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The developmental history of a sensory ganglion cell

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The sensory ganglion cell (e.g., in spinal and cranial nerve ganglia) arises from the crests of the neural tube; in its early life, the cell body (soma) has a bipolar form with 2 extensions (also called processes).

In the spinal cord region, one extension anchors itself metabolically to the thick epithelium of the ectodermal ring; this extension is called a *dendrite*. The dendrite growth-elongates between the soma of the ganglion cell and the periphery as the embryo becomes wider and longer. Dendrites make up the bulk of a peripheral sensory nerve.

The other extension is sucked metabolically into the rapidly growing dorsal grey matter of the embryonic spinal cord; this process is called a *neurite*; it continually elongates from the soma to the dorsal horn. Neurites constitute the dorsal rootlets.

Cajal shows the form of the soma in a cross-section through the developing spinal cord of 56-hour chicken embryo (Fig. 392 below; from Bailey FR. and Miller AM. *Text-Book of Embryology.* 1921).

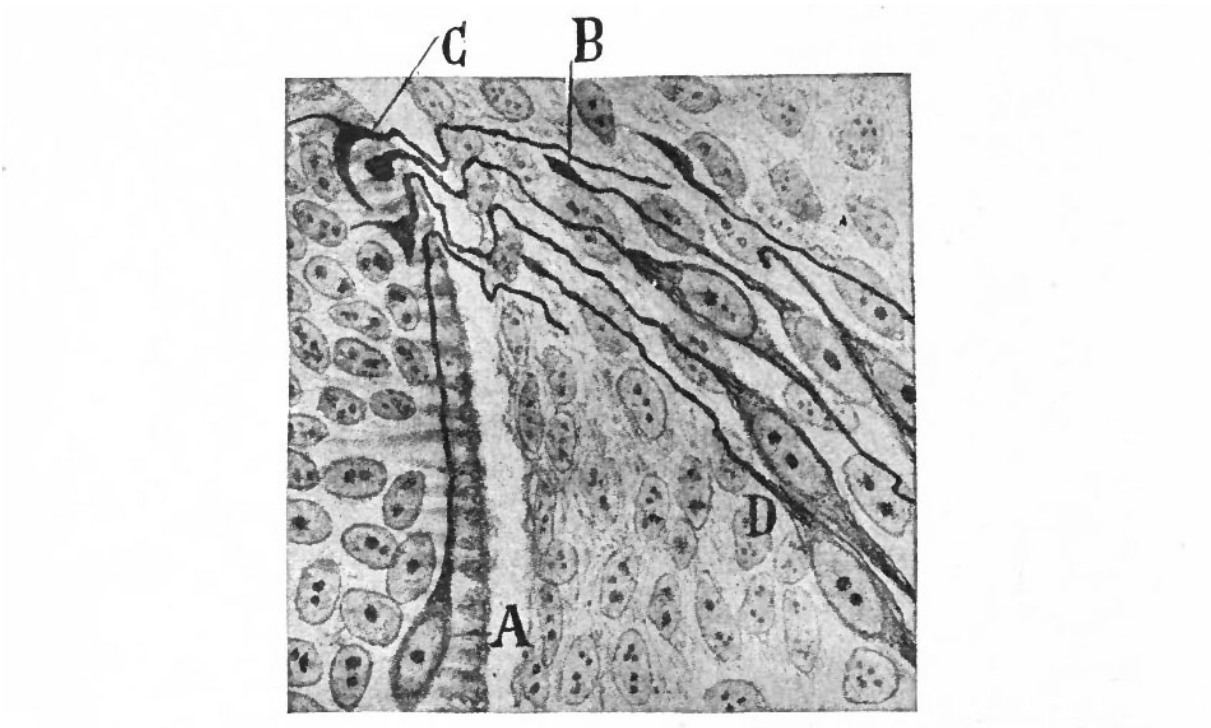
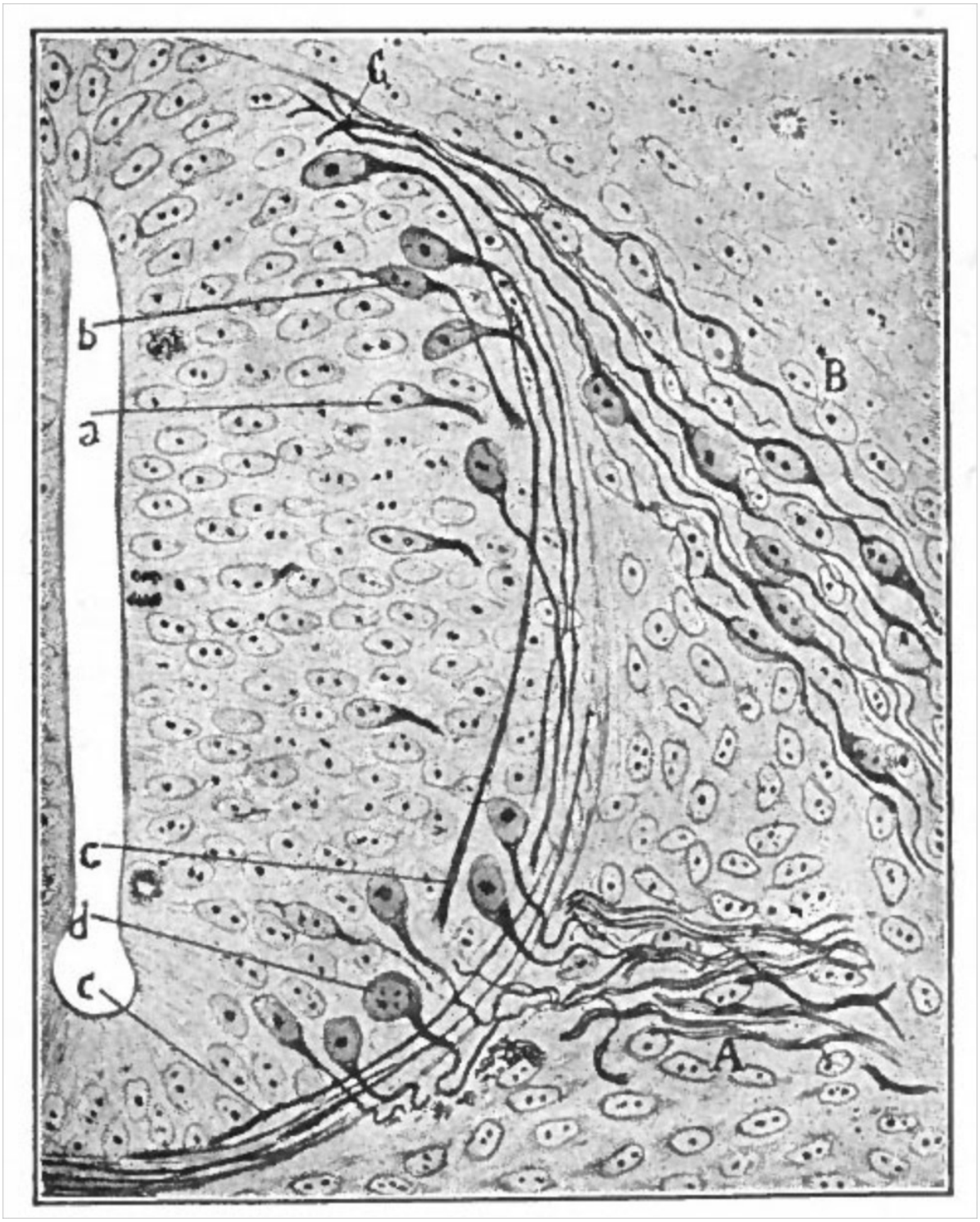


FIG. 392.—Part of a transverse section through the cord and spinal ganglion of a 56-hour chick embryo (combined from two sections). *Cajal.*

In this figure, the bipolar neurons of a developing spinal ganglion are shown above D on the right of the figure; the wall of the spinal cord is on the left of the figure; dorsal rootlets (neurites) are developing near C; Cajal labels B as a growth cone on a neurite.

Blechschmidt's working hypothesis for the form of the bipolar cell is that the shape of the soma is a sign of metabolic–biomechanical tension between the periphery (ectodermal ring) and the centre (dorsal grey matter of spinal cord).

Cajal showed that the spinal ganglion cells retain this form and arrangement of neurites and dendrites in a 76-hour chicken embryo (see figure next below).



The caption for this figure from Bailey & Miller states: "Fig. 403. Part of a section through the lumbar spinal cord of a 76-hour chick embryo. Cajal. A, Ventral root; B, spinal ganglion;

C, bifurcation of dorsal root fibers forming beginning of dorsal funiculus; a, b, c, neuroblasts showing various stages of differentiation into intermediate neurones, some, at least, (c) becoming heteromeric column cells; d, efferent neurone."

At 76 hours, the somas of the spinal ganglion are still bipolar as shown on the right of the figure under B. Later in development, probably with a decrease in metabolic–biomechanical tension between the periphery and the centre, the soma lies slightly to one side of the axis of dendrite and neurite. Still later the soma grows laterally away from the dendrite and neurite, which makes it appear that the dendrite and neurite grow closer together (the cell looks like an octopus missing 6 of its legs). Later still there is a single process that leaves the soma that branches at a T-junction into the peripherally directed dendrite and the centrally directed neurite.

Cajal documents these changes nicely in a single figure (Fig. 393).

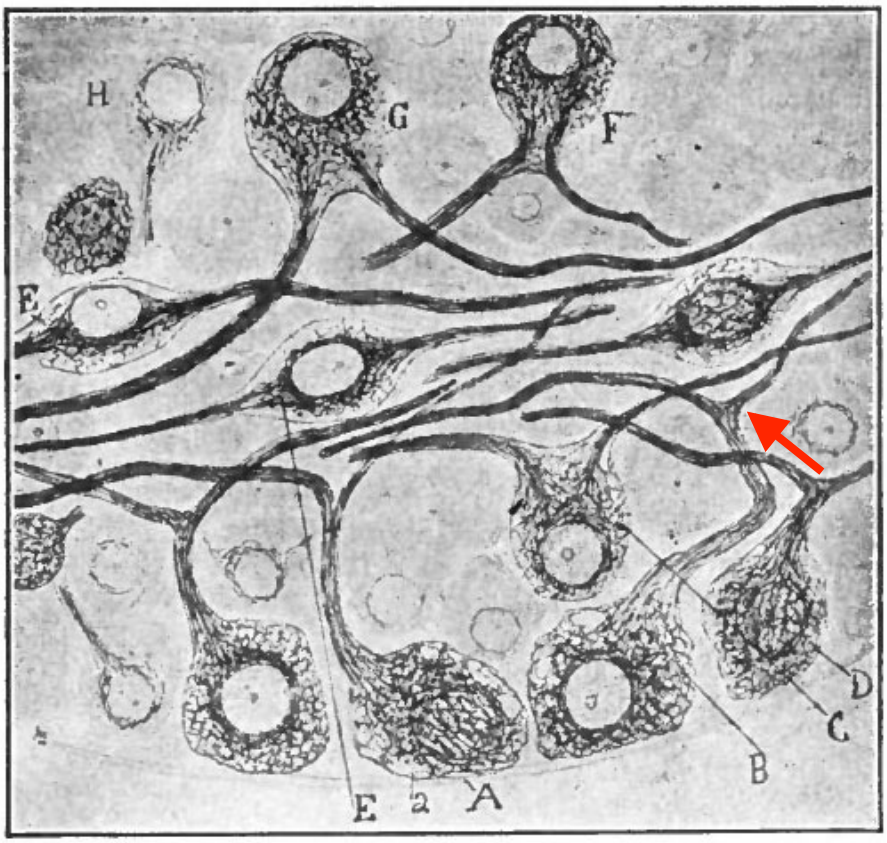


FIG. 393.—Section of spinal ganglion of 12-day chick embryo. *Cajal.*

The caption from Bailey & Miller states: "Fig. 393. Section of spinal ganglion of 12-day chick embryo. Cajal. Showing various stages of the change from the bipolar to the unipolar condition. A,B, Unipolar cells; C, D, F, G, cells in transitional stage; E, bipolar cell; H, immature cell. The neurofibrils are well shown."

There is no information of the orientation of this figure, so we do not know which side represents dendrites and which side neurites. However we can guess the history of changes in the soma as follows: cells at E represents the youngest, bipolar form; C represents a state when the soma grows asymmetrically to one side of the dendrite–neurite junction; G

represents the next stage, then F, and then cell D, where the soma grows a distance from the junction of dendrite and neurite. Cell A may represent an even later stage, and cell B the most mature in the illustration, with the longest distance from the soma to the junction of dendrite and neurite (red arrow). The old term for the common trunk between soma and branch point is *crus commune*; let us use the word *axon* for the present, remembering that unfortunately the term "axon" is also applied indiscriminately to dendrites and neurites.

Cajal described this cell in its mature state as a *unipolar neuron*. To call it "pseudo-unipolar" only brings confusion and makes it harder to explain to students the history of the cell's development.

Why does the soma grow to the side of the line of tension and the shape change from bipolar to unipolar? Blechschmidt's working hypothesis implies that the biomechanical tension between periphery and centre is relieved and that this might allow the soma of the cell to grow asymmetrically to the side of the neurite–dendrite. This relief from tension might arise because the rate of increase of the distance from periphery to centre has decreased.

However the soma cannot grow more than a certain distance away from the dendrite–neurite junction because it is probably constrained by satellite (capsular) cells, which flatten around the large soma of the ganglion cell. Of course, these complexes of soma + satellite cells are confined within the connective tissue capsule of the whole sensory ganglion.

As the ganglion cells mature, the axon growth-elongates within the complex of soma + satellite cells. The axon becomes coiled to a varying degree over the surface of the soma; the arrangement of a coiled axon confined by satellite cells is described as a *glomerulus* or *glomerulum*. Here are 2 pictures from E.A. Schäfer (*Textbook of Microscopic Anatomy*, 1912).

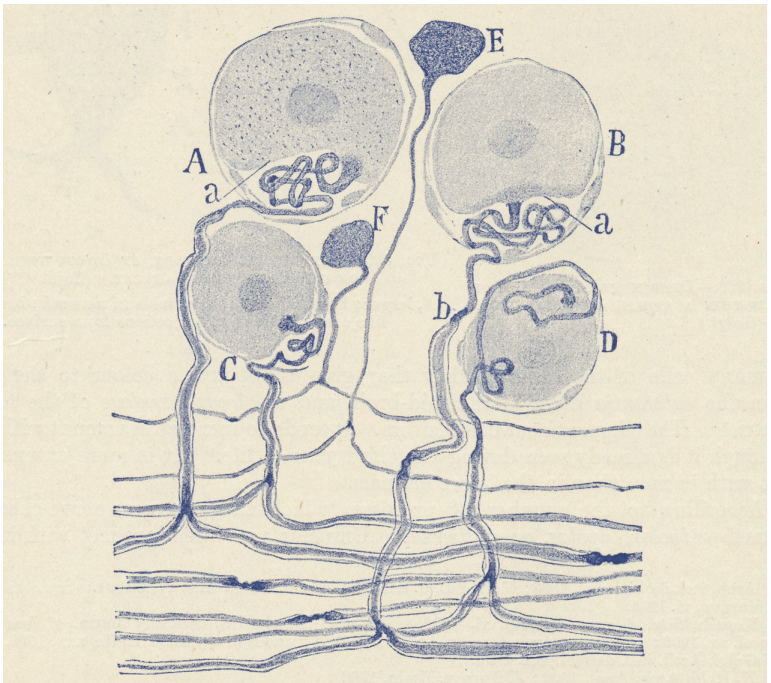


FIG. 341.—CELLS OF VAGUS GANGLION OF CAT. Ehrlich method. (Cajal.)
A, B, large clear cells with axon much convoluted near origin; C, D, smaller clear cells E, F, smallest cells, staining darkly and without convolutions of axon.
a, indented portion of cell-body; *b*, commencement of medullary sheath.

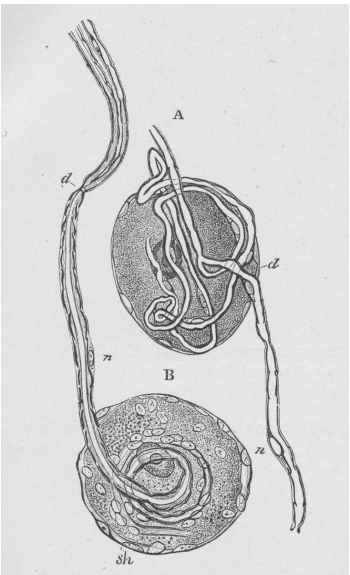


FIG. 342.—TWO NERVE-CELLS FROM A SPINAL GANGLION (HUMAN). (Retzius.)
sh, nucleated sheath; *n*, *n*, nuclei of the primitive sheath of the nerve. From each cell a fibre can be seen to arise, and, after a convoluted course on the surface of the nerve-cell, to bifurcate (opposite *d*); from which point the divisions pass either in the opposite direction to one another, as in A, or at first in the same direction as in B. The nuclei of the sheath of the nerve-cell are all represented in B, but only those seen in profile have been represented in A.

Blechschmidt's working hypothesis for the formation of the twisted axon in the glomerulum (-us) might be something along the following lines. On account of the shell-like nature of the satellite cells, the ganglion cell soma cannot translocate but can only move within the capsule. This movement would cause the axon the elongate between its origin on the soma (= axon hillock), which is moving, and its bifurcation into neurite and dendrite, which is relatively fixed. The folded nature of the axon in cell A & B of Fig. 341 could be explained by an oscillatory movement of the soma (like a pendulum), whereas the axonal spiral in cell B of Fig. 342 could be accounted for by a precessional movement of the soma (like a spinning top).

The majority (but not all) mature spinal ganglion cells exhibit some kind of coiling or convolution of the axon (crus commune).

Lastly, intermediate forms from the earliest bipolar type to the most complex glomerular type (with both axonal folds and coils) can be found in adult spinal and most cranial ganglia. This is seen in the following picture by Cajal, taken from the volume *Sensible Ganglion* by J-H Scharf (1958; *Handbuch der mikroskopischen Anatomie des Menschen*, Vol IV, No. 3, p. 201) – here cell B represents the early form and cell A, the most common mature form of the soma.

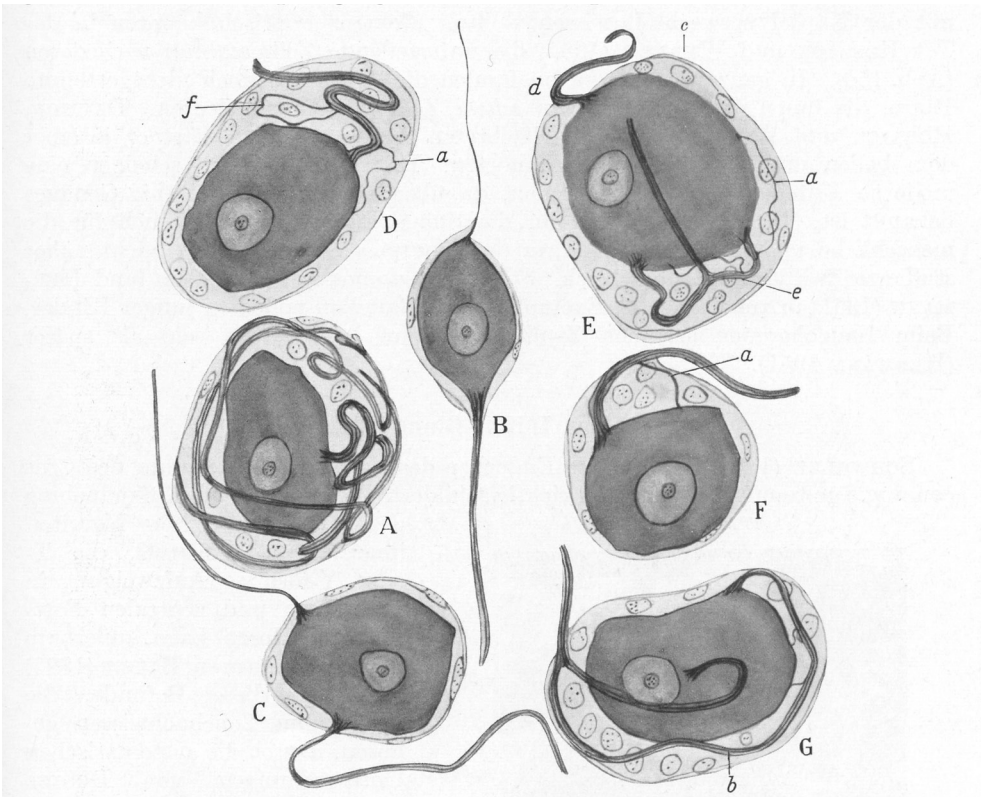


Abb. 151. Verschiedene Typen sensibler Perikarya aus dem Ganglion nodosum (plexiforme) vagi vom *Menschen*. *A* normaler pseudounipolarer Typ mit Glomerulum; *B*, *C* bipolare Elemente; *D*, *E*, *F*, *G* gefensterte Zellen; *a* dünne Zellfortsätze, die in den Neuriten einstrahlen; *b* Nebenneurit, der durch dünne Plasmabrücken mit dem Perikaryon verbunden bleibt, bevor er den Hauptneuriten erreicht; *c* Kapsel; *d* Hauptneurit; *e* Pseudodendriten, die später zum Hauptneuriten ziehen; *f* Pseudokollaterale des Neuriten. Nach Silberimprägnationspräparaten. (Aus Ramón y Cajal 1907.)

Why do vestibular and cochlear ganglion cell somas remain bipolar?

Like the spinal ganglion cell, the cell body in the ganglia of the vestibular and cochlear divisions of CN-8 starts life as bipolar, with a peripheral dendrite and a central neurite. Glomeruli do not appear to exist in the ganglia of CN-8. In some cases the myelin sheath appears to continue over the cell soma between dendrite and neurite (Scharf, 1958, p. 283).

Hypotheses for why the bipolar state continues throughout life in ganglia could be the following, singly or in combination:

(i) Metabolic–biomechanical tension might be maintained for a longer period, relative to the spinal ganglion, due to the spiral growth of the cochlear duct. The biomechanical tension between the periphery (organ of Corti) and the centre (brainstem) is not relieved until the surrounding tissues become semi-rigid (otic capsule). This explanation would also apply to the vestibular ganglion cell if there were sufficient continual traction between the sensory organs of saccule, utricle and ampullae and the brainstem as the head widens.

(ii) The behaviour of the satellite (capsule cells) in the spiral ganglion and in vestibular ganglia could be different to the behaviour in the spinal ganglion, such that the satellite cells in CN-8 ganglia impede the growth and displacement of the soma.

(iii) Early on, the somas of the ganglion cells of CN-8 become partially confined within compartments in the cartilage of the otic capsule. This partial confinement in dense connective tissue (which soon ossifies) represents a greater biomechanical restriction, compared to the collagenous framework of the spinal and other cranial ganglia. The vestibulocochlear somas have less spatial opportunity to grow to the side of the line of tension between their dendrites and neurites (no octopus-like somas).

The working hypotheses above suggest that the following small research projects, to compare spinal ganglia and CN-8 ganglia, might yield fruit:

1. Check for the presence of the glomerulum in ganglia of CN-8.
2. Compare properties of satellite cells: spinal *vs.* CN-8.
3. Measure ganglion cell density and compartment volume: spinal *vs.* CN-8.
4. Measure ganglion cell soma volume: spinal *vs.* CN-8.
5. Measure rate of increase of distance from periphery to centre in embryos and fetuses: spinal *vs.* CN-8.

Some of the information may already be available in the scientific literature, possibly even for human ganglia.
