orbital floor were shattered, and it was obvious that the contents had collapsed into the right maxillary sinus. There was also a fracture involving the right nasal bone, which was separated from the left nasal bone at the midline suture between the bones.

**Treatment.** The mandibular fragments were reduced, realigned, and stabilized by means of stainless steel wire interosseous fixation near the lower border of the mandible, thus avoiding injury to the tooth buds.

Intermaxillary wires were applied using the Ivy loop technique, and satisfactory occlusal relationships were established between the maxillary and mandibular teeth. The teeth were in sufficiently good condition to retain the eyelet (Ivy) loops. The maxillary and zygomatic fractures were treated by realignment of the fragments and direct interosseous wiring under direct observation through the open wound.

The periorbita was raised over the orbital rim and floor of the right orbit medial and lateral to the area of the comminuted fracture. The continuity of the inferior orbital rim was reestablished by realignment and wire fixation of the fragments. The orbital contents were then elevated from the maxillary sinus, and a Silastic implant (Dow-Corning #600-802), measuring approximately 20 x 20 x 2 mm was inserted over the orbital floor.

A PE-50 polyethylene catheter was threaded through the punctum of the right lower eyelid, through the distal end of the divided canaliculus, and passed into the medial portion of the canaliculus and lacrimal sac. The protruding end of the catheter was sutured to the lower lid, and the lid wounds were closed with interrupted 6-0 nylon sutures.

The distal end of the parotid duct could not be located in the midst of the badly damaged tissue. As it seemed to have been destroyed and restoration of the continuity of the duct was not possible, the proximal stump was ligated.
The facial nerve branches anterior to the parotid gland were too fragments for individual repair. Under magnification the proximal stump of the severed cervicofacial branch was sutured, using 8-0 nylon sutures, to the distal stump, which has been located with the nerve stimulator.

The remaining facial lacerations were closed with subcutaneous plain catgut and fine nylon skin sutures. A pressure dressing was applied over the face after an occlusive suture was placed through the right eyelid. A feeding tube was inserted through the nose.

Postoperatively the patient took fluids by the second day, and the feeding tube was removed. The tracheotomy opening was closed on the fifth postoperative day. The polyethylene catheter was removed from the right lacrimal duct on the seventh day after the operation. The child was discharged from the hospital on the seventeenth postoperative day with the intermaxillary wires in place. Epiphora of the right eye had subsided before the patient's discharge from the hospital, and he was able to close the right upper lid well enough to protect the cornea. Extraocular movements of the right globe seemed to be close to normal on discharge from the hospital. Contractions of the orbicularis oculi and frontalis muscles were weaker than on the unaffected side. Paralysis of the muscles innervated by the lower branches of the facial nerve persisted.

During subsequent months, the postoperative result was considered to be satisfactory in view of the severity of the initial injury. Facial nerve function became the main concern. Periodic clinical observation and electrodiagnostic studies during the ensuing year showed a progressive reinnervation of the muscles supplied by the right facial nerve. Serial electromyographic studies of the right orbicularis oculi muscle showed evidence of a partial lesion of the seventh nerve. Polyphasic potentials indicated that some regeneration was still occurring eight months after injury. Progressive return of movement was observed in the lower facial musculature with associated movements, movements of the mouth being observed then the child closed his eyes tightly. The synkinesis thus observed suggested that, in addition to the section of the cervicofacial division, the main trunk of the facial nerve had also been injured. Weakness of the frontalis muscle had been observed soon after injury, also suggesting some degree of nerve injury. The "splitting" of regenerated axons and the resultant associated movements were evidence of injury to the main trunk of the facial nerve. One year after injury the patient was able to whistle without movements of the orbicularis oculi muscle, evidence of return of function of the buccal musculature through the repaired cervicofacial branch. The patient's condition was relatively satisfactory in view of the severity of the injuries. Scar revision and a medial canthoplasty of the right eye will be required to improve the contour of the area.

**Discussion of Management**

**Tracheotomy.** When treatment of the patient was begun in the emergency room, the major hemorrhage had ceased, and the patient was not in shock. Vital signs remained stable throughout the initial period of treatment. The immediate problem of impending airway obstruction, because of the unstable mandible, indicated the need for tracheotomy. The severe injuries to the nasal and oral cavities which might also cause airway obstruction were additional indications. Oliver, Richardson, Clubb and Flake (1962), in a review of 204 tracheotomies in children under 18, stressed the importance of prior intubation. Difficulty with
decannulation of the tracheostomy was encountered in 14 cases; seven formed fistulae requiring operative closure, and three developed tracheal stenosis.

in our patient, because of extensive wounds and fractures of the lower jaw, intubation prior to tracheotomy was not possible. Severe swelling of the oral and nasal airways combined with the intermaxillary wiring forced postponement of the decannulation until the seventh postoperative day.

**Treatment of Fractures.** After the tracheotomy, the wounds were carefully explored, preserving all attached fragments of skin, while dirt and debris were removed. Reestablishment of the continuity of the mandible and maxilla by means of direct interosseous and intermaxillary wire fixation was first accomplished. The undamaged left maxilla acted as the fixed point for the restoration of near-normal occlusal relationships and the fixation of the mandibular and maxillary fragments.

The presence of the permanent tooth buds in a child 5 years of age left minimal space near the lower border of the mandible for drill holes and wires. Direct interosseous wiring of the fragments was done on each side of the body of the mandible. After the interosseous wiring, the fragments were still somewhat unstable. A number of deciduous teeth were loose, and some permanent tooth buds were dislodged at the fracture sites. The tooth buds were replaced in their sockets. There was a sufficient number of firmly fixed deciduous and permanent teeth to permit the application of Ivy loops on each side of the fracture lines on both the anterior and posterior fragments of the fracture of the body of the mandible. This wiring technique was selected because of its simplicity and easy adaptability with a minimum of special equipment. The other facial fractures were reduced through the open wounds and wired under direct vision with 26-gauge stainless steel wire.

**Repair of the Orbital Floor Fracture.** A massive comminuted fracture of the right orbital floor with ptosis of the orbital contents into the maxillary sinus does not usually result in restriction of ocular movements (see also Chapter 250. Indeed, in this case, the forcedduction test was characteristically negative. Restoration of the continuity of the orbital floor was an essential requirement in order to reestablish the size of the orbit and avoid enophthalmos, which would have been massive had no treatment been instituted. The use of the alloplastic implant was justified as the simplest method of repairing the orbital floor in a severely injured child.

**Repair of the Canaliculus.** Beard (1967) described a technique for canalicular repair with the Worst probe and the use of polyethylene tubing as a conformer left in place in the duct for two weeks (see also Chapter 28). Beard observed that, if the lower canaliculus alone is severed, the upper canaliculus usually can handle the normal flow of tears. If both canaliculi are severed, however, dacryocystorhinostomy should be done, with excision of the caruncle and placement of a Pyrex tube between the medial commissure and the nasal cavity.

Fortunately, in our patient, at the eight-month follow-up visit, epiphora occurred only when the eye was irritated on a cold or windy day.
Ligation of Stensen's Duct. When a repair of the parotid duct is not feasible, ligation of the proximal stump of the duct results in subsequent progressive atrophy of the parotid gland. In this manner, subsequent painful swelling of the gland is avoided.

Repair of the Facial Nerve. Restoration of the continuity of the branches of the facial nerve should be done; Maxwell (1954) first demonstrated the remarkable results obtained after reapproximation of severed branches and nerve grafting (see also Chapter 36). Because the orbicularis oculi and frontalis muscles seemed to be functioning, the temporofacial division of the facial nerve was thought to be intact. The severed nerve located in the posterior aspect of the wound was too large to be the mandibular marginal branch; it was felt to be the cervicofacial division and was reapproximated by suture. The buccal branches were badly damaged and could not be repaired. Converse and Goodgold (1959) have reported spontaneous regeneration of these nerves after section in adults and are of the opinion, as are Hanna and Gaisford (1965), that cross innervation occurs through the plexuslike connections between the peripheral branches of the facial nerve and also between branches of the fifth nerve. A review of the anatomy of the facial nerve branches anterior to the parotid gland (Hollingshead, 1958) shows numerous plexuslike interconnections. Despite some divergent views, there seems to be some clinical evidence supporting the opinion that the power of nerve regeneration is greater in children than in adults (Önne, 1962).

The associated movements observed during the period of return of function of the musculature can be explained by an undiagnosed lesion of the main trunk of the facial nerve; the weakness which was observed in the orbicularis oculi muscle reinforces this hypothesis. Associated movements are attributed to misdirection of regenerating nerve fibers and can occur without section of the nerve (see Chapter 36). Associated movements are observed, for example, in cases of Bell's palsy (Ford and Woodhall, 1938), in which there is no loss of continuity of the nerve, but there is loss of conduction due to inflammatory edema of the nerve within the fallopian canal.

Developmental Malformations of the Facial Skeleton

Many facial developmental malformations can be attributed to trauma in early childhood. Trauma may have a deleterious effect on the growth and development of facial bone in postnatal life similar to that of a defective gene during prenatal development. In many cases it is difficult to ascertain whether the disturbance occurred before or after birth.

In order to provide an understanding of some of the developmental deformities resulting from prenatal or postnatal insult, a review of facial development follows.

Postnatal Growth of the Face

Knowledge regarding craniofacial growth has been determined by a variety of methods reviewed by Enlow (1968). The cross-section approach requires the utilization of large numbers of skulls of varying ages (Hellman, 1927; Keith and Campion, 1922; Krogman, 1930). Other methods can be employed which permit serial measurements on the same growing individual to evaluate the actual amount of growth. Four principal methods have been employed. The first involves the use of vital stains such as madder, as first practiced by John Hunter (1835-1837); the second involves vital staining of calcifying bones by means of a
single intraperitoneal or intravenous injection of a 2 per cent solution of alizarin red (Schour and coworkers, 1941). Thirdly, Björk (1955) was the first to study facial growth in man with the aid of metallic implants. Gas and Sarnat (1951) utilized implants of amalgam on each side of frontozygomatic, frontomaxillary, zygomaticomaxillary, zygomaticotemporal, and premaxillomaxillary sutures. These implants were placed after incisions were made to expose bony areas. Finally, serial cephalometric roentgenograms were employed by Broadbent (1931, 1937), Margolis (1940, 1947), Higley (1936), Gans and Sarnat (1951), Krogman and Sassouni (1957), Moyers (1963), and Salzmann (1961).

The growth of the face is rapid and is best illustrated by the changes in facial size. At three months the face is less than half the size of that of the adult (approximately 40 per cent). At two years it has reached approximately 70 per cent; at 5.5 years it attains approximately 80 per cent of the adult size.

Earlier in the text it was reported that the proportions of the face change markedly during the period of postnatal growth. The skull at birth presents a relatively large cranial portion and a small facial component when compared with the skull of the adult; thus the proportions are 8 to 1 at birth in favor of the cranial portion over the facial portion, but they fall to 4 to 1 at 5 years, and 2 to 1 in the adult.

These changes are due to two factors: (1) the actual growth of the face, and (2) the modification of the proportions which brings forth characteristics, distinguishing the faces of males from those of females and establishing distinctive individual features.

1. The Growth of the Face. The facial skeleton is relatively small at birth. The nasal cavities and paranasal sinuses are also small; the nasal cavities are as wide as they are high. The pyriform aperture is broad, and its lower border and the floor of the nasal cavities are on a level slightly below that of the lower rim of the orbit and a horizontal line passing approximately through the two infraorbital foramina.

The growth of the maxillary sinus parallels that of the face. The maxillary sinus is narrow in the newborn and is not sufficiently developed to reach beneath the orbit; the sinus progressively increases in size. During the first year the medial-lateral dimensions have reached beneath the orbit, but no further laterally than the infraorbital foramen. During the third and fourth years the medial-lateral dimension of the maxillary sinus has increased considerably; at 5 years it extends to a point lateral to the infraorbital canal. The floor of the maxillary sinus remains above the level of the floor of the nose in the child up to the age of 8 years. It is only after the eruption of the permanent dentition in the twelfth year and the development of the alveolar process that the maxillary sinus descends below the level of the floor of the nose.

Increase in the vertical dimension of the face is due in part to the development and eruption of the dentition. In the newborn the crown portions of the upper and lower teeth or the alveolar processes do not contribute to vertical height, as the teeth have not yet erupted. A gradual facial change occurs at 7 years as a result of a general increase in size in all dimensions. The completion of facial growth varies, occurring from the eighteenth to the twenty-fifth year.
2. Changes in the Proportion of the Face. Increase in facial height is greater in the middle third of the face than in the lower third; the increase in the anterior-posterior direction is greater in the lower jaw than it is in the upper jaw; and the face widens more in the lower jaw than in the upper jaw.

The changes in the proportions of the face during the period of postnatal growth are well illustrated by comparing the face of a 3 month old infant with that of the same individual at the age of 23 years. The growth of the middle and lower thirds of the face is striking.

At birth the portion of the nasal fossa occupied by the ethmoid bone is twice the height of the maxillary portion. During childhood the growth of the maxillary portion is accelerated, approximating the ethmoidal portion at the seventh year when adult proportions are attained. The growth of the maxillary portion of the nasal fossa is due in part to the increase in size of the maxillary sinus and to the eruption of the dentition and the supporting alveolar process. Changes in the maxilla and mandible result in characteristic changes of profile.

The peak rate of growth in the head and face occurs between 3 and 5 years. After this period, growth proceeds slowly, but an acceleration occurs again between the thirteenth and fifteenth years. Growth is greatly diminished after the age of 15 years. Growth of the nose is completed between the eighteenth and twenty-fifth year. From a surgical standpoint, one may consider the growth of the nose completed at about the age of 16 years. Minor changes occur throughout life.

Postnatal Growth of the Mandible

The mandible is most frequently involved in developmental malformation. To explain the influence of extraneous factors upon the development of the mandible, one should recall the embryologic development of this bone.

The dorsal part of the first mandibular arch grows forward beneath the developing eye region to the olfactory area, forming the maxillary process. As the result of the formation of this process, the mesenchymatous condensation, which gives origin to the first pharyngeal arch, becomes bent, and part of this dorsal portion becomes chondrified, forming a small cartilaginous mass which represents the pterygoquadrate bar of lower vertebrates. The remaining ventral and much larger portion of the pharyngeal arch chondrifies to form Meckel's cartilage.

The posterior extremities of the pterygoquadrate bar of Meckel's cartilage articulate with each other. The intermediate portion of Meckel's cartilage retrogresses, and its sheath becomes ligamentous, forming the anterior ligament of the malleus and the sphenomandibular ligament. The dorsal portion, in contact with the pterygoquadrate cartilage, becomes recognizable as the definitive cartilaginous rudiment of the malleus, whereas the ventral portion is involved in the development of the incus.

Later in development, two membrane bones are laid down on the outer side of Meckel's cartilage: (1) The anterior of these, which appears very early, is related to the lateral aspect of the ventral portion of the cartilage and forms the mandible. At first it is a small
covering of membrane bone, but by growth and extension it soon surrounds Meckel's cartilage, except at its anterior extremity, where some endochondral ossification occurs. (2) Upward growth forms the mandibular ramus at the posterior end of the developing mandible. This portion of the mandible comes into contact with the squamous part of the temporal bone to form the temporomandibular joint, in which a fibrocartilaginous articular disk develops. Part of the ramus of the mandible is transformed into cartilage before ossification occurs.

In mammals, as in many other vertebrates, arches of the membrane bone are laid down lateral to the cartilages of the first pharyngeal arch and in the substance of the maxillary and mandibular processes. In the maxillary processes of each side, four such ossification areas form the premaxilla, maxilla, and zygomatic and squamous temporal bones.

The mandible, small at birth, is destined to grow both by development of the alveolar process, which accompanies the development of the teeth, and by bone growth.

John Hunter (1835-1837) demonstrated the mode of growth of the mandible. He applied the discovery of Duhamel (1734), who had studied the growth of bone by feeding animals madder. The observation that madder, the root of a plant, had the property of acting as a vital stain for living bone cells had been described by Belchier (1738). Belchier fed some of his fowls with madder and noted that living bones were stained red by the madder.

Hunter few two young pigs on a madder diet for a month. He sacrificed one of the pigs at the end of the month and retained the other for an additional month on ordinary food before sacrificing it. Hunter found that the appearance presented by the bones of these two pigs met his expectation in the most exact manner. What had been the condyle and the posterior border of the mandible during the period of madder ingestion were not included in the substance of the ramus, which had grown during the period in which the pigs had not received madder. The madder-stained bone was almost completely removed by absorption from the anterior border of the ramus. Hunter concluded that growth of the bone is due to the addition of bone on the extremity of the mandible, combined with absorption of bone in other areas (Keith, 1919).

The recognition of condylar growth centers (Charles, 1925; Brodie, 1941) confirmed Hunter's original findings and showed that the forward projection of the mandible is a consequence of this posterior growth. Elongation of the mandible involves continued additions of bone at each condyle and along the posterior border of the ramus. Posterior appositional growth is only one of the many major movements associated with total growth, as all of the different portions of the bone participate in the growth process (Enlow, 1968). In addition to the centers of growth, increase in size is the result of surface apposition, the local contours of the mandible constantly undergoing changes as a result of relocation and remodeling, and resorptive and depository activities.

Growth of the condyle is the result of endochondral ossification in the epiphysis. Microscopic examination of human material (Orban, 1944; Rushton, 1946) showed chondrogenic, cartilaginous, and osseous zones. The condyle is capped by a narrow layer of avascular fibrous tissue, which contains connective tissue cells and a few cartilage cells. The inner layer of this covering is chondrogenic, giving rise to hyaline cartilage cells which form the second or cartilaginous zone. Destruction of the cartilage and ossification around the
cartilage scaffolding can be seen in the third zone. The cartilage of the head of the mandible is not similar to the epiphyseal cartilage of a long bone, for it differs from articular cartilage in that the free surface bounding the articular space is covered by fibrous tissue. Walker (1957) has emphasized the role of trauma to the condylar articular cartilage in producing mandibular hypoplasia, particularly if the trauma occurs before the age of 5 years.

Postnatal Growth of the Nasomaxillary Complex

The skeleton of midfacial area is formed from membrane, with the exception of the nasal cartilaginous capsule. These bones grow in a complex manner in a variety of regional directions. The growth and development of the nasomaxillary complex has been studied by numerous anatomists. Among the early studies are those of Disse (1889), Peter (1913), Stupka (1938), who was concerned with developmental anomalies, and Negus (1958), who was concerned with comparative anatomy. More recent studies in animals and man, with the use of vital staining, anatomical sections, and cephalometrics, include those of Scott (1953, 1956-1959, 1963), Baume (1968), and Enlow (1968). The anteroposterior growth of the nasomaxillary complex is related in utero and also after birth to the growth of the basal cranial cartilages and their synchondroses. The intersphenoidal and the septoethmoidal synchondroses show signs of activity until adulthood. At birth the nasal septum is continuous with the cartilages of the cranial base. Around the first year, the perpendicular plate of the ethmoid starts to ossify from the mesethmoid center. At 3 years of age there is bony union between the ethmoid and the vomer. The bony structures of the nasomaxillary area then follow a complex process of growth, which has been reviewed in detail by Enlow (1968).

There is not only a forward downward growth of the maxilla but also a constant remodeling of the multiple regional parts. The main steps in this development include a displacement away from the cranial base, a posterior enlargement corresponding to the lengthening of the dental arch, and an anterior resorption of the malar region. The nasal vaults grow forward and laterally, and the descent of the premaxillary area occurs by resorption on the superior and anterior surface of the nasal spine and by bony deposition on the inferior surface.

Considerable controversy has arisen over the role of the septum in the growth of the nasomaxillary complex and over the implications of trauma in causing abnormal growth of the area. Scott, reminding us that the midfacial area is formed of membrane with the exception of the cartilaginous nasal capsule, considered the septum to be the driving force in the growth of the midfacial area. Scott's hypothesis has been supported by Baume (1961), Wexler and Sarnat (1961, 1965), and Sarnat and Wexler (1966, 1969).

The role of the nasal septum is considered of lesser importance by Moss, Bromberg, Song, and Eisenman (1968) and Stenström and Thilander (1970). According to Moss, facial growth is controlled by a "functional matrix" which comprises the nonskeletal elements of the face, including spaces, muscles, and soft tissues.

Ross and Johnston (1972) concluded that the maxilla drifts forward as part of an overall genetic and environmental pattern of growth, bone being laid down in the sutures and on the maxillary tuberosity. The maxilla is more easily influenced in its growth than the mandible (see Chapter 42).
The role of trauma in interfering with growth and development of the midfacial area seems to be difficult to determine. In making a comparison with another facial area, namely the mandibular, one finds a considerable disparity between the extent of damage suffered by the condylar area and the extent of the ensuing maldevelopment. In some cases of fracture of the condylar area in children, complete restoration of anatomical form occurs without interference with growth and development; in other cases, what seems to be minor damage results in mandibular hypoplasia. Much depends, apparently, upon the extent of damage to the condylar cartilage (Walker, 1957). Reconstructive surgery for nasomaxillary deformities is discussed in Chapter 30.