ORIGINAL ARTICLE

Peculiarities in the Development of the Superior Semicircular Canal

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Abstract

Objective: Our objective was to study the ontogeny of the superior semicircular canal in order to describe its peculiarities.
Methods: We analysed 76 series of human embryos aged between 32 days (6 mm) and newborns. The samples were cut serially and stained using Martin’s trichrome technique.
Results: In semicircular canal development there were a number of peculiarities, such as: a defined chronological sequence of osteogenesis with a variable rate of ossification; the fact that each nucleus of ossification was involved in the formation of one of its covers (the upper in the superficial and the lower in the deep); the appearance of transitory dehiscence; and canal closure by means of bone with laminar pattern, with a minimum thickness of 0.1 mm.
Conclusion: The peculiarities in canal development could explain the origin of pathological dehiscence in the canal, whether congenital or acquired.

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PALABRAS CLAVE
Ontogénesis; Canal semicircular superior; Dehiscencia; Humano


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**Métodos:** Para ello se han analizado 76 series embriológicas humanas de edades comprendidas entre los 32 días (6 mm) y recién nacidos. Las preparaciones estaban cortadas en serie y teñidas con la técnica de tricrómico de Martins.

**Resultados:** En el desarrollo del canal semicircular hemos observado una serie de peculiaridades, como: secuencia cronológica definida de su osteogénesis con un ritmo de osificación variable, cada núcleo de osificación interviene en la formación de una de sus cubiertas, el superior de la superficial y el inferior de la profunda; la aparición de una dehiscencia transitoria, y el cierre del canal por hueso de tipo laminar con un grosor mínimo de 0,1 mm.

**Conclusión:** Las peculiaridades en el desarrollo del canal podrían explicar las causas del origen de la dehiscencia patológica del mismo, ya sean congénitas o adquiridas.

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**Introduction**

Anson, Olazola and Hotna, and Bergeron give a detailed description of the embryological development of the semicircular canals, showing that the superior semicircular canal forms from the dorsal utricle wall of the otocyst in week six (8-11 mm human embryo) as an outpouching or diverticulum in the form of a common disc for the vertical canals (superior and posterior), and how the mesodermal tissues surrounding it adapt to the morphology and rapid growth of the membranous labyrinth, progressively condensing and transforming into precartilage. This subsequently matures and develops into cartilage, and they showed how around week 18, the ossification process starts from the 2 primary and one accessory ossification centres.

Its size is complete at week 23 and computerised tomography shows how at week 19 the canal is surrounded by a partially ossified ring, with ring completion at week 21.

Bach-Peterson and Kjaer observe that, although ossification may occur more rapidly in some foetuses, the pattern follows a well defined chronological sequence and Dzieciolowska-Baran describes how between week 18 and 24 morphological forms are more dynamic and abundant.

Minor et al.'s description of dehiscence of the superior semicircular canal and the existing controversy regarding whether dehiscence is due to congenital or acquired defects led us to carry out a study on the ontogeny of the superior semicircular canal in order to describe its peculiarities and provide data to help establish its etiopathogenesis.

**Materials and Methods**

We studied the development of the superior semicircular canal in embryos and human foetuses. Analysis was performed on a series of human embryos belonging to the collection of the Department of Anatomy and Human Histology in the University of Zaragoza, aged between 9 mm (6 weeks) and newborns. The total number of series studied was 77.

We used the O’Rahilly and Muller tables to date the ages of the foetuses used. These are based on relating different measurements (maximum length, crown to heel length, foot length, biparietal diameter, abdominal circumference and head circumference) and body weights. These measurements were compared with data from the clinical record and ultrasound scan, when available.

In embryos and foetuses of under 12 weeks the whole head was set, whilst in older foetuses detailed and scrupulous dissection of the temporal bones was carried out.

All the samples were fixed in 10% formalin and decalcified with 2% nitric acid, at a temperature of 25 °C. Mean time of decalcification varied between 1 and 4 weeks, depending on specimen size and thickness. After decalcification, the acid was eliminated by washing under running water. The samples were progressively dehydrated in increasing alcohol concentrations, embedded in paraffin, cut with a Leitz microtome in 7–10 μm and stained using Martín’s trichrome technique.

All sections were observed under an OLYMPUS BH-2 dual headed microscope with 2, 4, 10, 20, 40, 60 and 100 x 3.3 lenses and photographed with an OLYMPUS PM-CBSP and a LEICA DMD108. The latter has an integrated calibration system for microimaging measurement, with which the morphometric data were obtained or measured with microscopic precision.

**Results**

The superior semicircular canals develop from the mesenchyme of the future optic capsule which contains the membranous ducts.

At 6 weeks, the ducts are surrounded by mesenchymal tissue, characterised by looseness, made up of stem cells which are rounded or elongated, with large nuclei and little cytoplasm.

At 7 weeks, the mesenchyme is differentiated into chondroblastic cells. At this stage, the future canal presents 2 areas. The closest to the duct is precartilaginous (1) in appearance whilst the distal area (2) is cartilaginous (Fig. 1a).

At 8 weeks, the canal has a cartilaginous structure, its exterior or superficial cover is clearly developed and adopts its shape as a characteristics arch, the convexity of which leans towards the middle cerebral fossa. Its mean thickness is 0.2 mm, tapering as it reaches the apical area.

At 9 weeks of development we observe the beginning of the formation of the future periosteal and endosteal layers of the canal wall through the mineralisation of the cartilage matrix and cellular differentiation in the future perilymphatic space into 2 strata, the first of which is fibrous and the second loose. At 10 weeks of development, the mineralisation process of the cartilage matrix increases in the periosteal layer (Fig. 1b).
Ontogeny of the Superior Semicircular Canal

Figure 1  Development of the superior semicircular canal. Note how at 7 weeks, the cells of the future canal form into precartilage (1) and cartilage (2). In b, at 10 weeks the future periosteal (p) and endosteal (e) layers form from mineralisation of the cartilage matrix. C shows the increase of the endosteal layer (arrow) at 12 weeks. D shows the partial destruction of the superficial covering of the canal at 20 weeks (arrows). E shows how the periosteal lamina which separates the middle cerebral fossa through the osteoprogenitor cells and osteoblasts deposit an osteoid substance inside and F shows the wall reconstructed by a layer of periosteal bone at 23 weeks. G shows how the bone laminate presents a width of approximately 0.1 mm, at 35 weeks. H shows the presence of a thinner (arrow) area in the width of the canal in the newborn. Martins’ trichrome technique: a, b, c, 20×; d, f, g, 10×; e, 40× and h, 4×.

At 11 weeks, the maximum thickness of the canal is 0.5 mm, decreasing from the basal area (0.5 mm) to the apical (0.3 mm) area.

At 12 weeks, the endosteal layer (arrow) increases in size, both around the mineralised cartilage matrix and the chondroblasts which form in 3 or 4 rows (Fig. 1c).

Between 13 and 16 weeks, two of the most notable events take place. The subarcuate fossa is formed on the inside of the otic capsule and as a result the deep canal covering is formed and separates from the capsule.

At 17 weeks, the canal is still cartilaginous in structure and its enclosure consists of 3 layers (periosteal, endochondral and endosteal).

The first sign of endochondral ossification of the superior semicircular canal is observed at 18 weeks of development through 2 primary ossification centres. The first canalicular
nucleus to appear is the superior one and subsequently the inferior.

The ossification of canals continues its development process between weeks 19 and 26. Although this process has a well defined chronological sequence in each foetus, the ossification rhythm is different.

One significant aspect of this process is the progressive destruction of the surface cover (Fig. 1d). The periosteal layer does this first, followed by the endochondral and lastly the endosteal layer, producing a dehiscence characterised by the absence of a part of the canal bone. This leads to the membranous duct being separated from the middle cerebral fossa only by a fibrous periosteum layer (Fig. 1e). The presence of osteogenitor and osteoblast cells may be observed in said periosteum, which will deposit an osteoid substance leading to the formation of the bone and subsequent reconstruction of the layer. This new bone covering (Fig. 1f) is very thin, ranging from 0.08 to 0.1 mm over its arch.

Throughout this period we observed how in some foetuses the layers disappeared whilst in others the periosteal bone layer had reconstructed, closing the canal (Table 1).

The canal wall is completely formed in 27 and 28 week foetuses. It presents well formed bone tissues, composed of concentric enveloping layered systems, with osteoplast gaps which contain osteocytes and Volkmann’s canals. We observed blood vessels and nerve fibres in their interior.

Once closure has taken place, the most superficial layer of the canal grows by means of appositional mechanisms, which increases its thickness, although with a continual minimum thickness of between 0.1 and 0.2 mm (Fig. 1g).

In the newborn, the semicircular canal is completely ossified and has a fine, thin, complete and compact structure. Its thickness varies throughout the arch, with the apical areas being the thinnest (arrows) with a thickness of around 0.1 mm (Fig. 1h).

**Discussion**

Our findings revealed a series of peculiarities related to the origin, development and ossification of the superior semicircular canal, which sometimes corroborated findings from other authors and at others offered different points of view. These events led us to believe that they were due to the speed and complexity of the changes which occurred in this canal during its development.

The semicircular canals develop from the mesenchyme surrounding the otocyst and which subsequently forms the otic capsule. The mesoderm which envelops the superior semicircular duct will transform into precartilage (we observed this at 7 weeks), and subsequently into cartilage (between the eighth and ninth week of development). It will remain with this cartilaginous structure up to week 18, when the ossification of the 2 primary centres will begin, one close to the capsule and the other inferior or vestibular, adjacent to the posterior canal arch.

The first peculiarity we wish to highlight is how these ossification centres follow a well defined chronological sequence, but with a variable rate of ossification; we therefore observed how different foetuses of the same chronological age presented different phases in their osteogenesis. A similar event was observed by Bach-Peterson and Kjaer, who noted that ossification of the semicircular canals may take place more quickly in some foetuses.

The second is that each ossification nucleus prevalently intervenes in the formation of one of the coverings. The superior canicular nucleus therefore forms the larger part of the superficial or exterior covering of the canal and is connected to the middle cerebral fossa and the interior or interior wall is linked to the subarcuate fossa. This was not reflected in the bibliography reviewed for this manuscript.

The third peculiarity is the appearance of the transitory dehiscence in the early stages of its ossification. The canal coverings are made up of 3 layers or bony tunci. The periosteal and endosteal layers are developed by direct or membranous ossification, and the middle layer by indirect or endochondral ossification, as observed by Anson.

From the start of ossification, we observed how the canal layers disappeared in the following sequence: first the periosteal layer, then the endochondral layer and finally the endosteal layer. The result of this is that for some time only the fibrous periosteous layer comes between the duct and the middle cerebral fossa. This lack of covering is transitory since a bony periosteal layer to close the canal is later reconstructed.

As a consequence of the different ossification rates, we observed how canal closure is very variable, and we could see the dehiscent canals up to 26 weeks of development, from when the canal is closed and constituted by compact bony tissue.

The fourth peculiarity is the bony reconstruction and later wall closure, which takes place through a membranous or direct ossification process. For this, the osteoprogenitor cells located in the periosteum area are converted into osteoblasts which segregate an osteoid substance and later

**Table 1 Distribution of the Type of Canal During its Ossification.**

<table>
<thead>
<tr>
<th>Age, weeks</th>
<th>Number of cases</th>
<th>Cartilaginous canal</th>
<th>Closed canal</th>
<th>Dehiscent canal</th>
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<td>4</td>
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<td>3</td>
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form separate bone trabeculae. The appearance of new trabeculae superimposed to the preceding ones will give rise to the formation of an osseous lamina which will close the canal roof. We have only seen this process reflected in the development of the most lateral portion of the external semicircular canal, in the immediate vicinity of the oval window and in the fissula ante fenestrang.2

We therefore observed a critical period, between week 19 and 26, when the superficial covering destroys the periosteal, endosteal and endochondral layers. We believe that the persistence of this communication, due to the failure of later osseous reorganisation of the canal covering which impedes its complete reconstruction, could be one of the causes of the origin of superior semicircular canal congenital dehiscence, as we saw in the posterior semicircular canal.12

The fifth peculiarity is the presence of laminated bone tissue covering the superior semicircular canal in the middle cerebral fossa. Once the canal is closed, it is made up of laminated bone tissue, with an estimated width of 0.1 mm. These observations are very similar to those of Carey et al.,13 which describe an extreme uniform thinness of the bone, at birth, and a gradual, slow thickening up to 3 years of age.

The thinness of the canal wall means that during its development it is regarded as papyraceous, characterised by the presence of a very thin osseous lamina under 0.5 mm according to the Cisneros et al.‘s14 classification. We believe that the non-thickening of the canal due to a fragile papyraceous bony covering would be predisposed to an event on this lamina which could be a cranial trauma or sudden increase in intracranial pressure leading to breakage which would become an acquired type of dehiscence pattern.

The sixth is the presence of a translucent line which runs around the canal arch. We would point out that we observed the presence of an area which was not as thick in the canal and which we interpreted as the osseous band resulting from the fusion of the canicular ossification centres (superior and inferior). As a translucent area was not found in all bony areas, we believe the explanation is to be found in the fact that the canal gradually strengthens as it adheres to the periosteal bone.

Conflict of Interests

The authors have no other conflict of interests to declare.

References