

# The development of the spiral ganglion in the human foetus

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*The development of the spiral ganglion was studied in steps sections of 81 human temporal bones.*

*By the 8<sup>th</sup> week, the spiral ganglion has already separated from the vestibular ganglion. At 13 weeks two distinct populations are observed that correspond to neuron and Schwann cells. At 15 weeks the spiral ganglion has increased its distance from the cochlear duct and is surrounded by mesenchyme near the scala tympani. At 14 weeks a gradual decrease in the nucleus-to-cell area ratio was observed in spiral ganglion neurons that may reflect a morphological adaptation to function. By the 23<sup>rd</sup> week the modiolus begins to ossify and the spiral ganglion is surrounded by bony trabeculae.*

*The time course of spiral ganglion development follows that of the stria vascularis and organ of Corti, although maturation changes are still observed in the neuronal population even beyond 20 weeks.*

**Key words:** spiral ganglion, development, human foetus

## INTRODUCTION

The spiral ganglion is a population of bipolar cells situated at the base of the bony spiral lamina. In the human adult cochlea it contains approximately 35 000 neurons. Their peripheral processes synapse with the hair cells of the organ of Corti, while their central processes form the cochlear nerve. Two distinct populations of neurons have been identified, type I and type II. A third type of neuron, the intermediate cell, has also been described by Rosbe et al, with a cell area that significantly varies from type I and type II neurons [13]. It is suggested that this is a subtype of the large type I cell.

The development of the spiral ganglion has been extensively described in small mammals [1, 11, 12]. However, few studies have been published regarding its development in the human foetus, and these either involve a small number of temporal bones or concentrate mainly on postnatal maturation [7, 14, 15]. The purpose of this paper is to present a comprehensive

light microscopy study covering consecutive steps in the development of the human spiral ganglion.

## MATERIAL AND METHODS

Sections of human temporal bones ranging in age from 8 weeks of gestation to full term were examined in this study. The material was derived from the temporal bone collection of the Institute of Laryngology and Otology and obtained from perinatal deaths. All foetal specimens were decalcified, embedded and then cut horizontally, commencing at the upper surface of the temporal bone. The embedding medium in the majority of cases was low-viscosity nitrocellulose, a substance related to celloidin. In a small number of cases paraffin wax was used. In the nitrocellulose-embedded material sections had been cut at 20  $\mu\text{m}$  thickness and every tenth section was mounted on glass slides and stained with haematoxylin and eosin. Paraffin wax sections were cut at 7  $\mu\text{m}$ .

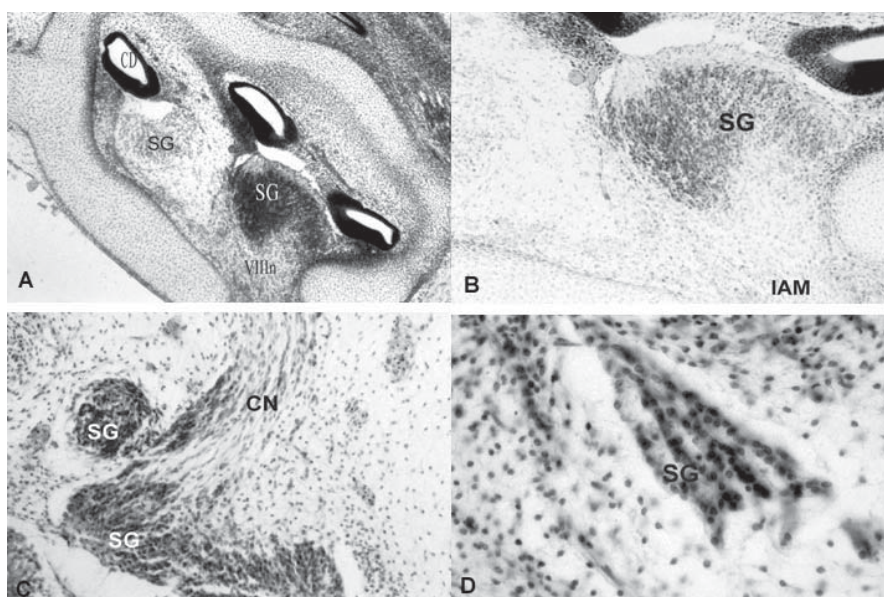
From 208 human fetuses 98 were initially selected. Inclusion criteria for the study included absence of evidence of congenital disease in the medical history, a recorded age of gestation and/or a measured crown-rump length. During the study specimens that were observed to suffer from severe autolysis and were not suitable for any meaningful observations were excluded. Foetuses with obvious congenital abnormality were equally excluded. Eighty-one temporal bones from 45 fetuses were finally studied. The temporal bones of one child and four adults were used as controls. In 41 fetuses the age was estimated using the crown-rump length. In the remainder the age was calculated from the first day of the last normal menstruation as this appeared in the medical notes.

## RESULTS

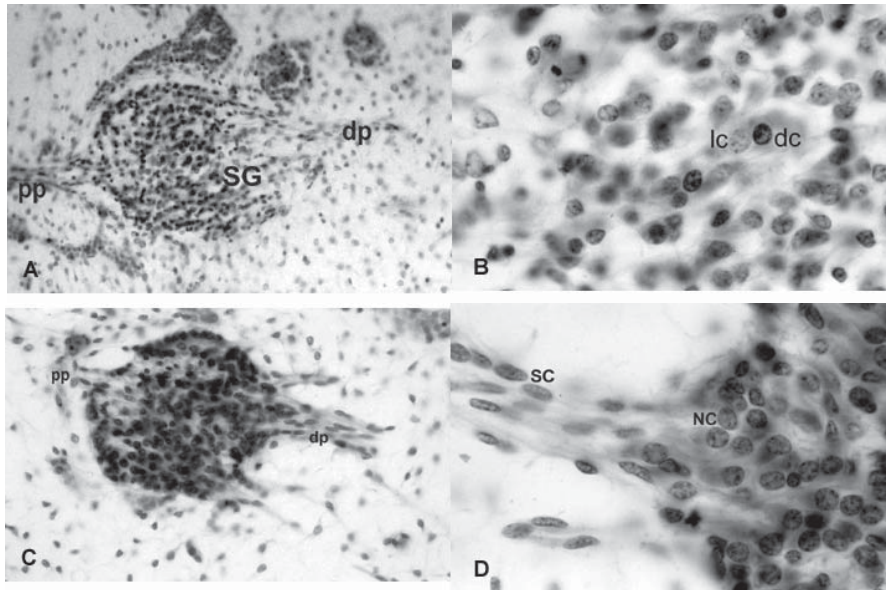
At the end of the 8<sup>th</sup> week the acoustic ganglion had already separated from the vestibular ganglion. Two large populations of neuroblasts could be distinguished, a smaller one near the basal turn of the cochlear duct, and a relatively larger one near the developing apical turn (Fig. 1A). Both were surrounded by undifferentiated mesenchyme. The spiral ganglion primordium in the basal turn was kidney

shaped. The primordium in the apical turns was more rounded in shape and two areas with different staining properties could be distinguished in low magnification. There was a lighter staining area, which was apposed to the developing cochlear duct, and a darker staining region that faced the developing internal auditory meatus (Fig. 1B). In the lighter stained area there were very few cells and abundant neuroglia. In the darker staining area there was a cluster of cells with round nuclei and staining variability. Schwannoblasts and neuroblasts could not be identified morphologically. By the end of the 11<sup>th</sup> week the spiral ganglion primordium of the apical turn had a spherical appearance and was beginning to separate into three different populations, each innervating a different part of the developing cochlear duct (Fig. 1C). At the basal turn it had assumed a triangular shape, with its apex towards the developing cochlear duct (Fig. 1D). It was still difficult to differentiate between Schwann cells and neuroblasts.

At 13 weeks the distance between the spiral ganglion and the cochlear duct increased. The spiral ganglion assumed a more oval shape with two processes: a proximal one attached to the cochlear duct and a peripheral one forming the cochlear nerve (Fig. 2A). Schwann cells were clearly distinguished in the



**Figure 1.** **A.** 8-week foetus (specimen C22). The cochlear duct has completed 1½ turns. CD — cochlear duct, SG — spiral ganglion; VIII<sub>n</sub> — cochlear nerve ( $\times 25$ ). **B.** Spiral ganglion primordium at the apical turn of the developing cochlear duct (specimen C22); SG — spiral ganglion, IAM — internal auditory meatus ( $\times 50$ ). **C.** 11-week foetus (specimen C11). Spiral ganglion primordium branches off to innervate different parts of the developing cochlear duct ( $\times 50$ ); SG — spiral ganglion; CN — cochlear nerve; **D.** Spiral ganglion primordium has assumed a triangular shape in the basal turn (specimen C11); SG — spiral ganglion ( $\times 100$ ).



**Figure 2.** **A.** 13-week foetus (specimen T194). The spiral ganglion has assumed a more oval shape; SG — spiral ganglion, pp — proximal process, dp — distal process. ( $\times 50$ ). **B.** Higher magnification of previous specimen with lighter (lc) and darker (dc) stained cells in the spiral ganglion ( $\times 250$ ). **C.** 14-week foetus (specimen C42); pp — peripheral process; dp — distal process ( $\times 100$ ). **D.** Higher magnification of previous specimen; NC — neuron cells, SC — Schwann cells ( $\times 250$ ).

central processes by their elongated light stained nucleus. In the spiral ganglion itself two distinct cell populations with different staining properties could be observed (Fig. 2B): cells with a lighter stained nucleus (neuron cells) and cells with a darker stained nucleus (Schwann cells).

At 14 weeks Schwann cells appeared as dark elongated cells in the proximal process of the spiral ganglion and as dark round satellite cells at the periphery of neuron cells (Fig. 2C, D). The nucleus-to-cytoplasm ratio of neuron cells was just beginning to decrease and the cytoplasm looked clearer. Some of the neuron cells had developed a prominent nucleolus. By the 15<sup>th</sup> week the spiral ganglion had increased its distance from the cochlear duct and was surrounded by mesenchyme near the developing scala tympani. The number of Schwann cells in the central and peripheral processes had increased considerably. The nucleus-to-cytoplasm ratio in neuron cells was still decreasing. At 18 weeks neuron cell cytoplasm stained mildly and was not as clear as in previous sections. The Schwann cells had now assumed a sickle-cell shape, hugging the neuron cells (Fig. 3A, B). The spiral ganglion was now close to the scala tympani and still surrounded by mesenchyme.

By the 23<sup>rd</sup> week, as the modiolus begins to ossify, the spiral ganglion was surrounded by bony trabeculae. The population of neuron cells seemed to

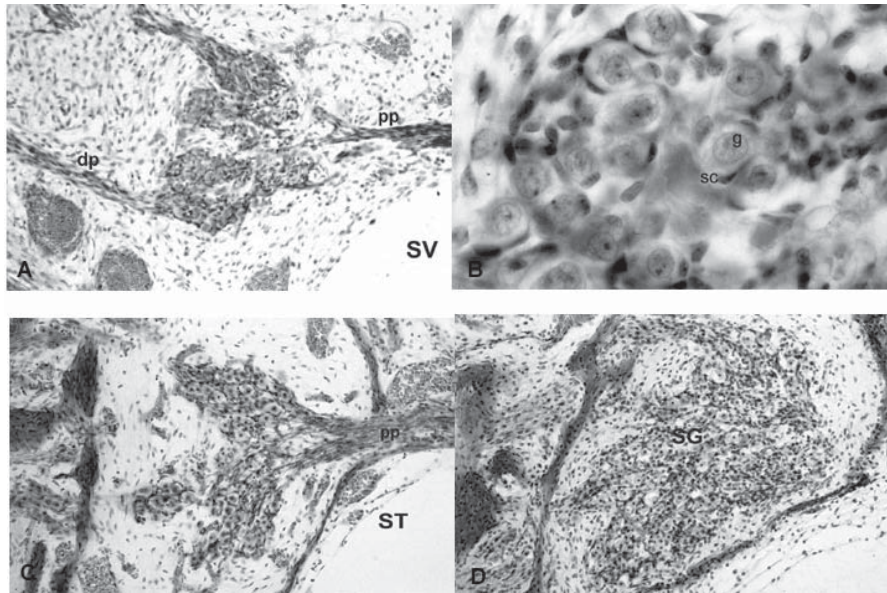
have decreased (Fig. 3C, D). In general, the neuron cells in the apical turn appeared larger than those in the basal turn. By the end of the 25<sup>th</sup> week a further decrease in the nucleus-to-cytoplasm ratio of neuron cells was observed. No major changes were observed after the 26<sup>th</sup> week.

## DISCUSSION

The vestibulocochlear and geniculate ganglia are formed from a common ganglionic complex surrounded by mesenchyme [6]. The first sign of differentiation of the vestibular and cochlear ganglia is observed as early as the 4<sup>th</sup> week [16]. As the foetal period commences, the spiral ganglion has already separated from the vestibular ganglion. Even though the cellular population looks heterogeneous, it is still not possible to distinguish between Schwann cells and neuron cells. The cochlear duct has already completed one and a half turns and the initial ganglion cell population has branched off to innervate the basal turn. As development progresses, ganglion cell clusters become separated to innervate the developing cochlear duct in a progressive fashion as it continues its coiling.

The origin of the spiral ganglion primordium has been a matter of considerable speculation and controversy. The two main theories are that it is of otocystic origin or that it is of neural crest origin [5],





**Figure 3** A. 18-week foetus (specimen T202); dp — distal process, pp — peripheral process; SV — scala vestibuli ( $\times 50$ ). B. Higher magnification of previous section. Nucleus-to-cytoplasm ratio has decreased considerably; g — neuron cell, sc — Schwann cell ( $\times 250$ ). C. 23-week foetus (specimen C306). Spiral ganglion in the apical turn ( $\times 50$ ); pp — peripheral process; ST — scala tympani. D. Previous specimen. Spiral ganglion in the basal turn; SG — spiral ganglion ( $\times 50$ ).

although studies in birds postulate a double origin from both structures [14]. However, no definite conclusions can be drawn from our study. The proximity of the spiral ganglion primordium to the developing cochlear duct in the early stages of development may be a strong indication in support of the otocystic theory. On the other hand, one cannot fail to observe the increased presence of Schwann cells along the central auditory nerve projections through the foetal period of development. These cells may be migrating towards the periphery, thus supporting a neural crest origin, as suggested by other authors [14]. A study on the embryonic development of these structures is needed to draw more definite conclusions.

Another debate concerns whether hair cells differentiate before or after being contacted by nerve endings. With only a light microscopy study, such as ours, it is difficult to shed light on this subject. Transmission electron microscopy has shown that afferent fibres can be observed as early as the 9<sup>th</sup> week, at a stage when it is impossible to distinguish within the otocyst the cells that are destined to become hair cells [10].

After the 14<sup>th</sup> week of development we observed a gradual decrease in the nucleus-to-cell area ratio in spiral ganglion neurons of all turns. This probably reflects a morphological adaptation to function and

has also been observed in other human and animal studies [2, 14].

In our study spiral ganglion neurons reached their final size at the end of the 18<sup>th</sup> week and neuron cell bodies in the apical turns were larger than in the basal turn. This is consistent with the findings of Sanchez del Rey et al. [14]. Characteristics of the human neonatal spiral ganglion have been described in a light and electron microscopic study of five temporal bones [8]. The prevalence of type II spiral ganglion cells was found to be greater than in adults, constituting 24% of all neuronal cells in the middle turn and 26% in the basal turn, which decreased with increasing age. The study confirmed that there is a clear differentiation between type I and II neurons in the human neonate. Ultrastructural studies of mature human spiral ganglion cells have demonstrated that the diameter of large cell axons remain consistently larger in the basal turn of the cochlear than the middle and upper middle turns [9]. This seems to be a maturation rather than a developmental process. It has been proposed that type II neurons are precursors to type I neurons [14] and that the maturation process occurs in an apical direction. The findings from our study would not dispute this, as neurons were consistently larger in the apical turns than in the basal turns, the opposite of the proportions found in adult studies.

In general the time course of spiral ganglion development follows that of the sensory epithelium and the stria vascularis. At week 20 the neuron cells have already reached their final size, while the organ of Corti exhibits quite well developed fluid spaces and specialised cells and the stria vascularis has formed completely [3]. This period is also the time by which the first responses to pure tone stimulation can be detected in human fetuses [4]. However maturation changes are still observed in the neuronal population even beyond 20 weeks. The population of neuron cells seems to have decreased, while a further decrease in the nucleus-to-cytoplasm ratio of neuron cells is observed by the end of the 25<sup>th</sup> week.

### CONCLUSION

A gradual decrease in the nucleus-to-cell area ratio was observed in spiral ganglion neurons in all turns. This is likely to reflect a morphological adaptation to function and has also been observed in other human and animal studies. It has been proposed that type II neurons are precursors to type I neurons and that the maturation process occurs in an apical direction. The findings from our study would not dispute this. The time course of spiral ganglion development follows that of the stria vascularis and organ of Corti, although maturation changes are still observed in the neuronal population even beyond 20 weeks.

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