

J. Physiol. (1955) 129, 167-176

THE DISTRIBUTION OF MYELIN ON NERVE FIBRES FROM PACINIAN CORPUSCLES

BY T. A. QUILLIAM AND M. SATO*

From the Departments of Anatomy and Physiology, University College London

(Received 20 January 1955)

Gray & Sato (1953) recorded potentials from nerve fibres at the points where they left Pacinian corpuscles; when the Pacinian corpuscles were stimulated mechanically, they observed potentials which had three phases. The first of these phases, called the receptor potential, was graded to the stimulus strength, while the second and third phases represented diphasic impulse activity. On indirect evidence they assumed that the site of recording lay between the 'non-myelinated' terminal and the first node of Ranvier, and consequently that the receptor potential and the second phase were generated in the 'non-myelinated' terminal, while the third phase originated from the first node of Ranvier.

It is surprising that comparatively little is known about those histological features of the nerve fibre, which are necessary for the full interpretation of the potentials mentioned above; this, in spite of the fact that the presence of Pacinian corpuscles was first detected over two centuries ago (Lehmann, 1741) and that their histological appearance has been described in considerable detail on a number of occasions during the last 120 years (Pacini, 1835, 1840; Henle & Kölliker, 1844; Todd & Bowman, 1845; Stöhr, 1928; etc.). An attempt has, therefore, been made to describe the myelination of nerve fibres from Pacinian corpuscles.

METHODS

Twenty-two Pacinian corpuscles with their nerve fibres were dissected from the mesenteries of adult cats (body weights 1.6-3.5 kg), using the technique described by Gray & Sato (1953). In four of these specimens, a number of the laminated connective tissue layers of the corpuscle were removed in order that the fibre lying inside might be more clearly visible after staining.

Most of the specimens were then placed in osmic acid (0.5% in normal saline) for 30 min. After dehydration in ascending concentrations of alcohol, the material was cleared in cedarwood oil and mounted on glass slides in canada balsam. In a few instances the gold chloride staining technique

* Present address: Department of Physiology, Kumamoto University College of Medicine, Kumamoto, Japan.

of Ranvier, as modified by Carey (1941), was used, and this proved to be particularly suitable for displaying the intra-corporcular endings.

A complete photomicrograph ($\times 350$) was made of each preparation. Most of these were 0.7 m in length but others were much longer. The exact sites of the nodes of Ranvier were confirmed microscopically by reference to the original specimens. Each internode in every specimen was examined, and measurements of internodal lengths and diameters were made. The diameters proved to be somewhat variable in any one internodal region and so a maximum, a minimum and an intermediate value were obtained by both authors working separately; the intermediate value was that of a part of the internode which appeared typical; six figures were thus obtained, and the mean of these six was recorded. The absolute magnification of each photomicrograph was checked against a micro-scale.

General description

RESULTS

The Pacinian corpuscles were usually ellipsoid in shape, and each was supplied by a single myelinated nerve fibre; this fibre entered at the proximal pole and then passed along the major axis of the corpuscle (Pl. 1, fig. 1). In the first quarter of its intracorporcular length the fibre took a tortuous course and was clearly myelinated, but the outline of the myelin was much less regular than elsewhere. At the end of this section the axon entered what is best described as the central core of the corpuscle (see Pl. 1, fig. 4), and at this point the fibre became very much thinner, more lightly stained and quite straight (Pl. 1, figs. 2, 3). It then passed in the longitudinal axis of the corpuscle to the distal extremity of the central core. Here the fibre frequently bifurcated, each branch ending in a small swelling (Pl. 1, figs. 4, 5).

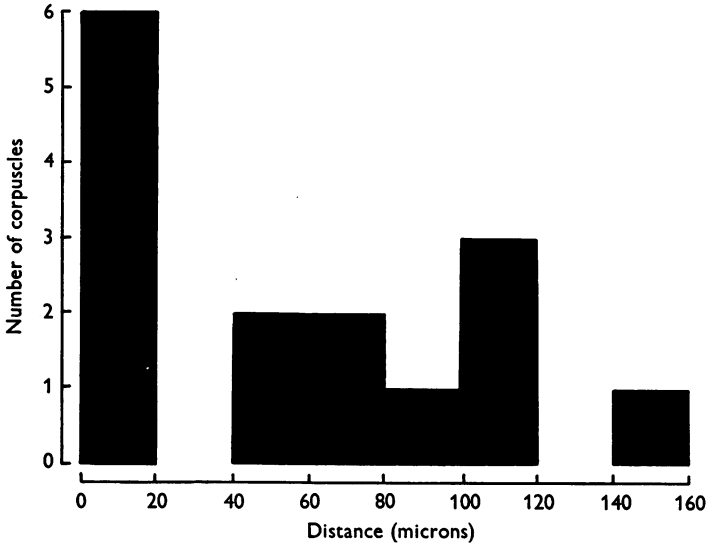
The fibre outside the corpuscle

This had the appearance of a conventional mammalian myelinated nerve fibre (Ranvier, 1878) and was surrounded by a sleeve of connective tissue some 20μ in diameter. This sleeve was continuous with a similar structure inside the corpuscle which in its turn blended with the material forming the central core (Pl. 1, fig. 2). A number of the nodes of Ranvier observed did not manifest all the morphological criteria enunciated by Hess & Young (1952). Usually, however, there was little difficulty in locating the exact position of the nodes under the microscope.

A node of Ranvier was always identified lying just outside the corpuscle (Pl. 1, fig. 2) and, since the distance of this structure from the margin of the corpuscle was of considerable importance in the interpretation of potentials recorded from this region, special attention was paid to its whereabouts. In fifteen specimens, the distance of this first node from the corpuscle varied between 0 and 150μ (mean value 53μ), but in only one specimen did this figure exceed 150μ and in six cases it was less than 20μ . The actual measurements are summarized in Text-fig. 1.

The first internode lying entirely outside the corpuscle was measured in each of twelve specimens, and it was found that the total diameter of the fibre

(axoplasm plus myelin sheath) varied from 4.1 to 6.9 μ (mean value 5.8 μ , s.d. about mean, 0.8), whilst the length of the internode ranged from 144 to 496 μ (mean value 285 μ , s.d. 85.)



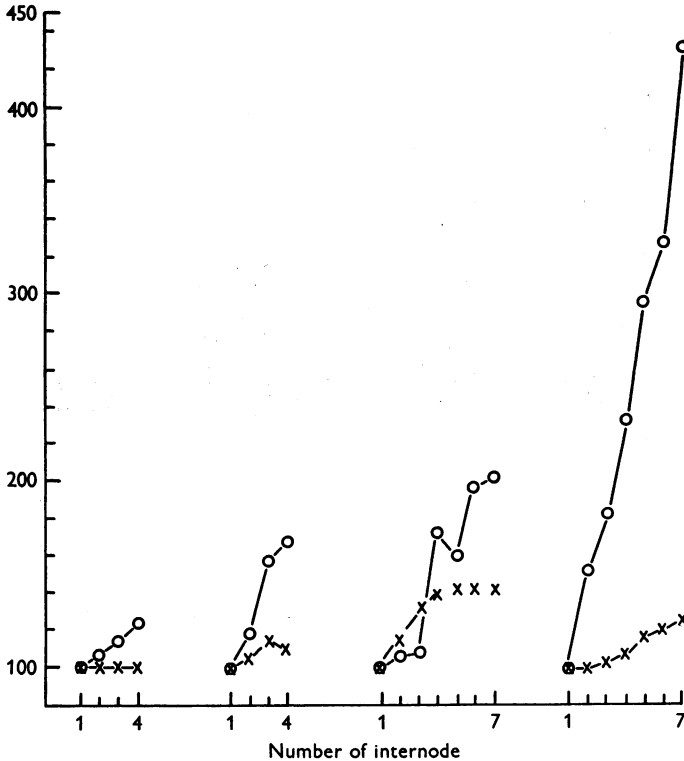
Text-fig. 1. Frequency distribution of the distance between the margin of the corpuscle and the first extra-corporeal node.

In several specimens the fibre was dissected for several millimetres, and it was possible to measure, in each, a number of successive internodes. The nodes of Ranvier were found at more or less regular intervals along each fibre, but in every preparation there was a tendency for the more proximal internodes to be longer without being appreciably wider. The results from four typical specimens are shown in Text-fig. 2. Similar changes in internode length near the termination of nerve fibres in the skin plexuses of fishes and frogs have been observed by Whitear (1952).

The relationship between internode length and fibre diameter was examined in twenty-eight internodes derived from seven specimens in each of which four successive internodes were studied. There is a wide scatter in the values of the internode lengths and a smaller range of variation in the diameter measurements (see Text-fig. 3). On the whole, the fibres which had the larger diameters possessed the longer internodes. The correlation coefficient between internode length and diameter is 0.59 and this is significant by Student's *t* test, the probability lying between 0.001 and 0.01%. The regression equation of the internode length on the diameter is

$$L = 115d - 283,$$

where L represents internode length in μ and d diameter in μ . The standard error of the regression coefficient (i.e. the index of slope) is 32. The correlation of internode length and diameter is not close, nor, indeed, would it be expected to be, as there is a relation between internode length and the position of the internode (with reference to the corpuscle) a relation not accompanied by a



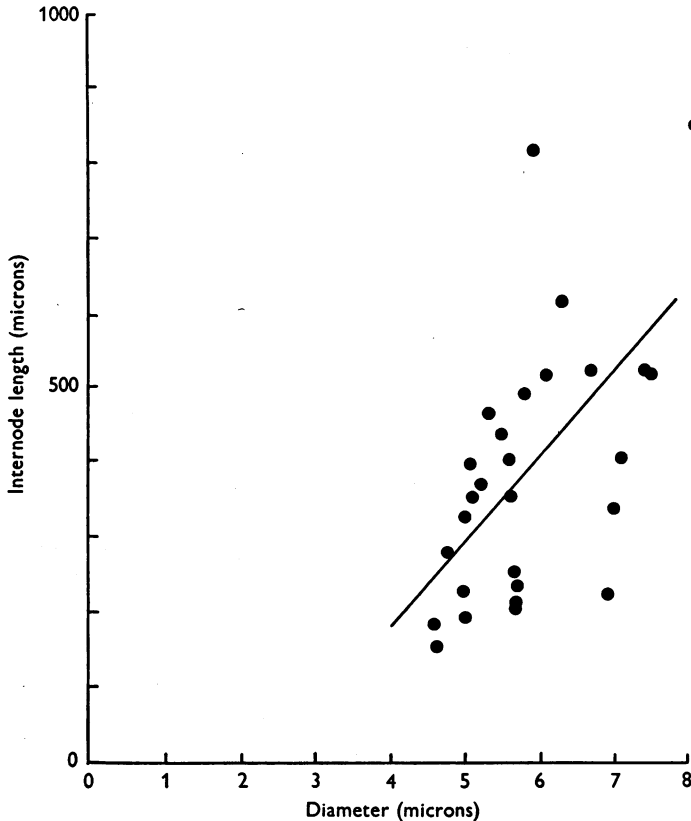
Text-fig. 2. Relation of internode length and fibre diameter to the number of the internode, counting centrally and starting with the first completely extra-corporal internode. Ordinate: dimensions of length of internode (circles) and fibre diameter (crosses) as a percentage of those of the first internode of each preparation, which were: (a) 205, 5.7 μ ; (b) 280, 4.8 μ ; (c) 495, 5.8 μ ; (d) 223, 6.9 μ . Abscissa: number of internode.

corresponding change of fibre diameter (Text-fig. 2). The length of internodes is influenced by the amount of growth of the region after myelination (Vizoso & Young, 1948). It is not easy to forecast how such growth factors would influence the internode length in the present case.

The fibre inside the corpuscle

The convoluted segment. For the first quarter of its intra-corporal course the fibre was tortuous and irregular in outline. Measurements were thus difficult to make accurately, but in any one specimen the diameter of this part of

the fibre was approximately the same as that outside the corpuscle. In some instances that part of the fibre inside varied more in diameter than the part outside the corpuscle; for example, in one specimen in which this variation was especially well marked the apparent diameter of the fibre in the convoluted segment varied between 14.5 and 5.7μ , whereas along the first extra-corporeal internode the same fibre had a mean diameter of 6.8μ (range $5.7-8\mu$).



Text-fig. 3. Relation of internode length to diameter in seven nerve fibres from Pacinian corpuscles; four successive internodes measured in each fibre. Ordinate: internodal length (microns). Abscissa: diameter (microns). Regression equation $L = 115d - 283$.

The most interesting feature in this region was the presence of a gap in the myelin sheath located roughly mid-way between the first extracorporeal node and the beginning of the terminal segment (Pl. 1, fig. 2). In nine specimens, the distance between this node and the gap varied between 175 and 430μ (mean 247μ , s.d. 68). The distance between the gap and the beginning of the terminal segment of the fibre ranged from 140 to 452μ (mean value 247μ , s.d. 86) (see fig. 4).

Whether these discontinuities in the myelin sheath of the fibre were nodes of Ranvier or were artifacts was a question of special interest and importance. The only other non-traumatic deficiencies in the myelin coat described as occurring regularly in normal nerve fibres are the incisures of Schmidt-Lantermann, and these are different in shape and periodicity from the structures under discussion. Since these gaps were seen through a number of connective tissue lamellae, which might produce some optical distortion, some of the lamellae were removed before staining; a photograph of a typical gap from such a preparation is shown in Pl. 1, fig. 6. It will be seen that these gaps in the myelin are similar in shape to nodes of Ranvier. Their general appearance and their regular presence about half way along the tortuous part of a fibre strongly suggests that they were, in fact, nodes of Ranvier.

The terminal segment. At the point at which the fibre entered the central core of the corpuscle, it suddenly became narrower. No branching was detected to account for this change in diameter. Hitherto it has been generally assumed (e.g. Stöhr, 1928) that the myelin sheath is lost at this point and that this loss accounts for the change in diameter. Our results show that the terminal portion possesses a weakly osmiophilic sheath without any nodes or other gaps.

The terminal segment was straight and lay in the longitudinal axis of the corpuscle in the middle of its central core. There were no marked or sudden changes in diameter along its entire course nor were there any structures resembling nodes of Ranvier. In some specimens it was possible to measure this terminal part of the nerve fibre; the mean length was about 600μ and the mean diameter about $2-3\mu$; in one particular example the diameter varied between 2.8 and 5μ , while the mean diameter of the fibre outside the corpuscle was 6.4μ .

At the distal end of the central core, the fibre usually bifurcated. The branches so formed were about $50-100\mu$ in length and each ended in a rounded osmiophilic swelling of about $8-12\mu$ in diameter.

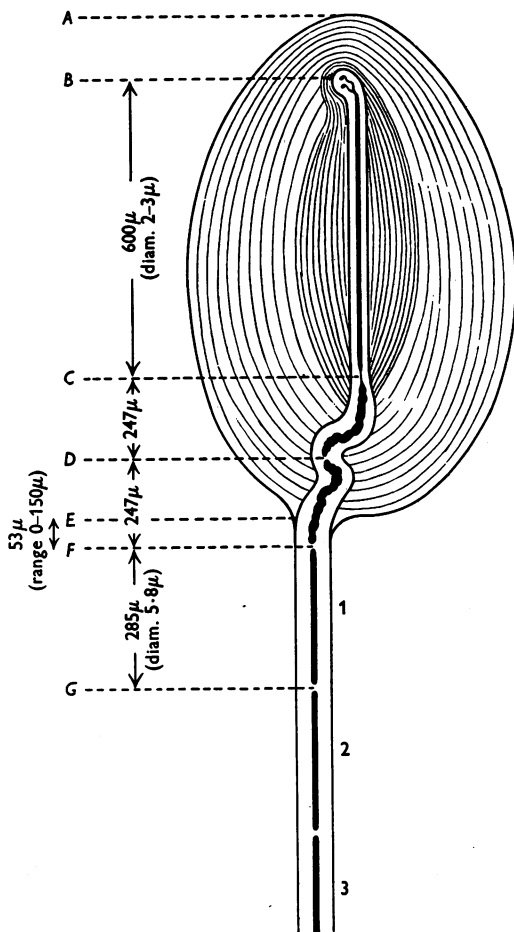
The dimensions of the corpuscle

The length of eighteen corpuscles stained by osmic acid (not chosen as a random sample) varied between 0.46 and 1.55 mm (mean value 1.02 , s.d. 0.24 mm) and their breadth ranged from 0.33 to 1.13 mm (mean value 0.67 , s.d. 0.31 mm). These figures were in substantial agreement with those of Henle & Kölliker (1844), who examined unstained Pacinian corpuscles from adult men. They found that these structures varied from 0.8 to 1.2 mm in length and from 0.45 to 0.6 mm in breadth. Sometimes, however, small corpuscles, which were less than a quarter of the average size, were seen.

Todd & Bowman (1845) stated that larger corpuscles were supplied by larger fibres. Our results confirm this statement in general, there being a positive

correlation of 0.5 between fibre diameter and length of corpuscle ($0.01 < P < 0.05$). The correlations between other dimensions and fibre diameter or inter-node length were similar.

The measurements obtained in the present study are summarized in the diagram in Text-fig. 4.



Text-fig. 4. Diagram of a typical Pacinian corpuscle.

DISCUSSION

It is generally agreed that, of the routine myelin staining techniques, osmic acid causes the least transverse shrinkage and that this is less than 10%, (Sherrington, 1894; Duncan, 1934; Rexed, 1944). The largest source of error in these measurements of fibre diameters was the irregularity of the outline (cf. Eccles & Sherrington, 1930; Barnes, 1932; Hursh, 1939), but there is no

reason to suppose that any systematic error was introduced from this cause. It thus seems reasonable to suppose that the mean values of diameter approximate to those in life.

Longitudinal shrinkage of nerve fibres during staining processes has been little studied, but it has been shown that normal and regenerating sural nerve trunks may shrink by about 20% of their original length during preparation for staining (Quilliam, 1954). At least half of this diminution occurs during the cutting of the long nerve trunk into segments of a convenient length and embedding in paraffin wax. Since these procedures were not employed in the present work it is thought unlikely that the fibres of the Pacinian corpuscles shrank by more than 10% of their extent *in vivo*. Whilst this would affect the absolute values of internode lengths, comparison between individual specimens would not be affected.

Previous quantitative studies of fibres innervating Pacinian corpuscles are both scanty and incomplete. Thus Gernandt & Zotterman (1946), using Alzheimer Mann stain modified by Rexed (1944), found that the diameters of these fibres in the mesenteric nerve trunk varied between 6 and 10 μ , and Glees, Mohiuddin & Smith (1949), using a variety of stains, recorded a diameter range of from 8 to 10 μ . Both these figures are slightly in excess of those mentioned in the present study, but in both the older accounts the nerve fibres were measured farther away from the Pacinian corpuscle than in the present experiments; the apparent discrepancy in diameter may therefore be due either to a tapering of the fibres towards their ends or to differences in the staining techniques used.

The first extracorporeal node usually lay within 0.1 mm of the margin of the corpuscle, and the next node was located approximately 0.3 mm further in a central direction. Gray & Sato (1953) recorded from a 0.25 mm length of the nerve fibre and placed the preparation so that this recording length was as close as possible to the corpuscle; it appears that, in nearly all preparations, their recording length must have effectively coincided with the first completely extra-corporeal internode, i.e. between *F* and *G* in Text-fig. 4. This being so, the peak of the second phase of the potential they describe must have been due to activity at the first extracorporeal node (*F* in Text-fig. 4), and the peak of the third phase to activity at the second extracorporeal node (*G* in Text-fig. 4). The conclusion reached by Gray & Sato (1953) that both the receptor potential and the second phase of the complete potential were due to activity of the 'non-myelinated' terminal must therefore be rejected.

SUMMARY

1. Pacinian corpuscles and their nerve fibres were dissected from the mesentery of the small intestine of cats and stained either with osmic acid (0.5%) or by a gold chloride method.

2. A node of Ranvier was invariably present on the fibre just proximal to its point of entry into the corpuscle (mean distance from corpuscle 53μ , range 0–150 μ).

3. The first internode situated completely outside the corpuscle had a length between 144 and 496 μ (mean 285 μ , s.d. 85), whilst the diameter of the fibres in this segment ranged from 4.1 to 6.9 μ (mean 5.8 μ , s.d. 0.8). The inter-nodal lengths usually increased centrally.

4. In the proximal part of the corpuscle the fibre followed a tortuous course and was of irregular outline; a node of Ranvier was identified approximately half way along this part of the fibre.

5. On entering the central core of the corpuscle, the fibre became narrower, straight and fairly uniform in calibre but retained a weakly osmiophil sheath. The fibre ended some distance from the distal extremity of the corpuscle, frequently by bifurcation; each branch ended in a small terminal swelling 8–12 μ in diameter.

6. The corpuscles varied from 0.46 to 1.55 mm (mean 1.02 mm \pm 0.24) in length and from 0.33 to 1.13 mm (mean 0.67 mm \pm 0.31) in breadth.

We are very grateful to Dr J. A. B. Gray for his encouragement and advice throughout this study. We are also indebted to Miss Rose Smith and Mr D. Botheral for technical assistance.

REFERENCES

- BARNES, T. C. (1932). The significance of fibre diameter in the sensory nerves of the crustacean limb. *Amer. J. Physiol.* **100**, 481–486.
- CAREY, E. J. (1941). Experimental pleomorphism of motor nerve plates as a mode of functional protoplasmic movement. *Anat. Rec.* **81**, 393–413.
- DUNCAN, D. (1934). A determination of the number of nerve fibres in the eighth thoracic and the largest lumbar ventral roots of the albino rat. *J. comp. Neurol.* **59**, 47–60.
- ECCLES, J. C. & SHERRINGTON, C. S. (1930). Numbers and contraction values of individual motor units examined in some muscles of the limb. *Proc. Roy. Soc. B*, **106**, 326–357.
- GERNANDT, B. Z. & ZOTTERMAN, Y. (1946). Intestinal pain: electrophysiological investigation on mesenteric nerves. *Acta. physiol. scand.* **12**, 56–72.
- GLEES, P., MOHIUDDIN, A. & SMITH, A. G. (1949). Transplantation of Pacinian bodies in the brain and thigh of the cat. *Acta anat.* **7**, 213–224.
- GRAY, J. A. B. & SATO, M. (1953). Properties of the receptor potential in Pacinian corpuscles. *J. Physiol.* **122**, 610–636.
- HENLE, F. G. J. & KÖLLIKER, A. (1844). *Über die Pacinische Körperchen an den Nerven des Menschen und der Säugethiere*. Zurich: Meyer & Zeller. Abstracted by *British and Foreign Medical Review*, 1845, **19**, 78–83.
- HESS, A. & YOUNG, J. Z. (1952). The nodes of Ranvier. *Proc. Roy. Soc. B*, **140**, 301–320.
- HURSH, J. B. (1939). Conduction velocity and diameter of nerve fibres. *Amer. J. Physiol.* **127**, 131–139.

- LEHMANN, J. G. (1741). *Dissertatio inauguralis medica de consensu partium corporis humani occasione spasmi singularis in manu eiusque digitis ex hernia observati; exposito simul nervorum brachialium et cruralium coalitu peculiari atque papillarum nervearum in digitis dispositione.* Vitembergae.
- PACINI, F. (1835). *Proc. Florentine Med. Phys. Soc.* 22 November. Reprinted in *Sperimentale*, 1924, 78, 275.
- PACINI, F. (1840). *Nuovi organi scoperti nel corpo umano.* Pistoja.
- QUILLIAM, T. A. (1954). The determination of nerve fibre diameter. Ph.D. Thesis, University of London.
- RANVIER, L. A. (1878). *Leçons sur l'histologie du système nerveux.* Paris: Savy.
- REXED, B. (1944). The post natal development of the peripheral nervous system in man. *Acta psychiat., Kbh.*, Supplementum 33.
- SHERRINGTON, C. S. (1894). On the anatomical constitution of nerves of skeletal muscles. *J. Physiol.* 17, 211-258.
- STÖHR, P. (1928). *Möllendorfs Hb. d. mikr. Anat. IV, Nervensystem I Teil.* Berlin: Springer.
- TODD, R. B. & BOWMAN, W. (1845). *The Physiological Anatomy and Physiology of Man.* London: John W. Parker.
- VIZOSO, A. D. & YOUNG, J. Z. (1948). Internode length and fibre diameter in developing and regenerating nerves. *J. Anat., Lond.*, 82, 110-134.
- WHITEAR, M. (1952). Internode length in the skin plexuses of fish and the frog. *Quart. J. micr. Sci.* 93, 307-313.

EXPLANATION OF PLATE

- Fig. 1. Whole corpuscle stained by osmic acid.
- Fig. 2. The convoluted segment of the fibre inside a corpuscle.
- Fig. 3. The terminal segment of the fibre inside a corpuscle.
- Fig. 4. A Pacinian corpuscle from which a number of outer lamellae have been removed, stained by osmic acid.
- Fig. 5. A Pacinian corpuscle from which a number of lamellae have been removed, stained by the gold chloride method.
- Fig. 6. Node of Ranvier inside corpuscle, from which a number of lamellae have been removed. Osmic acid staining.
- Fig. 7. A typical node of Ranvier outside the corpuscle stained by osmic acid.

