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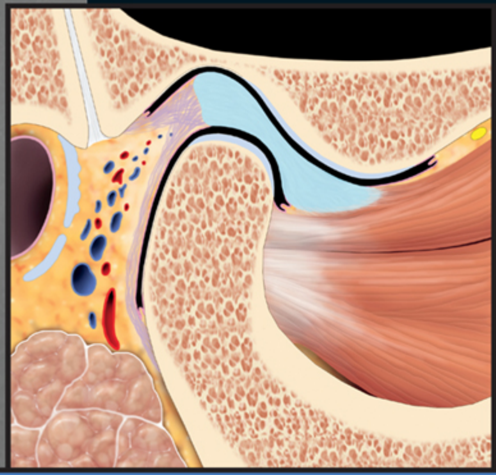

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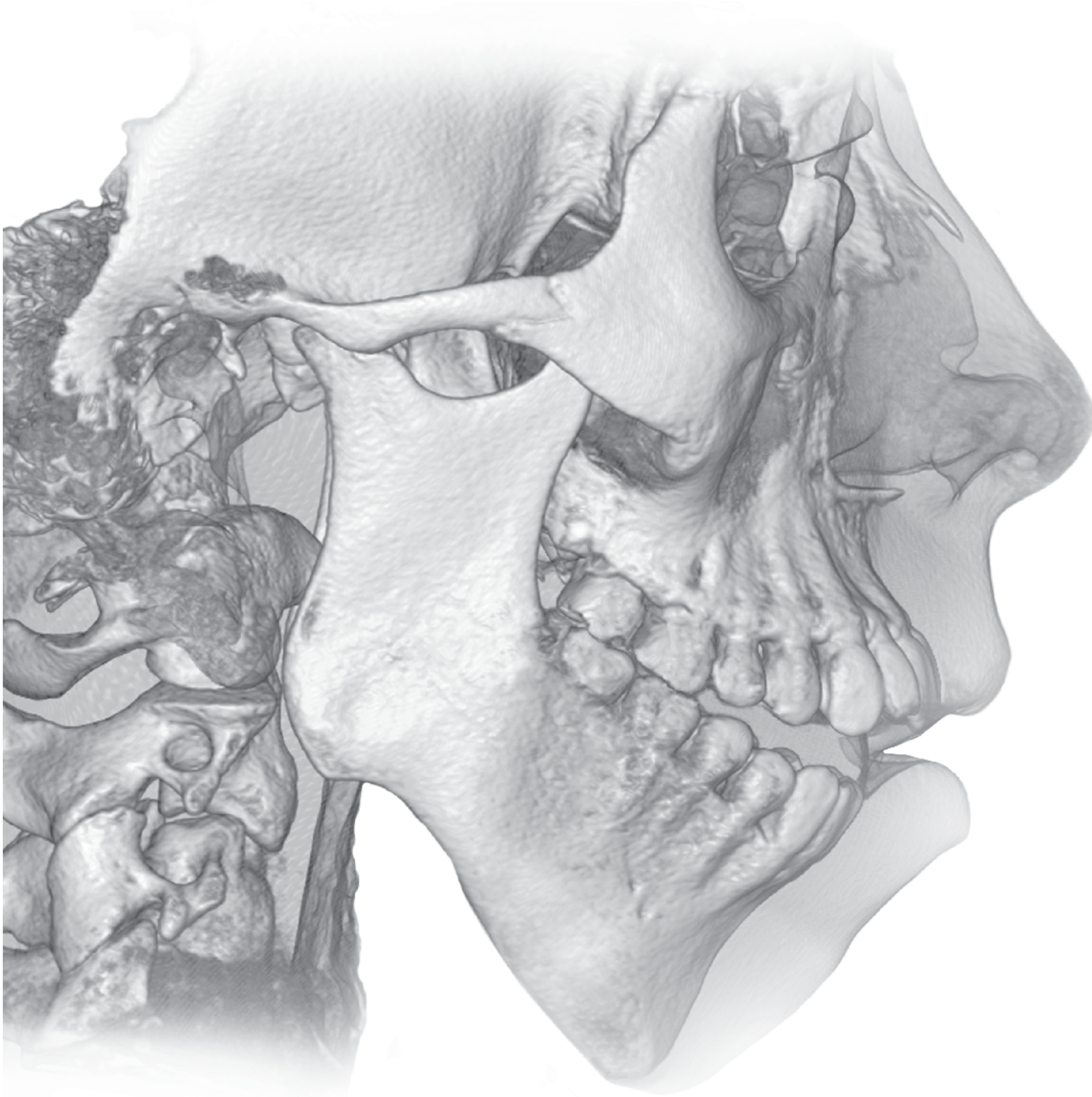

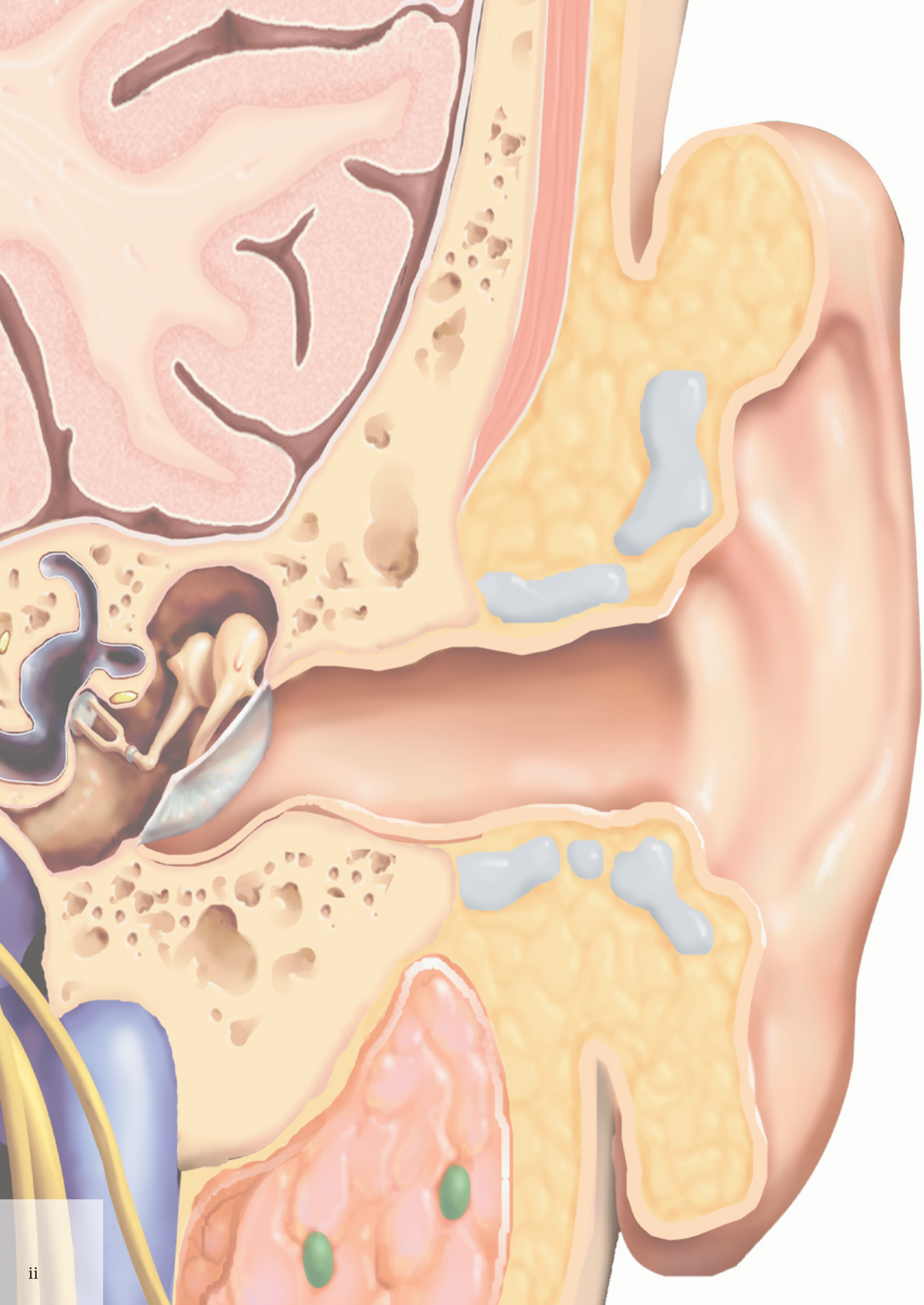

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DEDICATIONS

To the Almighty God. "And above every knowledgeable one is one with more knowledge" – I bring my empty cup to the fountain.

To my wonderful, patient Tamer and amazing, sometimes impatient Zakaria, Noor, and Yousef. Mommy's back!

To my parents. I hope I make you proud.

To David. Thank you for your mentorship on this fabulous TMJ book.

DT

I would like to acknowledge Dr. H.M. Worth for encouraging me to pursue a career in oral and maxillofacial radiology. He was influential in my choice to attend the graduate program at the University of Toronto with an emphasis on the principles and practices of radiographic interpretation. Dr. Doug Stoneman was program director, and he influenced me to pursue a path of continuous and diverse learning. I am grateful to both of them.

My journey has been a learning continuum, and I am thankful to all of the individuals who have shared their knowledge with me. It has been a joy to work with and learn from clinicians, academics, engineers, veterinarians, statisticians, patients, computer scientists, and graduate students.

To my loving wife Sandra; the book is complete. It is spring, so it is time for us to golf and enjoy life.

DCH

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To the oral radiology resident: It's not just a TMJ; it's how you become the link between dentistry and medicine and a key player in clinical dentistry.

DT and DH

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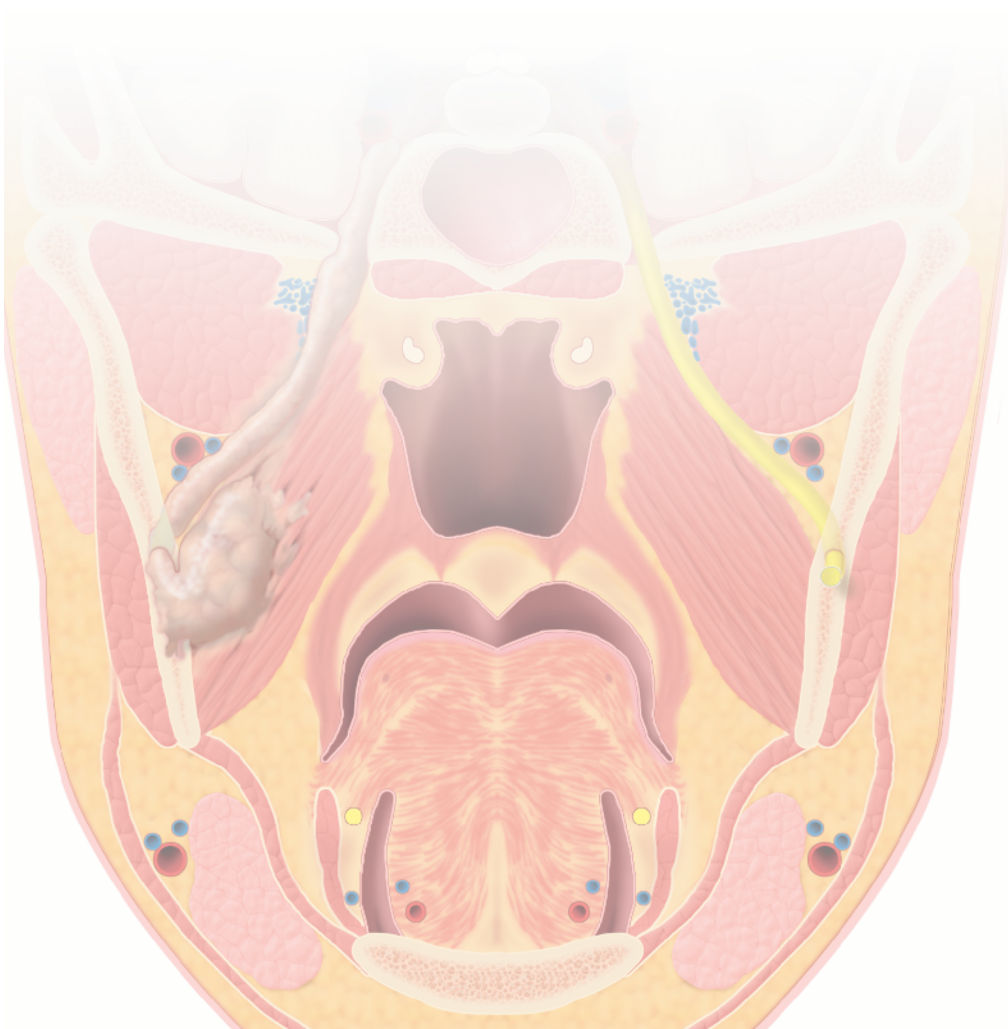

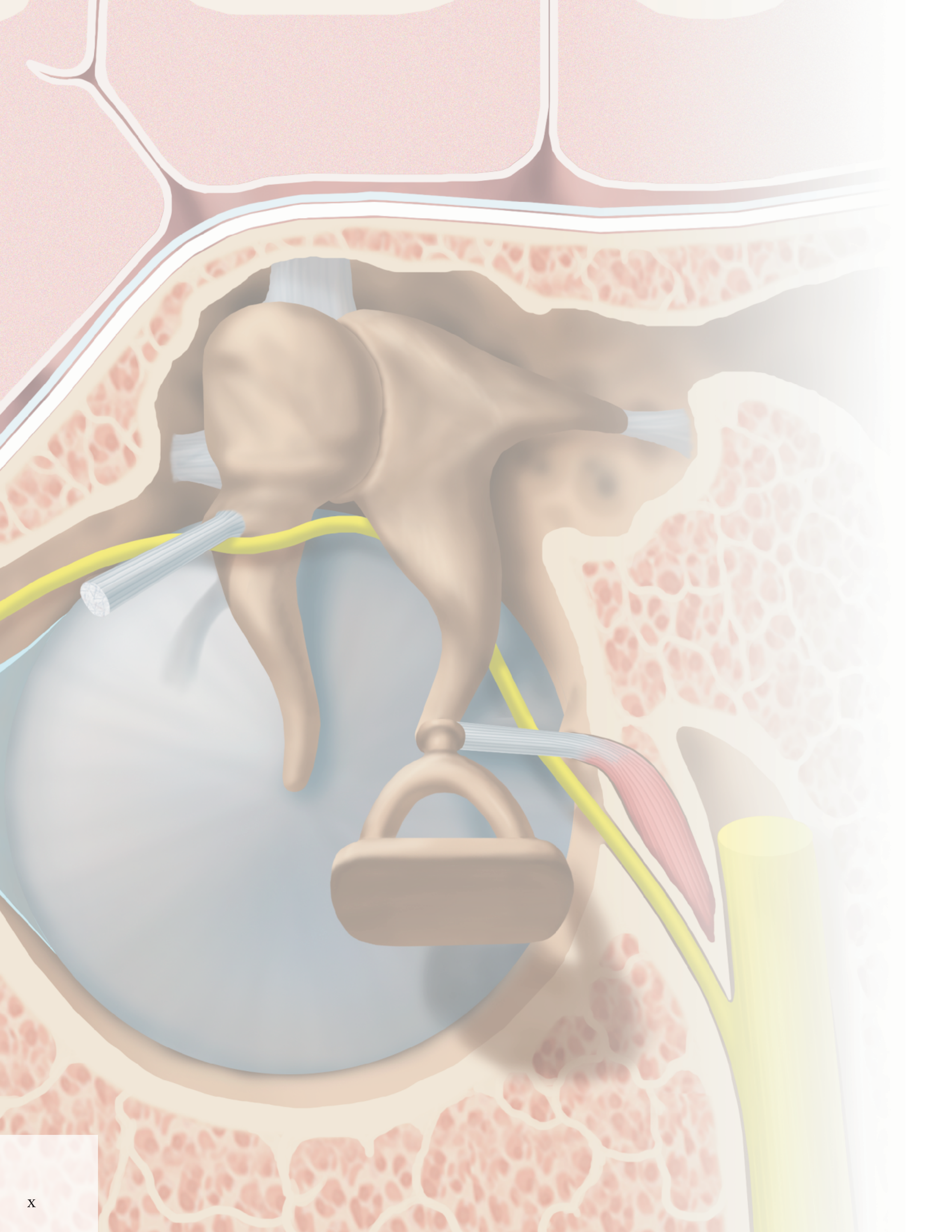

PREFACE

The temporomandibular joint (TMJ) is the most complex structure of the oral and maxillofacial complex. It is a foundation piece of anatomy that influences occlusion, growth of the jaws and face, airway dimensions, and jaw function. To
correctly analyze this structure, one must have an understanding of the role that the TMJ plays in facial growth and development, function of the somatognathic system, and how abnormalities affecting the TMJ will change the dimensions of the facial skeleton and surrounding structures. The close proximity of the TMJ to the temporal bone and skull base contents necessitates an understanding of how conditions of one can affect the other. In order to perform a complete evaluation, the clinician must know the nerve distribution, patterns of pain referral, and extracapsular conditions that may mimic temporomandibular disorders (TMD).

In this book, medicine meets dentistry at the TMJ. There are unique and common grounds including anatomic zones, imaging modalities, patient conditions, and presenting clinical signs and symptoms. The patient seeking clinical care may enter the practice of medicine or dentistry with TMD or conditions that mimic TMD, and if the clinician is not aware of how the TMJ affects other structures and does not interact with other specialists that can offer their unique insight, the diagnosis may not be complete. This book is designed to look at a variety of presenting clinical signs or symptoms, develop imaging strategies, discuss the associated conditions revealed by imaging, and formulate a differential diagnosis.

We start the book with a section on understanding the TMJ, from growth and development, function, biomechanics, and anatomy, and then describe the imaging modality options available for TMJ analysis. The different abnormal conditions that may affect the TMJ are discussed, as well as conditions in adjacent structures that may contribute or mimic TMD. There are two sections on differential diagnosis: One utilizing the clinical signs and one for radiographic signs. The last section delineates how imaging can be used for some of the interventional and surgical TMJ procedures.

This book was written for all professionals involved in the study, diagnosis, and treatment of TMD. This includes dentists (oral and maxillofacial radiologists, surgeons, orthodontists, TMD/orofacial pain and dental sleep medicine specialists, and restorative dentists) and physicians (head and neck radiologists, surgeons, and otolaryngologists).
We hope this tome will encourage cross-talk between the specialties and help bridge the gap between medicine and dentistry through this articulation.

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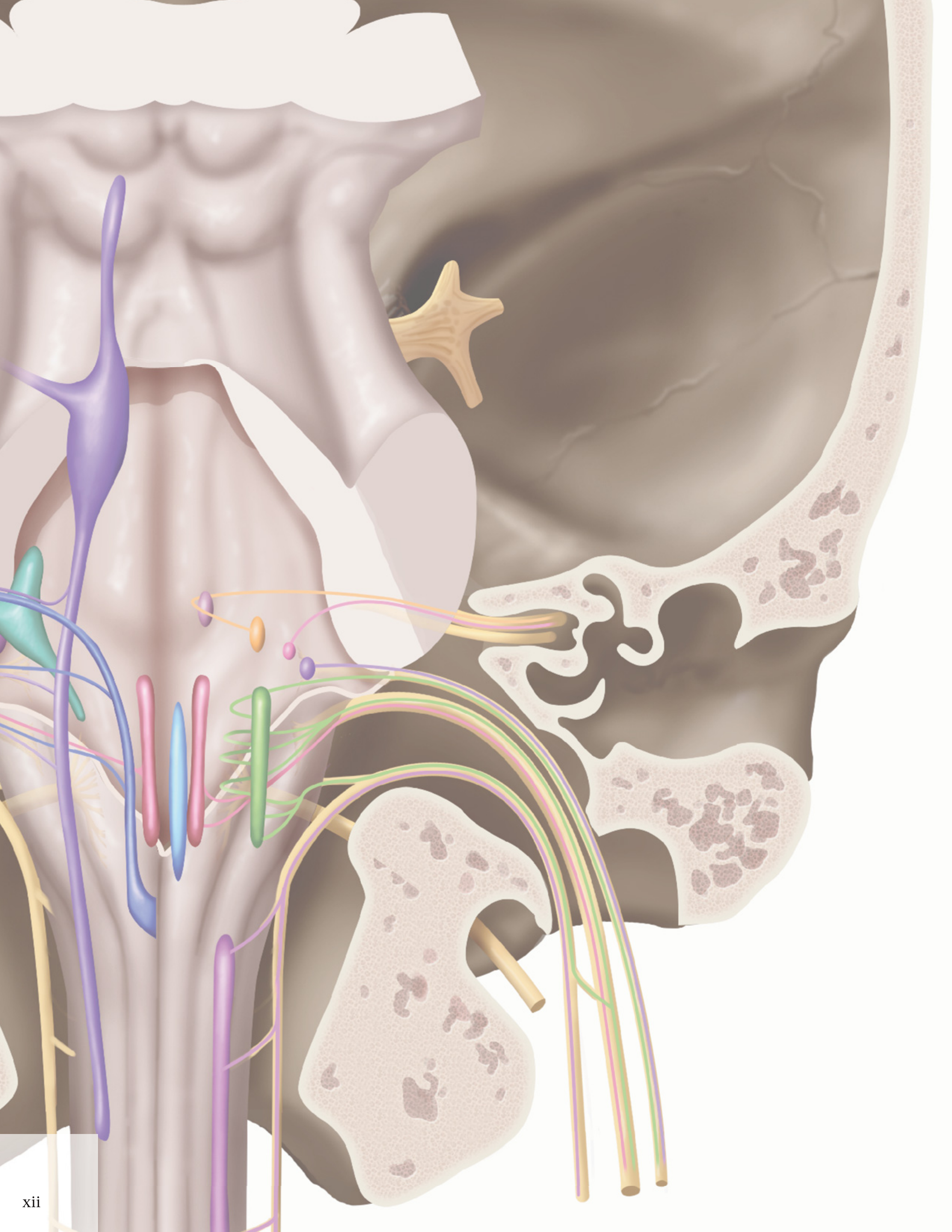

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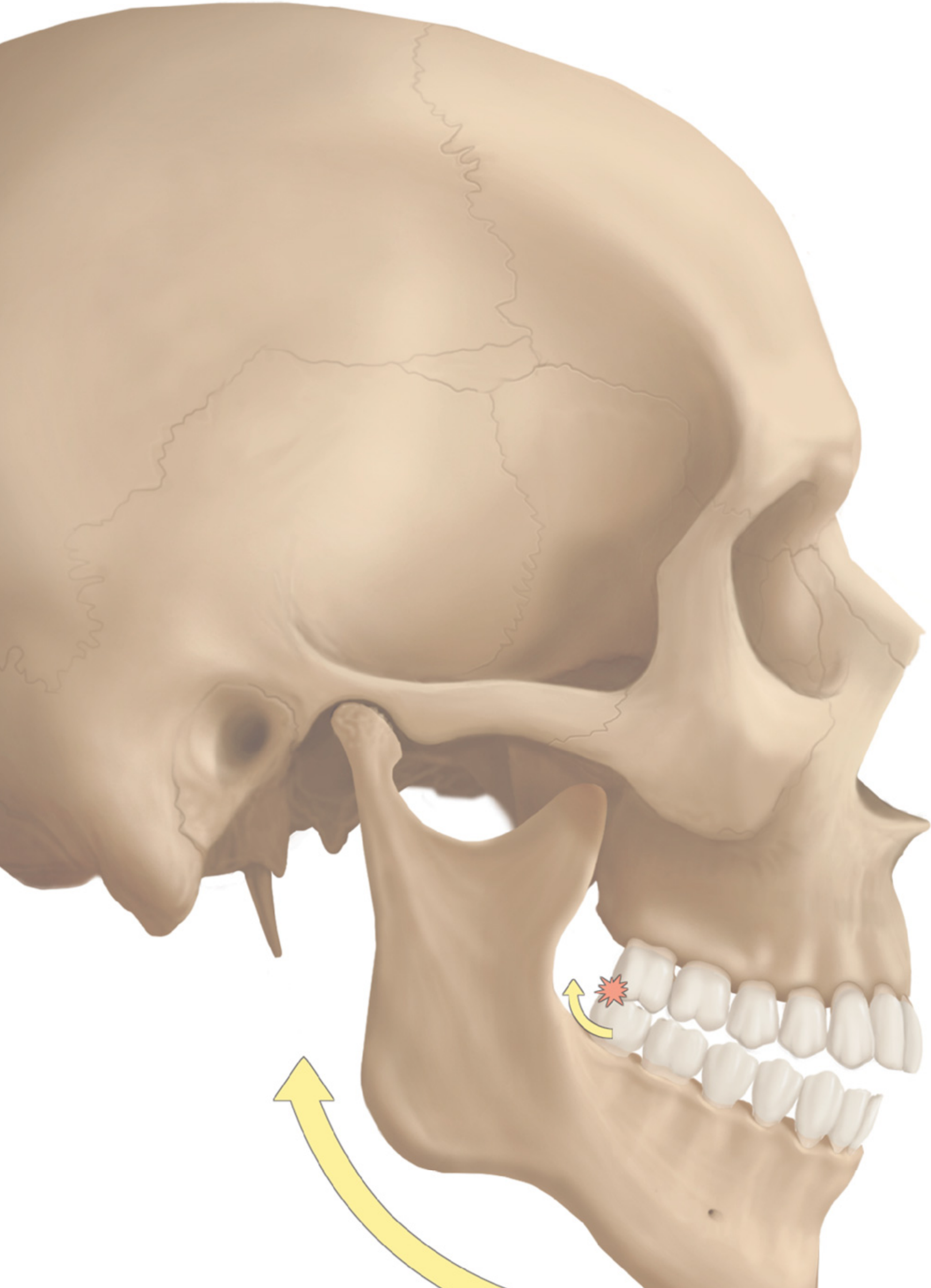

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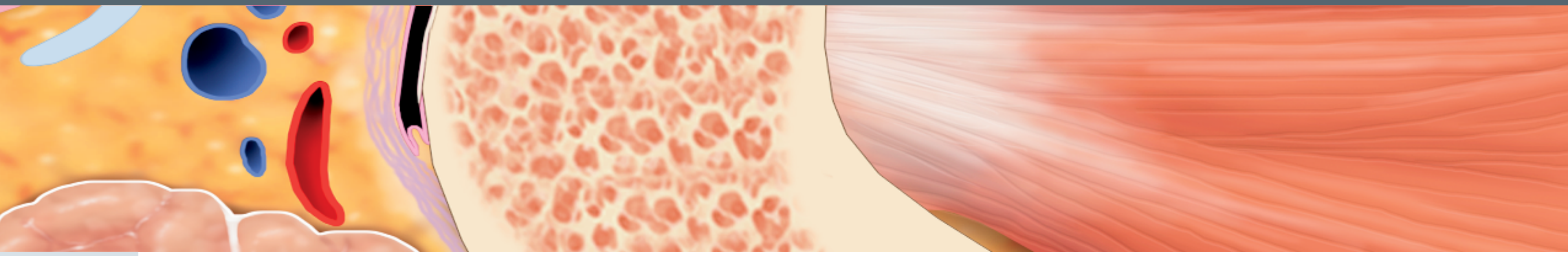

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FUNCTION AND BIOMECHANICS

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JAWS

TEMPORAL BONE

SKULL BASE

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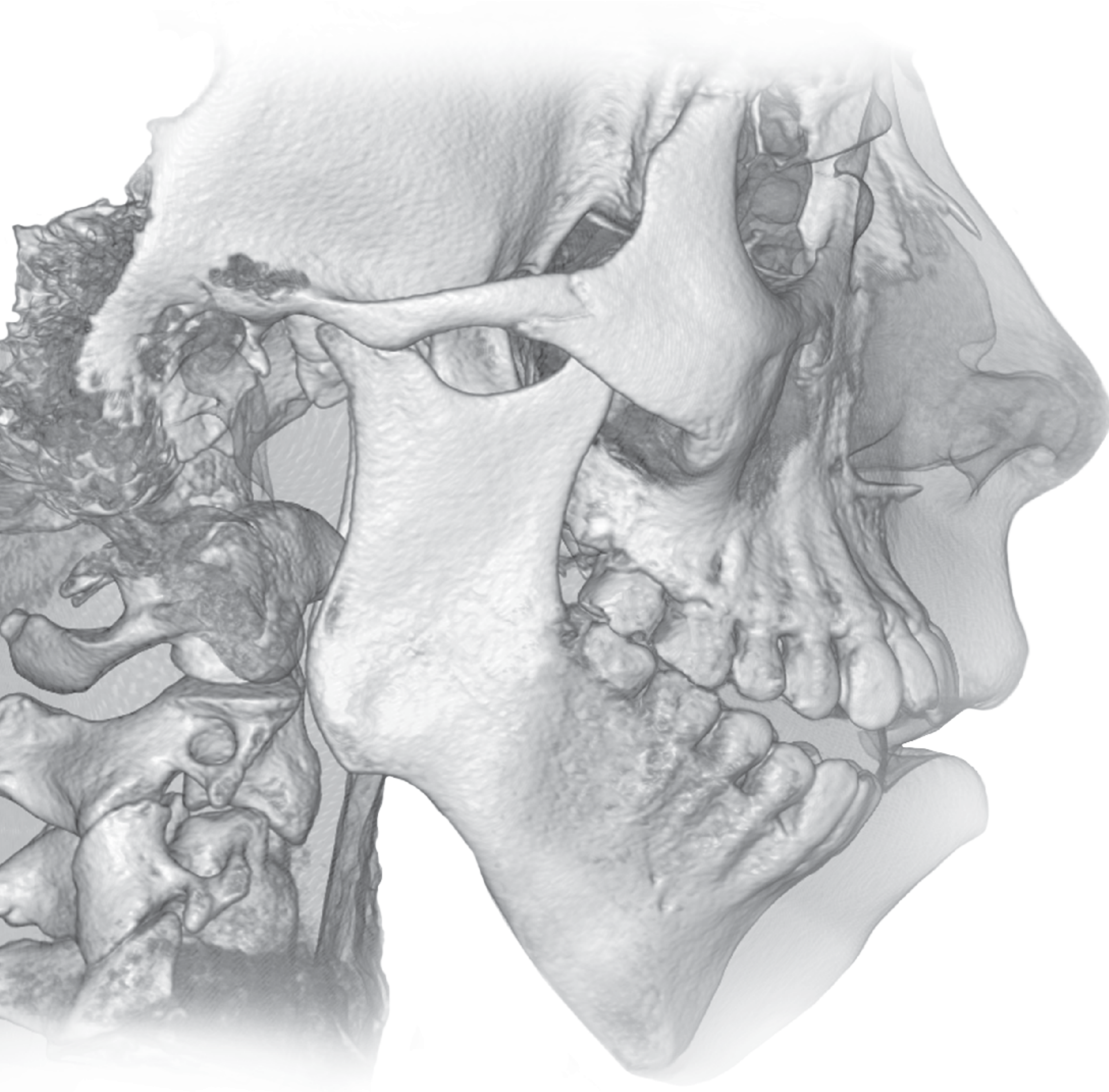

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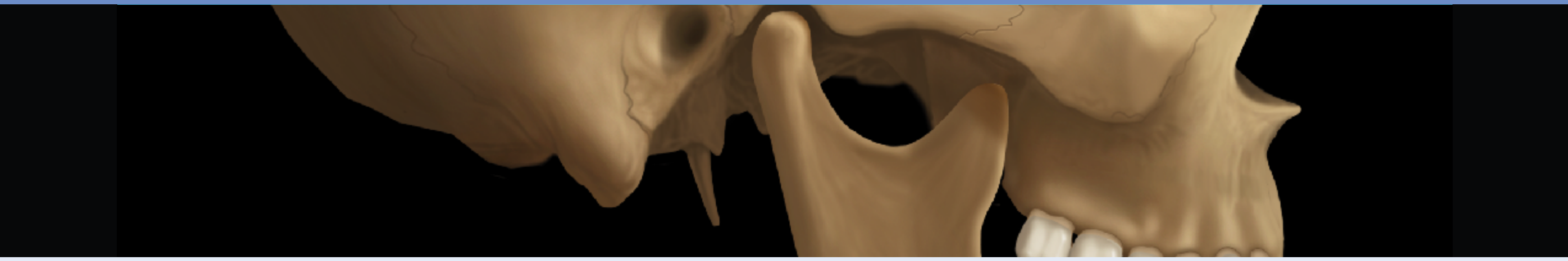
Section 1

Understanding the TMJ



Growth and Development

Function and Biomechanics

GENERAL CONCEPTS

Branchial Arches

- Form during 4th and 5th weeks of embryonic development
- 4 branchial arches (BAs) appear as bars of mesenchymal tissue
- BAs are separated by clefts
  - Branchial grooves
- BAs and groove composition
  - External ectoderm
  - Internal endoderm
  - Central mesoderm
  - Migratory neural crest cells

Swellings Form on Branchial Arches

- Prominences
- Placodes
  - Migrate and fuse to form face
- Failed migration and fusion leads to common facial anomalies

Lymphatics

- Initial separate paired lymphatics
- Fuse with venous system
- Drain head, neck, upper limbs
- Failure to form or fuse leads to lymphatic disorders

NOSE, LIPS, AND PALATE

Frontonasal Prominence

- Anterior cranial bulge of tissue
- Contains forebrain

Nasal Placodes

- Develop on frontonasal prominence (FNP)
  - 5th week of embryonic life
- Bilateral, oval-shaped thickenings
- Eventually evaginate
  - Form nasal pits

Medial With Lateral Nasal Prominences

- Develop on FNP
  - 6th week of embryonic life
- Mesenchyme proliferation of nasal margins
  - Horseshoe-shaped elevations
- Deepening of nasal pit forms nasal sacs
  - Nasal sacs grow dorsal and superior
  - Initial separation between oral and nasal cavity
  - Primitive choanae forms posterior to primary palate
    - Rupture of oronasal membrane
- Medial nasal prominences merge
  - Fusion of midline medial prominence
  - Form intermaxillary segment
    - Becomes philtrum of lip

Maxillary Prominences

- 5th to 8th week of embryonic life
- Start as paired swellings lateral to primitive mouth
  - Enlarge and grow rapidly toward midline
- Fuse with lateral nasal prominences
  - Lateral margins of philtrum
    - Just below nostrils

Palate

- 6th to 12th week of embryonic life
- Forms from 2 primordia
- **Primary palate**
  - Innermost part of intermaxillary segment
    - From medial nasal prominence
  - Wedge-shaped segment
  - Eventual small section of adult hard palate
    - Anterior maxilla to incisor foramen
    - Includes incisor teeth
- **Secondary palate**
  - Primordia of most of hard palate and soft palate
  - Develops from maxillary prominences
    - Lateral palatine shelves
  - Palatine shelves grow toward midline and superiorly
    - Over developing tongue
  - Lateral palate shelves fuse
    - Medially with each other
    - Anteriorly with primary palate
    - Superiorly with nasal septum
  - Neural crest cells concurrently ossify palate
    - Posterior portion is without bone (soft palate)

MANDIBLE AND EARS

Mandible

- 4th to 8th week of embryonic life
- Jaw is 1st part of face to form
- Paired mandibular prominences
  - Caudal boundary of primitive mouth
  - Fuse medially by end of 4th week
- Part of Meckel cartilage migrates
  - Forms incus and malleus of middle ear

Ears

- 4th to 8th week embryonic life
- Inner ear arises from hindbrain
- Middle ear arises from 1st pharyngeal pouch
- External ear from 1st branchial groove
  - Inferior and dorsal to mandibular prominence
    - Early ears are located in upper part of future neck
    - Migrate lateral and superior as mandible develops
  - Auricle from 6 swellings (hillocks)

EYES

Lens Placode

- Forms on FNP during 3rd week
- Induced by optic vesicles
  - From forebrain
  - Becomes lens vesicle and final lens of eye
- Form optic cups
  - Large at 1st, then invaginate

Orbits

- From mesenchyme that encircles optic vesicle
  - Neural crest cells
- Walls of orbit from 7 skull bones
  - Superiorly: Frontal bone
  - Inferiorly: Maxilla, zygomatic
  - Medially: Frontal, lacrimal, maxilla

- Lateral: Zygomatic, frontal

LYMPHATICS

Lymph Sacs

- Begin to develop at end of 5th week
  - 2 weeks after cardiovascular system
- Develop alongside vessels
- Lymph sacs form from fusion/dilatation of adjacent mesenchymal spaces
- **6 primary lymph sacs**
  - **Paired jugular lymph sacs**
    - Subclavian and internal jugular vein junction
    - Drain head, neck, thorax, upper extremities
  - **Cisterna chyli**
    - Lymph sac below diaphragm
    - Along posterior abdominal wall
  - **Retroperitoneal (mesenteric) lymph sac**
    - Root of mesentery
    - Posterior abdominal wall, anterior to cisterna chyli
  - **Paired iliac lymph sacs**
    - Junction of iliac and posterior cardinal veins
    - Drain abdominal wall, pelvis, lower extremity
    - Joins cisterna chyli
- Lymph sacs eventually become groups of lymph nodes
  - Exception is superior cisternal chyli
- Lymphatic vessels grow out from lymph sacs and make connections with venous system

Thoracic Duct

- 2 channels connect jugular sacs with cisterna chyli
  - Right and left thoracic ducts
- Anastomosis and attrition occurs between paired ducts
- Final thoracic duct anatomy
  - Superior part from left duct
  - Central part from anastomosis
  - Caudal part from right duct
- Variations of thoracic duct anatomy common

EMBRYOLOGY OF COMMON ANOMALIES

Cleft Lip and Palate

- **Isolated cleft lip**
  - Involves lip ± primary palate
    - Incisive foramen is boundary of 1° and 2° palate
    - Secondary palate intact
  - Maxillary prominence fails to unite with nasal prominence
    - Results in persistent labial groove
  - Rare cases
    - Median isolated cleft lip
    - Bilateral isolated cleft lip
- **Cleft palate ± cleft lip**
  - Failure of lateral palatine processes fusion
    - Nonunion with each other
    - Nonunion with nasal septum
    - Most often involves lip and 1° and 2° palate
  - Isolated cleft palate (intact lip and 1° palate)
    - Posterior to incisive foramen
- **Rare facial clefts**
  - Median cleft of mandible
  - Lateral or transverse facial cleft
    - From mouth toward ear
  - Oblique facial cleft
    - Upper lip to medial margin of orbit

Eye Anomalies

- Hypertelorism and hypotelorism
  - Optic migration follows forebrain migration
    - Holoprosencephaly: Hypotelorism, cyclopia
  - Associated with craniofacial dysostosis
    - Hypertelorism
- Absent or small eye/orbit
  - Failure of optic vesicle or lens placode to form

Hypognathia

- Insufficient 1st BA
  - From poor neural crest cell migration
- Syndromes
  - Pierre Robin syndrome
    - Hypoplasia of mandible
    - Cleft palate with ear anomalies
  - Treacher Collins syndrome
    - Mandibulofacial dysostosis
    - Eye and ear anomalies

Ear Anomalies

- Low-set ears
  - Ear migration follows mandible development
    - Small chin associated with low set ears
- Abnormal hillock development
  - Auricular appendages (tags)
  - Ear duplication
  - Anotia (absent ear), microtia (small ear)

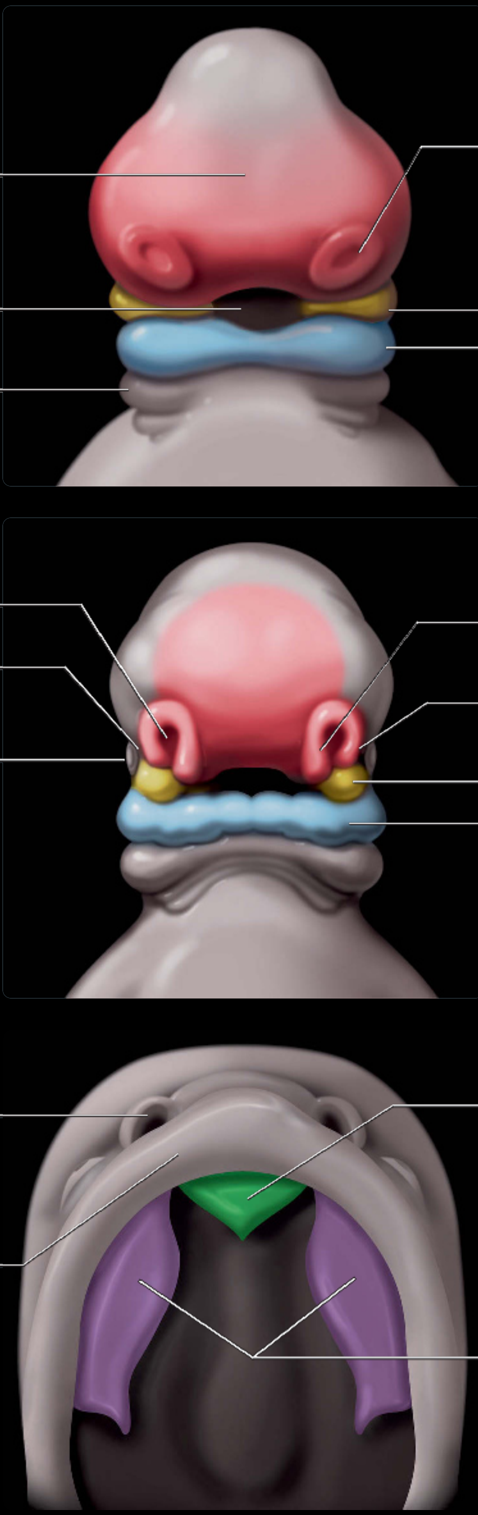
Nose and Mouth Anomalies

- Congenital microstomia (small mouth)
  - Excessive merging of mesenchymal masses
- Absent nose
  - Paired nasal placodes do not form
- Single nostril
  - Only 1 nasal placode forms
- Bifid nose
  - Medial nasal prominences do not merge completely

Lymphangioma

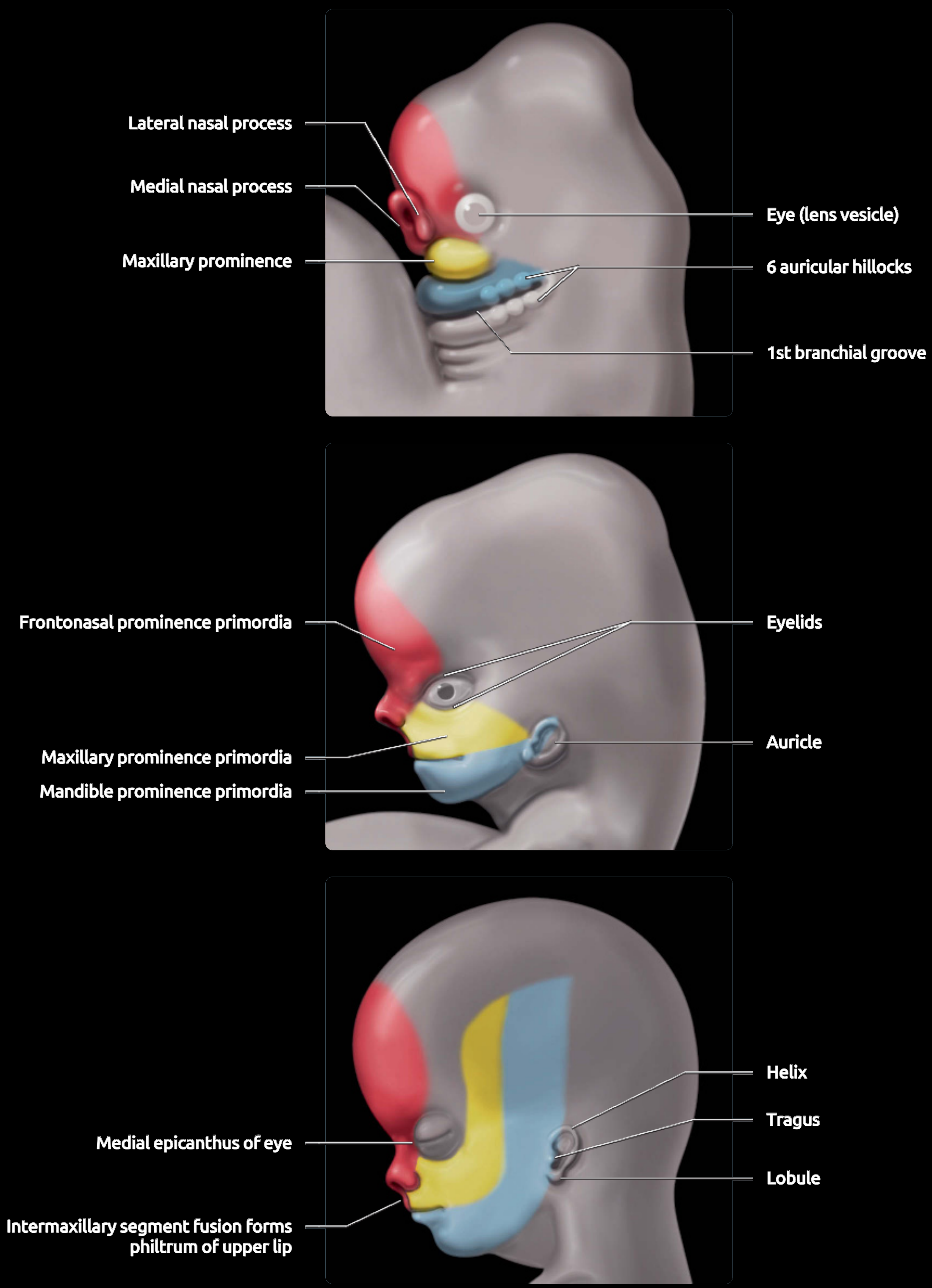
- Dilated primitive lymphatic channels
  - Diffuse congenital lymphedema
  - Focal cystic mass
- Cystic hygroma
  - Failed jugular sac → venous connection
  - Primary fluid collection in dorsal and lateral neck
    - Multiseptated fluid
  - Associated with hydrops fetalis and aneuploidy
    - Turner syndrome most common
    - Trisomy 21 is 2nd most common
- Body lymphangioma
  - Sites
    - Axillary (most common)
    - Intraperitoneal, retroperitoneal
    - Extremities
  - Often large, infiltrative cystic mass

EMBRYOLOGY OF FACE AND PALATE



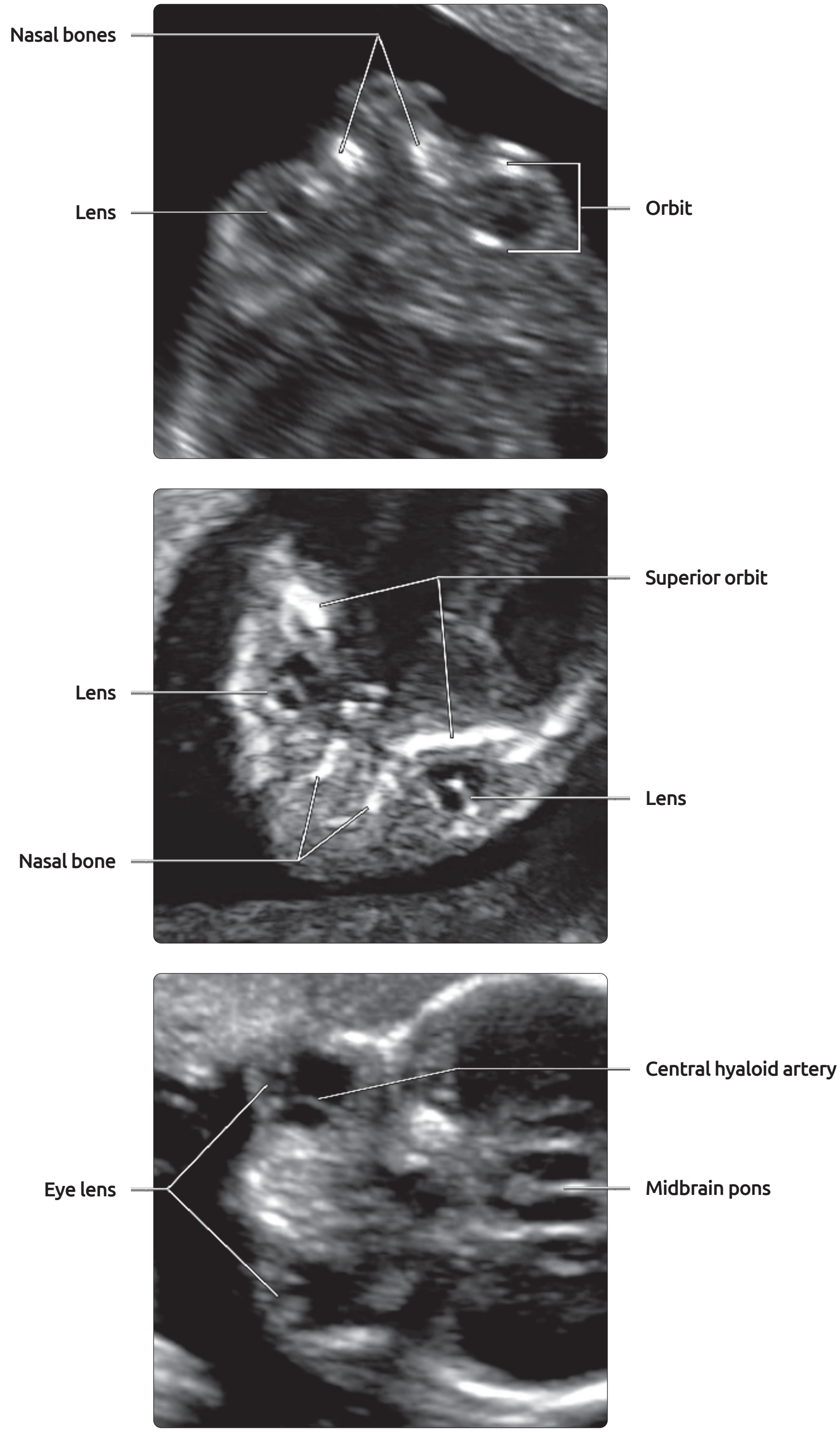
(Top) *Graphic shows a coronal view of a 5-week embryo. The face forms from 5 primordia that appear in the 4th week (frontonasal prominence, 2 maxillary prominences, and 2 mandibular prominences). By the 5th week, the mandibular prominences have fused. Nasal pits form on a pair of ectodermal thickenings, the nasal plates.* **(Middle)** *Graphic shows a coronal view of a 6-week embryo. Invagination of the nasal pits has occurred. Medial nasal processes will fuse to form an intermaxillary process and, subsequently, the upper lip filtrum. In addition, the maxillary prominences will fuse with the intermaxillary process to form an intact upper lip.* **(Bottom)** *Graphic shows an axial view of the palate at 7-8 weeks. The primary palate arises dorsally from the intermaxillary process, and the secondary palate originates from the maxillary prominence. Complete fusion occurs by the 10th week.*

EMBRYOLOGY OF FACE AND EAR



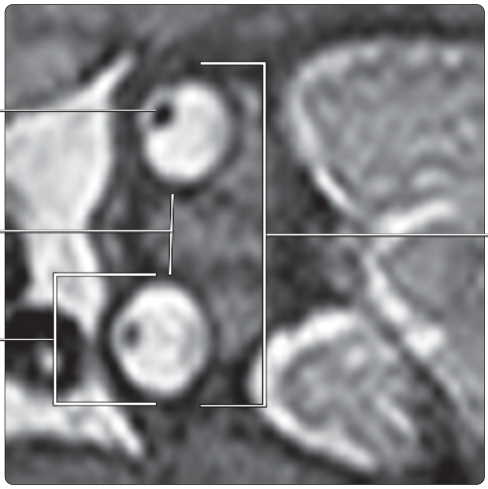
(Top) *Graphic of a 5-week embryo profile shows the lateral and medial nasal processes, not yet fused with the maxillary prominence. Arising from the 1st and 2nd pharyngeal arches, the auricular hillocks of the external ear flank the 1st branchial groove.* **(Middle)** *Graphic of a 10-week embryo profile shows the development of eyelids and the external ear. The ear position is medial and low at this time. As the mandible grows, the ear migrates superiorly.* **(Bottom)** *Graphic of a 14-week fetus profile shows that the philtrum of the lip has formed from fusion between the paired medial nasal processes. The philtrum and maxillary prominences have also fused. The ear is now at its final location with the top of the helix at the same level as the medial epicanthus of the eye.*

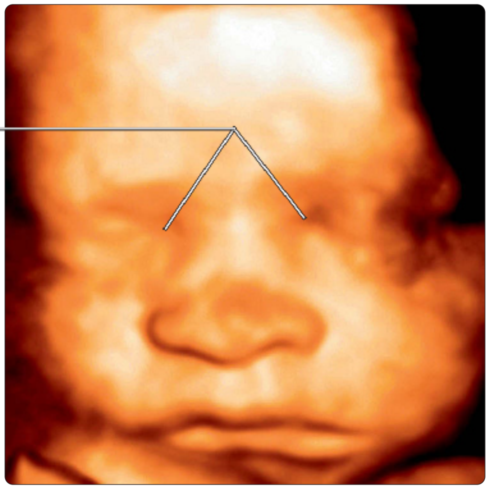
EYES

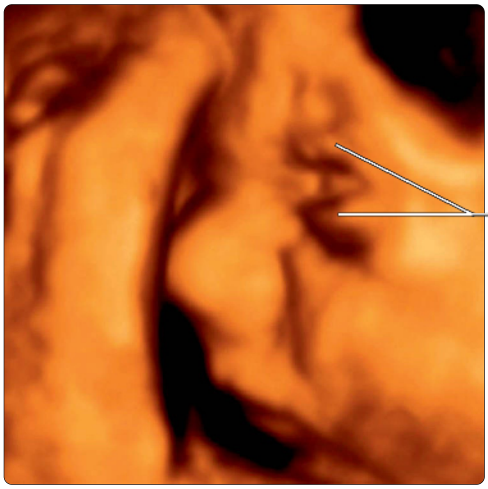


(Top) *Transvaginal axial image through the orbits of a 12-week fetus shows paired nasal bones and normal-sized orbits. The lens of the eye can be seen even at this early gestational age.* **(Middle)** *Coronal transvaginal ultrasound of a 13-week fetus shows the frontal bones and nasal bones contributing to the superior and medial borders of the bony orbit. The eyes and lens are once again seen very well.* **(Bottom)** *Axial ultrasound through the eyes in an early 2nd trimester fetus shows the normal central hyaloid artery, which is located within the hyaloid canal. This artery supplies nutrients to the developing lens and is a normal finding at this time, usually regressing during the 3rd trimester.*

EYES

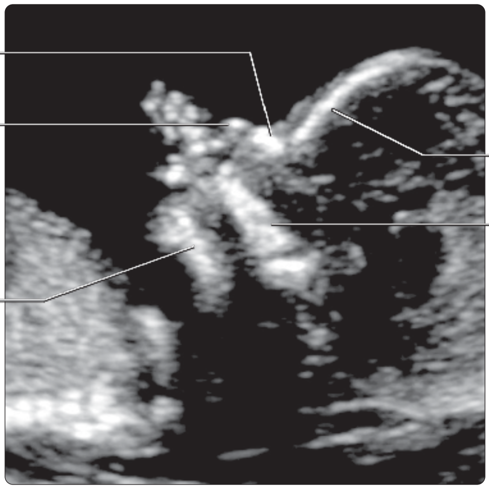


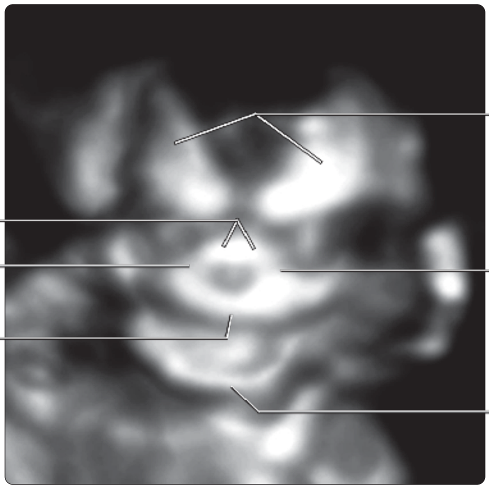


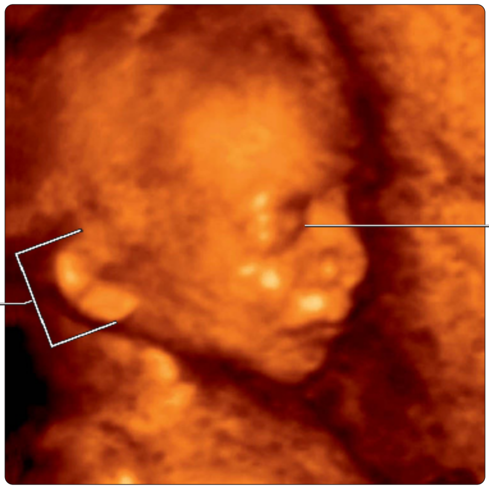


(Top) *Axial T2WI MR of a late 2nd trimester fetus shows the orbits. MR or ultrasound can be used to measure the globe diameter, interocular distance, and binocular distance. The lens of the eye is low signal on MR.* **(Middle)** *3D ultrasound of a 3rd trimester fetal face shows the eyes, nose, and lips. The interocular distance and the medial epicanthus of the eyes are seen well.* **(Bottom)** *3D ultrasound of a fetal profile shows open eyes. In the 3rd trimester it is common to see the eyes open and close. In addition, globe movement is also commonly seen with real-time imaging.*

NOSE

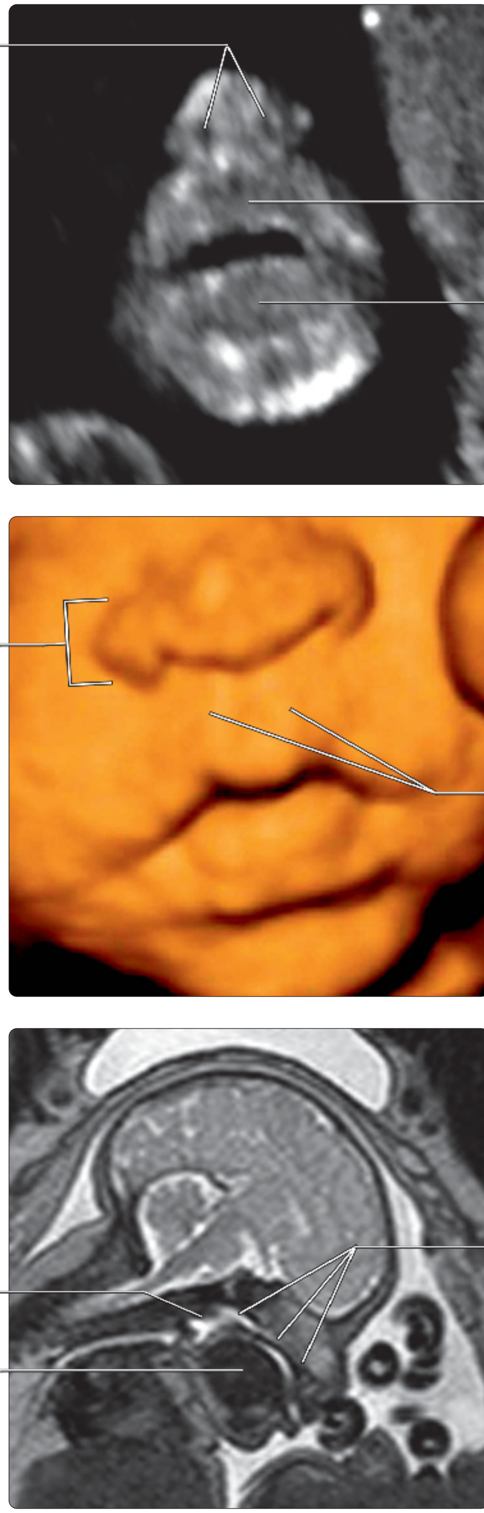






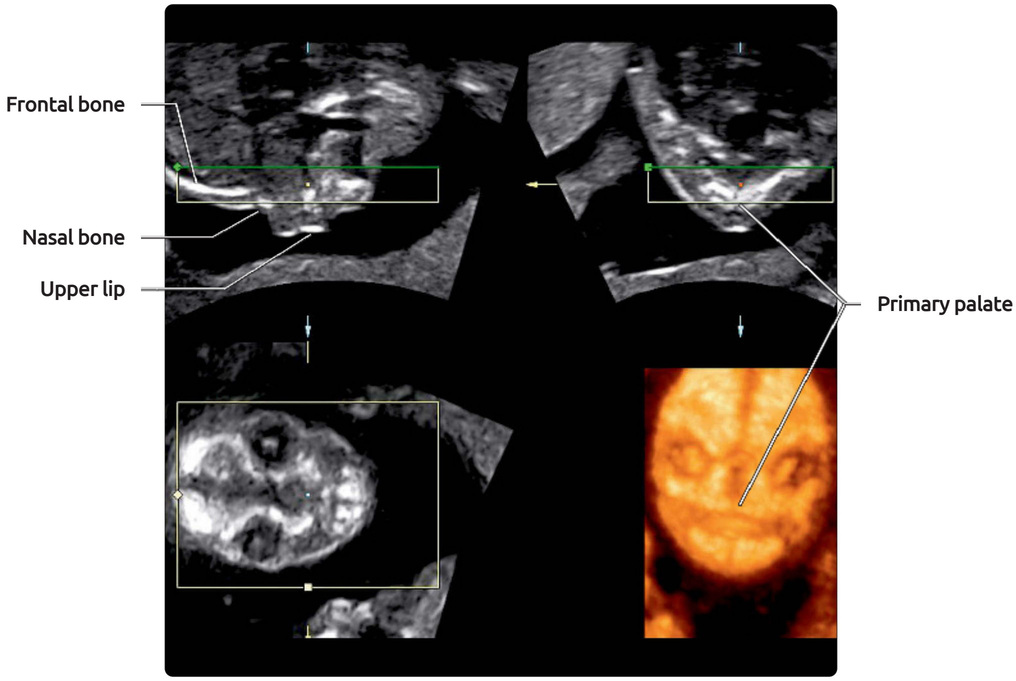
(Top) *Sagittal ultrasound of a 12-week fetus shows a normal nasal bone. The echogenic nasal bone is as bright as the frontal bone, and it is seen separately from the nasal skin.* **(Middle)** *3D ultrasound with skeletal reconstruction of a 13-week fetus shows the retronasal triangle view composed of the paired nasal bones superiorly, the frontal process of the maxilla laterally, and the inferior primary palate.* **(Bottom)** *3D ultrasound profile view that includes the nose, eye, and ear shows normal relationships. The top of the helix should be at the same height as the medial epicanthus of the eye.*

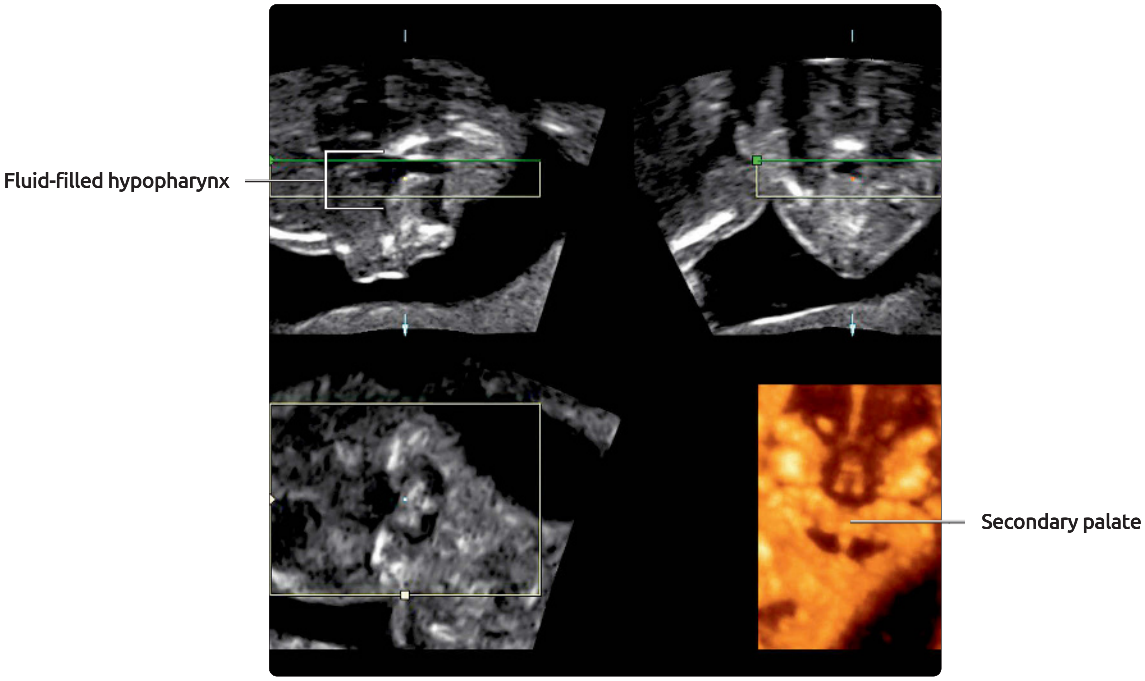
LIPS AND PALATE



(Top) *Coronal ultrasound through the nose and lips shows the nostrils and intact upper lip. This view is considered standard for anatomy scans.* **(Middle)** *3D ultrasound with soft tissue reconstruction shows the normal rounded nares of the nose and the intact philtrum of the upper lip.* **(Bottom)** *T2WI MR of a 30-week fetus shows an intact secondary palate. A sliver of high-signal fluid in the mouth, superior to the tongue, provides excellent contrast, allowing for visualization of the palate. The fluid-filled hypopharynx is also seen extending down to the upper trachea.*

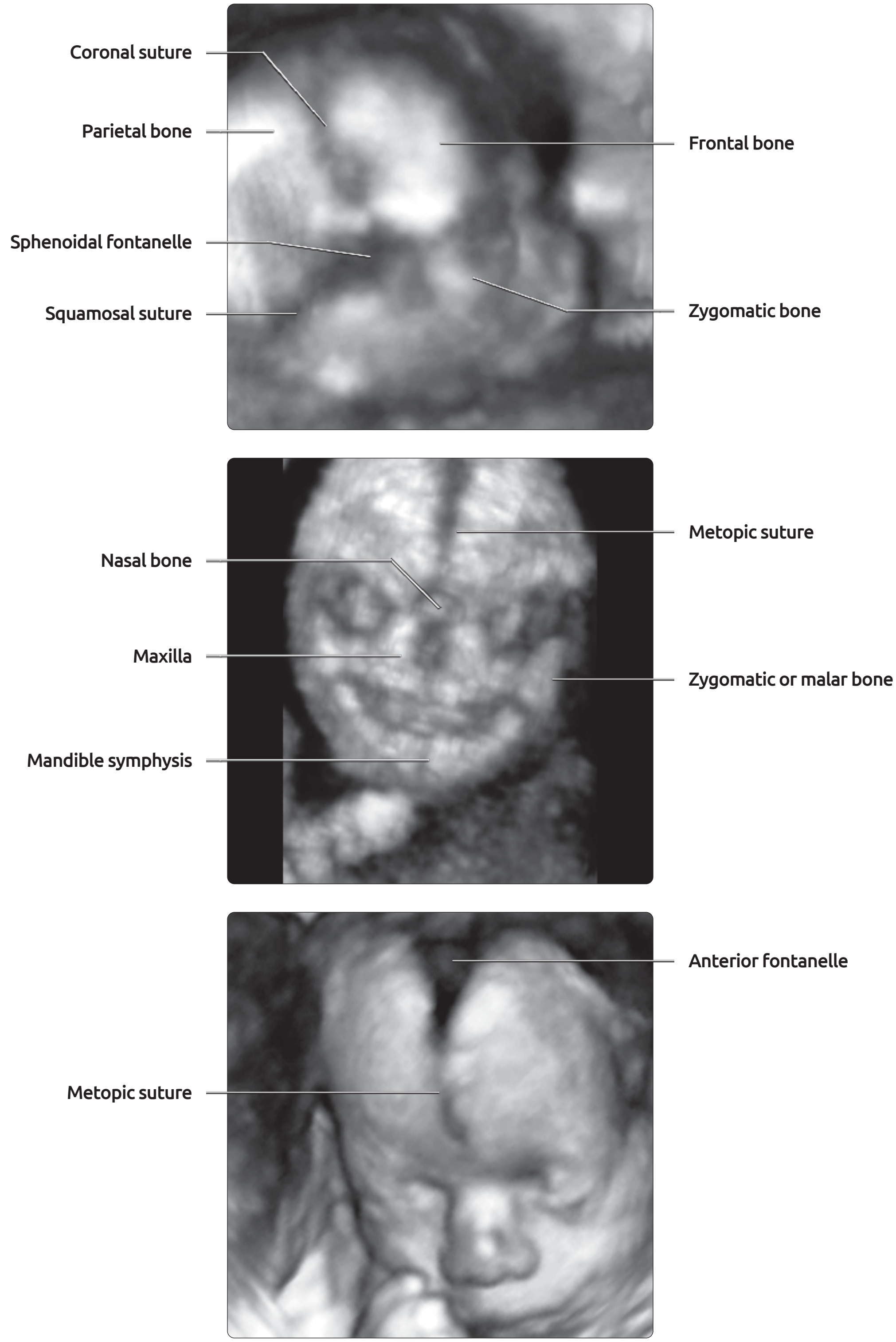
PALATE





(Top) *3D planar and skeletal reconstruction views of a 2nd trimester fetus performed through the anterior palate show an intact alveolar ridge.* **(Bottom)** *3D planar and reconstruction views through the posterior palate and hypopharynx show an intact secondary palate. The reversed face technique (lower right) is helpful in minimizing palate shadowing artifact.*

SKULL AND SUTURES



(Top) *3D ultrasound of an 18-week fetus profile shows normal skull and suture anatomy.* **(Middle)** *Coronal 3D ultrasound with skeletal reconstruction of a 20-week fetus shows normal skull bones and sutures.* **(Bottom)** *3D ultrasound of an early 3rd trimester fetus shows the anterior fontanelle and metopic suture.*

TERMINOLOGY

Definitions

- **Temporomandibular joint (TMJ)**
  - Articulation of condylar process with glenoid fossa of temporal bone
  - 2 joint spaces
    - Superior: Translation movement
    - Inferior: Rotational movement
- **Meckel cartilage**
  - Cartilaginous bar of 1st pharyngeal arch
  - Serves as embryologic anlage to developing mandible
    - Posterior segment forms incus and malleus, sphenomalleolar ligament
    - Fibrocellular capsule remains to form sphenomandibular ligament
- **Mesenchyme**
  - Embryonic connective tissue
- **Pharyngeal arch**
  - Mesenchymal swellings lateral to pharynx in developing embryo

IMAGING ANATOMY

Temporomandibular Joint

- Derivative of 1st pharyngeal arch
- Derived from secondary blastema formed after body and ramus of mandible
- Condylar process develops through endochondral bone formation
  - Represents epiphyseal plate of mandible (growth and length)
- Joint space forms through process of cavitation
  - Results from mouth opening in embryo (7.5 weeks)
  - Inferior joint space appears 1st
- Squamous portion of temporal bone develops through intramembranous ossification

3 Stages of TMJ Development

- Blastemic stage (7-8 weeks)
  - Broad band of undifferentiated mesenchyme between developing ramus of mandible and squamous tympanic bone
  - Band of mesenchyme reduces into dense strip (future articular disc)
  - Beginning of condyle, disc, and capsule organization
  - Intramembranous ossification of temporal squamous bone (8 weeks)
- Cavitation stage (9-11 weeks)
  - Mesenchyme adjacent to dense strip breaks down to form joint cavity
  - Formation of inferior joint space (9 weeks)
  - Condylar chondrogenesis begins (endochondral bone formation)
  - Formation of superior joint space (11 weeks)
  - Vascularity around TMJ closely related to articular cavity and formation of synovium
- Maturation stage (12 weeks to birth)
  - Joint capsule clearly demarcated at 17 weeks
  - Cellular and synovial tissues differentiated at 26 weeks

Mandible

- Develops in close positional relationship lateral to Meckel cartilage
- 6 weeks: Meckel cartilage extends from otic capsule to midline of fused mandibular processes
- 7 weeks: Intramembranous ossification begins lateral to Meckel cartilage to form ramus and body
- 3 secondary cartilages assist growth
  - Condylar (blastema)
    - Appears at 12 weeks
    - Cone-shaped mass
    - Occupies developing ramus
    - Endochondral ossification leaves thin layer of cartilage in condyle by 20 weeks, remains growth center through 2nd decade of life
    - Multidirectional growth capacity
  - Coronoid
    - Appears at 16 weeks
    - Transient, disappears before birth
  - Symphyseal
    - 2, in connective tissue between ends of Meckel cartilage (midline)
    - Degenerates by age 2 years

Temporal Bone (Squamous Portion)

- Intramembranous ossification
  - Ossification begins at 10-11 weeks
- Transient growth center, which forms articular eminence
- Mandibular fossa
  - Develops from protrusion at site of zygomatic arch, which grows anteromedially

Trigeminal Nerve

- Nerve of 1st pharyngeal arch
- Stimulates differentiation of mesenchymal tissue
- Mouth opening begins at 7.5 weeks in utero
  - Trigeminal system must be mature by birth
    - Mouth opening, locating and latching onto nipple, suckling
- Movement contributes to morphogenesis
- Auriculotemporal nerve visible at 12 weeks
- Nerves visible within disc diminish rapidly at 20 weeks

Articular Disc

- Horizontal concentration of mesenchyme (7.5 weeks)
- Typical cartilaginous structure evident at 19-20 weeks
- Compression between temporal bone and condyle influence shape and avascularity of central zone

Lateral Pterygoid (Recognizable at 9-10 Weeks)

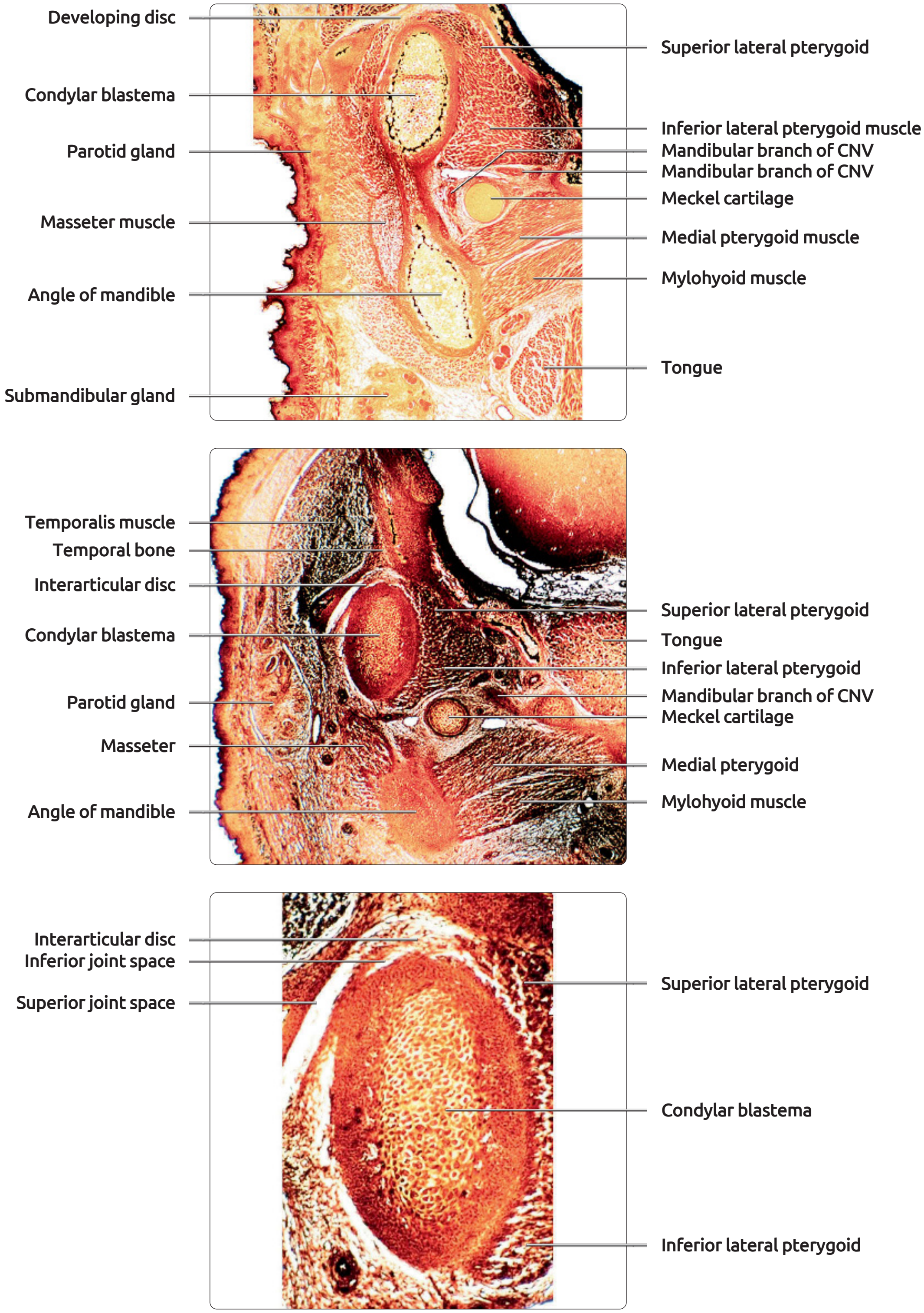
- Superior head inserting on disc, capsule, and condylar neck (pterygoid fovea)
- Inferior head inserting on condylar neck (pterygoid fovea)

CLINICAL IMPLICATIONS

Morphogenesis

- Critical morphogenesis occurs between weeks 7-11
- Direct relationship between structure and function
- Malformation occurs if mandibular movement is inhibited
- Shape of condyle, fossa, and disc influenced by forces in movement

HISTOLOGY OF DEVELOPING TMJ



(Top) *Coronal thin section through the posterior mandible of a developing rat fetus at 17 days is shown. The trigeminal nerve plays an integral role in guiding development of these tissues, along with Meckel cartilage. The trigeminal system must be mature at time of birth. Movement of the temporomandibular joint in humans begins at 7.5 weeks in utero.* **(Middle)** *Coronal thin section through the posterior mandible of a developing rat fetus at 19 days in utero is shown. The developing interarticular disc and temporal bone region are more visible in this cut.* **(Bottom)** *A close-up image of the rat fetus at 19 days of development in utero is shown. This coronal thin section was made through the developing condyle, or condylar blastema. The superior and inferior joint spaces are visible in this section. Also note the blending of superior lateral pterygoid fibers with the condyle and articular disc. Embryologically, the articular disc may be viewed as a specialization of lateral pterygoid muscle cells.*

TERMINOLOGY

Definitions

- Growth
  - Composite change of all components
- Growth activities
  - Localized, regional remodeling, "genic" tissues
  - Displacement movements of separate parts

CRANIOFACIAL GROWING PARTS

Basicranium (Foundation for Face)

- Inferior region of skull
  - Endocranium and lower parts of skull roof
- Bones
  - Ethmoid, sphenoid, occipital, frontal, parietal, and temporal (petrous portion)
- Growth to accommodate enlarged brain
- Spheno-occipital synchondrosis
  - Growth center for basicranium
  - Provides elongation of midline portion of cranial floor through endochondral ossification

Airway

- Functions as keystone of face
  - Stabilizes remaining parts of facial arches
    - Orbit, maxillary, and zygomatic arch forms
    - Sinuses
    - Causes growth process to function normally
    - Activating signals from emerging deviations of development result in morphogenic variation and malocclusion
- Growth proportionate to growing body and lung size

Oral Region

- Growth linked to developmental stages involving CNV and CNVII and associated musculature through
  - Suckling process
  - Dental eruption stages
  - Masticatory development

GROWTH AND DEVELOPMENT

Facial Growth

- Exceeds cranial growth postnatally
- Regulated by genes, tissue interaction, muscle attachments, and mechanical stress
- Klinorhynchy
  - Migration of facial skeleton under brain case
  - Downwardly bent face accommodates upright posture
  - Dental arch form and TMJ followed
  - Led to formation of oropharynx

Maxillary Growth

- Ethmomaxillary complex
  - Downward displacement accompanied by remodeling throughout entire nasomaxillary region
    - Produces space within which enlargement occurs, expanding soft tissue at suture
    - Allows downward displacement as growth occurs in basicranium
- Nasomaxillary complex undergoes remodeling rotation to maintain proper position to vertical reference line and neutral orbital axis

Mandibular Growth

- Endochondral and periosteal (interstitial) activity
  - Functional loading of articular surface along anterosuperior surface of condyle differentiates the mesenchymal cells
    - Fibrocartilage thickens along axis of principle force vector (anterosuperior direction)
    - Endochondral bone replacement of cartilage enlarges condyle along same force vector
- Condylar growth displaces mandible in counterclockwise rotation (CCWR) (viewed from right side)
  - CCWR of mandible projects chin anteriorly and inferiorly
- Ramus resorbs anteriorly with appositional growth posteriorly
- Dimensional growth completed in following order
  - Width
    - Before adolescence
  - Length
    - Continues through puberty
  - Height
    - Continues through puberty
- Sites of growth
  - Posterior ramus
    - Appositional bone growth, lengthening body of mandible
  - Condylar process
    - Hyperplasia and hypertrophy occur simultaneously
    - Endochondral replacement leads to increased height of ramus
      - Vertical dimensions of ramus and body are proportional to condylar growth
  - Coronoid process
    - Influenced by temporalis muscle activity
- Rotation during childhood and adolescence (averages)
  - Internally and forward 15°
  - Externally and backward 11-12°
  - Decrease of 3-4° in mandibular plane angle

Mandibular Condyle Growth and Development

- Condylar cartilage
  - Secondary cartilage (growth site not growth center)
  - Thickness and vascularity decrease with age
  - Functions
    - Major site of growth in craniofacial complex
      - Growth in wide range of directions
      - Highly diverse growth and morphology
    - Articulating function
- Cortical bone
  - Cortical bone at periphery of condyles begins to form in adolescence
  - Compact cortical layer on superior surface established early 3rd decade
  - Adverse loading prior to mature cortication may predispose to bony remodeling, osteoarthritis, osteoarthrosis, or condylar resorption

Glenoid Fossa Growth and Development

- Relatively flat at birth
- Lined by connective tissue at birth
- Becomes less vascular and more collagenous with increasing age
- Usually moves straight downward without anteroposterior displacement of mandible
- Occasionally moves posteriorly, reducing prominence of chin

Articular Eminence Growth and Development

- Thin strip of growth cartilage at slope of eminence converts to fibrocartilage with function
  - Functional differentiation of mesenchymal cells, cell division, and endochondral bone replacement drives eminence growth
- Size and shape of eminence is functionally derived: Response to joint loads
  - Joint loads (magnitude and vector) result from interaction teeth and muscles
  - Slope of eminence tends to form at right angles to principle force vector
  - Shallow slope at birth
  - No function: No eminence
  - ~ 1/2 adult size by age 3: Period of deciduous teeth development
  - Nearly adult size and shape by age of 12 (2nd molar eruption)
  - Remodeling and slight growth occurs through completion of somatic growth
- Bony remodeling during growth
  - Shape optimized for minimization of joint load
  - Proliferative activity in response to functional changes
  - Additions to joint surface can increase face vertical dimension
  - Regressive remodeling can decrease vertical dimension

Cranial Base Growth

- Little affect on growing condylar process
- Negligible displacement of TMJ
- If growth of cranial base is retarded (e.g., craniofacial synostosis syndromes), transverse dimension of mandible can be affect due to decreased lateral space between glenoid fossae

MAXILLOFACIAL SKELETAL MORPHOLOGY

Classifications

- 3 classifications based on anteroposterior jaw relationship
  - **Skeletal class I**, normal relationship
  - **Skeletal class II**, mandible distal of maxilla
    - Protruded maxilla &/or
    - Retruded mandible
  - **Skeletal class III**, mandible anterior to maxilla
    - Retruded maxilla &/or
    - Protruded mandible
- 3 classifications based on vertical jaw relationship
  - Classification scheme: Angle formed by sella-nasion mandibular plane [SN-MP (degrees)]
  - **Medium angle (normal)**
    - SN-MP = 30-37°
  - **Low angle (short face)**
    - SN-MP ≤ 28°
    - Brachyfacial pattern
    - Skeletal deep bite
    - Hypodivergent
    - Anterosuperior growth of condyle
    - Absorption of inferior gonial border
    - Anterior displacement of mandible
  - **High angle (long face)**
    - SN-MP ≥ 39°
    - Dolichofacial pattern
    - Skeletal open bite
    - Hyperdivergent: Steep mandibular plane
    - Obtuse gonial angle
    - Posterosuperior growth of condyle
    - Inferoposterior displacement of mandible
    - Anterior region of mandible has large vertical dimension and thin AP dimension
    - Higher probability of degenerative or inflammatory disorders

Effect of Condylar Growth on Maxillofacial Skeletal Growth and Development

- No key anatomic part can be segregated or altered without affecting balance of other parts and their state of physiologic equilibrium
- Disturbance of condylar growth influences maxillofacial morphology
  - **Bilateral**
    - Mandible rotates posteroinferiorly
      - Results in anterior open occlusal relationship
      - Can influence airway dimensions
      - Can influence jaw shape
      - Reduces vertical dimensions of ascending rami and body of mandible
      - Increases vertical dimension of anterior region of mandible and reduces thickness of alveolar bone
  - **Unilateral**
    - Mandible displaces to affected side
      - Results in horizontal inverse occlusal relationship
      - Occlusal plane elevated on isilateral side
      - Vertical dimensions of ipsilateral condylar process, ascending ramus and body of mandible are reduced
      - Results in facial asymmetry
- Maximum opening increases from childhood to adulthood

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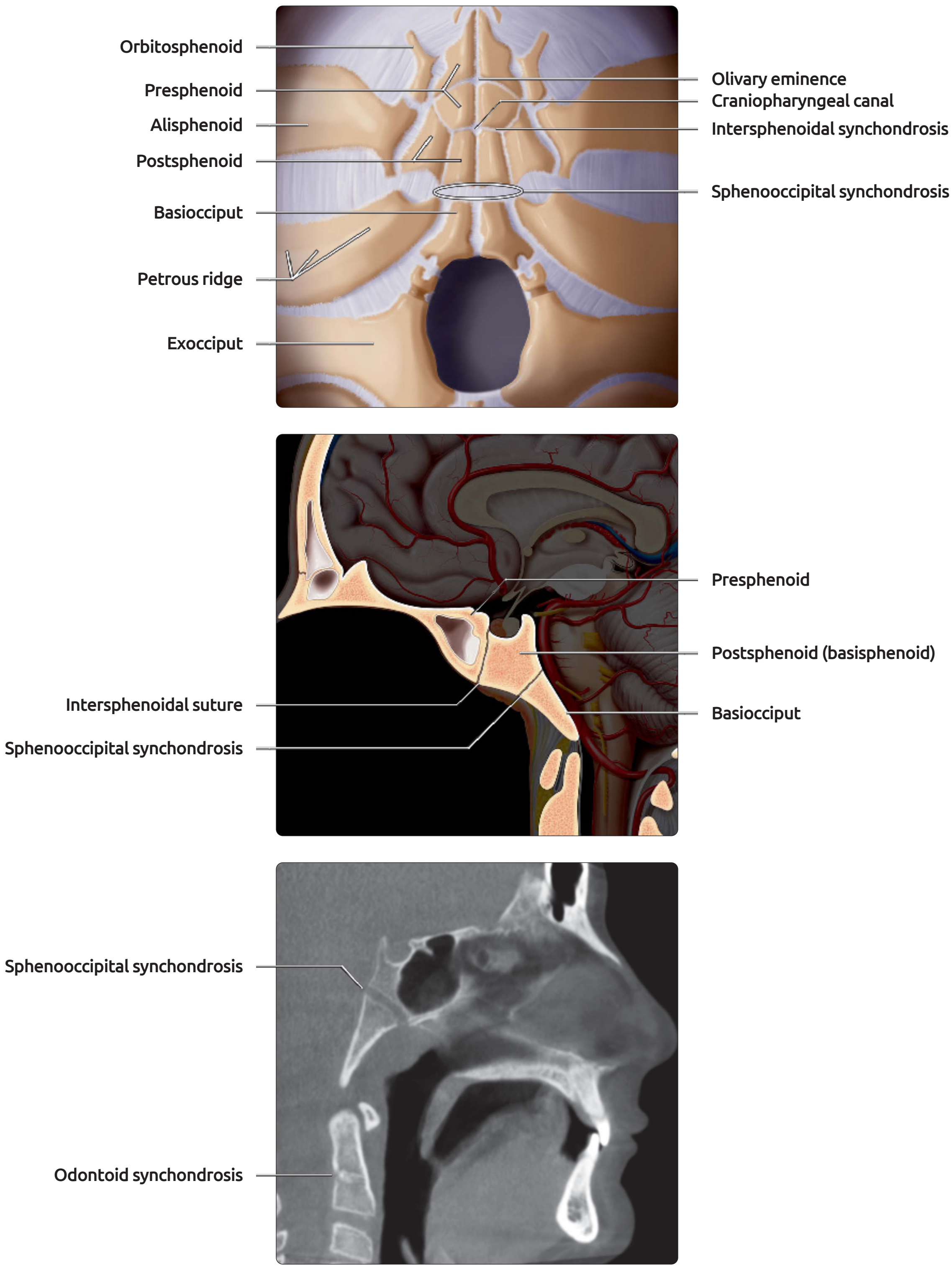
DEVELOPMENT OF CENTRAL SKULL BASE



(Top) *Schematic of central skull base (CSB) from above shows its many ossification centers. Between ossification centers of presphenoid is a cartilaginous gap called the olivary eminence, obliterated shortly after birth. A persistent cleft, called the craniopharyngeal canal, can also variably be seen in intersphenoid synchondrosis. These variants should not be confused with pathology.* **(Middle)** *Lateral graphic of CSB shows major ossification centers and location of sutures. Intersphenoidal suture closes at around 3 months of age. At ~ age 2, the presphenoid begins to demineralize and become pneumatized. Pneumatization progresses posteriorly into postsphenoid until about age 5-7. Sphenooccipital synchondrosis is one of the last sutures to fuse at ~ age 16. It is the suture most responsible for growth of skull base.* **(Bottom)** *Midsagittal CBCT of 10-year-old girl shows the unfused sphenooccipital suture (synchondrosis). C2 vertebra also shows the odontoid synchondrosis between the odontoid process and the body of the C2 vertebra.*