MAXILLOFACIAL TRAUMA

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To my loving wife, Deena, and our children,
Tiby, Heather, Lauren and Jason,
who patiently provided me with the time
and encouragement for this project.

Preface

Maxillofacial trauma is an important medical-dental and surgical condition for which optimal management requires almost continual review of factual information and acknowledgment of the more recent advances in the evaluation and treatment of the patient. This book offers one of many sources that is available to assist the student and practitioner in achieving this special competence.

Unfortunately, trauma to the face and associated structures often presents with an impressive array of problems. To the patient there is disfigurement, dysfunction, and potential loss of income; to the employer there is reduced productivity, and to mankind, a medical bill that knows few if any limitations. Traumatic facial deformity is not easily concealed, and even following the best of treatment, signs may persist. Beyond aesthetics, there is a possible total or partial loss of vision and hearing and abnormalities of smell and taste. Mastication and deglutition may be affected, seriously threatening the patient's nutritional status, articulation, and communicative skills. Vital functions such as respiration can be altered. The sequelae of central nervous system damage can take their toll, undermining motor and cognitive functions.

As a result of these significant and complex facial injuries, the patient demands an expertise in the surgeon for evaluating and managing the deformity and dysfunction. The practitioner must be able to recall a scientific base and a treatment armamentarium that deal with each of the many specific problems. For optimal care, one specialty group or individual can hardly profess such ability. Despite clinical overlap among specialties, the best results are obtained from combined efforts in diagnosis and treatment of the injured patient. Thus, it is intended that the various specialties that deal with acute care of head and neck injury are represented in this book. In addition to the contributions of the traditional specialists, such as plastic surgeons, otolaryngologists, oral surgeons, and maxillofacial surgeons (Europe), the thoughts of other practitioners such as orthopedists, ophthalmologists, neurosurgeons, general surgeons, and vascular surgeons are included. Such cooperation provides a comprehensive approach to patient care and enhances the understanding of what each specialist has to offer. Unfortunately, limitations of the size of the book preclude recognition of all specialty activities and prevent incorporation of the many valuable contributions from other "rehabilitative" experts.

In attempting to present a basic, yet comprehensive text, it is necessary to consider the importance of and include the basic knowledge of the scientists. Through their understanding, new insights into the causes of injury and better methods of management can be provided. Consequently, morphology becomes an essential part of the discussions on restoration of function and appearance. Normal and pathological healing processes of soft tissues and bone are included as they impact on the efforts for reconstruction.

Although provincial geographic borders frequently limit recognition of the innovation of others, it is appreciated that science and medicine have no international boundaries. This textbook integrates such valuable information. The traditional methods of intermaxillary fixation and interosseous wiring as provided in the United States are supplemented with cap splints and the concepts of a rigid internal fixation from abroad. Some of the more aggressive surgical approaches, such as those pioneered by Tessier, are also included.

Since one of the goals of the book is to satisfy interests of both student and practitioner, it is intended that the reader be able to review the basic pertinent anatomy and physiology prior to study of the available methods for evaluation and treatment. Standard management techniques are described, followed by the preferred methods of the author. Complications of treatment are also considered. In addition to traditional considerations of patient management, important subjects to be discussed include the:

1. Indications for exploration of cervical vessels.
2. Preferred treatment of cervical cord injury.
3. Indications and methods for the salvage of injured teeth.
4. Open *vs.* closed reduction of mandibular fractures.
5. Preferred treatment of jaw fractures in children and the elderly.
6. Evaluation of occlusion and facial deformity.
7. Prevention and correction of complications of mandibular fractures, *i.e.*, nonunion, ankylosis, and malunion.
8. Methods and indications for reduction of maxillary, malar, and nasal fractures.
9. Osteotomy and implantation techniques for facial deformity.
10. Indications for "blow out" fracture.
11. Indications for use of splints and stents for facial and laryngeal injury.
12. Diagnosis and repair of cerebrospinal fluid leaks.
13. Indications for exploration of frontal sinus injury.

The contributions to this book also offer the reader certain challenges and include presentations of controversial issues. The concept of the "functional matrix" is discussed, and the combined effects of healing from trauma with the growth and development of facial bones are reviewed. The phenomenon of piezoelectrical charges to promote healing of bone is described. Additional discussions address indications for exploration of suspected damage to the cervical vascular system in combination with central nervous system injury. Several other chapters define indications for salvaging teeth and what to do with teeth in fracture lines.

Recognizing that technology for patient evaluation and treatment continues to advance, several chapters will discuss the present "state of the art." The applicability and limitations of CAT scans, sonograms, and radioactive isotope methods will be considered. Treatment protocols will update the use of acrylics for splints and stents, and the latest concepts in orthognathic principles for correction of malpositioned facial bones. External and rigid internal fixation is debated, as is the use of implants or osteotomy to correct enophthalmos and maxillary and zygomatic deformities. Therapeutic models are also given for the treatment of frontal bone and laryngeal injury.

Lastly, the general restrictions of a book must be recognized. The written word, illustrations, and photographs can only serve as a guide and stimulus for further education and progress. Hopefully, this book will excite the student and, while challenging the preconceptions of the teacher, stimulate the thoughts of both to result in improved patient care.

Acknowledgments

This book of maxillofacial trauma required the cooperation and assistance of many individuals, without whom the undertaking would not have been possible. I am very much indebted to them.

The authors are well-known and respected practitioners, teachers, and investigators in their specialties. Some have written their own textbooks on facial injury. I am particularly honored to have worked with these unselfish people and totally respect their time and effort.

For the secretaries, there is particular appreciation. I am grateful to Candy Balmas and Gail Schook, who helped in the development of this manuscript and in the communications that were a necessary part of the process. Our special editorial assistant, Denise Gruska, was invaluable in manuscript revision and for all those administrative chores that brought the project to completion. The patience and cooperation of the publisher, Williams & Wilkins, and the editorial assistance that was provided under the direction of Barbara Tansill are deeply appreciated.

There is also a special thank you to Richard Webster, M.D., the individual who stimulated this undertaking. Without his support and perseverance for a book such as this to be written, I am not certain that it would have evolved. His dedication to interdisciplinary cooperation and basic knowledge served as an important guide.

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Contents

CHAPTER 1A

Prenatal Development of Facial Skeleton

DAVID B. MEYER, Ph.D.

As an integral part of the developing skull, the facial skeleton undergoes a complicated morphogenesis involving the deposition, growth, and resorption of bone within various mesenchymal prominences forming the primitive face. In close association with most of the developing facial bones are the cartilages enveloping the ventral aspect of the brain and forming the nasal capsule and septum (chondrocranium), as well as those supporting the first branchial arch (viscerocranium). Most of the facial bones develop intramembranously, *i.e.*, within a membranous (fibrous) environment occupying these developing facial prominences, and are termed *membrane* or *dermal bones*. A few, however, arise endochondrally, *i.e.*, within a cartilaginous substrate, and are termed *endochondral* or *cartilage bones*. Moreover, one or more ossific loci may participate in the formation of the individual bones of the face, and several facial bones arise by the fusion of both endochondral and intramembranous ossific elements. Regardless of the environmental origin of the osseous tissue, however, it must be strongly emphasized that the process of bone production, deposition, and resorption is the same and that as a tissue, only one type of bone can be recognized histologically.

Bone grows by apposition (surface accretion) only. Since its calcified matrix is incompressible and does not permit growth from within (interstitial growth), as cartilage can, bone can expand only by adding new bone along free surfaces (pre-existing bone, calcified cartilage). Both membrane and cartilage bones must operate under these restrictions. In the case of intramembranous ossification, which is initiated by osteoblastic activity within a fibrocellular mesenchymal condensation, bone, once formed, serves as the scaffolding upon which new bone is subsequently deposited. The direction which a bone takes during its so-called migration or displacement depends, therefore, on the site of most active osteoblastic activity. Bone deposited on the end of pre-existing bony spicules, for example, will result in an increase in its overall length, whereas bone laid down along the sides of the developing spicules will increase its thickness. In the case of endochondral bone formation, on the other hand, the incorporation of cartilage greatly facilitates bone growth (particularly in length) by providing continual interstitial growth and a calcified cartilage matrix for additional appositional bone growth.

Each of the facial bones has its own intrinsic mode of morphological osteogenesis which is influenced by many local environmental factors (*e.g.*, local pressures or tension forces) produced either externally or from muscular functions (1). The progressive maintenance of bone morphology during facial (as well as skull) growth is accomplished by the synchronous activity of bone deposition (osteoblastic activity) and resorption (osteoclastic activity). Termed *remodeling*, this extremely intricate and coordinated process involves bone formation and destruction at strategic surface sites on the developing bone to enable each bone to preserve its proper thickness, shape, and topographical relationships (muscular attachments, foramina, etc.). For more details concerning this very interesting process, see Ham and Cormack (2) and the pertinent review found in chapter 1B, Basic Concepts of Postnatal Facial Growth.

The important sequence of morphological events concerned in the formation of the human face occurs during the second month of prenatal development, *i.e.*, the last half of the embryonic period proper (Table 1A.1). Human prenatal development is conveniently divided into two periods: the *embryonic period* proper and the *fetal period* (Fig. 1A.1) (3). The embryonic period includes the first eight postovulatory weeks and terminates when the "embryo" has attained a crown-rump (CR) length of approximately 30 mm and weighs approximately 2 to 2.7 gm, and the onset of marrow formation can be recognized in the humerus (4). The fetal period begins at this "time" and extends until birth of the "fetus." Streeter (5–8) divided the embryonic period into 23 stages or "horizons" based upon precise ratings of the degree of morphological development of specific organs in accurately documented (age) and well-preserved human specimens. The first nine stages (from fertilization to the first appearance of somites), *i.e.*, the first three postovulatory weeks, have been redefined by O'Rahilly (9). His recommendations, which will be followed here, advocate the use of "stages" rather than "horizons" and postovulatory age, instead of the misnomer menstrual "age." Likewise abandoned are Streeter's determinations of embryonic age, which are based on the macaque monkey.

Streeter (7), utilizing the Carnegie Collection of precisely staged and excellently preserved human embryos, has provided excellent data on the progressive morphogenesis of the human face beginning in the 4th week (stage 13) when the embryos measure between 4 and 6 mm CR, have 30 or more somites, and present distinct arm and leg buds for the first time.

Table 1A.1
Chronology of Events in Facial Development

Age (Wk)	Stage (Carnegie)	Length (CR in mm)	Age (Days)	Features
	10	2–3.5	22–23	Neural folds begin to fuse (9)
	11	2.5–4.5	22–23	Rostral neuropore closes (9)
4th	12	3–5	26–30	Caudal neuropore closes (9); nasal placode appears (11); stomatopharyngeal membrane ruptures (17); mandible begins to fuse (5)
	13	4–6	28–32	
5th	14	5–7	31–35	
	15	7–9	35–38	Nasal pit appears (7); distinct lower jaw (7)
6th	16	8–11	37–42	Nasal pit faces ventrad (9); Nasal fin appears (11) olfactory bipolar neurons present (14); mesenchymal Meckel's cartilage (15)
	17	11–14	42–44	Nasofrontal groove distinct (9); inferior conchal swelling (11); upper lip and jaw (11); primary palate (7); and nose (16) discernible.
7th	18	13–17	44–48	Ossification may begin in mandible (27); Meckel's cartilage present (27); oronasal membrane ruptures (7); vomeronasal organ primordium (7); mesenchymal nasal septum (7); maxillary palatal processes appear (40)
	19	16–18	48–51	Ossification may begin in maxilla (27)
	20	18–22	51–53	Ossification may begin in premaxilla (27); septopremaxillary condensation present (41); nasal septum and capsule begin to chondrify (40)
8th	21	22–24	53–54	Bony mandibular angle and coronoid (43); mandibular condyle condensation (69)
	22	23–28	54–56	Temporomandibular joint rudiment (24)
	23	27–31	56–60	Ossification begins in zygomatic, squamous temporal, palatine, vomer, frontal, Malleus (ant. proc.) (27); elevated palatal shelves (64); fused palatal processes (53)

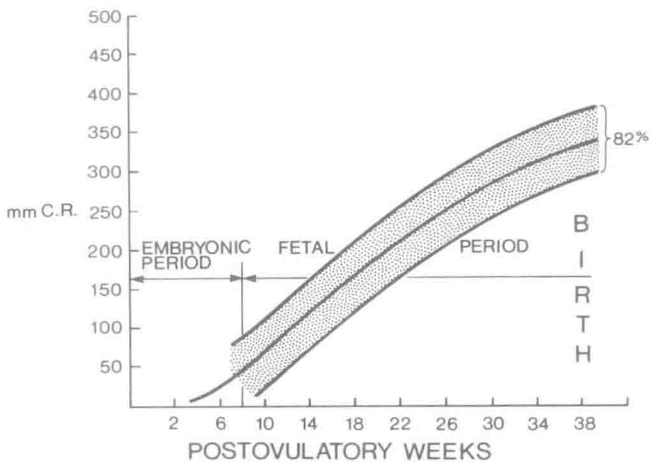

Figure 1A.1. Graph (3) showing crown-rump (CR) length plotted against age in postovulatory weeks. The menstrual age is approximately 2 weeks later in each case. The stippled area is expected to encompass 82% of the fetuses. (Modified with permission from E. Boyd (3).)

EMBRYONIC PERIOD

Fourth Week (Stage 13)

At the end of the fourth week (stage 13), the future head region consists of several swellings which encircle a depression, the primitive mouth, or *stomodeum* (Fig. 1A.2*A*). The largest of these swellings, termed the *frontonasal prominence*,* is produced by the enlarged rostral end of the forebrain. Lying rostral to the stomodeum and bent ventrally toward the heart, it will contribute to the formation of the forehead and nose. The lateral and caudal walls of the stomodeum, on the other hand, are formed by the *maxillary* and *mandibular prominences*, respectively, of the first branchial arch. The mandibular prominences have already begun to coalesce to form the primitive lower jaw, whereas the maxillary prominences are widely separated from one another so that one cannot now speak of an upper jaw. The stomodeum at this time is bounded internally by the *stomatopharyngeal* (*buccopharyngeal*) *membrane*, which is beginning to disintegrate. Forward growth of the facial prominences will increase the depth of the stomodeum which, upon the disappearance of the stomatopharyngeal membrane, contributes to a confluent *oropharyngeal chamber* lined by a continuous ectodermal (stomodeal) and endodermal (pharyngeal) epithelium. Thus, continuity is established, for the first time, between the foregut and the external environment.

During the fourth week (stage 12), oval convex thickenings of the surface ectoderm can be recognized histologically (11), one on each side covering the ventrolateral aspect of the frontonasal prominence (Fig. 1A.2*A*). Termed the *nasal* (*olfactory*) *placodes*, these epithelial placques represent the primordia of the olfactory apparatus. Verwoerd and Van Oostrom (12) characterize the nasal placode as a dispersed portion of the brain anlage which, like the brain, has the

* As recommended by *Nomina Embryologica* (10), the term *prominence* is preferred to the more popular term *process* because it more appropriately denotes the appearance of these swellings, *i.e.*, local elevations. Whenever possible, the anatomical terminology proposed by the International Anatomical Nomenclature Committee (*Nomina anatomica*, ed 4; *Nomina Histologica* and *Nomina Embryologica*, 1977) will be employed. Popular synonyms will be indicated parenthetically.

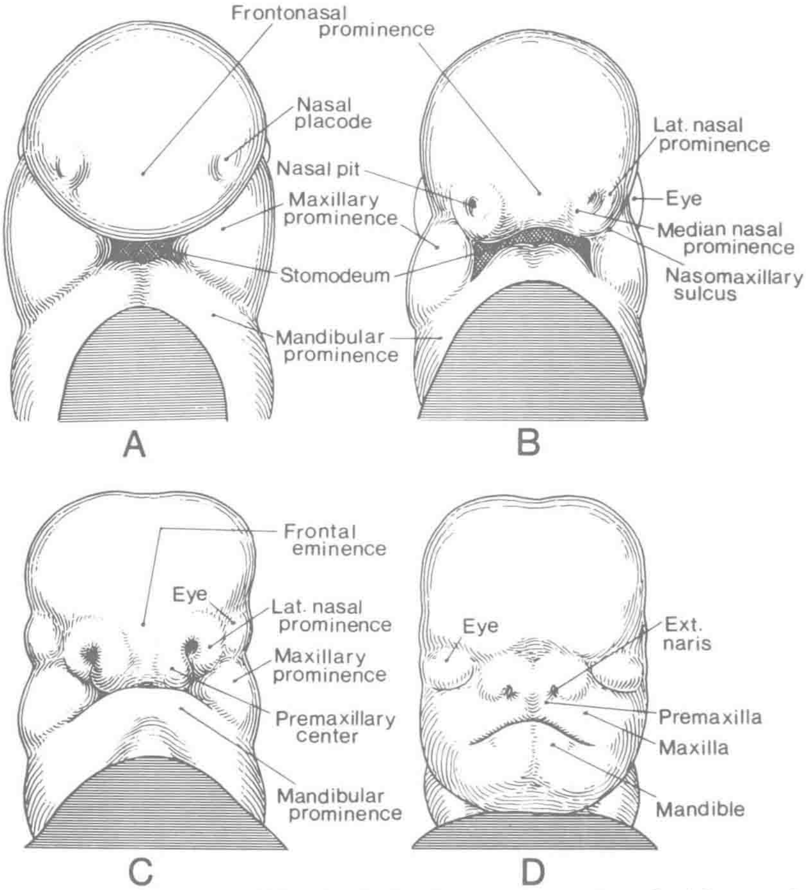

Figure 1A.2. Drawings of the ventral aspect of the developing human face at 4 weeks (*A*), 5 weeks (*B*), 6 weeks (*C*), and 7 weeks (*D*) of age.

potential to form nerve cells. They see it in the mouse as a zone of thickened ectoderm connected medially with the neural ectoderm along the margins of the closing rostral neuropore. Noting that a similar appearance is shown in sections of human embryos of stages 10 (8 to 11 somites) and 11 (13 to 16 somites) (13), they surmise that this placode develops similarly in man and mouse.

Fifth Week (Stages 14 and 15)

The nasal placodes gradually begin to recede from the surface owing to active proliferation and differentiation of the surrounding mesenchyme, as well as growth of the forebrain, so that by the fifth week (stage 15) depressed *nasal pits* are formed (Fig. 1A.2*B*), bordered medially and laterally by distinct ridges. The medial ridges, termed the *median nasal prominences*, represent the lateral portions of the frontonasal prominence which have elongated ventrocaudal to the nasal pit. The lateral ridges are more prominent, possess distinct lips, and are termed the *lateral nasal prominences*. Each separates the nasal pit from the developing eye (which is placed laterally at this time) and represents the anlage of the lateral wing of the nose. During its growth, the lateral nasal prominence makes contact with the maxillary prominence from which it is separated by a groove the *nasomaxillary sulcus* (Fig. 1A.2*B*). This shallow furrow eventually extends from the stomodeum to the medial angle of the developing eye and represents the course of development of the *nasolacrimal duct*.

Sixth Week (Stages 16 and 17)

At the sixth week the median nasal prominences each terminate in a low rounded swelling; the *premaxillary center* (globular process of His) and the undifferentiated tissue remaining between them now constitute a *frontal eminence* (Fig. 1A.2*C*). With further development the median nasal prominences will approach each other to form a single *premaxillary process* from which will develop the tip of the nose, the median part of the upper lip (disputed by some), and the primary palate. The constriction of the frontonasal region, concomitant with the expansion of the lateral aspects of the head, likewise results in a medial migration of the eyes. Thus, by the sixth week all of the nasal primordia, and the maxillary prominences as well, are still relatively wide apart, and only a slight resemblance to a human nose or upper jaw is apparent. The basic facial anlagen have been established, however, so that during the sixth and seventh weeks the human face gradually becomes morphologically recognizable (Figs. 1A.2*C* and *D*). This is accomplished by coalescence of the bilateral ridge-like prominences due primarily to subjacent mesenchymal growth centers. Formed originally by neural crest-mesenchymal migrations, these underlying growth centers actively proliferate and during their migration smooth out the furrows that lie between them in such a way that epithelial fusions and absorptions do not occur. Streeter (7) stressed the importance of understanding this migratory process of morphological change in order to interpret properly the factors involved in many of the common facial deformities, *e.g.*, harelip.

During the growth of the facial prominences, the nasal pit comes to face ventrally and is also enlarging and deepening in a dorsal, caudal, and medial direction to form a blind sac, the primitive *nasal sac* (Fig. 1A.3). In so doing, the opening of the original nasal pit now becomes the definitive *external naris*, and the precocious olfactory epithelium, replete with differentiating bipolar neurons (14), comes to lie on the upper portion of the nasal sac.

The ventral epithelium of the floor of the nasal sac meanwhile has maintained direct continuity with the epithelium of the roof of the stomodeum to form a temporary, actively proliferating, longitudinal septum, the *nasal fin* (Fig. 1A.3) (7). Marked externally by a groove indicating the boundary between the premaxillary and maxillary growth centers (Fig. 1A.2*C*), the nasal fin is initially discernible at the beginning of the sixth week (stage 16) (11). Also making its appearance at this time is a rod-like mesenchymal condensation within the mandibular prominence representing the future Meckel's cartilage (15).

During the latter part of the sixth week (stage 17), the epithelium constituting the anterior portion of the nasal fin (adjacent to the external naris and between the nasal sac and stomodeum) becomes replaced by mesenchyme (Fig. 1A.3*B*) derived from the adjacent maxillary and premaxillary growth centers (7). This mesoderm represents the *primary palate*, which maintains its position between the nasal and oral passageways (Fig. 1A.3*C*), as well as separating the bilateral nasal sacs. It will form the anterior part of the definitive palate. The posterior epithelial component of the

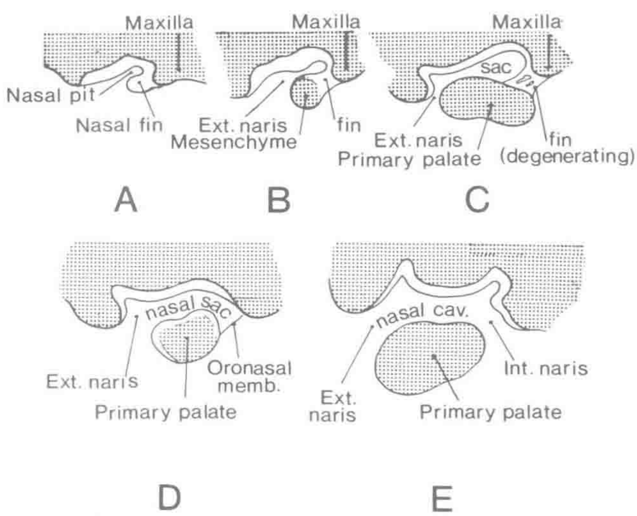

Figure 1A.3. Drawings of sagittal sections through the developing nasal pit (and sac) at the sixth (stage 16, *A*) (stage 17, *B* and *C*) and seventh weeks (stage 18, *D* and *E*). (Modified with permission from G. L. Streeter (7).)

nasal fin, on the other hand, is not invaded by mesenchyme but gradually becomes attenuated to form a temporary *oronasal* (*bucconasal*) *membrane* (Fig. 1A.3*D*). A nose is also said to exist at this time (stage 17) (16) since a transverse frontonasal groove has made its appearance separating the frontal eminence from the nasal prominences.

Seventh Week (Stages 18 and 19)

During the seventh week the nasal and maxillary prominences elongate, enlarge, and coalesce to establish the primitive face (Fig. 1A.2*D*) featuring, in addition to the previously formed lower jaw, a newly developed upper lip (and jaw), a respiratory by-pass and the beginning of partitioning of the oropharyngeal chamber into independent nasal and oral cavities. Ventromedial growth of the bilateral maxillary prominences (growth centers), for example, involving contact and coalescence (smoothing out of furrows), first with the lateral nasal prominence and then with the premaxillary process, gives rise to the upper lip and jaw and completes the formation of the external nares (Figs. 1A.2*D* and 1A.3). The external nares become delineated upon extension of the maxillary prominences across the caudal border of the developing nasal sac and their coalescence with both nasal prominences (Fig. 1A.4) (17). When coalescence occurs between the maxillary prominence and the premaxillary process, the nasolacrimal sulcus has completed its definitive course from the stomodeum to the developing eye. At stage 18 this groove gives rise to an irregular strand of epithelium which detaches itself from its lower surface and migrates into the mesenchyme. During fetal development this epithelial primordium will become transformed into the *nasolacrimal duct*.

It should be noted that some embryologists, *e.g.*, Boyd (18) and Wood *et al.* (19), contend that the upper lip and incisor teeth are derived from the extension and fusion of the bilateral maxillary prominences with the premaxillary (median nasal prominence) submerged beneath them. Recent evidence in favor of this derivation is the finding that the posterior superior alveolar artery (the intrinsic artery of the maxillary prominence) and not the anterior superior alveolar artery (the artery of the premaxillary process) is the artery which supplies the premaxillary area (and incisor teeth) in the prenatal period (20).

At the beginning of the seventh week (stage 18), the paired oronasal membranes rupture (7), forming bilateral openings, the *internal nares* (primitive choanae) (Figs. 1A.3*E* and 1A.4), thereby establishing continuity for the first time, between the nasal cavities (former nasal sacs) and the single oropharyngeal chamber, now termed the *oronasopharyngeal chamber* (Fig. 1A.5) (17, 21). The internal nares are not located at their definitive sites but will gradually take a more posterior position during the formation of the definitive palate. Prior to the establishment of these separate cavities, the lateral wall of the nasal sac presents a series of swellings, two of which represent the primordia of the *superior* and *middle nasal conchae* (turbinates) (22).

The partitioning of the newly established oronasopharyngeal chamber is accomplished by three septa: two horizontally placed *palatal processes* emerging from the medial