THE RELATION BETWEEN THE SCHWANN CELL AND THE AXON IN PERIPHERAL NERVES

By G. CAUSEY and H. HOFFMAN*
Department of Anatomy, Royal College of Surgeons of England

The very close relationship between the Schwann cell and the nerve cell process has been long recognized. Nageotte (1932) sums up the position: 'It (the Schwann cell) maintains singularly close anatomical and physiological relations with the neurite but, in this synthesis, the two protoplasms always remain distinct.' The nomenclature, however, as applied to the optical demonstration of stained sections, is by no means clear, its complexities have been discussed fully by Young (1942).

Electron-microscopic examination of thin sections has further emphasized this very close relationship. Gasser (1952) demonstrated the non-myelinated fibres running in the cytoplasm of the Schwann cell and connected to the surface of the Schwann cell by a 'mesaxon'. Hess & Lansing (1953) showed small myelinated fibres running in the Schwann cytoplasm, and Causey & Hoffman (1954) demonstrated these relationships in both normal and regenerating material. Geren (1954) reported a detailed examination of the relationship between the Schwann cell membrane and the myelin in the chick embryo. Gasser has recently published (Gasser, 1955) an extensive investigation of the structure and function of non-myelinated fibres in the dorsal roots of the cat.

The present paper is concerned particularly with the relationship of the Schwann cell and the non-myelinated fibres in normal nerves of the rat.

MATERIAL AND METHOD

The material illustrated is taken from the vagus nerve in the neck and from the lumbar dorsal roots of adult rats, anaesthetized with Nembutal. The material was fixed for 4 hr. in 1% osmium tetroxide, with veronal buffer pH 7·2–7·4 at 4° C. Embedded in methacrylate and cut at 200–400 A.U. The methacrylate was not removed, and the specimens were examined in a Metropolitan Vickers EM4, with 50 μ objective aperture.

RESULTS

In the normal vagus nerve the myelinated fibre is surrounded by a sheath of Schwann protoplasm. This sheath may be very thin in the parts of the internode between the Schwann nucleus and the node of Ranvier, such a region is seen in a myelinated fibre in Pl. 1, fig. 1. Throughout the length of the Schwann cell it is surrounded by a double-layered limiting membrane, which surrounds and delimits the whole axon, myelin, Schwann cell complex. As Cajal (1909) said: 'La membrane de Schwann doit être considérée, au point de vue histologique comme une véritable membrane cellulaire.'

* Prophit Research Fellow of the Royal College of Surgeons of England.

Between the myelinated fibres are bundles of non-myelinated fibres. There are single fibres, but most are aggregated together in collections of anything up to twelve or fourteen fibres, but whether there be one fibre or many the whole is contained within the cytoplasm of a Schwann cell. The area between the Schwann cell units, whether these contain one myelinated fibre, one non-myelinated fibre or a number of non-myelinated fibres, contains only bundles of collagen fibres.

The same general relations are seen in the dorsal root (Pl. 2, fig. 4) except for two points. First, the bundles of non-myelinated fibres, although contained in similar Schwann cytoplasm units, are less distinctly demarcated from each other and secondly, and probably also explanatory of the first, there is apparently less collagen between the bundles. In both Pl. 1, fig. 1, and Pl. 2, fig. 4, the double structure of the limiting membrane is seen, with the two electron dense lamellae.

Some of the detail of the relationship between the non-myelinated fibres and the Schwann cells is shown in figs. 2–6. Fig. 2 shows the axon in a depression on the surface of the Schwann cell, the fibre is incompletely enveloped by the cell membrane and there is no mesaxon: it seems probable that this appearance is associated with the fibre entering or leaving a Schwann cell. In Pl. 1, fig. 3, invagination is complete, but the mesaxon is short. The double-layered membrane around the axon is made up of one lamina continuous round the axon and the other formed by the inner layer of the double limiting membrane of the Schwann cell. The mesaxon is formed by the juxta-position of the invaginated inner layer of the Schwann limiting membrane, the continuity of the outer layer of the cell membrane being re-established. Pl. 2, fig. 5, shows a longer, two-layered mesaxon from the Schwann surface to the small nerve fibre. Here again the two laminae of the mesaxon are resolved.

In Pl. 2, fig. 6, the two-layered mesaxon has formed a second double layer round the nerve fibre. The complexity of these attachments becomes more marked when a number of the fibres are held close together within one Schwann cell, as can be seen in Pl. 1, fig. 1, but the basic pattern of a Schwann cell with two dense layers in the cell membrane, an axon with two dense layers in its limiting membrane and a mesaxon consisting of two dense layers only, is observed constantly.

DISCUSSION

The intimate enfolding of all the nerve fibres within a Schwann cell cytoplasm seems to be quite constant. It might be expected that when a nerve fibre is enfolded by or invaginates a Schwann cell a fold in the Schwann cell membrane would give rise to four electron dense laminae, but this fourfold mesaxon has never appeared in our material, there always seems to be a reformation of the outer layer of the Schwann cell membrane leaving only the inner layer thereof involved in the mesaxon. This outer layer has been called by Gasser (1955) a basement membrane. Geren (1954) also shows a double-layered mesaxon, but suggests that this attachment is formed in the chick embryo from a single-layered Schwann cell membrane. An observation that is perhaps pertinent to this subject has been reported elsewhere (Causey & Hoffman, 1955) in that, when the dorsal root ganglion cell is surrounded by the cytoplasm of a satellite cell, there are not four but two laminae in the resulting limiting membrane between the ganglion cell and its supporting cell, although adjoining satellite cell cytoplasms are separated by four lamellae.

Examination of the enfolding of an axon by the Schwann cell has shown very large numbers of partially enclosed fibres (similar to that shown in Pl. 1, fig. 3) in a sort of funnel-shaped depression. It may be that this is a very short part of the fibre as it sinks into or leaves the Schwann cell, or that at an early stage the length of the fibre continues in this sort of relation along the surface of the Schwann cell. The impression gained is that the former is the case, but the question cannot be really elucidated until large numbers of serial sections can be examined. It is, however, of some interest that in the large amount of material that has been examined there has not been a single fibre that could definitely be shown to be without any intimate contact with, or covering by, Schwann cell cytoplasm, emphasizing once more the complete interdependence of the peripheral nerve fibre and the Schwann cell.

SUMMARY

1. The relationship of Schwann cell and nerve fibre in electron micrographs has been examined.

2. The presence of an attachment or mesaxon between the Schwann cell surface and the nerve fibre is confirmed.

3. The detailed relationship between the lamellae in the surface membranes of the Schwann cell, nerve fibre and mesaxon are shown.

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EXPLANATION OF PLATES

PLATE 1

Fig. 1. Normal vagus nerve of the rat fixed in buffered osmium tetroxide. Two bundles of non-myelinated fibres as well as parts of myelinated fibres and single non-myelinated fibres. *s.m.*, surface membrane of Schwann cell; *m.*, mesaxons.

Fig. 2. Surface invagination of a Schwann cell by a non-myelinated fibre '*a*'. *s.m.*, Schwann membrane; *m.*, mesaxons going to a more deeply placed fibre.

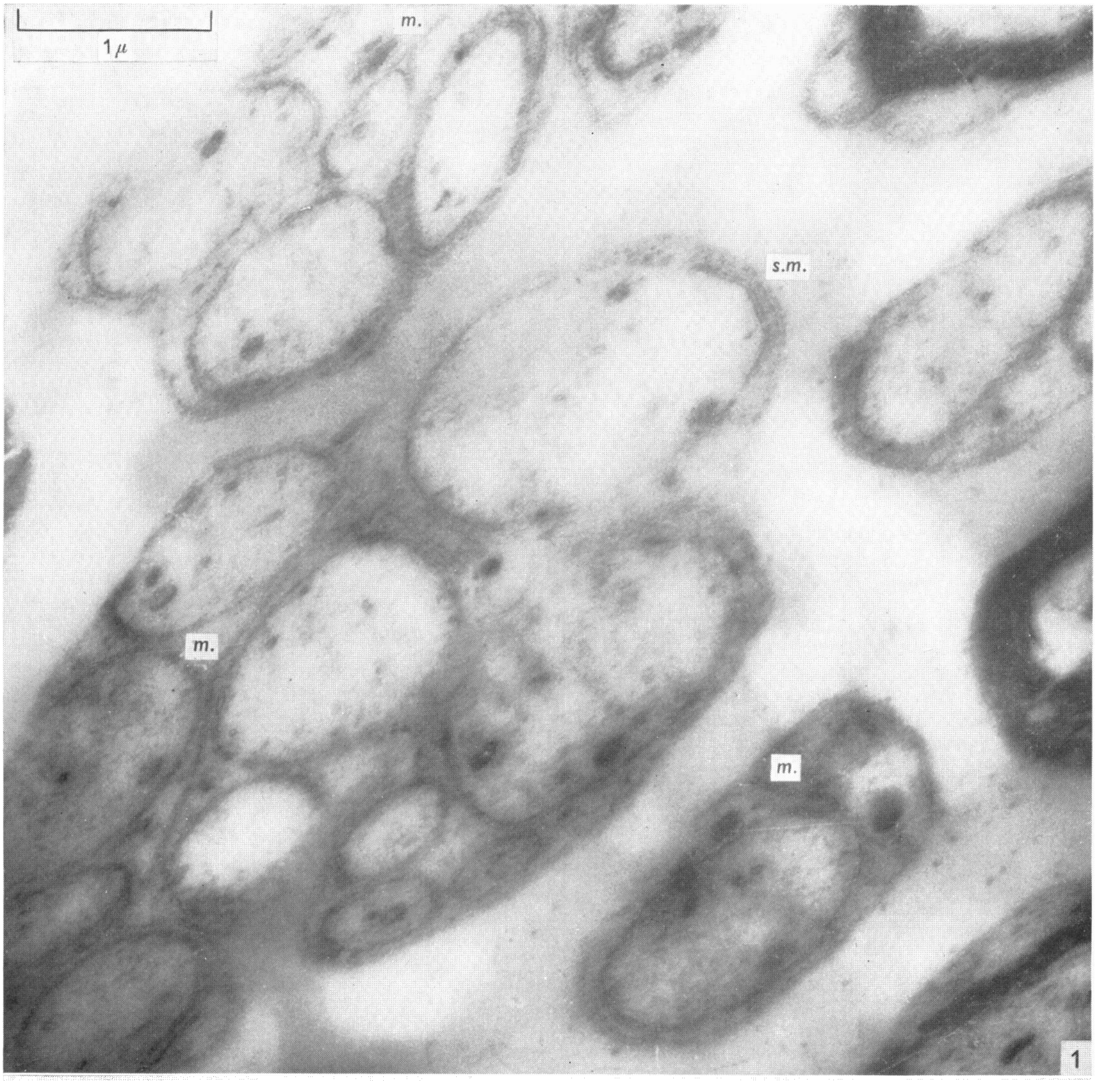
Fig. 3. Short mesaxon to a non-myelinated fibre. *a.*, axon; *s.m.*, Schwann membrane; *i.s.m.*, inner layer of Schwann membrane forming a mesaxon.

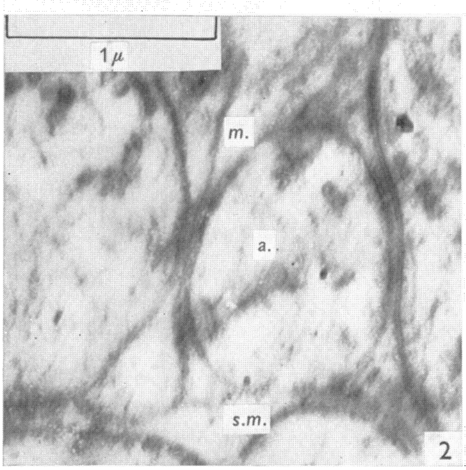
PLATE 2

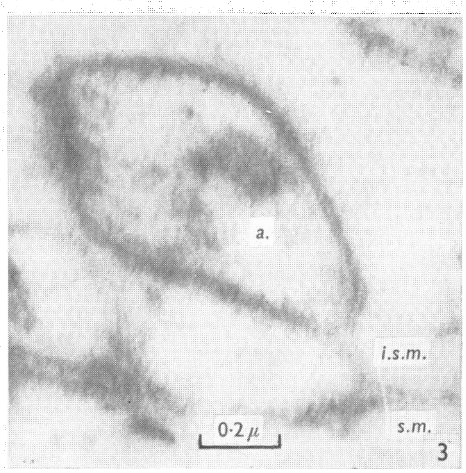
Fig. 4. Dorsal nerve root of the rat. The edge of a myelinated fibre with surrounding Schwann cell cytoplasm is seen at the bottom left. A bundle of non-myelinated fibres inside the Schwann cell fills the rest of the field. *s.m.*, Schwann membrane; *f.*, funnel-like invagination; *m*, mesaxons.

Fig. 5. Two non-myelinated fibres within Schwann cell cytoplasm. An elongated mesaxon is shown at '*m*'.

Fig. 6. Two coils of mesaxon '*m*' round an axon within the Schwann cell cytoplasm.







CAUSEY AND HOFFMAN—RELATION BETWEEN SCHWANN CELL AND AXON IN PERIPHERAL NERVES

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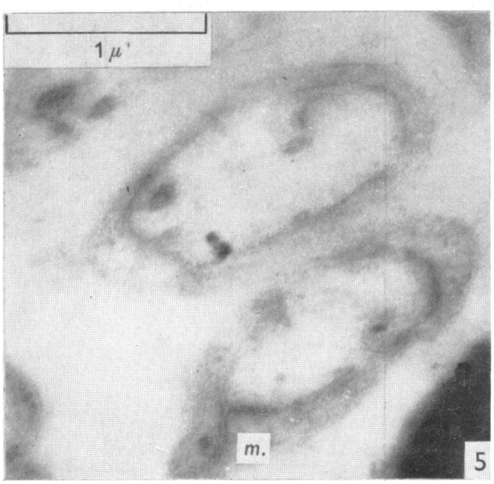

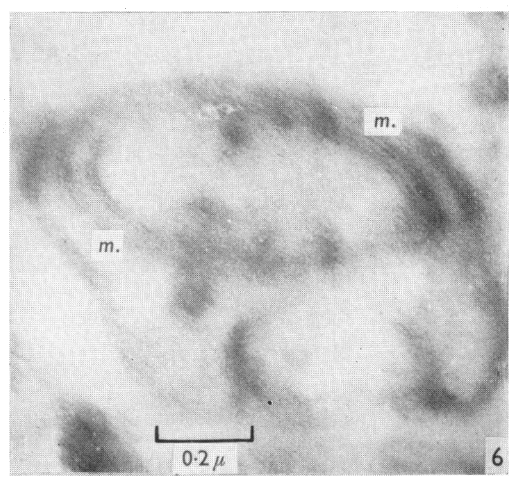

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