The Pediatric Mandible: I. A Primer on Growth and Development

James M. Smartt, Jr., M.A., David W. Low, M.D., and Scott P. Bartlett, M.D.

Philadelphia, Pa.

Learning Objectives: After studying this article, the participant should be able to: 1. Describe embryonic and fetal mandibular development. 2. Summarize the aggregate changes in mandibular form from birth to puberty. 3. Describe the eruption and maturation of the deciduous and permanent mandibular dentition.

Background: In this, the first of two articles addressing the surgical management of pediatric mandibular fractures, the authors provide a detailed discussion of mandibular development and anatomy during the fetal period, infancy, and childhood.

Methods: A review of the pertinent literature was performed. The changing structure of the developing mandible is discussed, with particular attention to surgically relevant anatomical structures.

Results: Throughout development, key anatomical structures with relevance to surgical therapy change markedly in position. The mandible undergoes significant change in its bony structure and the composition of its surrounding soft tissues. The mandible's bony structure becomes more robust, with an increasingly acute gonial angle and enlargement of the ramus and body. Furthermore, the mandible provides the bony structure from which tooth buds erupt as the deciduous and permanent dentition—a process that generates significant growth of the alveolar process. As a consequence, the distance between the developing dentition and the inferior mandibular border increases. While the canal of the inferior alveolar nerve undergoes significant superior displacement, the mental foramen becomes positioned more posteriorly over time. In addition, the ligamentous and muscular attachments that surround the temporomandibular joint become increasingly robust. Throughout childhood and adolescence, the blood supply of the mandibular body changes little, with the buccal periosteal plexus and inferior dental artery making significant contributions.

Conclusions: Mandibular growth provides the basis for normal occlusal relations and the generation of increasingly large masticatory force. Although the exact mechanisms of bone remodeling during mandibular development remain unclear, the process likely receives contributions from primary growth centers and the response to local alterations in biomechanical force produced by surrounding soft-tissue structures. A working knowledge of the changing mandibular anatomy is a prerequisite for effective clinical management of traumatic injury. (*Plast. Reconstr. Surg.* 116: 14e, 2005.)

The pediatric mandible is a dynamic structure whose anatomy is best understood at interval stages relevant to surgical therapy. However, a few developmental patterns are worthy of discussion, as they assist in understanding

From the Division of Plastic Surgery, Department of Surgery, University of Pennsylvania Medical Center, Children's Hospital of Philadelphia, and the Edwin and Fannie Gray Hall Center for Human Appearance. Received for publication May 28, 2004; revised December 10, 2004.

DOI: 10.1097/01.PRS.0000169940.69315.9C

the aggregate changes that occur during mandibular growth.

Viewed from a functional perspective, mandibular development provides the basis for normal occlusal relationships and the production of significant masticatory force. Through increases in the size of the ramus, body, and alveolar process and the eruption of teeth, the growth of the mandible occurs in parallel with that of the nasomaxillary complex and dentition. Through this reciprocal growth, proper occlusion is achieved. The growing mandible is also a housing for tooth buds that will ultimately develop into the permanent dentition. At birth, the mandible is composed of relatively thin cortices with tooth buds that occupy the majority of the body's volume (Fig. 1, *above*). As development continues and masticatory loads become increasingly large, the composition of the mandible and its surrounding soft tissues changes. The mandible itself becomes composed of thicker cortical bone, while the increasingly large muscles of the masticatory complex and pharynx replace the substantial surrounding layers of adipose tissue. Furthermore, tooth buds occupy a much smaller percentage of mandibular volume. These changes produce not only a more robust structure better adapted to increased masticatory loads but also different fracture patterns as well.

To achieve these functional goals, the mandible must undergo significant postnatal change in its bony structure. At any point in time, the dominant vectors of mandibular growth are a function of temporospatial specific sites of bone deposition and resorption. Although the mechanisms that underlie bone remodeling are not fully understood, it is widely accepted that the process receives contributions from primary growth centers and a series of local responses to biomechanical force through a "functional matrix" of surrounding soft tissues.[1–5] As such, while the presence of a particular mandibular subunit and its surrounding tissues is genetically determined, the development of that subunit, and its subsequent maintenance, is a function of the local mechanical strains to which it is subjected. This process of bone remodeling is most strikingly exemplified through the growth of the condyles and ramus. Traditionally, the growth of a significant portion of the body and ramus has been attributed to the presence of a growth center within the condylar cartilage. As the growth plate within the cartilage undergoes

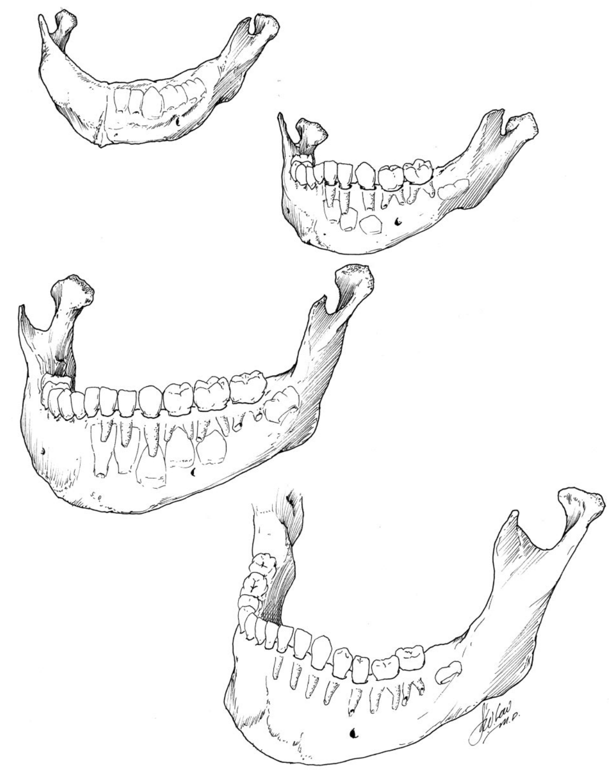

FIG. 1. The developing mandible at select ages throughout growth. (*Above*) The human mandible at birth. Note the obtuse gonial angle, presence of tooth buds, thin cortices, low-set mental foramen between the deciduous cuspid and the first molar, and small condyles. (*Second row*) The mandible at 2.5 years of age. Note the increasingly acute mandibular angle, eruption of the deciduous dentition, and the presence of tooth buds set low in the parasymphysial region. (*Third row*) The mandible at 6 years of age. Note the increasing predominance of tooth buds, enlargement of the alveolar process, and increased condylar height. (*Below*) The mandible at 12 years of age. Note the absence of tooth buds with the exception of the second and third molars, increased height of the ramus, and increased distance between the tooth buds and the inferior mandibular border.

endochondral ossification and grows in a superior and posterior direction, the mandible is displaced anteriorly and inferiorly through what Enlow and Harris have referred to as "area relocation."[5] In turn, the growing condylar neck is remodeled to contribute to the posterior portion of the ramus in a process elucidated more than two centuries ago by Hunter[6] and further refined by Brodie.[7] The primary importance of the condylar cartilage has been suggested by numerous clinical reports documenting the deleterious effect of condylar injuries on craniofacial growth.[8–10] After these injuries, subgroups of patients invariably experience growth disturbances, ankylosis, and malocclusion. However, experimental studies have demonstrated that after bilateral condylectomy in a variety of animal models, the mandibular body grows to nearly its normal size and with proper occlusion.[11–14] Clinical reports in humans have documented the significant remodeling capacity of the mandible following condylar injury.[15,16] Furthermore, studies utilizing a rat model suggest that decreased masticatory strains can result in hypoplasia of the mandibular condyle.[17] These and other studies suggest that, for the majority of the mandibular structures, growth of the soft-tissue components of the oral cavity and pharynx provides the impetus for growth through their stimulation of periosteal and endosteal bone deposition.[18] Ultimately, it is likely that mandibular remodeling is a complex process characterized by a diverse set of mechanisms. Furthermore, the sites of bone remodeling change markedly during the course of development, serving different functional purposes at each stage.[5]

Embryology and Prenatal Development

The mandible, a first pharyngeal arch derivative, originates from neural crest cells that travel ventrally to take their position within the mandibular and maxillary prominences during the fourth week after conception. After formation of the mandibular division of the trigeminal nerve, interactions between the mandibular ectomesenchyme and the mandibular arch epithelium result in the formation of an osteogenic membrane between days 36 and 38 of development (Fig. 2).[19] Meckel's cartilage, the initial nonossifying template for early mandibular growth, forms between 41 and 45 days after conception.[20,21] At the sixth week of life, a single ossification center for each half of the mandible forms lateral to Meckel's cartilage at the bifurcation of the inferior alveolar nerve and artery into its mental and incisive branches.[22] From this center, ossification proceeds ventrally to the body and dorsally to contribute to the mandibular ramus. Furthermore, bone deposition begins to proceed superiorly around the neurovascular bundles to provide a bony framework for the developing teeth.[19]

The primitive temporomandibular joint begins to organize during the seventh and eighth weeks of development, with condensation of a presumptive condyle and articular discs. At 9 weeks of development, following the initiation of muscle movements by the masticatory apparatus, cavitation of the inferior joint occurs. This process results in the formation of a recognizable joint capsule at the eleventh week.[23]

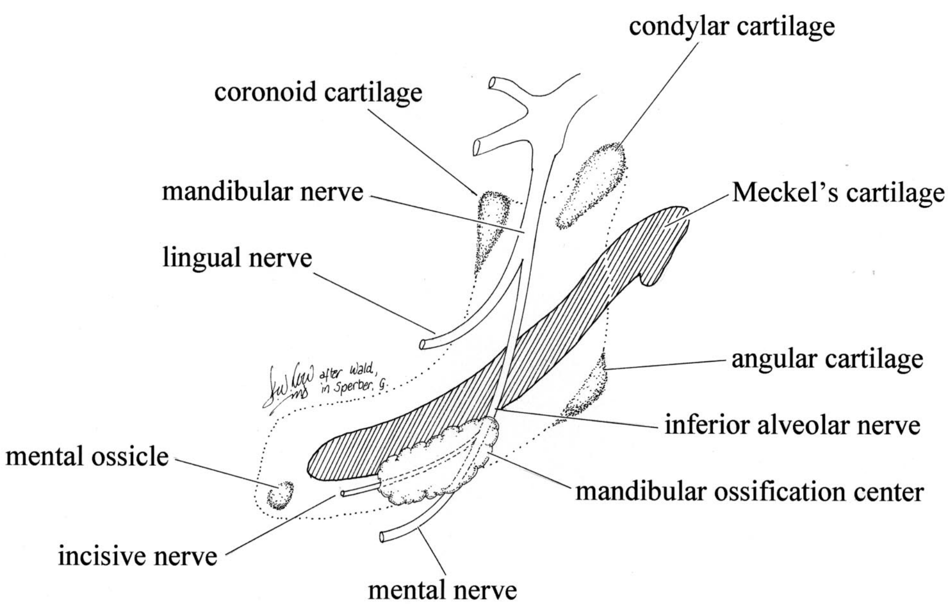

FIG. 2. Schematic diagram of embryological development of the prenatal mandible. Note the location of the mandible's primary ossification center at the bifurcation of the inferior alveolar nerve into its incisive and mental branches. Meckel's cartilage (*striped area*), the primitive framework for mandibular growth, will undergo nearly total osseous obliteration by week 24 after conception. Remnants at the dorsal border will transform into the sphenomandibular and anterior malleolar ligaments. The secondary cartilages of the coronoid, condyle, mental ossicles, and angular cartilage will all contribute to musculoskeletal structures later in development.

Between the tenth and fourteenth weeks of development, secondary cartilages form that will eventually give rise to the coronoid process, mental protuberance, and condylar head (Fig. 2). The secondary cartilage of the coronoid process gives rise to additional intermembranous bone and contributes to formation of the temporalis muscle. Secondary cartilages of the mental protuberance form ossicles in the fibrous tissue of the symphysis that will later aid in the conversion of its syndesmosis to a synostosis through endochondral ossification during the first year of life.[24] The condylar secondary cartilage is the primitive form of the future condyle, providing the cartilaginous material that will provide the stimulus for endochondral ossification of the condylar neck later in development. During this time and subsequently throughout development, the condylar cartilage takes on a stratified organization with five principal layers: (1) articular cartilage, (2) chondroprogenitor cells, (3) chondroblasts, (4) nonmineralized hypertrophic chondrocytes, and (5) mineralized hypertrophic chondrocytes.[25] It is this particular cellular organization that allows the joint to function as both an articular surface and a site of bone deposition, with the first endochondral bone being deposited during the fourteenth week after conception. With increasing age, the articular portion of the condylar cartilage increases in thickness, while the sizes of the chondroprogenitor cells and chondroblasts remain relatively stable.[26]

After formation of the mandible's primary components, the structure itself grows at a rate that is linearly related to gestational age and fetal weight.[26] At 24 weeks' gestation, almost all of Meckel's cartilage is replaced by intermembranous bone. Dorsally, at the temporomandibular joint, portions of the fibrous perichondrium associated with Meckel's cartilage transform into the sphenomandibular and sphenomalleolar ligaments.[19] Near the end of prenatal development, the secondary cartilage of the condyle is almost all replaced by bone, except for the upper end, which persists into adulthood, acting as both a growth and articular cartilage. The overall shape of the growing fetal mandible is not unlike that which exists at birth (Fig. 1, *above*). The formation of the deciduous dentition is first noted at 4.5 months after conception, with calcification of the central and lateral incisors taking place at that time (Table I). Growth of the condylar cartilage and remodeling of the mandibular woven bone to mature trabecular bone are both processes that to some extent depend upon the production of mechanical strain by the fetal masticatory apparatus.[19]

Anatomy of the Postnatal Developing Mandible

The essential landmarks of mandibular anatomy are present at birth but differ markedly from those of the adult (Fig. 1, *above*). At this point, the mandible consists of two individual bones connected by a cartilaginous portion not

TABLE I

Mandibular Tooth Development and Eruption: Chronology of the Deciduous and Permanent Dentition*

Tooth	First Evidence of Calcification	Crown Completion (months)	Eruption (months)	Root Completion (years)
Deciduous dentition				
Central incisor (i_1)	4.5 months†	4	6.5	1.5–2
Lateral incisor (i_2)	4.5 months†	4.5	7	1.5–2
Cuspid/canine (c)	5 months†	9	16–20	2.5–3
First molar (m_1)	6 months†	10–12	21–30	3
Second molar (m_2)	6 months†	10–12	21–30	3
Permanent dentition				
Central incisor (I_1)	3–4 months	4–5	6–7	9
Lateral incisor (I_2)	3–4 months	4–5	7–8	10
Cuspid/canine (C)	4–5 months	6–7	9–10	12–14
First premolar (P_1)	1.75–2 years	5–6	10–12	12–13
Second premolar (P_2)	1.25–2.5 years	6–7	11–12	13–14
First molar (M_1)	Birth	2.5–3	6–7	9–10
Second molar (M_2)	2.5–3 years	7–8	12–13	14–15
Third molar (M_3)	8–10 years	12–16	17–21	18–25

* Adapted from Berkovitz, B. K. B., Holland, G. R., and Moxham, B. J. *Oral Anatomy, Embryology and Histology,* 3rd Ed. Edinburgh: Mosby, 2002. P. 357.
† Months in utero.

yet ossified at the symphysis menti. The body, while large in proportion to the other parts of the mandible, is a relatively undeveloped structure that serves primarily as a shell for the unerupted deciduous teeth. Most noticeably, the angle of the mandible is obtuse (175 degrees), the ramus is small compared with the body, and the coronoid process is of relatively large size, projecting above the level of the condyle. Viewed axially, the condylar processes are in a nearly continuous straight line with respect to the body, with the condyles being attached within the mandibular fossa of the temporal bone by the capsular and temporomandibular ligaments.[27] At this point in development, the temporomandibular joint is comparatively loose, with stability being largely dependent on the capsule that engulfs the joint. Furthermore, the mandibular fossa is relatively flat, providing little additional structural stability.[19] While immature in their size, the muscular attachments differ little in position from those of the adult. In addition, the bone is surrounded by a generous amount of adipose tissue. At this point in development, the mandible lacks much dense cortical bone and houses the sockets of two incisors, a canine and two deciduous molar teeth (Table I). Tooth buds occupy a large proportion of the total mandibular volume, nearly approximating the inferior mandibular border (Fig. 1, *above*).[28] A relatively large mandibular canal runs near the inferior aspect of the bone. Furthermore, the mental foramen opens beneath the future site of the deciduous canine or first molar and points anteriorly and superiorly (Table II).[2,27,29] Blood is supplied to the majority of the mandible via the inferior dental artery and the periosteal plexus provided by the terminal branches of the lingual and facial arteries.[30]

From birth to roughly 3 years of age, the postnatal mandible begins to undergo the depository and resorptive changes that make room for the developing dentition and provide the structure of its dental arch. The two segments of the mandible, once separated by cartilage, are joined through ossification at the symphysis within the first year, leaving a trace of separation that may be visible at the inferior mandibular border (Fig. 1, *second row*). The anterior portion of the body's labial surface undergoes bone deposition and lingual-side resorption. This produces an elongation of the mandibular body, a process that provides length to accommodate the deciduous dentition and the three additional teeth that will develop in this part.[31] After increased use of the teeth and budding of the deciduous and permanent dentition, the anterior portion of the body and the alveolar process attain a greater vertical height than the posterior section of the body that falls behind the oblique line (Fig. 1, *second row*). Remodeling at the coronoid process further augments the growth of the dental arches, with resorption occurring on the buccal side and deposition on the lingual side in an enlarging V pattern, as described by Enlow.[1,5] Within the first 3 years of life, the mental foramen is located relatively anteriorly (Table II), generally falling between the deciduous canine and the second deciduous molar.

It is worth mentioning that the first 3 years of life witness the greatest increase in the mandible's bicondylar width, a fact that is consistent with the rapid rate of lateral growth of the cranial base before the age of 3 years.[32] This increased width receives contributions from the chondrogenic layers at the symphysis that undergo endochondral ossification and from

TABLE II

Position of the Mental Foramen at Different Stages of Dental Maturation*

Status of Dentition	Age Range (Years)	Tooth Overlying Position of Mental Foramen (% status)					
		c-m_1 (C-P_1)	m_1 (P_1)	m_1-m_2 (P_1-P_2)	m_2 (P_2)	P_2-M_1	M_1
No deciduous dentition (*n* = 236)	0–1	160 (67.7)	76 (32.3)	0	0	0	0
Lower deciduous dentition present (*n* = 250)	0.5–3	74 (29.6)	158 (63.2)	18 (7.2)	0	0	0
Permanent first molar erupted (*n* = 253)	3–9	20 (7.9)	155 (61.2)	73 (28.9)	5 (2.0)	0	0
Permanent first molar and other permanent teeth erupted (*n* = 463)	9+	3 (0.6)	62 (13.4)	297 (64.1)	83 (17.9)	13 (2.9)	5 (1.1)

* Combined data from Moss, M. L. Functional analysis of human mandibular growth. *J. Prosthet. Dent.* 10: 1149, 1960, and Coqueugniot, H., and Minugh-Purvis, N. Ontogenetic patterning and phylogenetic significance of mental foramen number and position in the evolution of Upper Pleistocene *Homo sapiens*. In J. Thompson, G. E. Krovitz, and A. J. Nelson (Ed.), *Patterns of Growth and Development in the Genus Homo*. Cambridge: Cambridge University Press, 2003.

c, deciduous cuspid/canine; m_1, deciduous first molar; C, permanent cuspid/canine; P_1, permanent first premolar; m_2, deciduous second molar; P_2, permanent second premolar; M_1, permanent first molar.

the growth of the condyles posteriorly and superiorly. During this developmental period, the deciduous dentition undergoes eruption in a mesiodistal gradient and complete formation of all of its roots, with the deciduous cuspid forming its root last at the age of 3.2 years (Table I). As before, tooth buds nearly approximate the inferior mandibular margin (Figs. 1, *second row*, and 3, *above*).

At the third year of life, mandibular growth begins along the vectors that will predominate during much of subsequent development. While it has traditionally been thought that major centers of growth reside within the mandible's lingual tuberosity and condyles, nearly all of its surfaces undergo some form of bone remodeling (Fig. 4).[1,2,4,5] Bone deposition on the medial portion of the developing ramus, combined with posterior growth via the lingual tuberosity, serves to further increase the size of the dental arches. Growth of the condyles in the superior and posterior directions results in an increased vertical length of the ramus. This

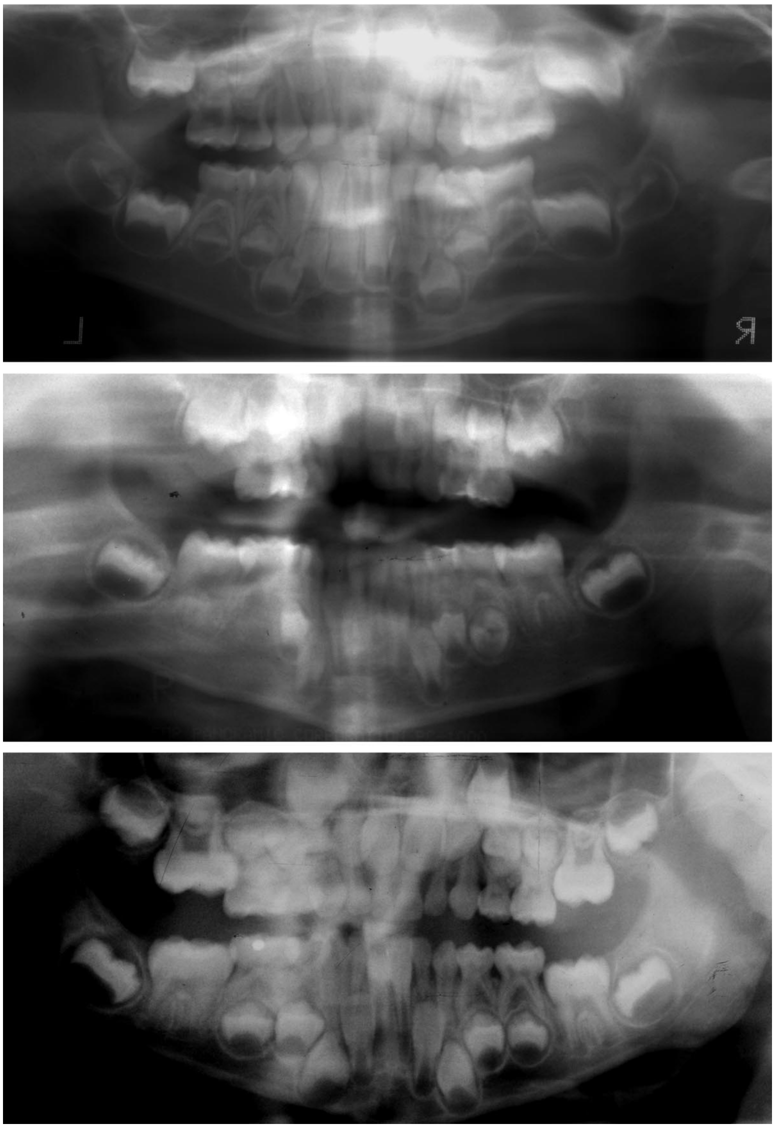

FIG. 3. Panorex radiographs of patients at 3.5, 5, and 6 years of age. (*Above*) Patient at 3.5 years of age with complete deciduous dentition. (*Center*) Patient at 5 years of age with stable deciduous dentition. Note the mesiodistal maturation of the underlying permanent dentition. (*Below*) Patient at 6 years of age, during eruption of the permanent incisors. Note the proximity of the tooth buds to the inferior mandibular border, especially in the parasymphysial region.

newly formed ramus in turn remodels in a complex fashion (Fig. 4), a process that is facilitated by periosteal resorption and endosteal bone deposition in much of the condylar neck and ascending ramus.[1,5,6] As a consequence, the mandibular angle becomes more acute (140 degrees by the fourth year), providing increased space for the development of the permanent dentition.[27] Meanwhile, the wing-shaped outgrowths of the coronoid processes undergo deposition on their lingual surfaces, with simultaneous resorption on the buccal side. This further provides bony mass to the dental arches and increased vertical growth with only minor lateral lengthening of the condyles.[5] The mandibular canal is situated just above the level of the mylohyoid line.[27] With the completion of root formation, the deciduous dentition becomes increasingly stable from 2 to 5 years of age. Nonetheless, the tooth buds of the permanent dentition still nearly approximate the inferior mandibular border, especially in the parasymphysial regions (Figs. 1, *second row*, 3, *above* and *center*).

At 5 or 6 years of age, the two principal parts of the mandible (the ramus and the body) are distinct anatomical entities whose growth oc-

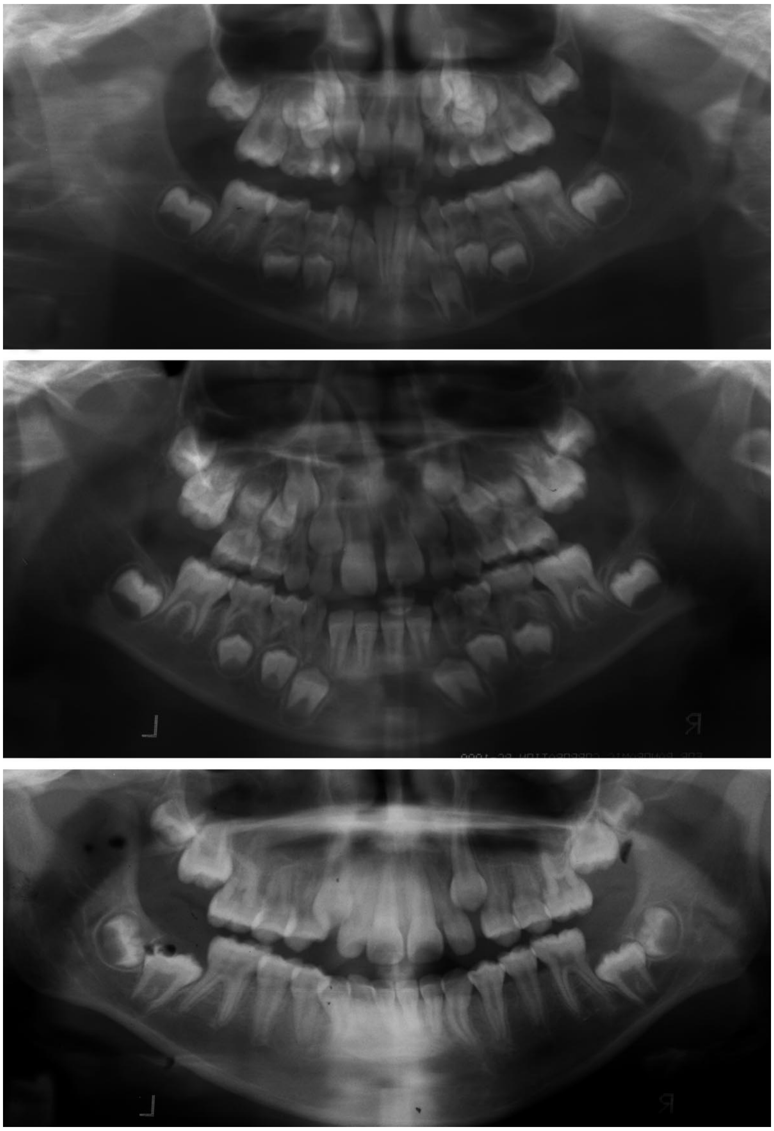

FIG. 4. Panorex radiographs of patients at 7, 8, and 12 years of age. (*Above*) Patient at 7 years of age, in the mixed dentition stage. (*Center*) Patient at 8 years of age, in the mixed dentition stage. (*Below*) Patient at 12 years of age. Note the increased distance between the tooth roots and the inferior mandibular border.

curs in a largely independent fashion in parallel to changes in the midface (Figs. 1, *third row*, 3, *center* and *below*, and 4, *above*). The growth of the ramus is at its maximal rate, with an increase in anteroposterior length and anterior projection that parallels the growth of the middle cranial fossa and pharynx. The vertical growth of the ramus mirrors the growth of the maxilla and eruption of the maxillary dentition. Meanwhile, further lengthening of the dental arches is accomplished posteriorly where the ramus is remodeled to become part of the body (Fig. 5).[1,31] This change in the direction of growth is necessary to accommodate the developing permanent molar teeth and continues well into adolescence. Further remodeling results in a posterior relocation of the ramus with simultaneous lengthening of the corpus and an increasingly acute mandibular angle. Ultimately, this process of remodeling results in the correct positioning of the mandibular corpus in relation to the maxilla and provides the basis for proper occlusion. It should be noted that at this point, the bone deposition on the labial surface of the anterior portion of the mandible has ceased and become resorptive, especially in its more superior aspect, thus providing the characteristic contours of the chin (Fig. 5).[1,31] Between the ages of 4 and 8, crown formation is completed for the majority of permanent teeth. This maturation sets the stage for another period of dental instability that accompanies the eruption of permanent teeth (Fig. 6). Again, this occurs in a mesiodistal gradient, with the incisors and second permanent molar erupting at 6 and 12 years, respectively (Table I). Furthermore, the mental foramen assumes a more posterior location and vertical orientation, generally falling under the first or second permanent premolar at 6 years of age (Table II).[2]

Between the ages of 10 and 12 years, the vast majority of mandibular growth relevant to surgical therapy will be completed. The alveolar and subdental portions of the body are of equal depth, providing the corpus with a more rectangular appearance (Figs. 1, *below*, and 4, *center* and *below*). Years of the aforementioned remodeling place the ramus in a more vertical orientation, with an angle measuring from 110 to 120 degrees.[27] While the majority of permanent teeth have erupted by the age of 12, root completion of the premolars and molars is often not complete until the age of 14 (Table I). Nonetheless, the vast majority of teeth provide stable structures for surgical intervention. The inferior alveolar nerve passes roughly equidistant from the inferior and superior border of the mandibular corpus, having ascended from its earlier developmental position near the inferior mandibular border. The mental foramen also assumes its adult position un-

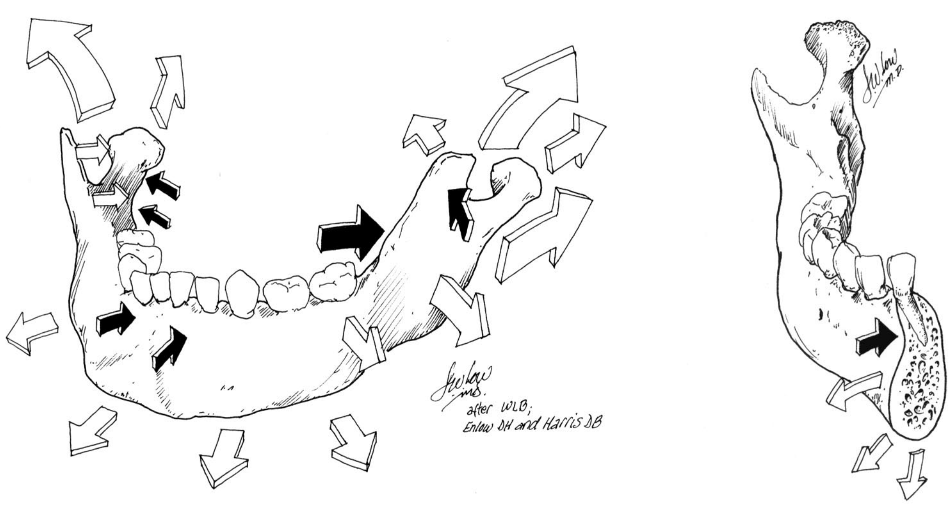

FIG. 5. (*Left*) Schematic diagram of the aggregate changes in bony remodeling of the mandible during childhood. *Black arrows* indicate areas of bone resorption. *White arrows* indicate bone deposition. Note the medial displacement of the coronoid process and the superior-posterior growth of the condyles. (*Right*) Schematic diagram of bony remodeling of the chin during childhood and adolescence. Note the resorption of the superior portion of the symphysis, near the tooth roots (*black arrow*). Simultaneously, bone deposition occurs at the inferior portion of the mandibular symphysis (*white arrows*). These remodeling changes produce the characteristic contours of the human chin.

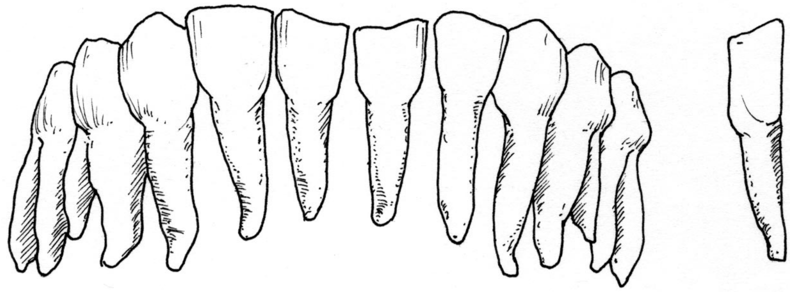

FIG. 6. The deciduous dentition. Note the presence of one central incisor, one lateral incisor, a cuspid or canine, the first molar, and the second molar. (*Right*) A lateral view of the deciduous incisor. Note the narrow occlusal surface and relatively wide cervical margin. This conical tooth shape has important implications for the placement of bridle wires, Essig loops, or any form of interdental wiring.

der the first or second permanent premolar oriented in a posterior and superior fashion (Table II).[2,29] In roughly 9 percent of adults, there exist multiple (two or three) mental foramina.[33] The predominant blood supply of the mandible is still supplied by the inferior dental artery and inferior buccal periosteum, with the latter providing the vast majority of mandibular circulation into adulthood.[30] The overall size of the mandible will increase markedly during the pubertal growth spurt between the ages of 11 and 17, with adolescents experiencing significant increases in condylar height during this period.[34]

SUMMARY

The pediatric mandible is a dynamic structure that undergoes significant changes during development. Although the mechanisms that underlie remodeling of the mandible are not fully understood, the process receives contributions from primary growth centers and the "functional matrix" of surrounding soft tissue. Throughout development, the locations of key anatomical structures change markedly. Over time, tooth buds occupy an increasingly smaller proportion of the mandibular volume. The mental foramen is also positioned more superiorly and posteriorly as development progresses. To avoid undesirable surgical outcomes, management of mandibular trauma requires knowledge of these changes over time. The next article in this series will discuss more specifically the various techniques that can be used in the treatment of pediatric mandibular fractures at various stages of maturation.[35]

Scott P. Bartlett, M.D.
Division of Plastic Surgery
University of Pennsylvania and Children's Hospital of Philadelphia
Edwin and Fannie Grey Hall Center for Human Appearance
1st Floor, Wood Building
34th and Civic Center Boulevard
Philadelphia, Pa. 19104
scott.bartlett@uphs.upenn.edu

REFERENCES

1. Enlow, D. H. *Handbook of Facial Growth.* Philadelphia: W. B. Saunders, 1982. Pp. 1-186.
2. Moss, M. L. Functional analysis of human mandibular growth. *J. Prosthet. Dent.* 10: 1149, 1960.
3. Moss, M. L. The primary role of functional matrices in facial growth. *Am. J. Orthod.* 55: 566, 1969.
4. Moss, M. L., and Rankow, R. M. The role of the functional matrix in mandibular growth. *Angle Orthod.* 38: 95, 1968.
5. Enlow, D. H., and Harris, D. B. A study of the postnatal growth of the human mandible. *Am. J. Orthod.* 50: 25, 1964.
6. Hunter, J. *The Natural History of the Human Teeth, Explaining Their Structure, Use, Formation, Growth and Disease.* London: J. Johnson, 1771.
7. Brodie, A. On the growth pattern of the human head. *Am. J. Anat.* 68: 209, 1941.
8. Topazian, R. G. Etiology of ankylosis of temporomandibular joint: Analysis of 44 cases. *J. Oral Surg. Anesth. Hosp. Dent. Serv.* 22: 227, 1964.
9. Lund, K. Mandibular growth and remodelling processes after condylar fracture: A longitudinal roentgencephalometric study. *Acta Odontol. Scand. Suppl.* 32: 3, 1974.
10. Bradley, P., James, D., and Norman, J. E. D. B. Injuries of the condylar and coronoid processes. In J. L. Williams (Ed.), *Rowe and Williams Maxillofacial Injuries,* 2nd Ed. Edinburgh: Churchill Livingston, 1994. Pp. 405-473.
11. Gianelly, A. A., and Moorrees, C. F. Condylectomy in the rat. *Arch. Oral Biol.* 10: 101, 1965.

12. Pimenidis, M. Z., and Gianelly, A. A. The effect of early postnatal condylectomy on the growth of the mandible. *Am. J. Orthod.* 62: 42, 1972.
13. Sarnat, B. G., and Muchnic, H. Facial skeletal changes after mandibular condylectomy in growing and adult monkeys. *Am. J. Orthod.* 60: 33, 1971.
14. Sarnat, B. G., and Engel, M. B. A serial study of mandibular growth after removal of the condyle in the Macaca rhesus monkey. *Plast. Reconstr. Surg.* 7: 364, 1951.
15. Thomson, H. G., Farmer, A. W., and Lindsay, W. K. Condylar neck fractures of the mandible in children. *Plast. Reconstr. Surg.* 34: 452, 1964.
16. Leake, D., Doykos, J., III, Habal, M. B., and Murray, J. E. Long-term follow-up of fractures of the mandibular condyle in children. *Plast. Reconstr. Surg.* 47: 127, 1971.
17. Kiliaridis, S., Thilander, B., Kjellberg, H., Topouzelis, N., and Zafiriadis, A. Effect of low masticatory function on condylar growth: A morphometric study in the rat. *Am. J. Orthod. Dentofacial Orthop.* 116: 121, 1999.
18. Arena, S. A., and Gianelly, A. A. Resection of the mandibular body and its effect on mandibular growth. *Am. J. Orthod.* 76: 218, 1979.
19. Sperber, G. The mandible. *Craniofacial Development.* London: B. C. Decker, 2001. Pp. 127-143.
20. Orliaguet, T., Darcha, C., Dechelotte, P., and Vanneuville, G. Meckel's cartilage in the human embryo and fetus. *Anat. Rec.* 238: 491, 1994.
21. Sperber, G. Pharyngeal arches. *Craniofacial Development.* London: B. C. Decker, 2001. Pp. 51-60.
22. Orliaguet, T., Dechelotte, P., Scheye, T., and Vanneuville, G. Relations between Meckel's cartilage and the morphogenesis of the mandible in the human embryo. *Surg. Radiol. Anat.* 15: 41, 1993.
23. Merida-Velasco, J. R., Rodriguez-Vazquez, J. F., Merida-Velasco, J. A., Sanchez-Montesinos, I., Espin-Ferra, J., and Jimenez-Collado, J. Development of the human temporomandibular joint. *Anat. Rec.* 255: 20, 1999.
24. Bareggi, R., Narducci, P., Grill, V., Sandrucci, M. A., and Bratina, F. On the presence of a secondary cartilage in the mental symphyseal region of human embryos and fetuses. *Surg. Radiol. Anat.* 16: 379, 1994.
25. Ben-Ami, Y., Lewinson, D., and Silbermann, M. Structural characterization of the mandibular condyle in human fetuses: Light and electron microscopy studies. *Acta Anat. (Basel)* 145: 79, 1992.
26. Berraquero, R., Palacios, J., Gamallo, C., de la Rosa, P., and Rodriguez, J. I. Prenatal growth of the human mandibular condylar cartilage. *Am. J. Orthod. Dentofacial Orthop.* 108: 194, 1995.
27. Gray, H. *Gray's Anatomy*, P. L. Williams and R. Warwick (Eds.). Philadelphia: W. B. Saunders, 1980. Pp. 152-157.
28. van der Linden, F. P. G. M., and Duterloo, H. S. *Development of the Human Dentition: An Atlas.* New York: Harper and Row, 1976. Pp. 11-50.
29. Coqueugniot, H., and Minugh-Purvis, N. Ontogenetic patterning and phylogenetic significance of mental foramen number and position in the evolution of upper Pleistocene Homo sapiens. In J. Thompson, G. E. Krovitz, and A. J. Nelson (Eds.), *Patterns of Growth and Development in the Genus Homo.* Cambridge: Cambridge University Press, 2003.
30. Bradley, J. C. A radiological investigation into the age changes of the inferior dental artery. *Br. J. Oral Surg.* 13: 82, 1975.
31. Kurihara, S., Enlow, D. H., and Rangel, R. D. Remodeling reversals in anterior parts of the human mandible and maxilla. *Angle Orthod.* 50: 98, 1980.
32. Hoyte, D. A. The cranial base in normal and abnormal skull growth. *Neurosurg. Clin. North Am.* 2: 515, 1991.
33. Azaz, B., and Lustmann, J. Anatomical configurations in dry mandibles. *Br. J. Oral Surg.* 11: 1, 1973.
34. Bjork, A. Variations in the growth pattern of the human mandible: Longitudinal radiographic study by the implant method. *J. Dent. Res.* 42 (Pt. 2): 400, 1963.
35. Osborn, J. W. (Ed.). *Dental Anatomy and Embryology.* Oxford: Blackwell Scientific Publications, 1981. Pp. 76-79.