POSTNATAL DEVELOPMENT OF THE INTERNAL AUDITORY CANAL STUDIED BY COMPUTER-AIDED THREE-DIMENSIONAL RECONSTRUCTION AND MEASUREMENT

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Postnatal development of the internal auditory canal (IAC) was investigated in 20 normal human temporal bones obtained from individuals 1 month to 72 years old. Computer-aided three-dimensional reconstruction and measurement of bones showed that the superior, inferior, anterior, and posterior walls of the IAC lengthen significantly from birth until about 10 years of age, with development mainly attributable to lengthening of the part of the IAC medial to the foramen singulare. The lengths of the part of the IAC lateral to the foramen singulare and of the transverse crest and Bill's bar did not appear to develop postnatally. The IAC diameter increased slightly at the porus for about the first year after birth, but not at the fundus or the middle portion of the canal. This finding was confirmed by studying the shape of the IAC. Postnatal increases in the volume of the IAC followed patterns similar to that of increases in length of the IAC walls. These results show that postnatally the IAC increases significantly in length until about 10 years of age and slightly in diameter until about 1 year of age, especially medial to the foramen singulare. This concentration of growth of the IAC medially implies that its postnatal development is mainly due to growth of the bone around the otic capsule, which has implications for IAC surgery.

KEY WORDS — computer-aided three-dimensional reconstruction, internal auditory canal, postnatal development.

INTRODUCTION

The internal auditory canal (IAC) is a short bony canal that lies between the posterior surface of the petrous pyramid and the bony labyrinth within the dense petrous bone; the IAC opens medially to the posterior canal fossa through the porus acusticus. The seventh and eighth cranial nerves pass through the IAC, and this canal has been clinically important as a region in which acoustic neuromas occur. Many investigators have studied the IAC on radiographs,[1-3] on casts,[4-7] in dissected temporal bones,[8-11] and in histologic sections,[12] and have found that the dimensions, shape, and volume of the normal adult IAC vary widely, even between two sides of the same individual, as well as among different individuals.[1,2,4-6]

After studying postnatal development of the IAC, Lang[13] reported the lengths and the vertical and horizontal diameters of the IAC in four age groups from newborn to adult. Similar studies by Papangelou[6,7] found no growth with age in the wall lengths, the diameter, or the volume of the IAC in individuals older than 10 years. To our knowledge, however, no previous report has described postnatal development of the IAC fully. To gain insight into this topic, we used a computer-aided three-dimensional (3-D) reconstruction and measurement technique to determine the size, shape, and volume of the IAC in individuals newborn to elderly to obtain new information regarding the surgical anatomy of the IAC.

MATERIALS AND METHODS

Twenty human temporal bones obtained from 20 individuals without a history of congenital anomaly or otologic disease were studied. Specimens were from 10 males and 10 females, 1 month to 72 years of age at death. After removal at autopsy, temporal bones were histologically processed according to a previously reported procedure,[14] reference-marked for computer reconstruction, and sectioned horizontally or vertically at a thickness of 30 µm. Every 10th section was stained with hematoxylin and eosin and was used for computer-aided 3-D reconstruction of the IAC.

The equipment we used for reconstruction consists of a personal computer (NEC 98-RL, model 5) with a frame buffer (Sapience HyperFrame +) for full color imaging on a color monitor (16.7 million colors, 640 × 400 pixels), a digitizer (Hitachi HDG-1515) with resolution set at 0.1 mm, and a printer. The software used in this study was developed by Takagi and Sando[15] and then revised by Fujita and Sando[16] to provide a surface-model image.

Using our computer-aided reconstruction method

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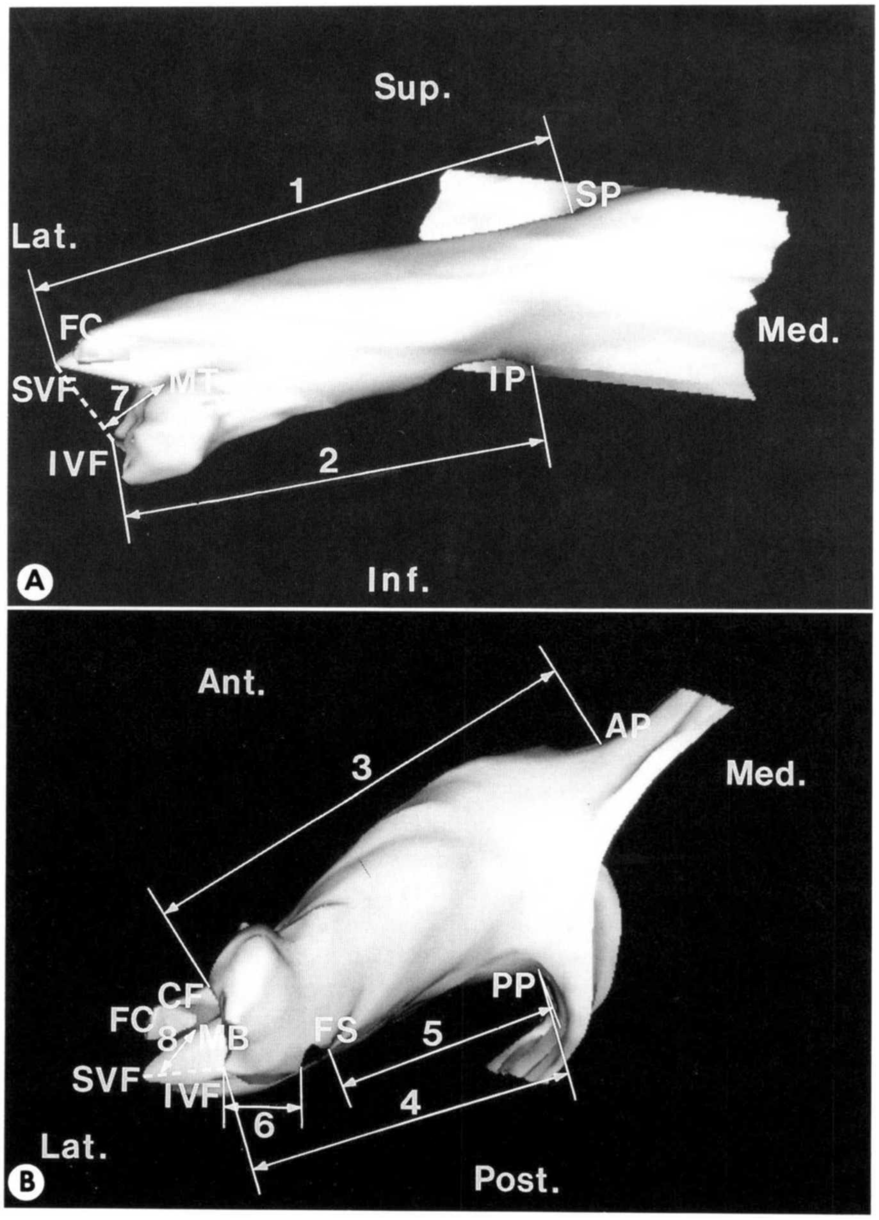

Fig 1. Reconstructed image of right internal auditory canal of 60-year-old man. A) Anterior view. B) Inferior view. SP — superior margin of porus, IP — inferior margin of porus, AP — anterior margin of porus, PP — posterior margin of porus, SVF — most lateral point of fundus in lamina cribrosa area for superior vestibular nerve, IVF — most lateral point of fundus in lamina cribrosa area for inferior vestibular nerve, CF — most lateral point of fundus in lamina cribrosa area for cochlear nerve, MT — middle portion of edge of transverse crest, MB — middle portion of edge of Bill's bar, FC — facial canal, FS — foramen singulare, 1 — length of superior wall, 2 — length of inferior wall, 3 — length of anterior wall, 4 — length of posterior wall, 5 — length of medial part of internal auditory canal, 6 — length of lateral part of internal auditory canal, 7 — length (depth) of transverse crest, 8 — length (depth) of Bill's bar. Dashed lines connect SVF and IVF.

described in detail elsewhere,[15] we reconstructed the IAC and made the following 14 measurements in three dimensions (Fig 1):

1. Length of the superior wall: the distance from the superior margin of the porus to the most lateral point of the fundus in the lamina cribrosa (LC) area for the superior vestibular nerve (SVN).

2. Length of the inferior wall: the distance from the inferior margin of the porus to the most lateral point of the fundus in the LC area for the inferior vestibular nerve (IVN).

3. Length of the anterior wall: the distance from the greatest curvature of the blunt anterior margin of the porus to the most lateral point of the fundus in the LC area for the cochlear nerve.

4. Length of the posterior wall: the distance from the posterior lip of the porus to the most lateral point of the fundus in the LC area for the IVN.

5. Length of the medial part of the IAC: the distance from the posterior lip of the porus to the medial margin of the foramen singulare.

6. Length of the lateral part of the IAC: the distance from the lateral margin of the foramen singulare to the most lateral point of the fundus in the LC area for the IVN.

7. Length (depth) of the transverse crest: the distance from the middle portion of the edge of the transverse crest to the line between the most lateral point of the fundus in the LC area for the SVN and that for the IVN (dashed lines in Fig 1).

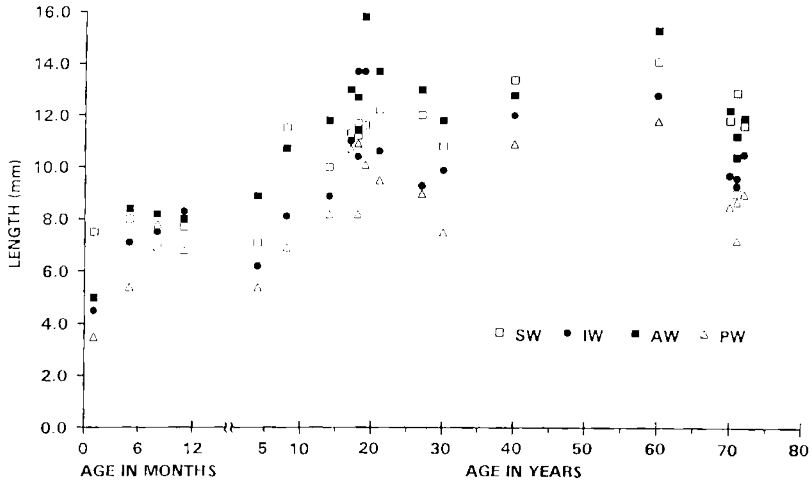

Fig 2. Lengths of superior, inferior, anterior, and posterior walls (SW, IW, AW, and PW, respectively) of internal auditory canal as functions of age.

8. Length (depth) of Bill's bar: the distance from the middle portion of the edge of Bill's bar to the fundus (dashed line in Fig 1).

9 and 10. Vertical and horizontal diameters of the IAC at the porus.

11 and 12. Vertical and horizontal diameters of the IAC at the fundus.

13 and 14. Vertical and horizontal diameters of the IAC at the middle portion of the canal.

The shape of the IAC in cross section was determined by comparing the diameters in the vertical and horizontal planes at the porus, the fundus, and the middle portion of the canal. The shape was classified as straight, narrowed medially, narrowed laterally, oval, or constricted in the middle. A canal was considered straight when there was no more than a 0.5-mm difference among the diameters at the porus, the fundus, and the middle portion of the canal. When the diameter at the porus was more than 0.5 mm less than that at the fundus, the IAC was considered narrowed medially; it was classified as narrowed laterally when the reverse was true. Likewise, when the middle portion diameter of the canal was more than 0.5 mm larger or smaller than both the porus and fundus diameters, the IAC was considered oval or constricted in the middle, respectively.

We also measured the volume of the IAC in each specimen, using a computer-aided technique developed and described previously.[17] Following this technique, we measured the medial border surface area of the IAC in each of the sections that included the porus of the IAC. In horizontal sections, a line was drawn between the point of greatest curvature on the blunt anterior margin of the porus and the point of greatest curvature on the posterior margin. Similarly, in vertical sections a line was drawn between the superior margin of the porus and its inferior margin. The lateral border of the IAC was taken to be the most lateral area of the fundus for the SVN, the IVN, and the cochlear nerve; the area along the edge of Bill's bar for the facial nerve was used as a reference also.

RESULTS

Length. The lengths of the superior, inferior, anterior, and posterior walls of the 20 IACs studied ranged between 6.9 mm and 14.1 mm (mean ± SD, 10.6 ± 2.2 mm), 4.5 mm and 13.7 mm (9.6 ± 2.4 mm),

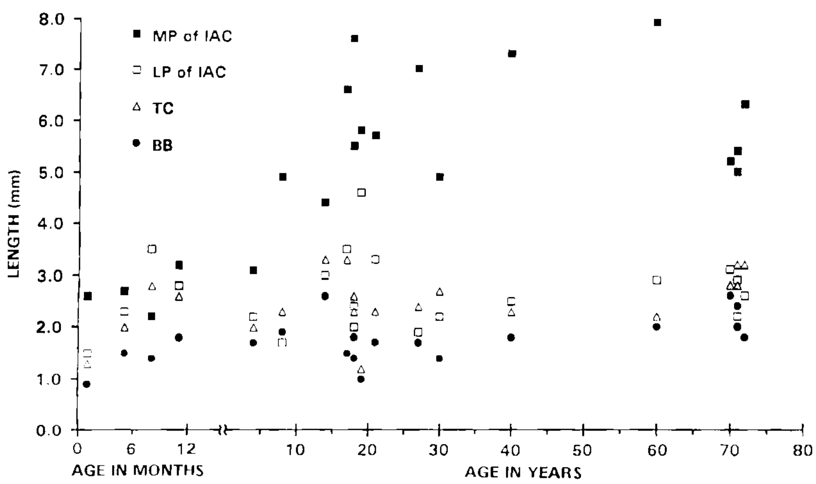

Fig 3. Lengths of medial part (MP) of internal auditory canal (IAC), of lateral part (LP) of IAC, and of transverse crest (TC) and Bill's bar (BB) as functions of age.

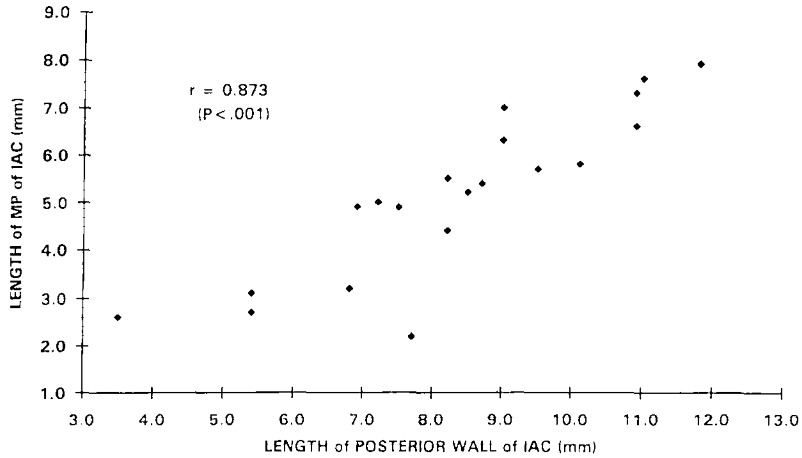

Fig 4. Correlation between length of posterior wall of internal auditory canal (IAC) and that of medial part (MP) of IAC.

5.0 mm and 15.8 mm (11.3 ± 2.6 mm), and 3.5 mm and 11.8 mm (8.3 ± 2.1 mm), respectively. Figure 2 shows the lengths of these four walls as functions of age. Regardless of age, for most of the IACs the anterior wall was the longest and the posterior one was the shortest. All four walls tended to lengthen significantly from birth to about 10 years of age, and no development was recognized after late adolescence, although individual measurements varied relatively widely. The rates of postnatal development appear to be similar for the four walls of the IAC.

The lengths of the medial and lateral parts of the posterior wall of the IAC and of the transverse crest

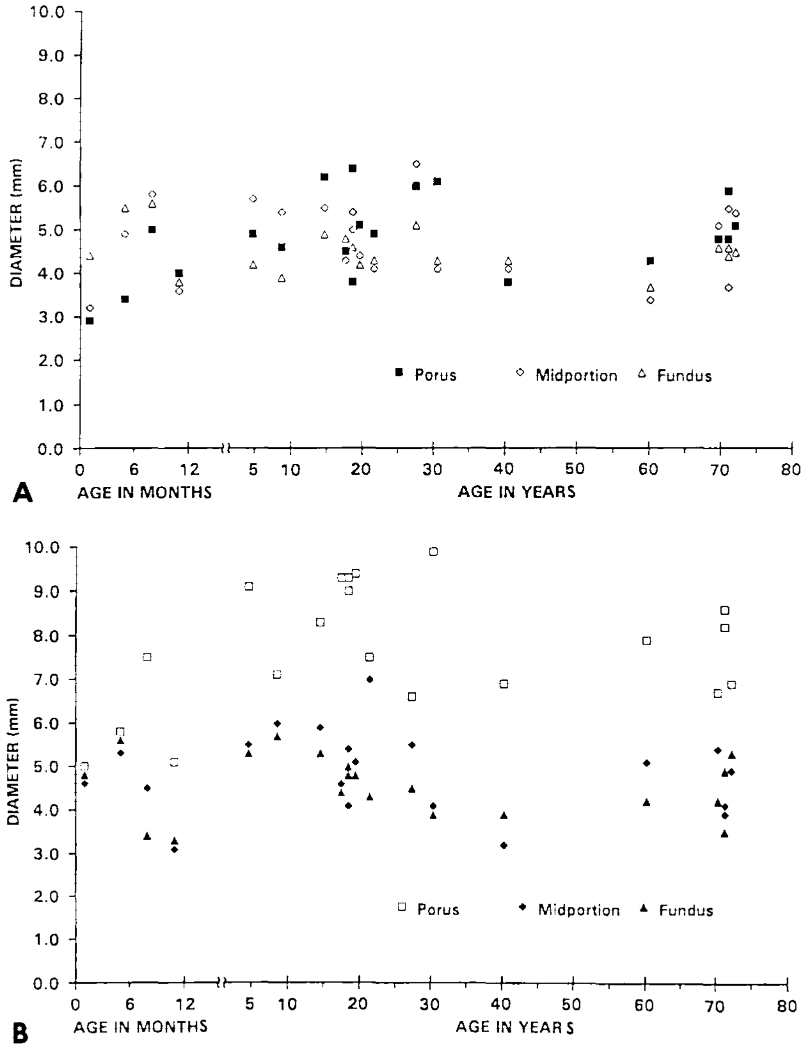

Fig 5. Diameters of internal auditory canal at porus, fundus, and middle portion of canal as functions of age. A) Vertical diameters. (Two triangles overlap at age 18 and 4.6 mm; hence appearance of 19 symbols instead of 20.) B) Horizontal diameters.

SHAPE OF HUMAN INTERNAL AUDITORY CANAL IN VERTICAL AND HORIZONTAL PLANES

			Shape	
Case	*Age*	*Sex*	*Vertical Plane*	*Horizontal Plane*
1	1 mo	F	Narrowed medially	Straight
2	5 mo	M	Narrowed medially	Straight
3	8 mo	F	Narrowed medially	Narrowed laterally
4	11 mo	F	Straight	Narrowed laterally
5	4 y	M	Oval	Narrowed laterally
6	8 y	F	Oval	Narrowed laterally
7	14 y	F	Narrowed laterally	Narrowed laterally
8	17 y	F	Straight	Narrowed laterally
9	18 y	M	Narrowed medially	Constricted in middle
10	18 y	F	Narrowed laterally	Narrowed laterally
11	19 y	M	Narrowed laterally	Narrowed laterally
12	21 y	M	Narrowed laterally	Narrowed laterally
13	27 y	M	Straight	Narrowed laterally
14	30 y	M	Narrowed laterally	Constricted in middle
15	40 y	F	Straight	Narrowed laterally
16	60 y	M	Straight	Narrowed laterally
17	70 y	M	Straight	Narrowed laterally
18	71 y	M	Narrowed laterally	Narrowed laterally
19	71 y	F	Constricted in middle	Constricted in middle
20	72 y	F	Narrowed laterally	Narrowed laterally

and Bill's bar are shown for different ages in Fig 3. The length of the medial part ranged between 2.2 mm and 7.9 mm (mean ± SD, 5.1 ± 1.7 mm), with greater lengths being measured in specimens from individuals in early adolescence and older. These results parallel those for the four walls of the IAC. In fact, the length of the medial part and the total length of the posterior wall were significantly correlated ($r = .8731$, $p < .001$), as shown in Fig 4.

In contrast, the lengths of the lateral part of the IAC posterior wall, of the transverse crest, and of Bill's bar ranged between 1.5 mm and 3.5 mm (mean ± SD, 2.7 ± 0.7 mm), 1.3 mm and 3.3 mm (2.5 ± 0.6 mm), and 0.9 mm and 2.6 mm (1.8 ± 0.4 mm), respectively, and showed no evidence of postnatal development. Moreover, these lengths varied less than the length of the medial part of the IAC wall, even in individuals older than their late teens (Fig 3).

Diameter. The vertical diameters of the IACs at the porus, the fundus, and the middle portion of the canal ranged between 2.9 mm and 6.4 mm (mean ± SD, 4.8 ± 1.0 mm), 3.7 mm and 5.6 mm (4.5 ± 0.5 mm), and 3.2 mm and 6.5 mm (4.8 ± 0.9 mm), respectively. The horizontal diameters ranged between 5.0 mm and 9.9 mm (7.7 ± 1.4 mm) at the porus, between 3.3 mm and 5.7 mm (4.6 ± 0.7 mm) at the fundus, and between 3.1 mm and 7.0 mm (4.9 ± 1.0 mm) at the middle portion of the canal. The diameters of the IAC at the porus, the fundus, and the middle portion of the canal as functions of age are shown in Fig 5. Both the vertical and horizontal diameters at the porus appeared to increase slightly during about the first year after birth, although no growth with age was found after that period. On the other hand, the diameters at both the fundus and the middle portion of the canal showed no postnatal development and were relatively constant regardless of age in comparison with those at the porus.

These results correspond with another finding concerning the shape of the IAC. As shown in the Table, most of the IACs from individuals older than 1 year were either narrowed laterally or straight when viewed in a vertical plane and narrowed laterally in a horizontal plane, although a few were classified as oval in a vertical plane or constricted in the middle in a horizontal plane. By contrast, in individuals less than 1 year old, more than half of the IACs were classified as narrowed medially in a vertical plane and straight in a horizontal plane.

Volume. The volumes of the IACs in this study ranged between 37.3 mm^3 and 220.6 mm^3 (mean ± SD, 159.6 ± 46.8 mm^3). They are shown as a function of age in Fig 6. As was noted for the IAC walls, IAC volume increased significantly after birth until about 10 years of age, but did not change significantly after late adolescence.

DISCUSSION

The computer-aided 3-D reconstruction and measurement method used in this study allows visualization of any temporal bone structure from any direction, without interference of surrounding structures. This method is also ideal for measuring these structures in three dimensions,[15] because it allows dimensional information to be obtained more accurately and easily than by other methods such as measuring

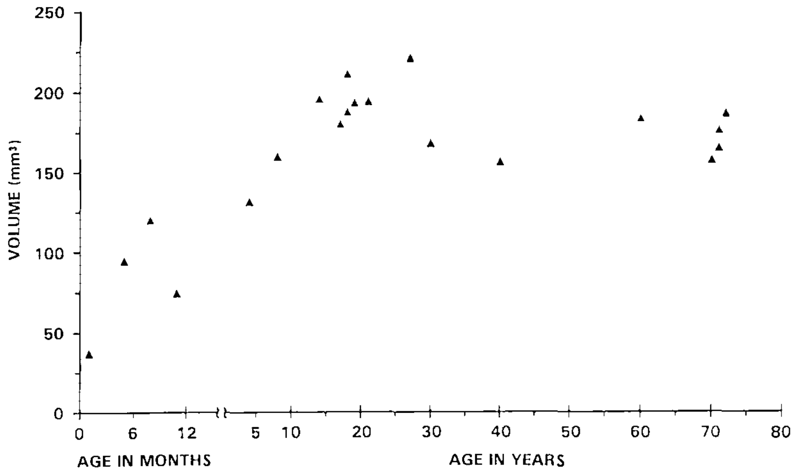

Fig 6. Volume of internal auditory canal as function of age.

radiographs, casts, or dissected temporal bones.

By using this method to study postnatal development in length of the IAC, we found that all of the walls of the IAC lengthen significantly from birth to about 10 years of age, and that their growth is probably complete by at least late adolescence. Furthermore, the medial part of the IAC develops similarly postnatally, although the lateral part of the IAC, the transverse crest, and Bill's bar do not change postnatally. These results suggest that most postnatal development in the length of the IAC is attributable to lengthening of the medial part of the IAC. The significant correlation between the length of the medial part of the IAC and the length of the posterior wall of the IAC supports this suggestion.

Development in diameter of the IAC was less obvious in this study compared with development in length. Slight increases were found in the vertical and horizontal diameters at the porus during about the first year after birth, but the diameters at the fundus and the middle portion of the canal were relatively constant over the life span in this study. This finding was confirmed by studying the shape of the IAC, and it indicates that postnatal development in IAC diameter is completed much earlier than development in length of the IAC. However, development in diameter is similar to development in length in that both are due primarily to growth at the medial end of the canal.

The present study showed that the volume of the IAC increases significantly from birth to about 10 years of age. This increase parallels increases in length of the IAC walls, indicating that postnatal increases in volume result predominantly from increases in the length of the canal, especially of its medial part, and not from growth in the diameter of the canal.

In summary, the IAC, especially its medial part, lengthens significantly until about 10 years of age and increases slightly in diameter until about 1 year of age. Thus, the IAC develops postnatally mainly along its long axis. Postnatal development of the IAC is shown schematically in Fig 7. The finding that the IAC develops postnatally in length until puberty is supported by the fact that the calvarium normally

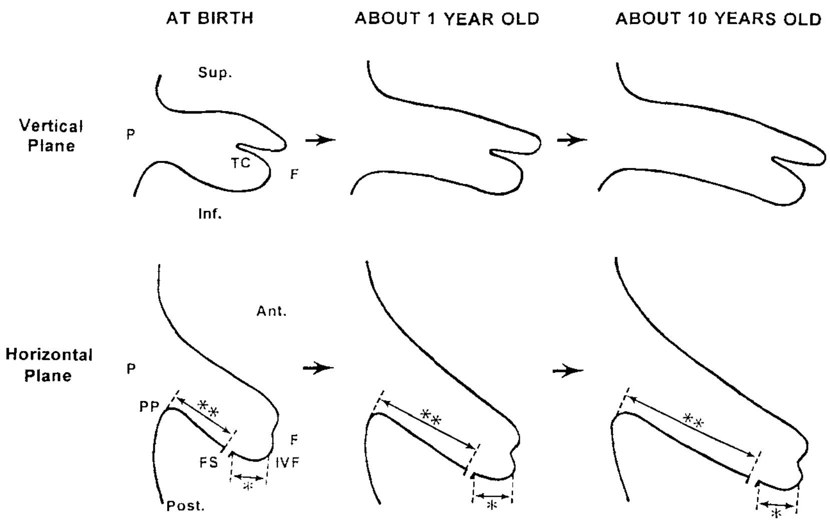

Fig 7. Schematic drawing of postnatal development of internal auditory canal as evident in vertical and horizontal planes. Internal auditory canal lengthens postnatally until about 10 years of age, mostly because of development of its medial part (**). Length of lateral part of internal auditory canal (*) is relatively constant throughout life. On other hand, diameters increase slightly at porus (P) for about 1 year after birth, so that internal auditory canal is narrowed medially in vertical plane and straight in horizontal plane and then becomes either narrowed laterally or straight in vertical plane and narrowed laterally in horizontal plane. F — fundus, TC — transverse crest, PP — posterior margin of porus, FS — foramen singulare, IVF — most lateral point of fundus in lamina cribrosa area for inferior vestibular nerve.

grows in capacity until 15 or 16 years of age. On the other hand, the fundus of the IAC and the adjacent walls are surrounded by the otic capsule, which is thought to attain adult dimensions by 21 weeks of gestation.[18] This fact may explain why we found no evidence of postnatal development in diameter of the fundus or lengths of the lateral part of the IAC, transverse crest, or Bill's bar. In other words, the concentration of IAC growth medially implies that postnatal development of the IAC is mainly due to growth of the bone around the otic capsule.

Another finding of interest was the relatively wide variations in the length of the medial part of the IAC and the porus diameters, even in adults. This variability might be due to differing degrees of pneumatization around the IAC, as described by Fujita and Sando[16] and Portmann et al.[19] These variations should be taken into account during IAC surgery. Furthermore, the size and shape of the IAC should be estimated as accurately as possible before IAC surgery. Silverstein et al[11] reported that the singular canal is valuable as a landmark to avoid fenestrating the labyrinth during surgery by a retrosigmoid IAC approach. In this regard the foramen singulare, the orifice of the singular canal to the IAC, also might be a useful landmark to estimate the distance to the fundus during IAC surgery, because we found the length of the lateral part of the IAC to be relatively constant over the life span.

The tissue shrinkage during fixation and processing is on the order of 10%.[20,21] Schuknecht[21] reported that fixation produced about 10% shrinkage of specimen; Igarashi et al[20] reported 9% shrinkage of the circumference of the posterior semicircular duct in celloidin-embedded specimens. However, to our knowledge, there has been no previous study concerning shrinkage of bony tissue. In the temporal bones from individuals over 10 years old, the lengths of the IAC walls obtained in this study tended to be a little shorter (approximately 8%) than those obtained by other methods using unfixed temporal bones.[4,5,7,10] It is not possible to determine whether this reflects shrinkage of bony tissue or the normal wide variations in these dimensions across individuals. In any case, our conclusions about the postnatal development of the IAC are not affected by potential shrinkage, because all our materials were processed identically.

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