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Imaging Findings of the Developing Temporal Bone in Fetal Specimens

William R. Nemzek, Hilary A. Brodie, Brian W. Chong, Catherine J. Babcook, Stephen T. Hecht, Shariar Salamat, William G. Ellis, and J. Anthony Seibert

PURPOSE: To trace the development of the normal fetal temporal bone by means of plain radiography, MR, and CT. **METHODS:** Eighteen formalin-fixed fetal specimens, 13.5 to 24.4 weeks' gestational age, were examined with a mammographic plain film technique, CT, and MR imaging at 1.5 T. Temporal bone development and ossification were assessed. **RESULTS:** The membranous labyrinth grows with amazing rapidity and attains adult size by the middle of the gestation period. The cochlea, vestibule, and semicircular canals are very prominent and easily recognized on MR images. The otic capsule develops from a cartilage model. Ossification of the otic capsule proceeds rapidly between 18 and 24 weeks from multiple ossification centers that replace the cartilaginous framework. The mastoid, internal auditory canal, vestibular aqueduct, and external auditory canal continue to grow after birth. **CONCLUSION:** The study of fetal developmental anatomy may lead to a better understanding of congenital disorders of the ear. Faster MR scanning techniques may provide a method for in utero evaluation of the fetal temporal bone.

Index terms: Fetus, growth and development; Temporal bone, anatomy

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The human ear evolved from simple beginnings. In a primitive aquatic animal, such as the shark, the auditory pit is an open cavity retaining connection with the surface ectoderm. The otocyst is in free communication with ambient sea water, which bathes the endolymphatic chambers (1, 2). In the human embryo, ectodermal continuity is lost and the fluid of the inner ear becomes encased in the form of endolymph in the dense bone of the otic capsule. At birth, the endolymph is placed in communication with air through the ossicles and the tympanic membrane (1).

The purpose of this study was to trace radiologically the development of the normal human temporal bone in fetuses.

Materials and Methods

Eighteen formalin-fixed fetal specimens from the Carnegie Embryological Collection of normal fetuses at the University of California, Davis, were examined with plain film radiography, computed tomography (CT), or magnetic resonance (MR) imaging (12 fetuses were examined with plain radiography, 15 with CT, and 18 with MR imaging). The Carnegie Embryological Collection was established by Franklin P. Mall in 1914. Dr Mall's successor, George L. Streeter, classified human embryos into stages. The Carnegie Collection is the cornerstone for the study and understanding of early human development, and has been called the "Bureau of Standards" for primate embryology (3). We determined gestational age on the basis of an average of the measurement of the biparietal diameter, the crown-rump length, and the femoral length. The 18 fetuses ranged in age from 13.5 to 24.4 gestational weeks. One fetal specimen was dissected to correlate anatomic relationships. Radiographs were made using a GE (Milwaukee, Wis) mammographic unit with magnification film screen technique. A GE 9800 CT unit was used to scan the specimens in 1-mm-thick sections. A GE Signa 1.5-T clinical MR imager was used. Three-dimensional spoiled gradient-echo sequences were obtained with parameters

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TABLE 1: Measurement of basal turn of the cochlea and lateral semicircular canal in fetuses and adults

Fetuses				Adults			
	Age, wk	Basal Turn, mm	Lateral Semicircular Canal, mm		Age, y	Basal Turn, mm	Lateral Semicircular Canal, mm
1.	13.5	4.8	. . .	1.	18	8.5	5.0
2.	14.2	5.0	. . .	2.	24	9.0	5.5
3.	14.4	7.5	. . .	3.	30	8.5	5.5
4.	15	6.5	. . .	4.	42	9.0	5.0
5.	15.5	4.8	. . .	5.	42	8.5	6.5
6.	16.2	8.5	. . .	6.	46	8.5	5.5
7.	17.4	9.0	4.3	7.	70	9.0	5.3
8.	18.4	8.5	. . .	8.	76	9.5	5.5
9.	18.5	8.5	. . .				
10.	19.3	8.5	4.3				
11.	19.5	9.0	5.0				
12.	19.5	9.5	. . .				
13.	20.5	8.5	5.0				
14.	21	8.3	5.0				
15.	21.4	8.5	5.5				
16.	22.3	8.5	4.8				
17.	23.3	8.5	5.0				
18.	24.4	9.0	5.3				

of 40/8/4 (repetition time/echo time/excitations) and a flip angle of 45°, an imaging matrix of 512 × 256, and a contiguous section thickness of 0.7 mm. Spin-echo T1-weighted sequences were obtained with parameters of 500/90/3, a matrix of 512 × 384, and 3.0-mm-thick sections with a 0.5-mm section gap. Fast spin-echo T2-weighted sequences were obtained with parameters of 4000–5000/90–96/3–4, an echo train length of 12, a matrix of 512 × 384, and 3.0-mm-thick sections with a 0.5-mm section gap.

The length of the basal turn of the cochlea and the diameter of the lateral semicircular canal were measured on CT scans and MR images obtained of the fetal specimens and of eight adult subjects who were referred with nonotologic disorders. The length of the basal turn of the cochlea was considered to be the longest diameter that could be obtained through the first turn of the cochlea.

Results

The average length of the basal turn of the adult cochlea was 8.8 mm and the average maximum diameter of the adult lateral semicircular canal was 5.5 mm. The measurements of the fetal specimens and normal adults are given in Table 1. The horizontal semicircular canals were not measured in all fetuses, because this structure could not be defined in all specimens. Note that the otic capsules of the fetus have achieved adult dimensions at approximately 21 weeks' gestational age.

The fast spin-echo T2-weighted sequences produced the best quality images, successfully differentiating bright signal intensity of endolymph and perilymph from the intermediate signal of unossified cartilage and the low signal of bone. In one adult, a fast spin-echo T2-weighted image (Fig 1A) showed high signal

Abbreviations for Figures 1 through 12

C	cochlea
CA	cochlear aqueduct
CC	common crus
ELD	endolymphatic duct
ELS	endolymphatic sac
L	labyrinthine segment of facial nerve canal
LSCC	lateral semicircular canal
PSCC	posterior semicircular canal
SIG	sigmoid sinus
SSCC	superior semicircular canal
SS	subarcuate space
TR	tympanic ring
V	vestibule
VA	vestibular aqueduct
i	incus
iac	internal auditory canal
is	interscalar septum
m	malleus
mo	modiolus
pp	pyramidal process
st	stapes

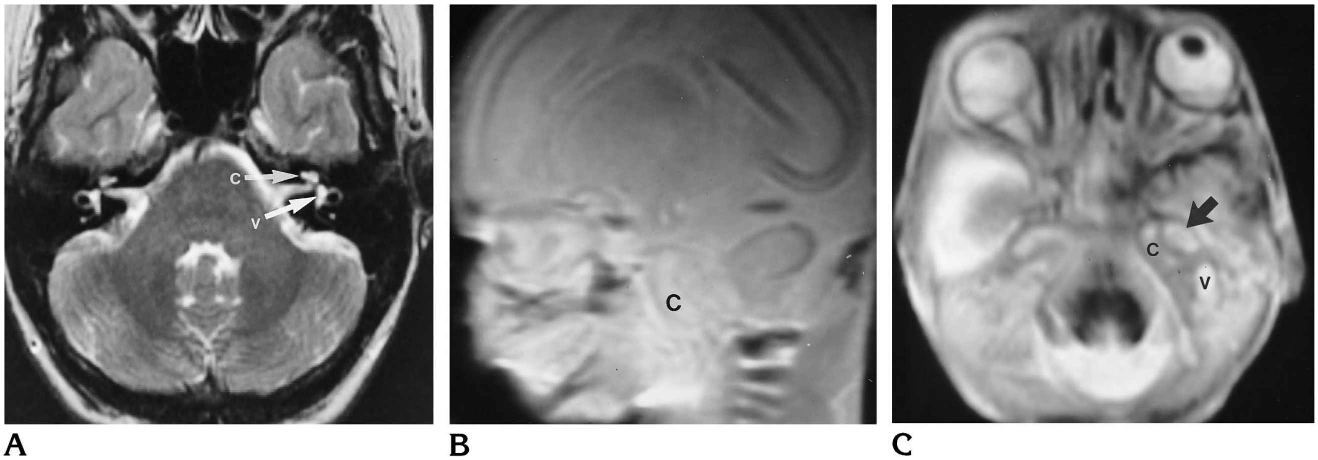


Fig 1. Comparison of adult and early fetal otic capsule structures on T2-weighted fast spin-echo MR images.

A, In the adult, there is high signal intensity of endolymph and perilymph in membranous cochlea, and vestibule and semicircular canals are surrounded by signal void of dense bony otic capsule.

B, Sagittal image of fetus, gestational age 14 weeks 4 days. Basal turn of cochlea is the first structure that can be readily identified.

C, Fetus, gestational age 15 weeks 5 days. Fluid is seen in cochlea and vestibule. Basal turn of cochlea is two thirds of adult size. The upper turns of the membranous cochlea are now visible (*arrow*) as a single space. Note unossified cartilage is of intermediate signal intensity.

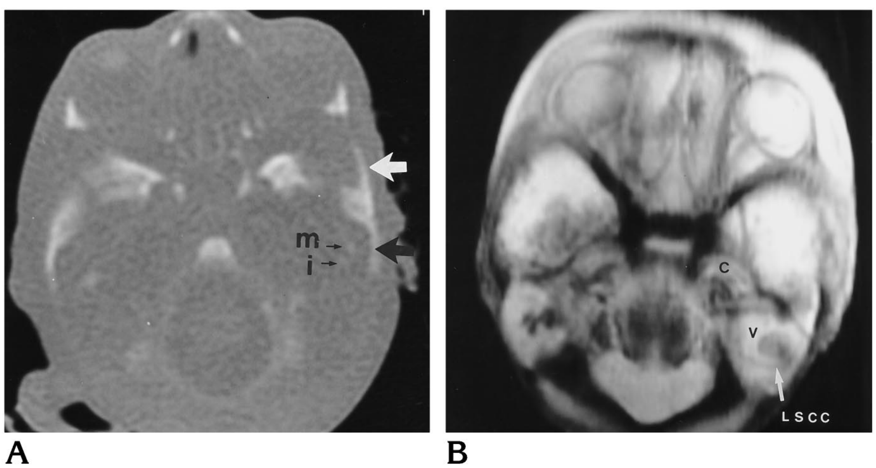


Fig 2. Fetus, gestational age 17 weeks 4 days.

A, CT scan shows ossification in squamous portion (*black arrow*) and zygomatic process of the temporal bone (*white arrow*). Note very early ossification of the malleus and incus.

B, T2-weighted fast spin-echo MR image shows vestibule and lateral semicircular canal before ossification.

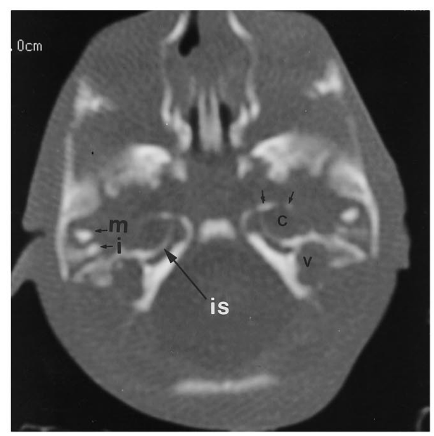


Fig 3. CT scan of fetus, gestational age 18 weeks 4 days, shows earliest ossification of otic capsule. Note discontinuous calcification around the apical turn of the cochlea (*small arrows*). Note interscalar septum and progressive ossification of ossicles.

intensity of fluid in the tiny membranous labyrinth surrounded by the signal void of the heavily ossified petrous pyramid and the dense bone of the otic capsule.

The basal turn of the cochlea was the first structure that was seen consistently in our material, and is easily identified on T2-weighted MR images. It was well seen in a fetus of 14 weeks 4 days' gestational age (Fig 1B). A fast spin-echo T2-weighted axial MR image of a fetus of 15 weeks 5 days shows fluid in the cochlea and vestibule (Fig 1C). These structures are nearly two thirds of adult size. Because ossification had not yet occurred, the otic capsule is depicted as a structure of intermediate signal intensity relative to cartilage. Note the large size of the otic capsule as compared with the remainder of the fetal skull.

A CT scan of a fetus of 17 weeks 4 days (Fig 2A) reveals ossification in the squamous and

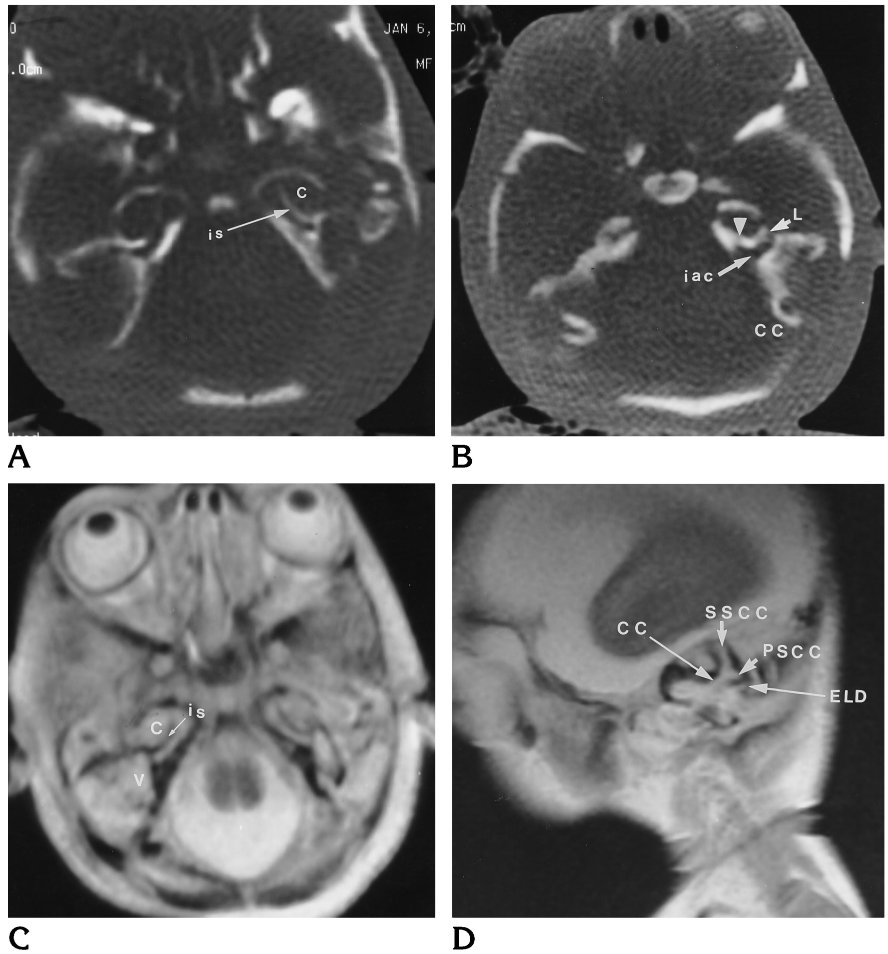


Fig 4. Fetus, gestational age 19 weeks 3 days.

A, CT scan shows that cochlea and vestibule are reaching full adult size. There is now a continuous shell of bone surrounding the cochlea.

B, CT scan shows short internal auditory canal. The canal for the cochlear nerve (*arrowhead*) passes directly anteriorly. The labyrinthine segment of the facial nerve canal is present. The common crus is partially encircled by bone.

T2-weighted fast spin-echo axial (*C*) and sagittal (*D*) MR images show ossification in cochlea and vestibule as decreased signal intensity. Endolymphatic duct is parallel to common crus.

zygomatic processes of the temporal bone. Note minimal ossification in the malleus and incus. The corresponding fast spin-echo T2-weighted MR image (Fig 2B) shows the cochlea, vestibule, and lateral semicircular canal, which are not yet ossified.

The earliest ossification of the otic capsule in this series is seen in a fetus of 18 weeks 4 days' gestational age (Fig 3). Discontinuous segments of calcification surround the apical turn of the cochlea. The layer of ossification is thickest at the basal turn and is beginning to surround the vestibule. The semicircular canals were not seen on CT scans. Ossification of the ossicles was also proceeding. The interscalar septum is identified; this is the spiral bony partition between the turns of the cochlea, extending from the otic capsule, which serves to anchor the modiolus.

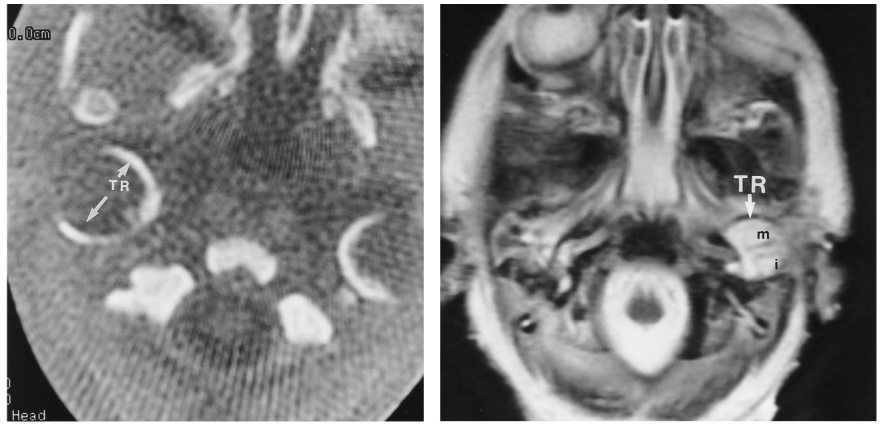
At 19 weeks 3 days, the vestibule and cochlea have nearly grown to adult size and the ossification of the cochlea is seen as a more continuous shell of peripheral calcification on CT scans (Fig 4A). The otic capsule is seen as a structure of low signal intensity on the fast spin-echo T2-weighted MR image (Fig 4C). Also note ossification of the malleus and incus on both the CT and MR studies. In Figure 4B there is a short internal auditory canal, and an opening for the cochlear nerve is coursing directly anteriorly. The common crus is surrounded by a partial ring of ossification. The lateral semicircular canal is not yet visible by CT. The labyrinthine segment of the facial nerve canal is well developed. The endolymphatic duct can be seen at the level of the common crus (Fig 4D).

A fetus of 18 weeks 5 days (Fig 5) shows more advanced ossification of the otic capsule despite a younger gestational age.

At 20 weeks 5 days (Fig 6) the tympanic ring is identified on both CT and MR studies.

At 21 weeks 4 days (Fig 7) the cochlea and lateral semicircular canal have reached adult size. There is further ossification of the otic capsule. The interscalar septum is denser. There is

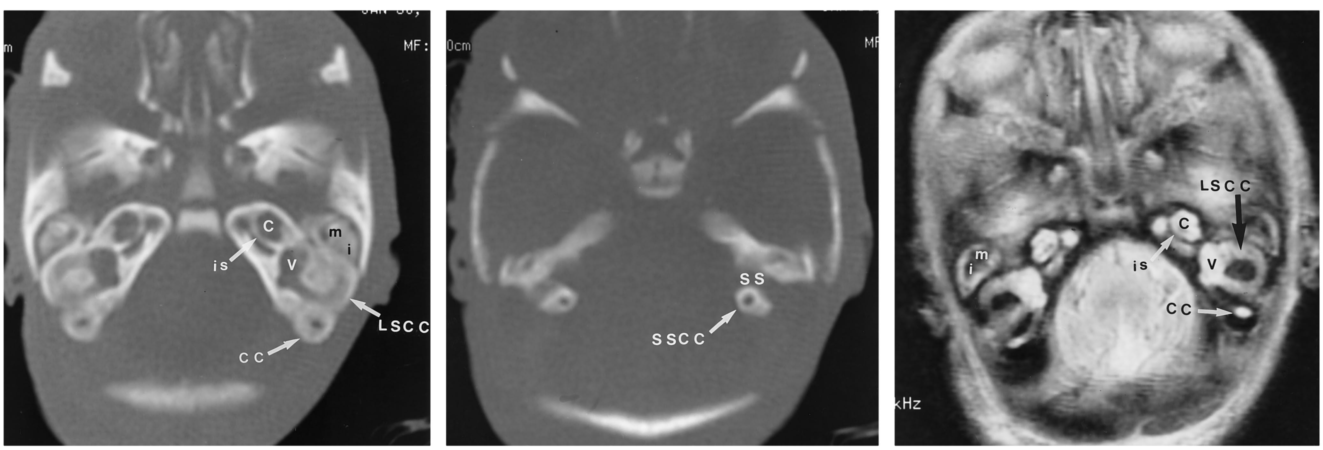
Fig 5. Fetus, gestational age 18 weeks 5 days. CT scan shows progressive ossification with thicker layer of bone surrounding cochlea and vestibule. Note canal for the cochlear nerve (*arrowhead*) is directed anteriorly.



A B

Fig 6. Fetus, gestational age 20 weeks 5 days.

CT scan (*A*) and T2-weighted fast spin-echo MR image (*B*) show tympanic ring as horizontal structure with adjacent ossicles.



A B C

Fig 7. Fetus, gestational age 21 weeks 4 days.

CT scans (*A* and *B*) and T2-weighted fast spin-echo MR image (*C*) show otic capsule structures are of adult dimensions. Bone surrounds the lateral semicircular canal and the common crus. Ossicles are visible by both CT and MR imaging. There is a large subarcuate space. Note all turns of the cochlea are visible on the MR image (*C*).

now bone forming a complete ring around the common crus. Bone encloses the lateral semicircular canal. The malleus and incus are clearly visible on both CT and MR studies. Note the relatively large unossified subarcuate space. The subarcuate space or fossa is capacious in the fetus and neonate, extending through the superior semicircular canal. The subarcuate space opens on the posterior surface of the petrous temporal bone above the internal auditory canal. It is the path of invasion by vascular connective tissue from the meninges that permits the canalicular cartilage of the otic capsule to become spongy and allows expansion of the arcs of the semicircular canals (1). In the adult it may persist as a tiny channel and transmit branches of the internal auditory artery and vein or a subarcuate artery arising from the cerebellar arteries (1).

On a plain radiograph of the skull of a fetus at 22 weeks 3 days (Fig 8), the superior semicircular canals appear to float because of the large subarcuate space. The tympanic ring is identified as a horizontal structure.

At 23 weeks 3 days (Fig 9A), a plain radiograph of the skull shows the tympanic ring to be

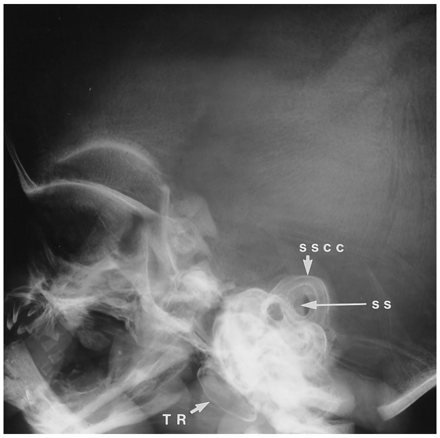


Fig 8. Fetus, gestational age 22 weeks 3 days. Lateral plain radiograph of the skull shows a large subarcuate space beneath the superior semicircular canal. The tympanic ring is an ossified horizontal structure that is separated from the squamous temporal bone.

horizontal on the anteroposterior projection (Fig 9B). The anterior aspect of the tympanic ring is seen on CT scans. The cochlear aqueduct and vestibular aqueduct are identified. The malleus and incus are seen, and the stapes (Fig 9C) is noted in the region of the oval window. The subarcuate space remains prominent (Fig 9D).

At 24 weeks 4 days (Fig 10), the subarcuate space is decreasing in size owing to progressive ossification. The otic capsule and modiolus are more dense. The ossicles are of adult size and are ossified. The internal auditory canal is diminutive relative to the structures of the otic capsule. The labyrinthine segment of the facial nerve canal is quite distinct and well developed. On MR images the endolymphatic duct and the endolymphatic sac and vestibular aqueduct are seen. Also visible are the pyramidal process, the facial nerve recess, and the sinus tympani on the posterior wall of the tympanic cavity.

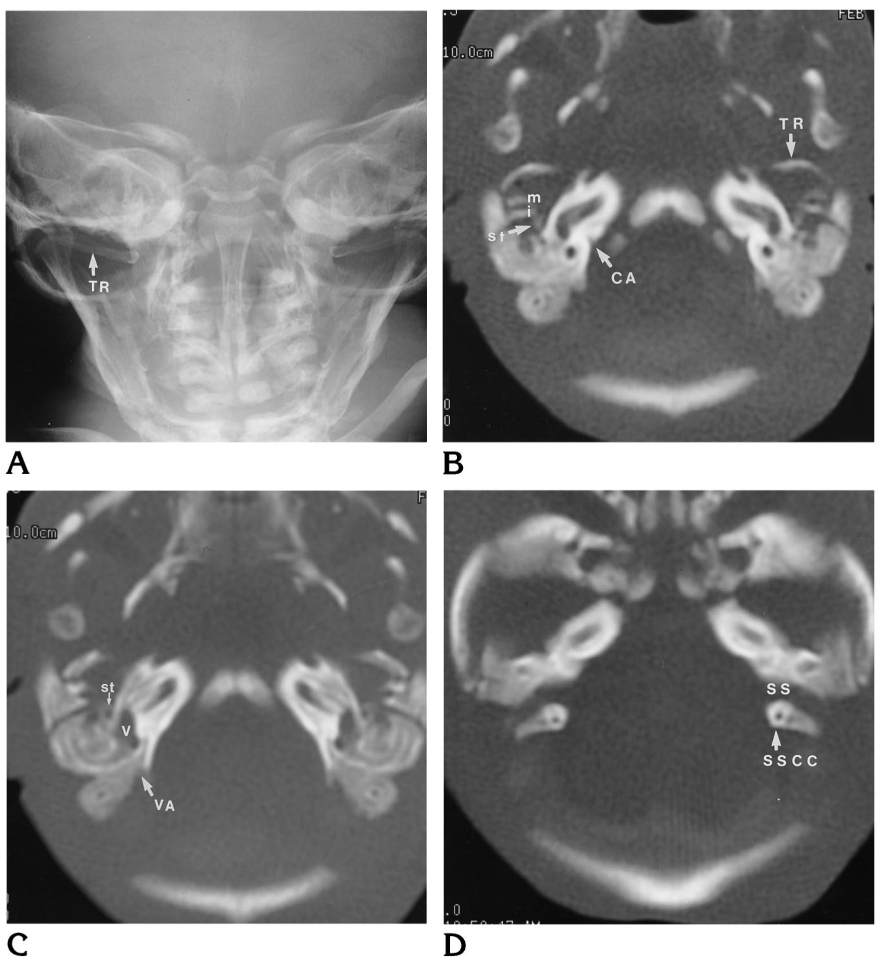


Fig 9. Fetus, gestational age 23 weeks 3 days.

A, Anteroposterior plain radiograph of the skull shows the horizontal tympanic ring is isolated from the rest of the temporal bone.

B–D, On CT scans, note the tympanic ring and vestibular and cochlear aqueducts. The stapes is now identified in the oval window. There is a large subarcuate space.

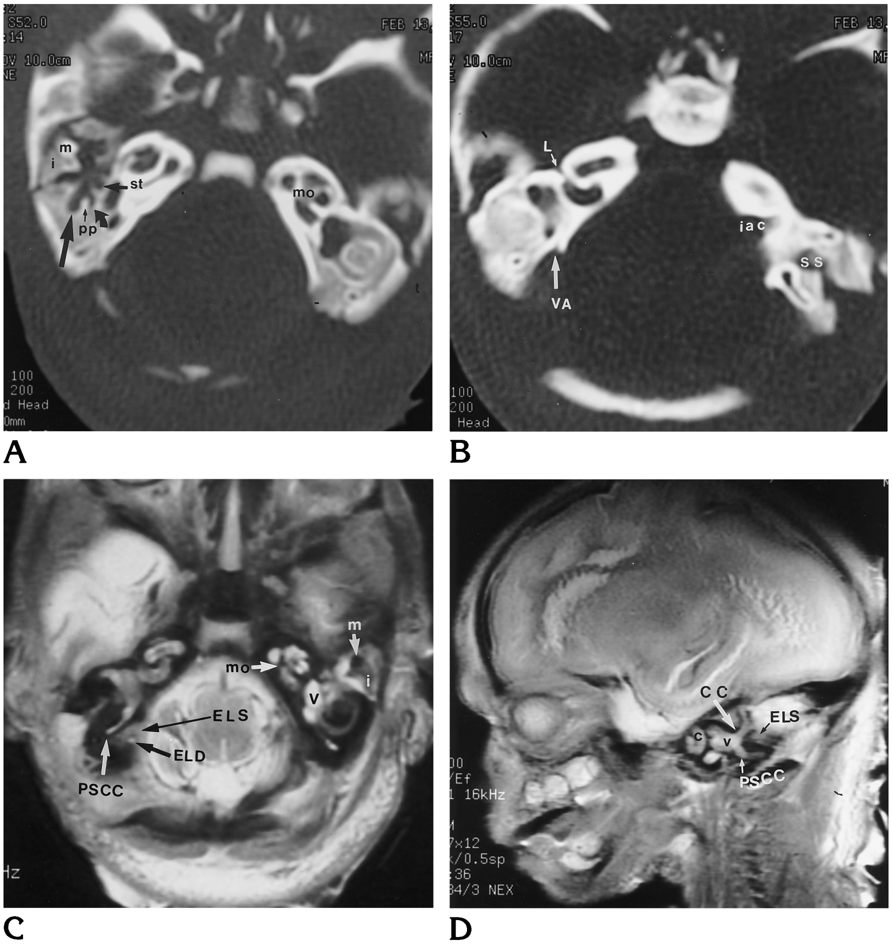


Fig 10. Fetus, gestational age 24 weeks 4 days.

A and *B*, CT scans show a thickening of bone surrounding the otic capsule and greater definition of the modiolus. The labyrinthine segment of the facial canal is better defined. The internal auditory canal remains short. Note the pyramidal process, the facial nerve recess (*straight arrow*), and the sinus tympani (*curved arrow*) on posterior wall of tympanic cavity.

On T2-weighted fast spin-echo axial (*C*) and sagittal (*D*) MR images, the endolymphatic duct and vestibular aqueduct and all the turns of the cochlea are identified.

Discussion

The developing fetal temporal bone has been extensively studied via dissection and histologic examination (1, 2, 4). The nondestructive imaging evaluation of preserved fetal specimens is an intriguing complement to previous work. The fetal skull has been imaged with low-resolution CT (5).

The inner ear structures, or membranous labyrinth, arise from the otic placode, which is a thickening of the surface ectoderm of the embryonic head (2, 6, 7). The membranous labyrinth includes the cochlea, vestibule, semicircular canals, and the endolymphatic duct and sac. Development of the inner ear begins at 21 to 24 days' gestation. The margins of the placode invaginate and appose to form a simple cavity called the *otocyst*. The otocyst sinks below the surface and loses continuity with the overlying ectoderm (6, 7). At 5 to 6 weeks, a diverticulum buds from the otocyst forming the endolymphatic sac, followed by the buds for the cochlea and vestibule. At 7 to 8 gestational weeks, formation of the membranous semicircular canals begins. The superior canal develops first, followed by the posterior and finally the lateral semicircular canal (1, 2, 4). At 8 weeks, the membranous cochlea has achieved one to one and one-half turns. At 10 weeks, two turns have formed (1). By 11 weeks, the full adult configuration of two and one-half to two and three-quarters turns are completed (4) (Table 2).

The otocyst induces the surrounding mesenchyme to form cartilage that conforms to the shape of the membranous labyrinth, which it "finds." This cartilage model will form the bony otic capsule (4, 7). The bony capsule surrounding the membranous labyrinth develops in the same way as a long bone, predominantly by enchondral bone formation. Membranous bone formation occurs in some phases of ossification or remodeling in the modiolus, in the osseous spiral laminae, in the tympanic wall of the lat-

TABLE 2: Milestones in temporal bone development and corresponding imaging findings

Gestational Age, wk	Developmental Milestone	Imaging Finding
3	Otic placode	. . .
4	Otocyst	. . .
5–6	Budding of diverticular for membranous labyrinth (first the endolymphatic sac then cochlea and vestibule)	. . .
8	Cochlea, one to one and one-half turns; formation of semicircular canals begins (first the superior, then the posterior, and then the lateral); otic capsule cartilagenous model	. . .
10	Cochlea, two turns	. . .
11	Cochlea, two to two and three-quarters turns; tympanic ring semicircle of bone	. . .
14	. . .	Basal turn of cochlea is first seen on MR
15	Ossicles reach adult size (ossification begins in incus, then malleus, and finally stapes)	MR shows basal and upper turns of cochlea and vestibule
16	Otic membranous labyrinth nearing adult size; ossification begins in cochlea	CT shows squamous and zygomatic process with minimal ossification of malleus and incus
17	. . .	CT shows tympanic ring; MR shows cochlea, vestibule, and lateral semicircular canal
18	. . .	CT shows cochlea, vestibule, and interscalar septum; posterior and lateral semicircular canals are partially ossified; short internal auditory canal is present with well-developed labyrinthine facial nerve canal
19	Tympanic ring forms nine tenths of a circle	CT shows confluent ossification of cochlea and vestibule; MR shows common crus and endolymphatic duct
20	Ossicles are of adult configuration; superior semicircular canal is full size; endolymphatic sac is small, parallel to common crus	CT shows well-ossified tympanic ring and incus; MR shows tympanic ring
21	Cochlea and posterior semicircular canal are full size; modiolus ossification begins	Plain radiography shows large subarcuate space; CT shows common crus completely surrounded by bone; lateral semicircular canal is well seen
22	Lateral semicircular canal is full size	. . .
23	. . .	CT shows cochlear and vestibular aqueduct
24	. . .	CT shows well-developed middle ear, including facial recess, pyramidal eminence, modiolus, and vestibular aqueduct

At birth: Tympanic bone is a flat ring that will form bony external auditory canal. External auditory canal continues growth till age 10. The endolymphatic duct, endolymphatic sac, and vestibular aqueduct are small at birth and continue to grow till age 3. The mastoid is beginning pneumatization; it will be well developed at 3 years. The styloid process develops after birth.

eral semicircular canal, and in the external ostium of the vestibular aqueduct (1). Unlike a long bone, such as the femur, which will continue to grow into the late teens, the otic capsule and ossicles grow with amazing rapidity to reach adult size by about 21 weeks' gestation (1). Ossification proceeds rapidly between 16 and 22 weeks. Cartilage is not changed to bone until each particular segment of the membranous inner ear has reached its adult size (1, 8).

The inner or endosteal layer of bone surrounding the otic capsule does not change throughout life after initial ossification at midgestation (Fig 11). This inner layer of bone completely encircles the labyrinth except in the region just anterior to the oval window. Here, at the fissula ante fenestram, cartilage may persist in the adult temporal bone. This is a site of predilection for otosclerosis (1, 9, 10). New bone may be produced in the inner layer of bone in re-

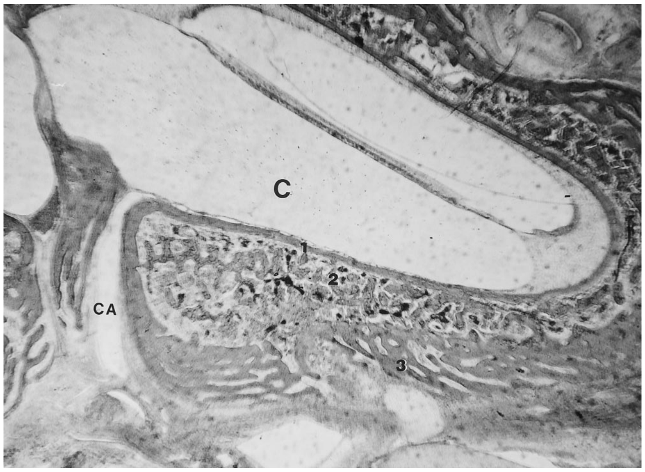


Fig 11. Fetus, gestational age 26 weeks. Histologic section shows the cochlear aqueduct at the basilar turn of the cochlea. There are three layers of bone: a thin layer of endosteal bone surrounding the cochlea (*1*), a middle layer of intrachondrial bone (*2*), and an outer layer of periosteal bone (*3*). (Photograph courtesy of Fred Linthicum, MD, House Ear Institute, Los Angeles, Calif.)

sponse to infection or trauma, which will obliterate the lumen of the labyrinth (1).

Growth of the phylogenetically older vestibular portion of the membranous labyrinth occurs before that of the canalicular portion (11). Ossification occurs later in the canalicular division of the otic capsule (1), as is noted in our study. The lateral semicircular canal is the most commonly malformed structure of the inner ear, perhaps because it is the last to develop (6). Isolated defects of the lateral semicircular canal are common, but if the superior semicircular canal is maldeveloped, then the posterior and the lateral semicircular canals are also abnormal (6). Again, cartilage is not changed into bone until the inner ear structure has reached maximum adult dimensions (1, 4, 8). Ossification begins in the region of the superior semicircular canal, followed by the posterior and then the lateral semicircular canals (4).

In our study, the T2-weighted MR images showed high signal intensity of fluid in the membranous labyrinth, which, at 14 weeks, was the first recognizable fetal temporal bone structure. Ossification was later identified by CT, first in the squamous portion of the temporal bone and later in the otic capsule. Ossification may proceed more rapidly in some fetuses (Figs 4 and 5), but the pattern follows a well-defined sequence (12).

The ossicles develop from the cartilage of the first and second branchial arches (Meckel and Reichert cartilage) (1, 7). Between 15 and 20 weeks, the ossicles attain adult size and configuration. Ossification proceeds by enchondral bone formation. Ossification begins first in the incus, followed by the malleus and stapes (2, 8). Ossicular bone, like that of the otic capsule, changes little during life and also demonstrates poor capacity for repair (2).

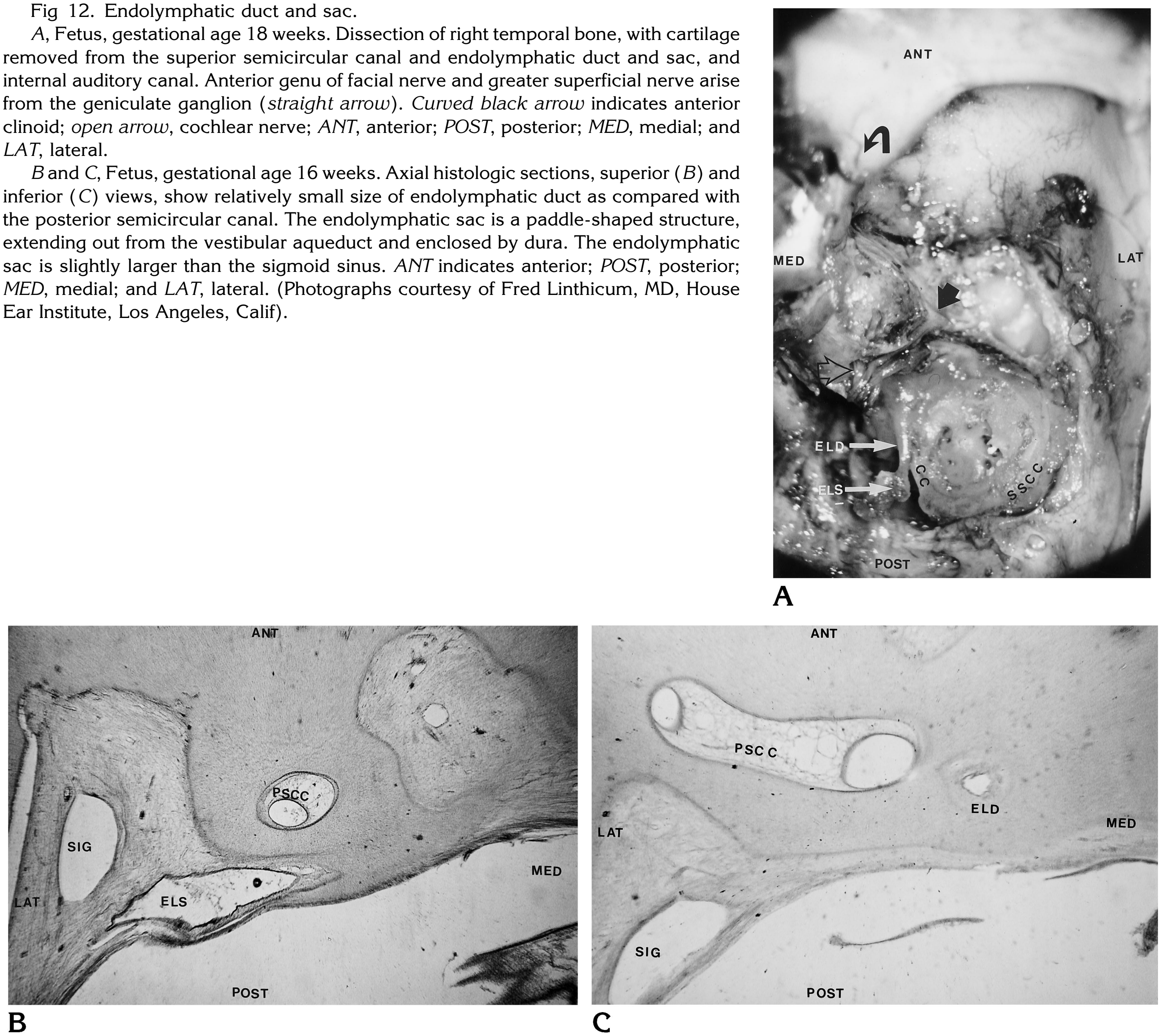
The tympanic ring is a semicircular structure formed from membranous bone (1). Ossification begins as two parallel plates oriented in a horizontal position (13). The ring will eventually close and join inferiorly, but the superior portion remains open, like an annulet. The tympanic ring has two functions: it provides the scaffolding for the attachment of the tympanic membrane and it forms the bony and cartilaginous external auditory canal. The tympanic ring remains horizontally oriented at birth, which accounts for the near horizontal position of the tympanic membrane in the neonate. The tympanic membrane continues to grow until about 3 years of age and gradually assumes the more vertical orientation seen in the adult. The definitive form of the external auditory canal is present at 1 year of age, but adult size is not attained until 10 years (13).

Even though the ossicles and labyrinth are full size in midgestation, the internal auditory canal is relatively short, and the vestibular aqueduct is small. MR imaging showed the endolymphatic duct in two of our specimens. The vestibular aqueduct and endolymphatic sac were seen posterior to the vestibule (Figs 9C and 10C). Note that the endolymphatic duct is a relatively small structure and the endolymphatic sac is a paddle-shaped structure lying almost parallel to the common crus in a dissected fetus of 18 weeks (Fig 12A). The endolymphatic duct is diminutive, but the endolymphatic sac is almost the same size as the sigmoid sinus in a fetus of 15 weeks' gestation (Fig 12B and C). During the latter half of fetal life, the endolymphatic duct continues to grow, and it changes from a straight to an inferior course bending downward at a 30° to 60° angle (1). The endolymphatic sac also continues to enlarge. The vestibular aqueduct and internal auditory canal continue to grow after birth. By 3 years of age the vestibular aqueduct has reached adult size (7, 14–16). The vestibular aqueduct and internal auditory canal grow synchronously in parallel with the periaqueductal air cells (14).

Fig 12. Endolymphatic duct and sac.

A, Fetus, gestational age 18 weeks. Dissection of right temporal bone, with cartilage removed from the superior semicircular canal and endolymphatic duct and sac, and internal auditory canal. Anterior genu of facial nerve and greater superficial nerve arise from the geniculate ganglion (*straight arrow*). *Curved black arrow* indicates anterior clinoid; *open arrow*, cochlear nerve; *ANT*, anterior; *POST*, posterior; *MED*, medial; and *LAT*, lateral.

B and *C*, Fetus, gestational age 16 weeks. Axial histologic sections, superior (*B*) and inferior (*C*) views, show relatively small size of endolymphatic duct as compared with the posterior semicircular canal. The endolymphatic sac is a paddle-shaped structure, extending out from the vestibular aqueduct and enclosed by dura. The endolymphatic sac is slightly larger than the sigmoid sinus. *ANT* indicates anterior; *POST*, posterior; *MED*, medial; and *LAT*, lateral. (Photographs courtesy of Fred Linthicum, MD, House Ear Institute, Los Angeles, Calif).



The tympanic cavity develops from the endoderm of tubotympanic recess of the first pharyngeal pouch. The tympanic cavity reaches adult size by 37 weeks' gestation (7). Expansion of the tympanic cavity is responsible for the formation of air cells in the mastoid and petrous temporal bone. The mastoid does not begin development until late in fetal life, and therefore was not observed in our specimens. Significant mastoid air cell formation occurs postnatally (1, 7). By 3 years of age, mastoid growth and pneumatization are well developed (15).

A knowledge of developmental anatomy may provide the key to understanding abnormalities in the completed structure (7). Congenital anomalies of the otic capsule may be due to an arrest of normal membranous labyrinth development. For instance, if development of the membranous labyrinth is interrupted before the cochlea has achieved a complete two and three-quarters turns, a Mondini malformation may result (6).

In utero studies of brain maturation have been performed with conventional spin-echo MR imaging (17, 18). With the evolution of faster and more sensitive MR technology, such as echo-planar imaging, in utero studies of fetuses will become more common, expanding the potential for prenatal diagnosis of fetal abnormalities.

Conclusion

This work details fetal development of the temporal bone with the use of high-resolution CT, MR imaging, and plain radiography. We have shown that the otic capsule and ossicles develop by enchondral bone formation through an intermediate cartilage model. By the middle of gestation these structures have reached adult size. Ossification begins in the cochlea, followed by the semicircular canals. Apposition of a shell of ossification proceeds rapidly between 18 and 24 weeks' gestation. There is very little subsequent remodeling after birth. The internal auditory canal, vestibular aqueduct, mastoid, and external auditory canal continue to grow after birth.

The study of fetal developmental anatomy may lead to a better understanding of congenital ear disorders.

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