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T H E S I S
presented for the Syme Surgical Fellowship
on
INJURIES TO NERVES
in relation to
the ORGANS of MUSCLE SENSE, in which is included an
account of the SENSORY NERVE ENDINGS in MUSCLE.

By William Kelman Macdonald.
M. D. 1910.

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I N T R O D U C T I O N .

This Thesis consists of two Volumes, the second one of which contains only Drawings and Photographs illustrating the subject matter detailed in Volume I.

The first Volume consists of five parts. The first part is a short general account of the results of Nerve Injury illustrated by five cases, for the use of which I am indebted to Dr. Alexander Bruce.

The second part is an account of the Sensory Nerve Endings in Muscle which is a mere preparation for the third part which includes an Experimental Investigation into some of the results of Nerve Injury in the nerve and in the muscle supplied by the nerve.

Part four is very short and includes only an account of a case where there were pathological changes in the Muscle Spindles - the organs of Muscle Sense. The case is important on account of the rarity of the degeneration described.

The last part of Volume I. contains the details of the Methods of Investigation employed and an indication of the scope of the work.

To accompany this Thesis ninety-six Microscope Slides
are sent in.

The slides in the boxes are numbered to correspond
with the numbers in red below the photographs.

PART I.

INJURIES TO NERVES.

INJURIES TO NERVES.

In this part of the Thesis a short account of the varieties of Nerve Injuries will be given, and the results noted. Five Illustrative Cases will be given to show the results of Injuries to Nerve, and the Treatment will be detailed.

The arrangement will be as follows:-

1. Varieties of Injuries to Nerves.
2. Illustrative Cases.
 - (1) Ulnar Nerve Paralysis.
 - (2) Musculo-spiral Nerve Paralysis
 - (3) Erb's Paralysis.
 - (4) Erb's Paralysis.
 - (5) Facial Paralysis.
3. Results of Injuries to Nerves.
4. Treatment of Injuries to Nerves.

VARIETIES OF INJURIES TO NERVES.

A contusion is the simplest; and perhaps, the most common form of injury to which a nerve is liable.

A Strained Nerve is commonly produced by a limb being unexpectedly drawn upon, or by any exceptional movement of a limb.

Compression of a nerve trunk may be brought about by a growth or by an aneurism, while displacement of bones as in Case 2 where both bones of the forearm were dislocated backwards, is a common form of Nerve Injury. Inclusion in callus after fracture, pressure of a crutch, pressure of a splint, pressure of an exudation in a narrow bony canal, are all examples of Injuries of Nerves brought about by Compression.

Rupture of a Nerve without an external wound is another common form of Injury and is exemplified by the two Cases of Erb's Paralysis. Fracture of the base of the skull, tearing across the Facial nerve was the form which the Injury to Nerve took in the fifth case. Fracture of the humerus quite often leads to trouble with the musculc-spiral nerve on account of the intimate relation of the latter to the former.

Total/

Total Division of a nerve may be brought about by an accident, as in Case 1. or may be produced surgically at an operation.

ILLUSTRATIVE CASES.

The five illustrative cases are as follows:-

Case 1. Joseph Johnston.

Musculc-spiral Nerve Paralysis.

Case 2. James Wallace.

Ulnar Nerve Paralysis.

Case 3. William Small

Erb's Paralysis

Case 4. Robert McLean

Erb's Paralysis.

Case 5. Polly McIntosh

Facial Nerve Paralysis.

A short account of each case will now be given, including, the condition on admission, the electrical reactions, the treatment employed, and the resulting improvement or otherwise. A few photographs are inserted.

JOSEPH JOHNSTONE.

Age 15. Apprentice at saw-mill.

Complaint. Weakness of right hand and arm.

Duration. Eighteen weeks.

HISTORY.

In July 1908 patient was oiling a machine at the saw-mill, and his right arm was caught in between the saw and the iron bar at the side, with the result that his right arm was crushed just above the elbow, but was not cut. There was no fracture or dislocation so the arm was merely bandaged up at the Carlisle Infirmary.

The arm became swollen from the hand up to the shoulder and from the time of the accident the patient was unable to bend his hand back at the wrist. After three weeks treatment at the Hospital the swelling had completely disappeared, but on taking the arm out of the sling he found that he could not straighten his arm at the elbow and was still unable to bend back his wrist. After being three weeks more in Hospital patient could straighten the arm at the elbow but the condition at the wrist had not/

not improved. He was admitted to Ward 31 of the Royal Infirmary Edinburgh under Dr. Bruce's care, on the 10th Dec. 1908.

(Dr. Bruce has been good enough to allow me to use the reports of the cases).

Personal, Family and Social Histories show nothing of special importance.

**CONDITION OF RIGHT ARM ON
ADMISSION.**

The right arm is held limply by the side, it looks more blue than the left arm and it feels colder. There is perfectly free movement at the shoulder joint. On the posterior aspect of the upper arm there are two small scars, which, according to patient, resulted from the accident.

Just above the right elbow joint the upper arm is markedly constricted and is quite cylindrical. The Biceps muscle forms a projection half way up the upper arm running up under the fold of the Deltoid muscle. In the lower half of the upper arm the belly of the Biceps muscle is wanting but is represented merely/

merely by a thin tendinous band. When the muscle contracts it moves further up the upper arm towards the shoulder joint.

The Triceps muscle is small but shows no abnormality apart from its size.

There is some fibrous thickening around the outer side of the elbow, implicating the outer border of the Branchialis Anticus muscle. The musculo-spiral nerve is felt to be thickened and held down by this fibrous tissue and pressure on the nerve causes pain to shoot up the arm to the shoulder.

The elbow joint is capable of quite free movement. The wrist hangs limply flexed, but patient has quite a good grip as long as the wrist is kept forcibly extended. There is absolutely no power in the extensors of the wrist or fingers and there is evident atrophy of the extensor muscles on the back of the right forearm.

There is no atrophy of the small muscles of the hand to be seen, and the flexors of the wrist and fingers show no wasting and are quite strong.

The skin all over the forearm and hand is/

is cold and moist and the capillary reflex is very slow (about six seconds).

There are no other abnormalities of any kind in the right arm. The other systems need not be discussed.

Right arm	Weak fibrillary	K. active >
		A. active
Right arm	Good cut. of outer	K. active > A. 4
	Weak of long	
Right arm	Absent	K. slow > A. 4
Right arm	Absent	K. absent
		A. slight 5
Right arm	Absent	K. absent, A.
		very slight 4
Right arm	Absent	K. weak & slow
		< A. slight 4
Right arm	Absent	K. slow >
		A. slight 4
Right arm	Absent	K. slow >
		A. slight 4
Right arm	Absent	K. slow >
		A. slight 4
Right arm	Absent	K. slow & to
		A. slight 4
Right arm	Active	K. active >
		A. slight 5
Right arm	Active	K. active >
		A. slight 5
Right arm	Active	K. active >
		A. slight 5
Right arm	Active	K. active >
		A. slight 5

ELECTRICAL/

ELECTRICAL REACTIONS. (Dec. 10th. 1908).

K. Cathode. $>$ = Greater than
 A. Anode. $<$ = Less than
 Numbers. Strength of current used. $=$ = Equal.

MUSCLE.	FARADIC.	GALVANIC.
Biceps.	Weak fibrillary cont.	K. active $>$ A. active.
Triceps.	Good cont. of outer head weak of long head.	K. active $>$ A. 4.
Supinator Longus.	Absent.	K. slow $<$ A. 4.
Ext. Carp. Rad. Long.	Absent.	K. absent. A. slight. 5.
Ext. Carp. Rad. Brev.	Absent.	K. Absent. A. very slight. 4.
Extensor Long. Digit	Absent.	K. weak & slow $<$ A. slight. 4.
Extensor Long. Pol.	Absent.	K. slow $>$ A. slight 4.
Ext. Prop. Indicis.	Absent.	K. slow $>$ A. slight 4.
Ext. Metac. Pollic.	Absent.	K. slow $>$ A. slight 4.
Ext. Brev. Pol.	Absent.	K. slow $>$ A. slight 4.
Ext. Carp Ulnar.	Absent	K. slow = to A. slight 4.
1st Dors. Inteross.	Active.	K. active $>$ A. slight. 3.
2nd. Dors. Inteross.	Active.	K. active $>$ A. slight. 3.
3rd. Dors Inteross	Active.	K. active. $>$ A. slight 3.
4th. Dors Inteross	Active.	K. active $>$ A. slight 3.

Pronat Rad. Teres, Flexors of fingers, Flexor Carpi Radialis, Flexor Carpi Ulnaris, small muscles of thumb, small muscles of little finger, Palmer Interossei, and Lumbricals are all active to faradic stimulation. With the galvanic stimulation the cathodal closing contraction is greater than the anodal which is slight and elicited when the index of the machine is at 3.

T R E A T M E N T.ELECTRICAL

Static Wave Stimulation was applied to the affected muscles daily for fifteen muscles.

Chlorine Ionisation was applied to the area of fibrous tissue thickening around the elbow. A large zinc electrode was placed as negative pole over the indurated area, a thick pad soaked in salt solution intervening between the electrode and the skin. A weak galvanic current was allowed to flow thus daily for about ten minutes, the other electrode being held in the patients left hand.

General tonics were administered in the shape of Cod Liver Oil and Malt, Syrup of the Hypophosphites, Quinine and Strychnine.

PROGRESS./

PROGRESS.

Jan. 6th. 1909.

ELECTRICAL REACTIONS.

MUSCLE	FARADIC.	GALVANIC.
Anconeus	Sharp	Sharp K. > A.
Supinator Longus	Slight	Slight A. > K.
Ext.Carp.Rad.Lo.	Slight	Slight A. > K.
Ext.Carp.Rad.Brev.	Slight	Slight A. > K.
Ext.Oss.Meta.Poll.	Cannot be stimul.	Absent.
Ext.Carp.Ulnaris.	Slight	Slight A. > K.
Ext.Commun.Digit.	Slight	Slight A. > K.
Ext. Longus Policis	Absent	Absent
Ext.Brevis Policis.	Absent.	Absent

Patient can now extend the wrist backwards to the full extent but only with the fingers closed. He can only reach the straight line with the forearm when the fingers are held straight out. The fingers all move well. No anaesthesia or analgesia are present. --

The musculo-spiral nerve is now felt as a slightly thickened band freely mobile on the/

the outer side of the upper arm. The adhesions of fibrous tissue seem greatly to have disappeared. The nerve is not so tender as formerly. The condition of the Biceps muscle is much the same as formerly, but it has regained some strength. Static wave stimulation is now applied to Biceps and Brachialis Anticus as well as to the extension of the hand, and forearm.

Jan. 16th. 1909.

The hand can now be extended to almost the normal extent, at the wrist, but the power is still very small so that the slightest pressure is sufficient to straighten out the hand to the line of the forearm. It requires a good deal of force, however, to flex the wrist beyond this against the patients efforts to extend the wrist.

Power in the Biceps is greater than before but it is still very weak, so that he cannot pull his body up on to horizontal bar. The general condition is now very much improved. He no longer suffers from cold hands and looks much stronger and healthier than on admission. Weight on admission 6 st. 12 lbs. Now is 7 st. 5 lbs.

Jan. 31st. 1909.

Full/

Full movement of the wrist is now established, and a good deal of power has returned to it. The Biceps muscle is improving in strength, and he tries to use the right arm as much as he can. Static Wave stimulation has been applied only to the upper arm flexors. Chlorine Ionisation was discontinued on the 16th. The Extensors of the wrist stand out now as strong bands and the fullness at the back of the forearm is almost as marked as the opposite side.

Feb. 11th. 1909.

Scarcely any difference can now be made out between the extensors of the wrist on the two sides. The right wrist is only very slightly weaker than the left and both have considerable power in them. No difference in size of the forearm below the elbow.

Electrical Reactions. Faradic excitability has returned very slightly to the extensors of the wrist and fingers. Galvanic stimulation produces a sharper contraction than formerly but it is very slight. There is now no reversal of Poles.

Feb. 12th. 1909.

Discharged to-day. To continue work as soon as possible.

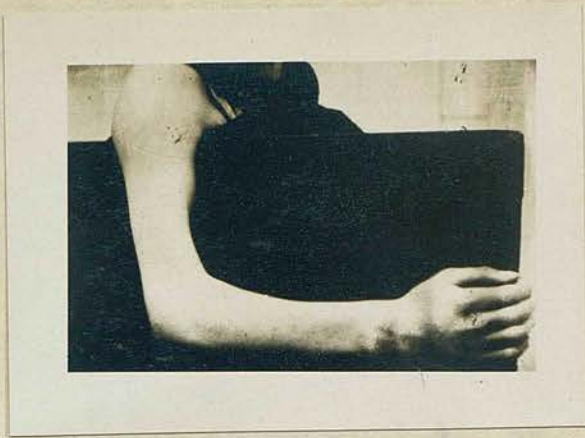


Fig. 1.

Right Arm at Rest

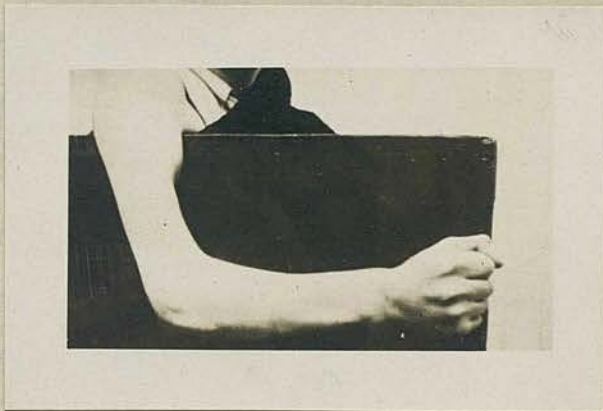


Fig. 2.

Biceps Muscle Contracted.

JAMES WALLACE.

Age 9, Schoolboy.

Complaint, Weakness of left hand.

Duration, Three months.

H I S T O R Y.

On Oct. 29th 1908 patient was knocked over in the playground by another boy, the left arm being bent under him and twisted across to the right side. He fell almost directly on his left elbow and dislocated both bones of the forearm backwards. The arm was set under chloroform and the arm carried in a sling, while massage and passive movements were carried out. Ever since the accident the fingers on the inner side of the left hand, especially the little finger and the ring finger, have been bent. He had difficulty in straightening the middle finger also.

In addition patient complains of a numb feeling over the back of the hand on the inner side and he cannot feel things very distinctly with the little and ring fingers of his left hand.

On Feb. 4th 1909 he was admitted to Ward 31, Royal Infirmary, Edinburgh, under Dr. Bruce's care.

Family /

Family, Social, and Previous Histories have nothing of a relevant nature.

CONDITION OF LEFT ARM AND HAND

ON ADMISSION.

There is some thickening around the left elbow joint. The elbow cannot be quite fully extended, but it is easily flexed to the normal extent without causing pain. Pronation and supination are easily carried out but there is some crepitus in the joint. The wrist can be well moved in all directions but there is some weakness of ulnar flexion. The fingers can be flexed well, but there is some weakness of the ring and little fingers. There is very marked loss of power of extension of the little finger, rather less of the ring finger and slight also of the middle and index fingers. The greatest loss of power seems to be in the little finger and more power to be had in the fingers as the radial side of the hand is approached. Full extension and some degree of hyperextension at the metacarpophalangeal joint is enjoyed but neither of the inter-phalangeal joints can be voluntarily straightened out although the joints are freely moveable. /

moveable. Extension of the fingers when the knuckles are flexed is impossible in the left hand but is well carried out in the right. The interosseus spaces are rather sunken. There is some atrophy of the hypothenar eminence and the skin over it is thin and glazed. The skin over the little finger is red and cracked, giving it the appearance of a chilblain. It is not itchy. The ulnar side of the forearm is considerably atrophied and there is a hollowing from the internal condyle to the inner side of the wrist.

Pain is elicited on pressure deeply over the ulnar nerve behind the elbow, but the nerve seems to be rather thickly matted in by adhesions of fibrous tissue and cannot be readily felt.

There is anaesthesia over the ulnar side of the hand, the little finger and the ulnar side of the ring finger. The little finger is insensitive to pain. These areas are shown in the accompanying photographs.

TREATMENT.

Electrical. Static wave stimulation has been applied to the muscles of the hand and the muscles of /

of the inner side of the forearm, for fifteen minutes daily.

Chlorine Ionisation. A weak galvanic current has been applied to the adhesion around the elbow, for half an hour daily, the current being allowed to flow through a thick pad of gauze soaked in saline solution. Patient had also Cod Liver Oil and Malt, teaspoonful thrice daily after food.

PROGRESS.

Feb. 22nd. 1909.

The condition has improved in the following way:-

- (1.) The elbow can now be extended fully but no hyper-extension is possible as it is in the right elbow.
- (2.) The ulnar nerve is more easily felt than before.
- (3.) The hollow on the inner side of the forearm has filled up considerably and ulnar flexion of the wrist is much stronger.
- (4.) The hand is firmer; the heads of the metacarpal bones are not so prominent and the first interosseus space is rather firmer than before. There is not much body in the thenar and hypothenare eminences yet.
- (5.) When patient is asked to straighten all the fingers, /

fingers, the ring finger becomes quite straight, but the little finger is still slightly bent. The power of extension at the phalangeal joints has been greatly increased.

(6.) The anaesthesia and analgesia have receded as is shown in the photographs.

(7.) There is as yet no power of abduction or adduction of the fingers apart from flexion or extension.

Feb. 27th 1909.

Patient left Hospital to-day.



Fig. 3.

Paralysis of Ulnar Nerve to show the position of the arm and hand.

Note the characteristic position of the finger.



Fig 4.

The black areas show the absence of sensibility on the hand on admission.

- I. Touch: Heat and Cold- Front of hand.
- II. Touch: Heat and Cold- Back of hand.
- III. Pain: Front of hand
- IV. Pain: Back of hand.

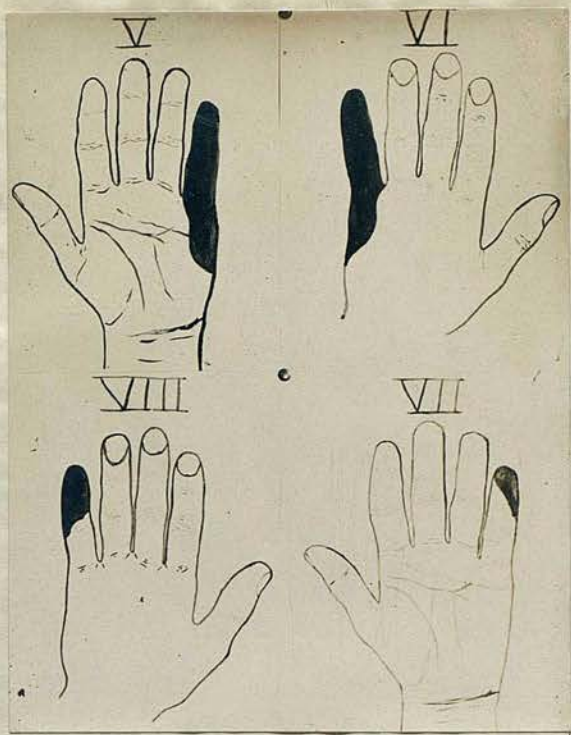


Fig. 5.

Improvement in sensibility after Treatment.

Back areas indicate absence of sensibility

- V. Touch: heat and cold: Front of hand
- VI. Touch: heat and cold: Back of hand
- VII. Pain: Front of hand.
- VIII. Pain: Back of hand.

WILLIAM SMALL.

Age 63. Plumber.

Complaint. Loss of power of right upper arm.

Duration. Doubtful.

H I S T O R Y.

Six months before admission to Hospital (July 7th. 1909) patient got an electric shock by touching a live wire with his right foot while he made contact with an iron roof with his right hand. In a few days the right arm began to show some weakness and he could not use his hammer so freely as before. He noticed that he was not able to do work which necessitated his raising his right hand above his head. While he could raise his empty hand above his head he could not lift a chair, as formerly, to that position. He was, however, able to do good work with his right hand, provided it was kept below the level of his shoulder. He did not consult a doctor, and this state of affairs persisted for five months, during which time he complained of a "funny feeling" in the right upper arm and a constant tired feeling in the right shoulder.

One/

One Month before admission patient was putting up rain-water pipes. A pipe was being handed down to him from above and he was just able to reach it with his left hand. He let it fall and caught it with his right hand, but, in so doing, he felt that he hurt his right upper arm considerably. After the accident he felt considerable pain shooting along the right upper arm, and in the right shoulder blade. He consulted a medical man who found that the patient had quite a powerful forearm but that the muscles of the upper arm and some of the muscles of the shoulder girdle could not do their work.

Except for four days, he continued to work up to the date of admission as he found that the arm felt best when he was working, provided he kept it warm. Previous, and Family History show little of note. Social History is somewhat unsatisfactory in so far as he has been a heavy drinker and an excessive smoker. He has been a plumber all his working years but has never shown any of the evidences of lead poisoning.

Patient is a healthy-looking man of sixty-three and is of good musculature. He can walk without any difficulty but has obviously very/

very little, if any, power in the right upper arm.

"STATE OF RIGHT ARM AND SHOULDER

ON ADMISSION. (7th July 1909.)"

I. MUSCLES.

Shoulder girdle. The Pectoralis Major muscle can be seen to adduct and draw the upper arm well forward, while the coracoid process can be pulled down by the Pectoralis Minor muscle. The Subscapularis muscle functionates well while of the Teres muscles, the Major is seen to adduct and draw back the upper arm and the Minor rotate the arm outwards. The Serratus Magnus stands out well when the patient uses the 'pushing' extension movement. The Supraspinatus and the Infraspinatus muscles are both distinctly atrophied and are correspondingly weak in their action. The Deltoid muscle, too, is atrophied and fibrous and shows a marked fibrous thickening at its lower part near its insertion.

Upper Arm The Tricipes muscle shows no obvious atrophy but the Biceps Flexer Cubiti, the Coraco-Brachialis and the Brachialis Anticus muscles are very much atrophied when compared to the/

the other side. The Supinator Longus muscle does not stand out nearly so distinctly on the right side as on the left and the right muscle is lacking considerably in tone. The other muscles of the arm show no departure from the normal condition.

II. MOVEMENTS. The movements possible at the shoulder joint are as follows

Flexion Unable to raise his hand higher than the waist line.

Extension is diminished to a corresponding degree.

Abduction can only succeed in getting the arm from the side a distance of three inches i.e. an angle of about five degrees with the body.

Adduction is very slight indeed. He is quite unable to bring his outstretched hand even as far as the middle line of the body. He cannot button his waist coat.

Circumduction, carried out to its utmost extent, only produces a very slight swing of the arm at the shoulder joint.

Internal Rotation and External Rotation are so far reduced that it needs very careful watching to detect any movement resulting from the required effort.

At the elbow joint power and amount of extension are/

are not diminished but flexion is markedly diminished in power and in amount and is mostly carried out by the Brachialis Anticus. What action is left in the Biceps muscle is used to produce a limited amount of Supination. The hand, indeed, can only be supinated to half the usual extent and very little resistance is necessary to prevent it taking place.

The movements at the wrist and finger joints are perfectly carried out.

ELECTRICAL REACTIONS ON ADMISSION.

MUSCLE	FARADIC	GALVANIC
Pectoralis Maj.	Satisfactory	Satisfactory
Supraspinatus	Absent	Sluggish
Infraspinatus	Absent	Sluggish
Deltoid	Diminished	Slow
Triceps	Satisfactory	Satisfactory
Biceps	Impaired	Slow & wave-like
Brachialis Ant.	Absent	Sluggish
Supinator Long.	Diminished	Sluggish

TREATMENT

Since admission patient has been having daily, either local vibration, applied by the Electric Vibrator, or Galvanic Electricity (i.e. on alternate days) for fifteen minutes and in addition daily massage for twenty to twenty five minutes. He was given fifteen grains of Iodide of Potassium thrice daily after food.

To indicate the improvement reached by this treatment the following report is given of the condition of the patient on the 20th. Sept 1909 (2½ months after admission to Hospital.)

STATE OF RIGHT ARM AND SHOULDER TWO
AND A HALF MONTHS AFTER ADMISSION.

FLEXION AT SHOULDER. On admission patient could not raise the hand higher than his waist, now he can easily put it into the position of a military salute and with a slight effort and employing a swinging movement at the shoulder joint he can get the arm up to the maximum degree.

Abduction.- He can now abduct the arm to an angle of 45 degrees with the side of the body, thus moving/

MOVEMENT ON ADMISSION AFTER TREATMENT

moving the hand eighteen inches out from the side: on admission the hand could only travel three inches out from the side.

Adduction is also very much improved. While on admission he could not get his hand to reach the middle line to adjust his dress he can now take the arm across the chest as well as place the hand on the opposite shoulder. He can now button his clothes with great ease.

Circumduction is now extremely free and he has quite good internal, and external Rotation at the shoulder joint although both these movements were absent on admission.

Extension at the elbow has remained strong and forcible throughout while there has been great improvement in the movement of Flexion. He can now perform Supination to the full extent.

The improvement is shown in the following Table.

MOVEMENT	ON ADMISSION	AFTER TREATMENT
<u>At Shoulder.</u>		
Flexion	Hand up to waist.	Can swing up to maximum degree
Abduction	To three inches	To eighteen inches
Adduction	Short of middle line	Can place hand on opposite shoulder
Circumduction	Slight swing	Large circle.
Int. Rotation	Absent	Well carried out
Ext. Rotation	Absent	Almost fully present

At Elbow.

Extension	Good	Good
Flexion	Much Reduced	Much improved.
Supination	Diminished to half	Present to full extent.

ROBERT McLEAN.

Age 17. Miner.

Complaint Loss of power of right upper arm.

Duration Five weeks.

H I S T O R Y.

June 15th. 1909. Patient had an accident in the mine. He was sitting on what is called the bogie in front of twelve hutches full of coal and was going down a steep part of the rails in the mine, when a wooden bar, used to support the roof, gave way and hit him on the right side of the neck just above the right clavicle. Falling backwards into the front hutch he was carried along for four yards and then fell off, and remembered nothing more till half an hour later he was picked up and taken home. He felt sick but did not vomit: he was quite conscious, had no broken bones or broken skin but was not able to walk. He was put to bed at 11 a.m. on the 15th. and in the evening he complained of pain all up the right arm and in the right side of his neck. He could grasp things with his right hand but could not move his right upper arm.

He/

He could move both lower limbs and had complete control over his bladder and rectum.

June 16th. Pain was still present in right arm and he felt his back sore and tender.

June 24th. Pain now all gone, having lasted 3 days in neck and right arm and a week in the back.

June 30th. Patient has been in bed now for a fortnight. No power in right upper arm, which has been rubbed for half an hour night and morning.

July 16th. 1909 Admitted to Ward 31. Royal Infirmary Edinburgh under Dr. Bruce's care.

Previous, Family and Social History show nothing of any importance. Patient is a healthy, intelligent, well developed, youth for his age.

STATE ON ADMISSION.

RIGHT ARM. I. JOINTS. All the movements at the wrist are easily performed, as are the movements of the fingers. Flexion at the elbow is much impaired, he can only raise 1 lb. 7 ounces up to the shoulder with flexion at the elbow alone. Extension at the elbow is quite strong.
Supination/

Supination can only be performed to a little more than 50% of the full but Pronation is quite full. Abduction at the shoulder joint is absent but ~~Abduction~~ is good. The points of the fingers can be pressed firmly together and the Pectorals stand out well. Rotation inwards is satisfactory but outward Rotation is distinctly weak. Circumduction is consequently limited while the pushing movements are quite strong.

II. MUSCLES. The small muscles of the right hand and the muscles of the forearm are well developed with the exception of the Supinator Longus, which does not stand out so prominently as it ought to, but there is some power in it still. The Dynamometer registers 65 with right hand and 70 with the left. The Biceps muscle is distinctly atrophied but the tendon can still be felt on the stretch when the arm is forcibly flexed. There is some atrophy of the Brachialis Anticus muscle but more of the Triceps muscle. The Deltoid muscle is wasted in all its parts, little remaining in parts but a fibrous sheet. Both the Supraspinatus and the Infraspinatus muscles show advanced atrophy and the bony outlines of the Scapula are rendered very/

very prominent. The Rhomboid muscles functionate well and shrugging of the shoulders shows no impairment. The Trapezius and Latissimus Dorsi show no atrophy whatsoever.

There is nothing of any importance in the other parts of the Locomotory System, and the other Systems merit no attention here.

REFLEXES.

Muscle	Right	Left.
Supinator Longus.	Absent	Present
Triceps	Present	Present
Biceps. (fl.cub.)	Absent	Present

All the other reflexes in the body, both deep and superficial, are active but not unduly so. No ankle clonus. No extensor response of the great toe.

ELECTRICAL REACTIONS/

ELECTRICAL REACTIONS IN MUSCLES OF RIGHT ARM.

MUSCLE	FARADIC	GALVANIC
Infraspinatus	No Response	Slow Contraction
Supraspinatus	No Response	Sluggish Response
Pectoralis Major	Active except at top part below outer end of clavicle	Quick Response
Deltoid	No Response	Slow Response Reversal of Poles.
Biceps	Slight Response	Sluggish Reaction
Brachialis Ant.	Slight Response	Diminished
Triceps	Active	Active
Supinator Long.	Slight Response	Sluggish Response.

Stimulation at Erb's Point above the clavicle causes the forearm muscles to contract strongly under the influence of the faradic current, not so the muscles of the upper arm. In the upper arm there is definite reaction in the Triceps/

Liquor Stramonias Hydrochloric triles

Triceps muscle and faint reaction in the Biceps muscle. Typical contraction as described by Erb. Stimulation of the nerves on the inner side of the upper arm gives a very strong response in the muscles of the hand and forearm.

Patient left Hospital on Oct. 5th. 1909.

TREATMENT.

MASSAGE. All the muscles of the right arm and shoulder girdle were massaged.

Quarter of an hour daily.

MOVEMENTS. Passive movements were carried out daily and the patient was encouraged to use active movements.

ELECTRICITY. The Galvanic current was applied daily to all the affected muscles of the right side.

VIBRATION. The Electric Vibrator was used to the muscles of the right arm generally, with the hope of improving the circulation, and the tone of the muscles.

MEDICALLY. Patient had seven minims of the
Liquor/

Liquor Strychninae Hydrochlor thrice
 daily and also ten grains thrice daily
 of Iodide of Potassium.

This treatment was carried out for two and a half
 months. At the end of two months the amount of
 improvement may be noted as under.

STATE TWO MONTHS AFTER ADMISSION. (13th. Sept. 1909.)

The muscles of the right forearm are
 well developed with the exception of the Supi-
 nator Longus which is not so large in size as the
 corresponding muscle on the other side. The
 Biceps muscle has regained much of its power, is
 now quite firm in consistence but is still smaller
 than the left muscle. Triceps is much improved
 but is still slightly flabby and deficient in
 bulk. The margins of the Scapula do not stand
 out so prominently as before as the Supraspinatus
 and the Infraspinatus are distinctly improved.
 There is general improvement also in the move-
 ments at the various joints. Movements at the
 wrist and finger joints are quite satisfactory.
 Supination is much improved. On admission the
 supination was reduced to less than half the
 normal/

normal amount but he can now supinate to within ten degrees of the complete movement. Pronation is unimpaired. Flexion at the elbow is much improved. On admission he could only lift one and a half pounds to his shoulder now he can lift five pounds by unaided flexion at the elbow. Extension at the elbow is quite strong.

At the shoulder joint there was, on admission, absolutely no abduction possible but he can abduct to an angle of fifty degrees. Adduction has never been limited. Inward Rotation was satisfactory from the beginning but on admission outward Rotation was very much limited; it is now greatly improved and is now almost complete. Circumduction is now almost completely restored. The results may be seen from a glance at the following table:-

MOVEMENTS./

POLLY MAGUIRE.

Age 31. Unemployed.

Complaint: Weakness of right side of face.

Duration. Eight months.

HISTORY.

MOVEMENTS.	ON ADMISSION.	AFTER TWO MONTHS.
Wrist Joint.	Satisfactory.	Satisfactory.
Finger Joints.	Satisfactory.	Satisfactory.
Supination.	50% of normal.	10% of normal.
Pronation	Satisfactory	Satisfactory.
Flexion at Elbow.	Lift $1\frac{1}{2}$ lbs.	Lift 5 lbs.
Extension at Elbow.	Slightly diminished.	Improved.
Abduct. at Shoulder.	Absent.	Present To 50 degrees.
Adduct. at Shoulder.	Satisfactory.	Satisfactory.
Inward Rotation.	Satisfactory.	Satisfactory.
Outward Rotation.	Very limited.	Almost normal.
Circumduction.	Much reduced.	Almost completely restored.

POLLY MACINTOSH.

Age 21, Housekeeper.

Complaint Weakness of right side of face.

Duration. Eight Months.

HISTORY.

On May 28th 1908 patient fell off her bicycle, striking her head against a stone wall. She remained unconscious for about five days after this. When she recovered consciousness she had no pain, but found that she could not move the right side of her face so well as before. The right eye would not close properly and the mouth was drawn over to the left side. There was no difficulty in swallowing or chewing but at first she had difficulty in drinking. The fluid she was drinking tended to flow out of her mouth slightly. There was a slight bruise on the left cheek. There was much haemorrhage from the right ear during the night following the accident. There was no discharge from the ear when she recovered consciousness. The ear was, however, syringed out regularly. Hearing was dulled in the right ear after the accident.

She/

She has tried electric battery and fly leaves to the back of the right ear. The battery was continued and the cheek was massaged every day after meals. She saw Dr. Bruce first in the beginning of Oct. 1908 and he advised her to use fly blisters. As this did no good he advised her to come into the Royal Infirmary Edinburgh where she was admitted on the 27th Jan. 1909. There is nothing in the other parts of the History of any importance to the present aspect of the case.

CONDITION ON ADMISSION.

The face shows a little asymmetry when at rest, and it does not move at all voluntarily or involuntarily on the right side.

The right naso-labial fold is much less distinct than the left fold but no laxity or drooping of this side is noted.

The mouth is drawn over to the left side when at rest, and it is kept slightly open at the left side. It is opened altogether from the left side.

The right eye has less expression than the left and the lid does not follow the eye properly on looking down. The right eyebrow/

brow cannot be moved either to be raised or for frowning, while the right eye cannot be closed, but the eyeball rotates upwards when the attempt is made to close the eyes, so that only a narrow strip of sclerotic one-eighth of an inch wide is seen between the lids.

The tongue is protruded straight out but is rather thinner on the right side than on the left. It is noticed that if the mouth is drawn out at the right side at the corner the tongue is then perfectly symmetrical.

There is difficulty in articulation, some words being badly pronounced. She says that she used to stutter over difficult words after but not before the accident.

OTIC EXAMINATION.

Subjective. Complete loss of hearing in the right ear. Loss of taste in the posterior two-thirds of the tongue.

Objective. Loss of vestibular reflex. The tympanic membrane is absent, and a fracture is seen along the upper part of the tympanic cavity, and there is a fracture of the handle of the malleus.

The/

The nerve is probably torn across in the internal meatus by a fracture across the temporal bone.

ELECTRICAL EXAMINATION.

There is complete loss of contraction to faradism in the muscles of the right side of the face, with the exception of the masseter muscle. The facial muscles, however, respond to strong galvanic shocks, the contraction being rather slow and weak requiring twelve milleamperes to elicit it. The contraction on the left side is sharp with six milleamperes. The anodal contraction is stronger than the cathodal on the right side of the face.

The other systems are of no interest to the present investigation.

After patient had been in Hospital for a fortnight it was decided to perform an operation in order to anastomose the proximal end of the hypoglossal nerve on to the distal end of the facial nerve and the proximal end of the lingual on to the distal end of the hypoglossal nerve.

OPERATION./

OPERATION. (Feb. 9th. 1909).

Incision about three inches long behind angle of jaw extending from just behind the lobule of the ear and curving forwards.

Facial nerve cut across as near to exit from stylo-mastoid foramen as possible Hypoglossal nerve found and also Lingual nerve, both cut across Proximal end of Hypoglossal anastomosed to distal end of facial. Proximal end of Lingual anastomosed to distal end of hypoglossal.

The stitches were left in 10 days.

The face was much swollen on the right side after the operation, but the wound healed well. Operation was performed on Feb. 9th. 1909, by Professor Alexis Thompson.

PROGRESS.

Feb. 23rd. 1909.

The face is much swollen on the right side. The wound has healed except for a small portion at the upper part from which serous fluid exudes. (This gives no culture on growth).

There is much wrinkling of the right side of the tongue with some atrophy. The tongue is protruded to the right and curved to the right. The tongue can be moved well in all directions, but food tends to accumulate under the cheek on the right side.

The speech is not quite so good as on admission, labials being formed with difficulty.

Sensation of all kinds is lost on the right side of the tongue. The mouth seems rather more paralysed on the right side than on admission, as even at rest it is drawn to the left side, but this may be due to the still existing oedema of the right side of the face.

All electrical reaction has gone from the right side of the face.

Feb. 28th. 1909.

Galvanic stimulation of the muscles of the right side of face and mouth started. One pole/

pole used over mastoid, the other moves over the cheek. No restriction as to the relative position of poles. The right eyelid is noticed to fall, immediately on winking the eyes, but only to reach a point one-eighth of an inch away from the lower lid. This takes place when patient is lying with head below the horizontal and seems difficult of explanation. No nervous influence from the facial could possibly cause this. It may be due to some innervation from the third, or to the tension of the skin over the malar bone, as if the skin is pushed towards the eye it does not take place so rapidly.

March 14th. 1909.

Swelling is now scarcely marked at all on the right side of the face. Asymmetry of the mouth at rest not nearly so marked as before. (Photo taken at this date). No defect of speech now, beyond what was present before. The tongue can be used much better in chewing.

April 2nd. 1909.

There is still a good deal of swelling of the right side of the face. When patient was examined to-day it was noted:-

- (1). That there were fine fibrillary tremors to be made out, around the right angle of the mouth. These were very distinct.
- (2). When patient's facial muscles are brought into use the left angle of the mouth is not drawn up so much as it used to be.

(3)./

- (3). The right eyelid can be closed rather more than before operation.
- (4). Slight return of power is noted in the right eyebrow.
- (5). The tongue does not deviate so much to the right side as formerly.

April 2nd. 1910.

During the past year patient has gradually continued to improve. The facial deformity is now very slight but the atrophy of the right side of the tongue is very marked.



Fig. 6.

At Rest.



Fig. 7.

On Closing Eyes.

RESULTS OF INJURIES TO NERVES.

The Results of an Injury which produces a total division of a nerve are immediate, and secondary, The immediate Results are four:-

- (1). Paralysis of those muscles which derive their motor fibres from the injured nerve.
- (2). Anaesthesia of the area of skin supplied by the injured nerve.
- (3). Vaso-motor Paralysis. Evidenced by the limb becoming cold and insufficiently supplied with blood.
- (4). Excito-secretory Paralysis. Evidenced by the skin being very dry.

The Secondary Results are five:-

- (1). Changes in the Nerve. Local, proximal, peripheral.
- (2). Changes in the Muscles. Paralysis, atrophy, altered electrical reactions.
- (3). Changes in Sensation. Special, general and muscular sense.
- (4). Trophic Changes. Hair, skin, etc.
- (5). Reflex Results. Epilepsy, etc.

It/

It will be interesting to arrange under these headings the results, which were obtained in the five cases, just reported, from the injuries to the various nerves.

Immediate Results.

Motor Paralysis.

- Case 1. Extensor muscles of forearm.
- Case 2. Small muscles of little finger, Inner lumbrical muscle. Flexor carpi ulnaris muscle.
- Case 3. Supraspinatus, Infraspinatus, Deltoid, Biceps, Brachialis Ant., Supinator Longus.
- Case 4. Supra - and Infraspinatus, Deltoid, Biceps, Triceps, Brach. Ant., Supinator Longus.
- Case 5. Right side of Face.

Anaesthesia.

- Case 2. Sensibility changes as in charts.

Vasomotor Paralysis.

- Case 1. Arm feels cold and looks blue.
- Case 5. Right side of face is cold.

Secondary Results.

Changes in Nerves. Investigated in Part III.

Changes in Muscles. Investigated in Part III.

Changes/

Changes in Sensation.

Case 2. Anaesthesia, and Analgesia along ulnar side of hand, along little finger, and along inner side of ring finger.

Trophic Changes.

Case 1. Arm feels cold, and looks blue.

Case 2. Skin is cracked and hard; it is red and looks like a chilblain, but is not itchy.

Electrical Reactions.

Case 1. Contraction to Faradism absent in Supinator Longus, Ext. Carp. Rad. Long., and Brev., Extens. Long. and Brev. Poll. Extens. Long. Digit. Extens. Prop. Ind. Extens. Met. Poll. Slight reaction to strong Galvanic.

Case 3. Faradic absent in Supra - and Infraspin, Brach. Ant. Faradic diminished in Deltoid, Biceps, Supinat. Longus.

Case 4. Faradic absent in Supra - and Infraspinat, Deltoid. Diminished in Biceps, Brach. Ant. and Sup. Lo.

Case 5. Loss of Faradism in right side of face. Weak reaction to Galvanism.

Within reasonable limits of a Thesis it would be undesirable, even if possible, to enlarge upon all the various results, immediate and secondary of injuries to nerves.

I intend, therefore, to deal with only some of the secondary results of nerve injury.

As indicated above, the secondary results include:- Changes in muscles, changes in nerves changes in sensation, trophic and reflex changes. I do not intend to deal with the trophic or reflex changes. Of the other three secondary results, the changes in the muscles include a large number of various results, but I wish to enlarge upon the changes in the muscles or in so far as they are concerned with the muscular sense.

The changes in nerves are local - at the seat of injury, proximal and peripheral.

The local changes in nerve at the seat of injury are dealt with in Part III, where the appearances are given from eighteen hours up to twenty two days. The changes in an injured nerve peripherally to the seat of trauma are investigated in Part III by means of the Marchi methods.

Changes in sensation include not only
general/

general and special sensation, which I will not refer to, but also the muscular sense. It is to the investigation of the muscular sense and changes in the organs of muscle sense consequent upon nerve injury, that I wish to pay special attention.

Before studying the pathological changes in any again it is essential to first master the details of the normal structure. Before detailing the changes, then, in the organs of muscle sense after nerve section, I intend to give an account of the normal organs of muscle sense and this account is included in Part II of this Thesis - The Sensory Nerve Endings in Muscle.

PART II.

THE SENSORY NERVE ENDINGS IN MUSCLE.

THE SENSORY NERVE ENDINGS
IN MUSCLE.

The Sensory Nerves end in voluntary muscle tissue in one of three ways, - in, what are called, the Muscle Spindles, - in the Golgi Tendon Organ, or in Pacinian Corpuscles or some other terminal end-organ.

This section will be arranged under the following headings:-

I. The Muscle Spindles.

- (1). Description of Muscle Spindles, with illustrations.
- (2). Short notes on the Function of the Muscle Spindles, and the Muscle Spindles in Disease.
- (3). History of the Muscle Spindles, with illustrations.
- (4). Literature of Muscle Spindles.

II. The Golgi Tendon Organ.

A mere reference.

III. Other Sensory Nerve Terminations in Muscle.

Pacinian Corpuscles.

Other End Bulbs.

THE MUSCLE SPINDLES.

THE MUSCLE SPINDLE is a fusiform body, varying somewhat in size, lying completely or nearly completely embedded in a voluntary muscle. The long axis of the muscle spindle is as a rule parallel to the direction of the muscular fibres among which it lies. It is frequently found very near to some fibrous septum, and in that case the long axis of the spindle is parallel to the fibres composing the fibrous septum. More rarely its long axis is found inclined at an angle with the long axis of the adjacent muscle fibres. They frequently lie along the course of the nerve which supplies them, and parallel to it.

Two spindles may be joined end to end, and even as many as three have been found so joined: several spindles may be seen in the same muscular plane, two together, three together, or even four so compounded, lying in one and the same plane of muscle.

The intrafusal muscular fibres, - as the muscle fibres contained within the muscle spindle are called, - always, however, run parallel to the long axis of the spindle itself.

SIZE./

SIZE. There is tremendous variation in the size of the muscle spindles. Some are exceedingly small, while the largest of them are just visible to the naked eye. One of the longest muscle spindles recorded was 11.7mm. in length, it was measured by Batten, and had a maximum breadth of .5mm. An average length is from .75mm. to 4mm. An average breadth may be given as from .15mm. to .4mm. The vast majority of muscle spindles found in any muscle will be found to fall within the following measurements, which have the additional advantage of being easily remembered:-

	Maximum.	Minimum.
Average Length. --	4mm.	1mm.
Average Breadth. --	.4mm.	.1mm.

To some extent the size of the muscle spindles depends on the age of the animals, the size of the animals, and the length of the muscles. They tend to be small when:-

- (1). The animals are young.
- (2). The animals are small.
- (3). The muscles are short.

These are mere generalities to which there are many exceptions.

I have measured a number of muscle spindles taken/

taken at random from the muscles of the rabbit, cat and human subject and the average breadths may be given as follows.

Rabbit	0.072	average of 40 spindles.
Cat	0.071	average of 14 spindles.
Human	0.187	average of 35 spindles.

NUMBER.

No recent attempt has been made to estimate the number of muscle spindles in a given muscle. They occur in nearly all muscles, but are certainly more easily seen in some than in others. The number probably varies immensely, and that is as one would expect, for should they not be more frequent in those muscles in which a fine muscle sense is required?

This will be referred to later. When Felix was working at the growth of muscle in 1889, he made an attempt to count the actual number of muscle spindles present in the Biceps muscle of the arm, and he found that that muscle contained 79 muscle spindles.

Other things being equal muscle spindles are much more easily seen:-

- (1). In the child than in the adult.
- (2). In the atrophied muscle than in the fully developed muscle.
- (3). In muscle which is the seat of certain pathological/

pathological processes, than in normal healthy muscle.

Looking at it from another point of view, the question might be asked;— How much of the actual demonstrable sensory nervous supply to a given muscle are the muscle spindles in that muscle sufficient to account for? This question has been answered by Sherrington, who has estimated that the number of spindle organs in the limb muscles are sufficient to account for nearly, if not quite, two-thirds of all the afferent nerve fibres demonstrated to exist in the nerve trunks of those muscles.

DISTRIBUTION OF MUSCLE SPINDLES.

Nearly every muscle of the body will, when carefully examined show specimens of muscle spindles. In some they are found in greater profusion than in others.

The actual situation in a given muscle varies;—

- (1). The muscle spindle may be absolutely completely buried in the muscular tissue.
- (2). The spindle may lie only partly in the muscular tissue the other part of the organ lying in connective tissue.
- (3). The muscle spindle may be entirely surrounded/

surrounded by connective tissue, no ordinary muscle fibres coming in contact with the muscle spindle.

It may, however, be noted that the vast majority of the spindles lie absolutely embedded in the muscular tissue, but that many are found in close proximity to the intermuscular septa and aponeurotic sheaths. They are much more frequent in the belly of the muscle than at either extremity, but as Batten has pointed out there is a gradual transition in the character of the organs as one passes from the muscle tissue to the tendon. This gradual transition of character is represented by the following organs in order:-

- a. The Muscle Spindle.
- b. The Musculo-tendinous Organ.
- c. The Tendon Organ of Golgi.

It seems a sensible suggestion that these should not be regarded as distinct organs, but as variations of the same organs adapting themselves to the tissues in which they happen to be situated.

It is, at present, impossible to give any accurate statement as to the relative frequency in the various muscles, but it is to be noted that in some they have been found to be very plentiful, while in/

in others, - only a doubtful few, - they have not been found at all.

Muscle spindles, then, are plentiful:-

- (1). In the small muscles of the hand.
- (2). In the intrinsic plantar muscles. I have used these muscles more than any others in studying the muscle spindles.
- (3). In the Biceps muscle of the arm. Batten has used this muscle very frequently.
- (4). In the Vastus Medialis of the thigh. Sherrington has found this muscle useful for the examination of muscle spindles, which he found were very plentiful on the under aspect of the aponeurosis at the lower end of the muscle.
- (5). The Gastrocnemius muscle contains a very fair number of muscle spindles. I often selected this muscle for examination, because the sciatic nerve is such a useful one for nerve section, and has been used by so many observers.
- (6). The extrinsic muscles of the Larynx are said by Forster to contain a large number of/

of muscle spindles.

There are certain muscles about which there is some doubt as to whether there are any muscle spindles in them or not. These muscles are:-

The muscles of the eye.

The intrinsic muscles of the Tongue.

The Diaphragm.

As to the muscles of the eye, Millbacher, Kerschner, Sherrington, and Batten, have failed to find any muscle spindles in those muscles. But in 1889 Siemerling was working at a case of a gumma of the base of the brain, and on examining the eye muscles he found in the atrophied inferior rectus muscle, what he is positive was a muscle spindle. I have found a definite muscle spindle in a cross section of the levator palpebrae superioris muscle in the human subject. I give a photograph of it later on Fig. (Vol. 11. p. 16).

Sherrington and Batten have both failed to find a muscle spindle in the intrinsic muscles of the Tongue. But on the other hand Forster states in 1894, that they are to be found in the hinder part of the tongue.

Muscle spindles are said not to exist in the Diaphragm. I have never had an opportunity of examining the diaphragm specially for muscle spindles, and/

and I have never come across the statement anywhere that they do exist in this muscle. There is no reason to suppose that the diaphragm would require muscle spindles, for it is not one of the muscles specially endowed with keen muscle sense. But on the other hand, has not the Diaphragm as much claim for muscle spindles as the intrinsic muscles of the Larynx?

Muscle spindles appear at all ages, from the fourth month of foetal life onwards. (Felix). I have seen muscle spindles in the muscles of the forearm of a human foetus four and a half months old.

(1) The Muscle Fibre.

(2) The Spindle Sheath.

The Axial Sheath.

The Centre.

Body.

CONSTITUENT PARTS OF A MUSCLE SPINDLE.

A MUSCLE SPINDLE consists of a central core of several FINE MUSCULAR FIBRES, to which nerve fibres run, and in, and between which, NERVE TERMINATIONS are situated. This central core of muscle and nerve runs along the longitudinal axis of the muscle spindle and is supported by an arrangement of fibrous tissue sheaths and capsules. The central core is immediately surrounded by the AXIAL SHEATH, and on the outside of this, is situated a large LYMPH SPACE with which LYMPHATIC VESSELS communicate. The whole is surrounded and limited by a SPINDLE SHEATH or CAPSULE, which is linked to the axial sheath by bridges of fibrous tissue SEPTA. This spindle-shaped organ is supplied with BLOOD-VESSELS, in connection with which, and with other structures, SYMPATHETIC NERVES are found.

The constituent parts of a Muscle Spindle therefore are:-

(1). The Muscle Fibres.

(2). The Spindle Sheath.

The Axial Sheath.

The Septa.

The/

The Nerve Sheath.

(3). The Nerves and Nerve Terminations.

(4). The Blood-vessels.

(5). The Lymphatics and Lymph Spaces.

✓ (6). The Symphatic Nerves.

These structures will now be considered seriatim in full detail, but before doing so it is advisable to mention and define certain terms which have been introduced, mainly by Sherrington, for the purpose of facilitating description.

Every spindle shaped body may be said to possess a central bulged portion or equator, - an equatorial region, - and to possess two ends or poles, - polar regions. The terms, which have been introduced, and which explain themselves are;-

The Equatorial Region.

The Proximal Polar Region.

The Distal Polar Region.

The EQUATORIAL REGION corresponds to the central bulged portion of the spindle, and occupies about one third of the whole length.

The Proximal Polar Region is the end of the spindle at which the muscle fibres enter to form the central core. It is also proximal in the true anatomical/

anatomical sense.

The DISTAL POLAR REGION of the spindle is the end at which the muscle fibres or their tendinous extremities pass out of the spindle.

The INTRAFUSAL MUSCLE BUNDLE is a term introduced by Sherrington to designate the bundle formed by the muscle fibres in the interior of the muscle spindle. The term "intrafusal" muscle fibre is applied to the muscle fibre inside the spindle to distinguish it from the "extrafusal" muscle fibres outside, - the ordinary muscle fibres.

(Fig. 8).

The first photograph illustrates some of these points: it is a longitudinal section of a muscle spindle from the muscle of the cat stained by Cajal's silver method.

Fig. 8./



Fig. 8.

(B. 57. S.11. Sc. 1). (Slide 1).

Two fine intrafusal muscle fibres are seen entering the spindle at the foot of the photograph at the proximal polar region and between them is a nerve fibre running up into the spindle. In the centre of the spindle the darkly stained nerve is seen turning around the intrafusal muscle fibre. The capsule of the spindle and the lymph space are well shown.

Length/

Length of Muscle Spindle	0.4mm.
Breadth of Muscle Spindle	0.08mm.
Diameter of Intrafuscal Muscle Fibre	0.014mm.
Diameter of ordinary Muscle Fibre	0.03mm.

The general relations on cross section of a muscle spindle can be well seen in Fig. 9 which is from the muscle of the rabbit.



Fig. 9.

(B.76. S.1 Sc. 3). (Slide 4).

Cross section of a muscle spindle from near the equatorial region showing the intrafuscal muscle bundle, composed of three intrafuscal muscle fibres, occupying only a small portion of the muscle spindle. The axial sheath, the peri-axial/

axial lymph space, and the capsule with a blood-vessel in it to the right are all well shown.

Diameter of Muscle Spindle 0.17×0.12 mm.

Diameter of Intrafusal Muscle Bundle 0.03 mm.

Diameter of Intrafusal Muscle Fibres. 0.015 mm

I. THE INTRAFUSAL MUSCLE FIBRES.

The intrafusal bundle of muscle fibres passes along the long axis of the muscle spindle forming a kind of central core. The fibres enter at the proximal polar region and after passing through the equatorial region, they pass out at the distal polar region either as muscle fibres, or as fine tendinous filaments.

Cross section at the proximal polar region shows the primitive muscle fibres closely surrounded by a specially thickened sheath of perimysium internum, while at the distal polar region the appearances are so similar that it is often difficult to distinguish the one from the other. In the latter, however, the sheath frequently contains tendon fibrils instead of muscle fibres, and it is extremely seldom, if ever, that one is able to find any evidence of nerve fibres, while in the former it is the rule rather than the exception to find nerve fibres among the muscle fibres.

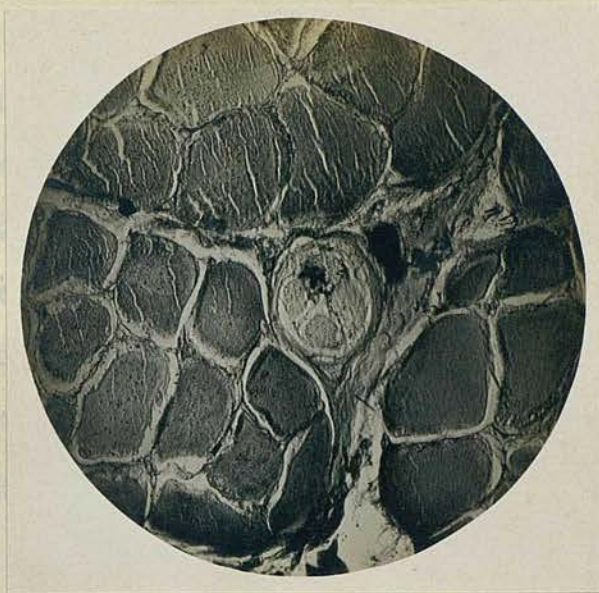


Fig. 10.

(B. 76. S.4. Sc. 3.)

(Slide 6.)

In the centre of the field is a representation of the proximal polar region of a muscle spindle cut in transverse section. Four small muscle fibres are seen filling up the entire area of the spindle.

Cross section at the equatorial region shows the intrafusal muscle bundle composed of an increased number of muscle fibres, lying in the axial sheath, but /

but widely separated from the limiting capsule by the large lymphatic space, and only occupying, it may be, not more than one sixth of the spindle itself. Occasionally I have found the bundle occupying an accurately central position, but as a rule the bundle is excentric in position on account, more of the localised bulging and asymmetry of the capsule, than of the true excentric position of the bundle itself.



Fig.11.

(B. 76, S.4. Sc. 1.)

(Slide 6.)

Cross /

Cross section of a muscle spindle from the Gastrocnemius muscle of the rabbit. Section passes through the equatorial region of the spindle. There are now five intrafusal muscle fibres, while Fig. 9 which is from the same spindle shows only three muscle fibres.

Diameter of Muscle Spindle	0.16
	0.12 mm.
Diameter of Axial Core.	0.04 mm.

Longitudinal section of a muscle spindle shows that the intrafusal bundle passes along in the long axis of the spindle, the component fibres being more or less parallel to one another. On the other hand many of my longitudinal sections of muscle spindles show distinct twisting of the intrafusal muscle fibres round one another, and one gathers the impression that the individual muscle fibres are somewhat loose as they run through the spindle. Huber has noted this and compares them to a "loose braid."

The number of muscle fibres entering at the proximal polar region varies very greatly. The numbers from 2 to 10 cover the majority of cases, but sometimes as many as 20 have been noted, while in the snake only one fibre as a rule enters into the /

the spindle.

In shape they are variously polygonal in contradistinction to the circular shape of the fibres inside the muscle spindle. They are of the "red" or "protoplasmareich" variety according to Sherrington.

Figures 12 and 13 show the shape of the muscle fibres which later entered into a muscle spindle, and they will be seen to be variously polygonal in shape before they enter into the muscle spindle.

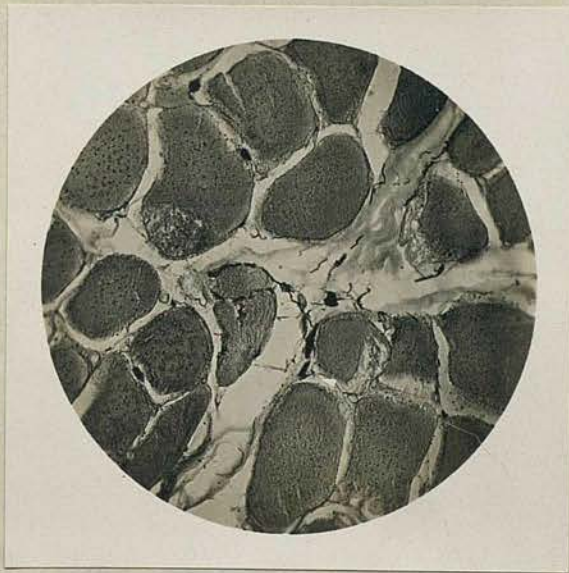


Fig. 12.

(B. 76. S. 19. Sc. 1.)

(Slide 16.)

Cross /

Cross section of the Gastrocnemius muscle of the rabbit, stained with Nitrate of Silver.

In the centre will be seen three muscle fibres, smaller than the others with black nerve fibres around them; Note their various shapes; they were later traced into a muscle spindle, when they became circular in outline.

That the muscle fibres about to enter into a muscle spindle lose their polygonal shape and tend to become circular even before they enter the confines of the muscle spindle, will be seen from the next figure, which is a section of the same muscle fibres as in Figure 11.



Fig. 13.

(B. 76.S. 22.Sc. 3.)

(Slide 19.)

The small muscle fibres in the centre of the figure are now tending to become circular in outline, they are not yet bound round by a capsule though they were later traced into the muscle spindle.

Diameter of small muscle fibres

later traced to spindle.	0.02 mm.
	0.008mm.
Diameter of ordinary fibres.	0.06 mm.
	0.032mm.

At the entrance into a spindle the muscles are distinctly smaller than the ordinary muscular fibres. Some of them are as small as .008 mm., while others come nearer to .028 mm. The majority are nearer this later figure. An ordinary extrafusul muscle fibre, which we may take as measuring about .06 mm., is thus seen to be:-

1. Twice as large as the largest intrafusul muscle fibre.
2. Three times as large as the great majority of intrafusul muscle fibres.
3. Ten times as large as some of the intrafusul muscle fibres.

I have taken one hundred and forty muscle spindles from the cat, rabbit, and human subject and measured the cross sectional area of the spindles, of the intrafusul muscle fibres, and of the ordinary muscle fibres. The result may be shown in the following table:-

SPINDLE /

SPINDLE. INTRAFUSAL FIBRE. ORDINARY FIBRE.

CAT.	0.071 mm.	0.014 mm.	0.022 mm.
RABBIT	0.072 mm.	0.015 mm.	0.044 mm.
HUMAN.	0.187 mm.	0.017 mm.	0.034 mm.

Although these figures are taken from one hundred and forty muscle spindles, a larger number of spindles would require to be counted before the figures would be of any value.

The muscle fibres entering at the proximal polar region are well striated both longitudinally and crosswise. That the cross striation is coarser than the striation of ordinary muscle fibres was noted by Kühne as far back as 1863, and it has been stated that 10 striations of the intrafusal muscle fibre occupy the same distance as 13 striations of the extrafusal muscle fibres.

The striation is more distinct at the two polar regions than at the equatorial region, where it is not only less distinct and confined to the periphery but where it is often absent altogether. This will be referred to later.

When the muscle fibres have passed well within the confines of the spindle longitudinal splitting takes place so that each fibre may give rise /

rise to 2, 3, or, (as in some of my preparations,) to 4 "daughter fibres". That this is a mere splitting is shown by the fact that the total area of muscle tissue is not increased. In one case where three fibres had split to give rise to six "daughter fibres" the total muscle area, calculated by measuring the diameters of all the muscle fibres, was less after division than on entering at the polar region.

More important than the sectional area of the new "daughter" fibres is the alteration of the outline of the fibres on cross section. The intrafusal muscle fibres are circular on cross section in contradistinction to the variously polygonal shape of the ordinary muscle fibres. The circularity is characteristic of the intrafusal muscle fibres, and when in cross section a bundle of small fibres all more or less circular in outline, are seen, the probability is that those fibres are from a muscle spindle and from nothing else.

As the fibres approach the equatorial region very interesting changes take place, but at the same time they are very difficult to dogmatise about, and there is a good deal of difference of opinion especially as to the nature and situation of the nuclei. /

nuclei. But one is probably correct in stating that as the equatorial region is approached, the following changes take place:-

- (1.) The muscle fibres become more numerous.
- (2.) The muscle fibres become circular.
- (3.) Striation becomes less distinct.
- (4.) Nuclei become more abundant.
- (5.) A central hyaline core is more clearly made out.

But before the equatorial region is reached some sections show nuclei even in the centre of the muscle fibres. So that when, as is often the case in my own preparations, the striation is limited to the periphery of the muscle fibre, an appearance is got which closely resembles the "myoblasts" described by Schafer.

The character of the intrafusal fibres as they lie in the Equatorial Region forms one of the most interesting points in the description of the muscle spindles.

No one will deny that the fibres become more numerous, and that they become more circular: no one will deny that the striation becomes less distinct, and that nuclei appear in great profusion. But all will not agree as to whether the nuclei really belong to the muscle fibre or not. The facts may well be arranged under the following headings:-

- (1.) Striation /

- (1). Striation of the fibres.
- (2). Nuclei (Seen in equatorial region).
- (3). Sarcolemma of the fibres.

(1). The Striation of the fibres.

It is certain that in the vast majority of preparations the striation is seen to become less distinct as the equatorial region is approached and to reappear again as the fibre nears the distal polar region. But it must be noted that some intrafusal muscle fibres pass through the equatorial region without the striation disappearing.

This is very rare. A large number show only slight striation at the very periphery all the way through the equatorial region of the spindle. But perhaps the majority, certainly the majority I should say after examining many sections for this point alone, of the fibres show absolutely no sign of any striation as they pass through the equatorial region of the spindle. Both in longitudinal and in cross section numerous fibres are seen where the highest magnification possible fails to detect anything of the nature of cross striation.



Fig. 14.

(B. 57. S. 10. Sc.).

(Slide 2.)

Longitudinal section from the Gastrocnemius muscle of the cat, to show the splitting of the muscle fibres as they pass up into the muscle spindle. It will be seen that at the foot of the photograph, the proximal polar region, the striation of the muscle fibre is very distinct, but that as the fibres pass into the equatorial region of the spindle, the striation is not so evident, but the nuclei become more numerous.

(2). The /

(2). The Nuclei seen at the equatorial region.

We can assert without fear of contradiction the following:-

- a. Great profusion of nuclei apparent at the equatorial region obscuring the striation.
- b. Nuclei are clear.
- c. Nuclei are rounded, oval, or spherical.
- d. Nuclei stain well with Haematoxylin.
- e. Nuclei are resting nuclei.
- f. Nuclei measure about 6 microns.

I frequently stain the nuclei with iron haematoxylin or some such stain in the attempt to find karyokinetic figures therein but have always failed.

From Sherrington we learn the following:-

- (1). Not clear as to whether nuclei belong to muscles.
- (2). Thin tubular fibrillated layer seen beneath the nuclear sheath on cross section.
- (3). There is a central core of hyaline substance running along inside the tubular layer.
- (4). Complete zone of 4 to 6 nuclei around the central hyaline core.

From /

From Huber we learn the following:--

- (1.) The sheet of nuclei is not a part of the intrafusal muscle fibre.
- (2.) Nuclei belong to a connective tissue sheath, which surrounds each intrafusal fibre, a sheath inside of the axial sheath with which it is partly fused, or to which it may be partly united by bands or septa of fibrous tissue.
- (3.) They are nuclei of endothelial cells lining the above mentioned fibrous tissue sheath, and well seen in longitudinal sections.
- (4.) The hyaline core is sarcoplasm.

With an oil immersion lens one can certainly at places make out the fibrous tissue sheath referred to by Huber, and one is inclined to believe that the nuclei in the equatorial region of the spindle do not strictly belong to the intrafusal fibre, for when it is possible to make out a sarcolemma round the fibres in the equatorial region, the nuclei were outside this sheath. But then on the other hand, before the equatorial region is reached nuclei can be /

be seen in the muscle fibres, centrally placed and certainly inside the sarcolemma.

The nuclei are best seen in transverse sections of muscle spindles about the equatorial region.



Fig. 15.

(B. 76.S.3. Sc. 3.)

(Slide 5.)

Cross section at the equatorial region of a muscle spindle from the muscle of the rabbit. The largest intrafusal muscle fibre shows a large number of nuclei, indeed, the nuclei have entirely taken the place of the muscle substance proper.

Diameter /

Diameter of Muscle Spindle.	0.16	mm.
	0.13	mm.
Diameter of Axial Core.	0.05	mm.
Diameter of Intrafusal Nuclei.	0.004	mm.

The difficulty of deciding the question as to whether the nuclei really belong to the muscle fibres or not, will be appreciated from the following section.



Fig. 16.

(B. 161. S. 6. Sc. 1.)

(Slide 24.)

Cross section from the Human muscle of forearm showing a muscle spindle with three intrafusal muscle fibres. The largest of these shows a profusion /

profusion of nuclei, but it is difficult to be sure whether they form part of the muscle fibre or not. The black dots are nerve terminations.

Diameter of Muscle Spindle.	0.16 mm.
	0.2 mm.
Diameter of Axial Core.	0.06 mm.
Intrafusal Muscle Fibres.	0.02 mm.
	0.028 mm.
Nuclei of Muscle Fibres.	0.004 mm.
Nerve Terminations.	0.002 mm.

The nuclei are, perhaps, better shown up when the section is stained with Haematoxylin and Picofuc-sine, as in the following Figure.



Fig. 17.

(B. 265 S. 1. Sc. 2.)

(Slide 44.)

Transverse section of a muscle spindle from the human forearm, stained with Haematoxylin to show the nuclei inside the intrafusal muscle bundle.

Diameter of Muscle Spindle.	0 2 mm.
	0 28 mm.
Diameter of Axial Core.	0 06 mm.
Diameter of Nuclei.	0 004mm.

(3). The Sarcolemma of the fibres.

In the greater part of their extent the intrafusal fibres certainly possess a definite sarcolemma, but after the difficulties mentioned above it will readily be seen that it is not easy to decide whether the sarcolemma remains as a distinct covering to each intrafusal fibre as it traverses the interesting area of the equator of the muscle spindle.

The DISTAL POLAR REGION now remains to be discussed. After the fibres have passed through the equatorial region the nuclei diminish in number, the striation becomes more marked, and thus the intrafusal fibres soon regain the appearance that they possessed at the proximal polar region. In addition, the fibres join up again, while their subsequent behaviour depends more upon the exact site of the muscle spindle as a whole than upon anything else. If the muscle spindle is lying /

lying entirely within muscular tissue the intra-fusal fibres pass out of the spindle very much as they passed in, and show no evidence of becoming tendinous.



Fig. 18.

(B. 264.S.1.Sc.2.) (Slide 43.)

Human muscle stained with Van Gieson's stain, showing muscle fibres passing out as such at the distal polar region of a muscle spindle.

This /

This can also be well seen in sections stained with one of the silver methods, as can be noted in the following figure.

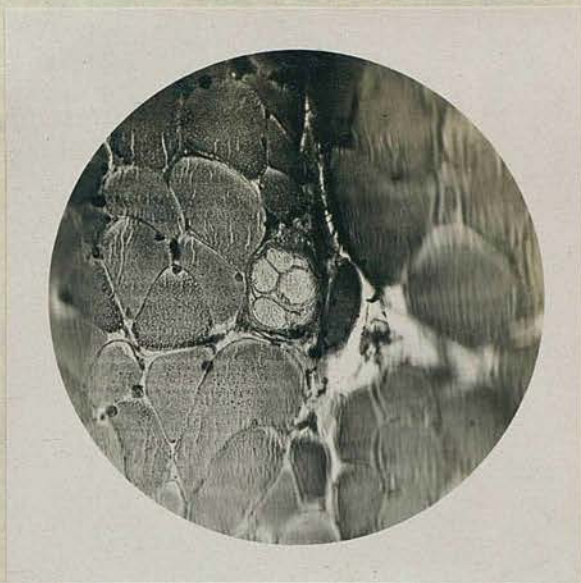


Fig. 19.

Transverse section of the distal polar region of a muscle spindle from the "silvered" muscle of a rabbit. The intrafusal muscle fibres are seen passing out of the spindle without becoming tendinous.

If the muscle spindle is lying near the tendon of the muscle or near any fibrous tissue sheath or aponeurosis, /

aponeurosis, then the intrafusal fibres become tendinous before passing beyond the confines of the spindle, and they either become fused with the capsule of the spindle or they pass outside of the spindle altogether and join themselves on to the tendon of the muscle, or the fibrous tissue septum lying near.



Fig. 20.

(B. 57. S. 10. Sc. 2.)

(Slide 2.)

Longitudinal section of a muscle spindle from the muscle of the cat, stained with Cajal's silver /

silver method. The characters of the three different areas of the spindle are well shown. At the foot of the photograph, the proximal polar region, the small striated muscle fibres pass into the spindle, as muscle fibres. In the centre, the striation has disappeared, the nerve terminations are very profuse, while at the top of the figure, - the distal polar region, the muscle fibres are passing out of the spindle, not as muscle fibres, but as fine tendinous bundles.

In many of my preparations it did not require the presence of any very large piece of fibrous tissue septum outside the spindle to induce the intrafusal muscle fibres to become tendinous before leaving the muscle spindle.

2. THE SHEATHS.

The spindle sheath is made up of numerous fine meshes. The frame work, so to speak, of the muscle spindle which supports the more delicate and more essential structures in the interior of the spindle, namely the muscle fibres just described and the nerve terminations to be described, is composed of white fibrous tissue. This fibrous tissue has a more or less elaborate arrangement which is best described under the heading of the various sheaths which it forms. Thus there is a sheath round the whole muscle spindle, forming the capsule to that organ, the SPINDLE SHEATH. Then there is a more delicate sheath round the axial core of the spindle, the AXIAL SHEATH. These two sheaths are joined together by fine bridges of fibrous tissue, the SEPTA. Lastly, when a nerve comes to the spindle it is enclosed in a very thick Henle's sheath, the NERVE SHEATH, which may be here considered since it becomes continuous with the spindle sheath and with the axial sheath. The sheaths fall to be considered, therefore, in the following order:-

- (1).The Spindle Sheath.
- (2).The Axial Sheath.
- (3).The Septa.
- (4).The Nerve Sheath.

(1.) THE SPINDLE SHEATH.

The spindle sheath is made up of numerous fine membranous lamellae of white fibrous tissue, arranged in a circular manner around the muscle spindle.

The circles of lamellae are laid down at right angles to the long axis of the organ, and on cross section the appearance is not unlike what one sees on cutting into an onion.

The number of the lamellae varies not only with the different animals, but also with the region of a particular spindle around which they are arranged. They are more numerous near the equatorial region than at either extremity of the spindle, and they are more numerous as one rises from the reptiles through the amphibia to the mammalia.. As many as 6 to 8 or even 10 layers may be made out in the mammalian muscle spindle but I have had great difficulty in distinguishing more than 2 layers in the lower animals.

The fibrous tissue shows a small number of small elongated nuclei, arranged somewhat after the manner of the nuclei in the Pacinian Corpuscles, commonly found in the mesentery of the cat.

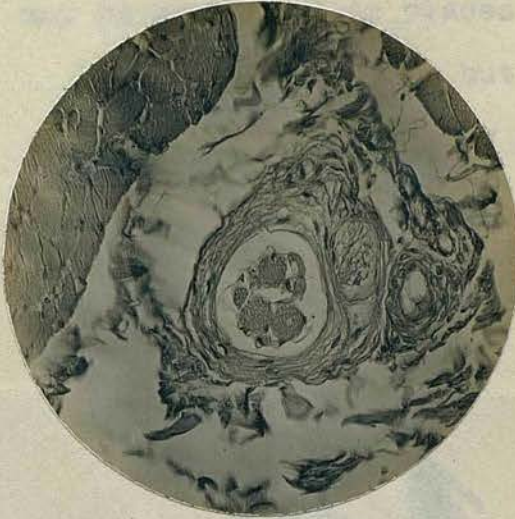


Fig. 21.

(B. 264. S.1. Sc. 1.

(Slide 43.)

Transverse section of the proximal polar region of a human muscle spindle, stained with Van Gieson's stain. The concentric layers of the capsule and the nuclei are well shown, as are the nuclei of the axial sheath.

Diameter of Spindle.	0.12	mm.
Diameter of Axial Core.	0.06	mm.
Diameter of Intrafuscal Fibres.	0.012	mm.
	0.024	mm.
Diameter of Ordinary Fibres.	0.028	mm.
	0.04	mm.

The lamella may be merely in close apposition.

may be fused together.

may be separated at places by small or large clefts, some, but by no means all, of which may show bloodvessels in their interior.



Fig. 22.

(B. 138.S. 11. Sc. 3.)

Slide 36.)

Cross section of a human muscle spindle, stained with Nitrate of Silver, Note the layers of the capsule. The spindle contains six muscle fibres in its interior and five medullated nerve fibres. To the left side, between /

between the layers of the capsule, is seen a bloodvessel and a nerve, the latter containing five medullated nerve fibres.

Diameter of Spindle.	0.1 mm.
Diameter of Muscle Fibres.	0.14 mm.
Diameter of Nerve Trunk.	0.008 mm.
Diameter of Nerve Fibres.	0.017 mm.
Thickness of Capsule.	0.005 mm.
	0.008 mm.
	0.026 mm.
	0.052 mm.



Fig. 23.

(B. 161. S. 9. Sc. 1.)

(Slide 26.)

In /

In this cross section of a human muscle spindle, vessels and nerves are seen in between the layers of the capsule. Stained with Silver.

No yellow elastic fibres are to be found in this sheath, for even when sections are stained specially with Unna's method, no fibres are shown up. I have stained many sections with Weigert's elastic tissue stain in the attempt to find yellow elastic tissue fibres, but the only elastic fibres which took on the stain in the spindle sheath, were actually in, and confined to, the walls of the blood vessels of the capsule or spindle sheath.

This spindle sheath of white fibrous tissue, then forms the true CAPSULE of the muscle spindle. The inner surface of the capsule will be referred to later when a description will be given of how it is in relation to what is called the PERIAXIAL LYMPH SPACE, and of how it is joined on to the AXIAL SHEATH by fine fibrous tissue septa.

On its outer side the capsule comes into relation with the ordinary muscle fibres, forming only little or no connections with the perimysium internum of the muscle fibres, except at special places. These /

These special places where the capsule has a firm connection with the structures outside the muscle spindle are:-

(1). The Proximal Polar Region where the capsule becomes continuous with the specially thickened perimysium internum as it winds around the small muscle fibres entering at this region to form the intrafusal bundle of muscle fibres. This is very well shown in the numerous cross sections at this area, and in the following figure.



Fig. 24.

(B. 76 S. 15. Sc. 1.)

(Slide 12.)

Transverse section through the proximal polar region /

region of a muscle spindle of the rabbit.

The layers of the capsule are seen to become continuous with the perimysium internum of the muscle tissue outside.

Diameter of Spindle.	0.034	mm.
	0.052	mm.
Diameter of Intrafusal Fibres.	0.008	mm.
Diameter of Ordinary Fibres.	0.05	mm.
	0.06	mm.

(2). The Distal Polar Region where the connection of the capsule is, if anything, rather more intimate and firmer. When the intrafusal muscle fibres pass out of the spindle at the distal polar region as muscle fibres without becoming tendinous the capsule becomes continuous with the thickened perimysium internum just as at the proximal polar region. When, on the other hand, the intrafusal muscle fibres pass out of the spindle as fine tendinous fibres, the capsule then becomes continuous with these fibres and with the fibres composing the aponeurosis, septa, or tendon which have induced the intrafusal muscle fibres to become tendinous by their mere proximity to the muscle spindle. I do not know whether there is any significance, but I have certainly noted the fact that this /

this state of affairs is much more frequently seen in the human muscle, while in the frog it is the exception rather than the rule that the intrafusal muscle fibres should pass out of the spindle as muscle fibres showing no tendency to become tendinous.

(3). At the Nerve Entrance the capsule forms a very firm connection with the sheath of the nerve. This will be described later, but the following figure may be inserted here to show the connection.



Fig. 25.

(B. 76. S. 21. Sc. 2.)

(Slide 18.)

The nerve fibre is seen approaching the muscle spindle /

spindle from the right side, its wide sheath becoming continuous with the layers of the capsule of the spindle. Cross section of a muscle spindle from the rabbit, stained with Silver Nitrate.

(2). THE AXIAL SHEATH.

(II). THE AXIAL SHEATH.

The AXIAL SHEATH is a thin layer of connective tissue immediately investing the axial core of the muscle spindle. It is richly nucleated and supports as well as invests the neuro-muscular elements of the core binding the whole into a definite bundle justifying the term "intrafusal bundle". The axial sheath keeps closely to the intrafusal bundle throughout its entire extent and as the total sectional area of the intrafusal muscle fibres diminishes towards the centre rather than increases, it follows that the axial sheath does not share in the general spindle shaped swelling, but runs unheeded through the spindle forming a lining tube to the true axial core.

Each spindle of a compound spindle retains its own axial sheath although the capsules of the comprising divisions become fused and common. This is very well shown in the following photograph of a compound muscle spindle.



Fig. 26.

(B. 161. S. 14. Sc. 4). (Slide 28).

Transverse section of a compound Human muscle Spindle. The larger division to the right contains three muscle fibres and four nerves.

The smaller division to the left contains two muscle fibres, a vessel, and a spindle nerve with a very wide sheath. A large vessel is seen at the lower part of the capsule.

The septum dividing off the two compartments is very distinct. Each division has a special/

special axial sheath of its own.

Diameter of Comp. Spindle	0.14 m.m.
	0.2 m.m.
Diameter of right compartment	0.1 m.m.
Diameter of left compartment	0.06 m.m.
Diameter of R. Axial Core.	0.048m.m.
Diameter of left Axial Core.	0.04 m.m.
Diameter of Intrafusul Fibres	0.012m.m.
	0.024m.m.

Between the capsule and the axial sheath there is a definite space which varies in size according to the region of the spindle examined. This space is a mere cleft at the polar regions, as can be seen in figure 27, but gradually increases in size as the equator is reached, where it may measure as much as 0.065 m.m. across.



FIG. 27.

Fig. 27.

(B. 76. S. 4. Sc. 3). (Slide 6).

In this section of the muscle spindle of a rabbit, the axial sheath is not much smaller than the capsule of the spindle, and is separated from it by the periaxial lymph space which is here represented merely as a slight cleft.

Sherrington has succeeded in injecting this space by injecting the lymphatics of the leg, and it has been called by him the Periaxial Lymph Space.

In the fixed muscle this space naturally, then, shows up as a homogenous material representing coagulated proteid material.



Fig 28

Fig. 28.

(B. 265. S. 1. Sc. 1). (Slide 44).

Transverse section of the equatorial region of a human muscle spindle, stained with Van Gieson's method. The layers of the capsule are well shown and also the nuclei of the axial sheath. The lymph in the large periaxial lymph space appears as dull homogenous material. Towards the lower corner of the capsule a spindle nerve and a vessel are seen.

Diameter of Spindle.	0.2 m.m.
	0.28 m.m.
Diameter of Axial Core	0.06 m.m.
Diameter of Spindle Nerve	0.032m.m.
	0.048m.m.
Diameter of Vessel	0.02 m.m.

In addition the space may show a few lymphocytes, but by no chance can one find red blood corpuscles in it, and fat cells are only seen in advanced stages of degeneration not so much of the ordinary muscle fibres, but of the muscle fibres in the interior of the muscle spindle. The periaxial lymph space is traversed by fine fibrous tissue septa, but this is referred to later.

We must recognise that it is the presence of the Periaxial Lymph Space which gives to the muscle/

muscle spindle its distinguishing spindle shape. The axial core has been shown not to share in the spindle shape and the capsule only acts as a limiting membrane and naturally takes the shape of the enclosed organ, so that it is to the periaxial lymph space, and to that space alone that the muscle spindle owes its characteristic spindle shape.

(III). THE SEPTA.

The SEPTA are thin membranes of fibrous tissue which run from the capsule or spindle sheath to the axial sheath, thus bridging across and subdividing the periaxial lymph space. They possess nuclei not unlike those of the capsule and fine prolongations of the septa have been traced in between the groups of muscle fibres and nerve terminations in the core of the spindle. They are of little importance.



Fig. 29.

(B. 161. S. 10. Sc. 5) (Slide 27).

Human muscle spindle in cross section to show fibrous tissue septa crossing, and subdividing, the periaxial lymph space. The granular lymph is well shown.

Diameter of Spindle	0.12	m.m.
	0.18	m.m.
Diameter of Axial Core.	0.04	m.m.

(IV). THE NERVE SHEATHS.

Sensory nerves approach the muscle spindles as large single fibres or as several fibres in a common connective tissue sheath. When the large single sensory nerves, - the spindle nerves, - approach the muscle spindle they are seen to be enveloped in a very large loosely-fitting sheath of Henle. This large sheath was noted nearly fifty years ago, and the large size of the nerve forms a useful guide to the muscle spindles in teasing muscles. The nerve sheath may be composed of as many as eight lamellae and when I was staining the muscle spindles with Weigert's elastic tissue stain I noted that some of the fibres in the nerve sheath took on the stain. A fibre of 0.008 mm. may be seen lying within a nerve sheath of 0.035 mm.



Fig 30.

(B. 138. S. 8. Sc. 2) (Slide 35).

At the right margin of this human muscle spindle is seen a large sheath of Henle. The axis cylinder of the fibre has dropped out. The layers of the capsule are well shown.

Diameter of Spindle	0.1 mm.
	0.18 mm.
Diameter of Sheath of Henle	0.02 mm.

As the spindle is reached the main portion of this nerve sheath becomes continuous with the capsule of the spindle, as is shown in figure 31. But as the still/

still-myelinated nerve fibre traverses the periaxial lymph space it carries with it some of its own investing sheath of Henle, as is apparent in figure 332.

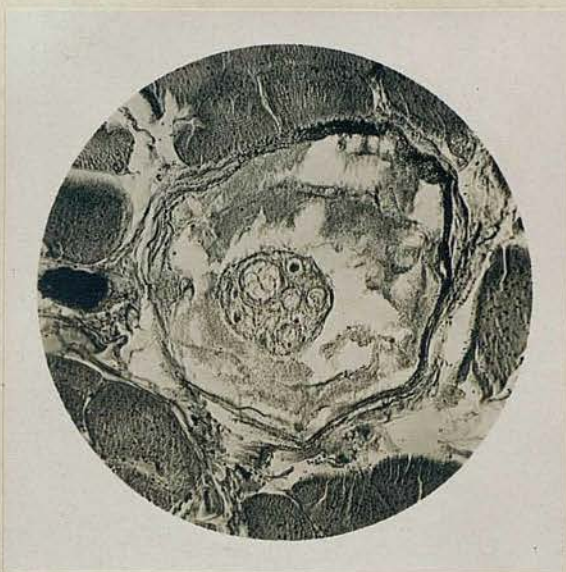


Fig. 31.

(B. 7. S. 6 Sc. 1.) (Slide 24).

Approaching this muscle spindle, - (muscle spindle - of the rabbit,) from the left side a large black nerve is seen, its sheath becoming continuous with the capsule of the spindle. On fine focussing the nerve can be seen to be composed of several fine nerve fibrils.

Diameter/

Diameter of Spindle.	0.14 mm.
Diameter of Axial Core	0.053mm.
Diameter of Sheath of Nerve	0.026mm.
Diameter of Nerve Fibre.	0.012mm.



Fig. 32.

(B. 161. S. 6. Sc. 1). (Slide 24.)

Cross section of a human muscle spindle, stained with Nitrate of Silver. Crossing the periaxial lymph space from the right side a medullated nerve fibre is seen, carrying with it some fibres from its sheath of Henle. The black spots in the intrafusal muscle bundle are/

are the terminations of this nerve fibre around the muscle fibres and nuclei.

Diameter of Spindle	0.16 m.m.
	0.2 m.m.
Nerve in Lymph Space.	0.0046 m.m.
Diameter of Nerve Terminations	
	0.002 mm.

The connective tissue fibres, which the nerve fibre carries in with it, are richly supplied with nuclei and resemble more the fibres of the axial sheath, than the spindle sheath or capsule. They terminate by becoming continuous with the axial sheath as the now non-myelinated nerve fibres pierce the axial sheath to terminate around the intrafusal muscle fibres.

In accurate longitudinal sections of muscle spindles in serial section, there are always some sections which pass through the periaxial lymph space without showing any of the capsule, except at the margins, and without showing any of the contents of the intrafusal muscle bundle at all. This may be shown in the following figure, which is a photograph of a longitudinal section of a muscle spindle from the Gastrocnemius muscle of the cat.



Fig. 33.

(B. 57. S. 11. Sc. 2.) (Slide 1.)

The ordinary muscle fibres are seen at the margins of the figure, then comes the capsule of the spindle in section. The clear area in middle represents the lymph in the periaxial lymph space. At the foot a nerve fibre is seen traversing the lymph space to reach the intra-fusal muscle fibres shown in the next section of the series.

Length of Muscle Spindle. 0.4 mm.

Breadth/

Breadth of Spindle.	0.06 mm.
Diameter of Capsule.	0.004 mm.
Diameter of Nerve Fibre	0.004 mm.

III. THE NERVES OF THE MUSCLE SPINDLES.

Muscle spindles are very abundantly supplied with large medullated sensory nerve fibres. Sherrington first experimentally proved that these fibres were sensory in nature being derived from cells of the posterior root ganglia. The root ganglion fibres pass to the muscles in small sensori-motor and purely sensory nerves. Of all the afferent nerve fibres demonstrated to exist in muscle it has been calculated that the muscle spindles account for nearly two-thirds. Sherrington has stated that two-thirds of all the afferent fibres in muscle are .007 mm. or more in diameter, and of these more than half are taken up by the muscle spindles, while the majority of the rest belong to the Golgi tendon organs.

The nerve fibres may approach the muscle spindles:-

- (1) Singly: in which case they are encased in large loosely-fitting sheaths of Henle, which are quite characteristic and have been already referred to in the preceding pages.
 - (2) In small bundles: in which case the fibres lie in a thick connective tissue sheath.
- These/

These bundles consist of 3 to 6 small medullated nerve fibres all bound for one and the same spindle:- the pure spindle nerves.

With regard to the number of the nerve fibres, at least two go to each muscle spindle, but more often four are seen going to an average sized spindle. The numbers may be given as:-

3 to 4 nerve fibres to majority of spindles.

5 to 7 nerve fibres to compound spindles.

1 nerve fibre to about every three intrafusal muscle fibres.

In counting these nerve fibres some care must be taken for a nerve fibre often branches very acutely some little distance from the muscle spindle, and this may be mistaken for two nerve fibres, whereas it is only two branches of one and the same nerve fibre.

Point of Entrance. This is of some interest in so far as there are two main places where the nerve fibres gain entrance to the muscle spindles. These are:-

1. Near the Equator, rather nearer the proximal pole than the distal pole. This is the principal area of nerve entrance, as here usually 2 or 3 large nerve/

nerve fibres are distributed to the spindle. The fibres measure at least .008 m.m. in diameter, and are sometimes even larger.

2. At the Proximal Pole. Nearly every muscle spindle of any size shows a certain number of fine medullated nerve fibres gaining admission to the inside of the capsule at the proximal polar region. These fibres are smaller than the fibres at the equatorial region, being commonly about .004 m.m. I have seen it stated that nerves also gain entrance at the distal pole but though I have frequently looked for this I have never been able to find any nerves entering a human muscle spindle at the distal polar region. Not finding it does not entitle me to deny the existence of it. In some of the lower animals I have noticed that the only nerve gains entrance to the spindle at the proximal polar region. Huber has noted this in the tortoise and snake.

It is difficult to give an accurate description of the behaviour of the nerve fibres as they approach and gain admission to the muscle spindles. For purposes of description it will be advisable to consider the characters of the nerve fibres at various places, - outside and inside the capsule, in the periaxial lymph space, at the axial sheath, and inside the axial sheath or core. These will be considered, then, in the following order:-

(1)/

- (1) Outside the Capsule, after the nerve has arrived at the muscle spindle.
- (2) At the Capsule. After having penetrated the outer layer of the capsule but before having reached the interior of the spindle.
- (3) Inside the Capsule. Under this heading the course and behaviour in the Periaxial Lymph Space only will be described, although it properly should include all the subsequent subdivisions.
- (4) At the Axial Sheath.
- (5) Inside the Axial Sheath. This may conveniently be termed the "Ultimate Nerve Endings" and I shall devote a special paragraph to it, not only because it is the most interesting and important but also because in my researches I have paid special attention to it.

(1) Outside the Capsule. When the spindle nerves arrive at the muscle spindle the thick Henle's sheath becomes in part attached, as previously described, to the capsule of the organ. It will be seen that perhaps the majority of the fibres pass straight into the spindle without dividing, but every now and then one comes across a nerve fibre which divides before/

before it reaches the capsule. The angle between the two divisions is always a very small one and the fibres consequently run along very close to one another. The length of the internodes is of interest on account of the change in size when the fibres are inside the spindle. Teased specimens, I have found, are much the best for studying this point, as many millimeters of the length of the spindle nerves can be got on the one slide. If one traces a spindle nerve from the place it leaves the nerve trunk, it is often seen to run singly for a considerable distance and one often has to travel at least a millimeter along the nerve before coming to the end of an internode. Sherrington has estimated the length of the internodes outside the capsule as being from .6 mm. to .9 mm.



Fig. 34.

(B. 266. S. 2.)

(Slide 38.)

This is a photograph of a teased muscle of the rabbit, stained by the intra-vitam Methylene Blue method.

At the top of the field, out of focus, a mixed nerve trunk is seen, giving off a single nerve fibre, which measures 0.003 mm. in diameter. After a course of 5.5 mm. the nerve fibre was seen to terminate in a muscle spindle, which was over 1 mm. in length. This nerve fibre would, in cross section, appear surrounded by a very wide sheath of Henle.

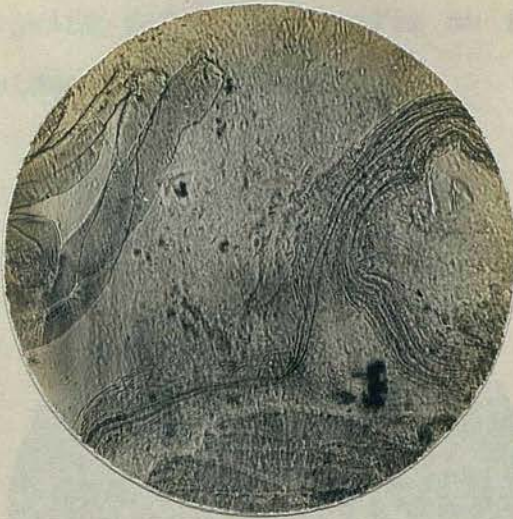


Fig. 35.

(B. 266. S. 1.)

(Slide 37.)

From the left hand top corner of the twisted nerve trunk two large nerve fibres are given off. The lower of the two is a sensory nerve and measures 0.005 mm. in diameter.

It was traced, after a course of 4 mm. to its termination in a muscle spindle 1-2 mm. in length. Teased muscle of rabbit, stained during life with Methylene Blue, and fixed in Ammonium Picrate.

Cajal's silver method is excellent for tracing the course of nerve fibres to their termination, but as the/

the sections are cut serially it is difficult to show much of the course of the nerve fibres on one section, but the following figure will give an indication of what is possible with this method.



Fig. 36.

(B. 76. S. 8. Sc. 1.)

(Slide 8)

Transverse section of the Gastrocnemius muscle of the rabbit. Cajal's Silver Nitrate method. Towards the foot right hand corner a small muscle spindle is seen, and at the opposite corner is a transverse section of a nerve trunk from which, in serial sections, nerve fibres could be traced to end in the muscle spindle shown in the photograph.

Diameter/

Diameter of Muscle Spindle.	0.04 mm.
	0.08 mm.
Intrafusal Muscle Fibres.	0.008 mm.
	0.02 mm.
Ordinary Muscle Fibres.	0.032 mm.
	0.06 mm.
Diameter of Nerve Trunk.	0.12 mm.
	0.2 mm.
Diameter of Nerve Fibres.	0.0087 mm.
	0.015 mm.

The difficulty of actually tracing, even in serial sections, the whole course of a nerve fibre into a muscle spindle will be appreciated by a glance at the two following photographs.



Fig. 37.

(B. 76. S. 19. Sc. 2)

(Slide 16)

Transverse/

Transverse section of a muscle spindle of the rabbit. The spindle shows five intrafusal muscle fibres, and running down towards it from the top left hand corner is a nerve fibre with a wide sheath.

Diameter of Spindle.	0.06 mm.
	0.048 mm.
Diameter of Nerve.	0.006 mm.
Diameter of Nerve Sheath.	0.012 mm.



Fig. 38.

(B. 76. S. 27. Sc. 2) (Slide 20)

A muscle spindle containing five muscle fibres cut somewhat obliquely. Below and to the right/

right is the artery to the spindle; above the spindle nerve fibres, which were traced into the spindle, are seen leaving the nerve trunk, which is shown at the top right hand corner.

Diameter of Spindle.	0.12 mm.
Diameter of Vessel.	0.02 mm.
	0.04 mm.
Diameter of Nerve Fibres.	0.0017 mm.
Diameter of Nerve Trunk.	0.032 mm.

(2) At the Capsule. In some teased specimens fine nerve fibres can be seen passing into the capsule, but yet not appearing within the spindle. Where do they go to? Fine focusing shows that they remain in the thickness of the capsule or spindle sheath, and when they have been stained with Methylene Blue or Silver they can be seen to terminate in and around the layers of the capsule as a fine branching network. In cross sections of muscle spindles nerve fibres, surrounded by their wide sheaths, are often seen lying in between the layers of the capsules of the spindles. They are sometimes cut in cross section, as in Figure 39, more rarely they are cut in longitudinal section, as they run at right angles to the long axis of the spindle. This is seen in Figure 40.

that its capsule is parallel to the long axis
of the spindle.

Diameter of Spindle.	0.12 mm.
Diameter of spindle sheath.	0.04 mm.



Fig. 39.

(B. 264. S. 1. Sc. 1.)

(Slide 43)

Transverse section through the proximal polar region of a muscle spindle from the muscle of the human forearm. Stained with Van Gieson's stain. The thick capsule contains between its layers on the right side a spindle nerve with numerous medullated nerve fibres; this nerve is cut in transverse section indicating that its course is parallel to the long axis of the spindle.

Diameter of Spindle. 0.12 mm.

Diameter of Spindle Nerve. 0.048 mm.



Fig. 40.

(B. 76. S. 11. Sc. 1.) (Slide 9)

Cross section of a muscle spindle from the rabbit, to show a nerve fibre running in the capsule of the spindle (at the right side). The nerve fibre is running round the spindle at right angles to its long axis.

Diameter of Spindle.	0.06 mm.
Diameter of Nerve in Capsule.	0.0026 mm.
Intrafusal Muscle Fibres.	0.02 mm.
Extrafusal Muscle Fibres.	0.04 mm.



Fig. 41.

(B. 161. S. 16. Sc. 5.) (Slide 30).

Transverse section of a human muscle spindle. At the right top corner on the capsule of the spindle is a large medullated nerve with numerous nerve fibres inside the wide sheath. Medullated nerve fibres can be seen running obliquely out of the nerve sheath into the periaxial lymph space, making their way towards the intrafusal muscle bundle.

Diameter of Muscle Spindle.	0.2	mm.
	0.24	mm.
Diameter of Axial Core.	0.06	mm.
	0.08	mm.
Diameter of Spindle Nerve.	0.08	mm.

(3). Inside the Capsule. Once the nerve fibre gets well within the confines of the muscle spindle many important changes are noticeable. Branching becomes very frequent and is always dichotomous. The branches run in all directions, each retaining a myeline covering which appears distinctly thinned. But in contradistinction to this the axis-cylinder after branching is often very much larger than before branching. It sometimes even happens that two branches possess axis-cylinders, each of them larger than the axis-cylinder of the parent fibre from which they were derived. Inside the capsule, too, the internodes are much smaller than outside. Outside, as above mentioned, the internodes are about a millimeter in length, but inside the capsule it requires very careful and prolonged searching to find an internode even as long as a tenth of a millimeter. The changes may be summarised as follows:-

Inside there is:-

- (1) More frequent branching.
- (2) Shorter internodes.
- (3) Thinner myeline covering.
- (4) Thicker axis-cylinder.

The course of the fibres through the PERIAXIAL LYMPH SPACE can be well seen in teased specimens, but I have had more satisfactory results on/

on this question from serial sections cut in a longitudinal direction. When the spindles have been previously impregnated with silver solution the small nerves show up a black line in the light background of the proteid material of the lymph space. The nerves are found to take a serpentine course towards the axial sheath, but at the same time, they have a general oblique direction from the spindle sheath to the axial sheath. Occasionally in longitudinal sections the nerves appear as very short dark lines and sometimes merely as black dots. The meaning of this is clear on cross section, for one can then see, in serial section, that the nerve fibres run in a more or less spiral manner from the spindle sheath towards and around the axial sheath.



Fig. 42./

Fig. 42.

(B. 57. S. 9. Sc. 3.) (Slide 3).

Longitudinal section through the periaxial lymph space of a muscle spindle from the cat, stained with Silver Nitrate.

The nerves appear as little, black, serpentine lines, on their way from the capsule of the spindle to the intrafusal muscle bundle.

Length of Muscle Spindle.	0.4 mm.
Breadth of Spindle.	0.06 mm.
Diameter of Nerve Fibrils.	0.0013 mm.

That the nerve fibres do not run straight from the capsule of the spindle to the axial core is also shown from the fact that in transverse sections of muscle spindles, it is not uncommon to find, as is seen in the following figure, that the nerve fibres are also cut in cross section actually inside the periaxial lymph space. That is to say that for the time being their course is parallel to the long axis of the muscle spindle.



Fig. 43.

(B. 161 S. 16. Sc. 3.) (Slide 30.)

Above the axial core of this human muscle spindle a small bundle of medullated nerve fibres can be seen cut in cross section. That they are medullated is evident; they were derived, as can be seen from Figure 41, from the spindle nerve in the capsule of the spindle. The nerve fibres in the axial core, on the other hand, are not medullated, but appear as simple black dots.

More frequently, however, in cross sections of muscle spindles, the nerves crossing the periaxial lymph space/

space are cut, not transversely, but somewhat obliquely, as is shown in Figure 44.



Fig. 44.

(B. 161. S. 9. Sc. 1.) (Slide 26.)

A medullated nerve is seen crossing the periaxial lymph space to reach the intra-fusal muscle bundle. It is sectioned obliquely, and measures 0.008 mm. in diameter.

(4) At the Axial Sheath. No nerve fibre loses its myeline sheath before it has completely penetrated the axial sheath. That is to say, one cannot find a non-medullated nerve in the periaxial lymph space./

space. As a rule whenever the nerve fibre has got well within the axial sheath it gives up its myeline covering and proceeds to terminate in the manner to be described. A few fibres, however, hold on to their myeline coats after having pierced the axial sheath, but this is an exception to the rule.



Fig. 45.

(B. 161 S. 14. Sc. 4.) (Slide 28).

At the top right corner of the photograph is a spindle nerve in the capsule of the spindle. At the top right corner of the axial core is a bundle of nerve fibres which have now traversed the periaxial lymph space and have/

have reached the axial sheath, being separated from the spindle nerve in the capsule, from which they were derived, by a distance of 0.032 mm. Some of the nerve fibres in the bundle adjacent to the axial sheath are still medullated. Inside the axial sheath are numerous bare black dots, -- the non-medullated nerve terminations.

(5) Inside the Axial Sheath. Once inside the axial sheath the nerve fibre has arrived at the structures around which it is destined to terminate, and while the actual mode of termination is one of the most interesting branches of this subject it is one of the most difficult. But thanks to the Silver methods of Cajal and the intravital Methylene Blue methods these difficulties can be overcome. It is the distribution of the nerve fibrils within the axial sheath that can be called the "ultimate terminations of the nerve fibres in the Muscle Spindles!"

THE ULTIMATE TERMINATIONS OF THE NERVE FIBRES
IN THE MUSCLE SPINDLES.

The ultimate terminations of the nerve fibres in the muscle spindles show such great diversity and the details are so different in the different animals, that it is extremely difficult to give a satisfactory description of them without becoming exceedingly tedious.

Although I have cut over eight thousand sections in the attempt to satisfy myself that I know the fine details of the ultimate terminations, I must confess that the details present such wide differences not only in the different animals, but also in the different spindles, and even in the different muscle fibres of the same spindles, that I am unable to give a short, accurate description, which would cover all the ground. There is absolutely no limitation to the different manners in which the fine nerve fibrils turn, twist, bend and circle round and between the intrafusal muscle fibres. I must content myself by giving some of the main points and a few selected photographs to illustrate the mode of termination.

For the study of the ultimate terminations I have made use of three processes:-

(1)./

(1). Sihler's Macerating Process, which is more useful for indicating the general course of the fibres than for giving the fine details.

(2). Intravital Methylene Blue Method.

This method is of great value in this connection, but it does not lend itself readily to efficient photography, as the specimens are mostly teased.

(3). Cajal's Silver Nitrate Method. Nothing could be finer than the details given by this method but here the difficulty is to get the muscle spindles cut in exact longitudinal sections. When the spindles are cut exactly longitudinally the details of structure in each section are complete, but if the section is even a fraction of a millimetre away from the exact longitudinal axis of the spindle, then the appearances are not only more difficult to interpret, but less useful detail is given in any one individual section.

The animals which I used in this part of investigation were, frog, mouse, guinea-pig, rabbit, cat. For the study of the human muscle spindles, muscle was obtained fresh from the operation table. Foetal human muscle was obtained two hours after death.

Up/

Up to now we have traced the sensory nerve to the axial sheath. When they reach this sheath they are still medullated as may be seen from figure 46.



Fig. 46.

(B. 161. S. 14. Sc. 4). (Slide 28).

At the top right hand corner of the photograph is the spindle nerve in the capsule. At the top right hand corner of the axial core is a bundle of nerve fibres which has traversed the periaxial lymph space and has now reached the axial sheath. The nerve fibres are still medullated, from human muscle stained with Silver.

When the fibres reach the axial sheath they generally course along the axial score for some distance in a serpentine manner and at times even wind themselves around the axial core.

Once inside the axial sheath the nerve fibres begin to divest themselves of their myelin coverings; they lose the covering either immediately, or after a very short intra-axial course. The non-medullated fibres then break up into numerous subdivisions, which gradually increase in number until a compact network of fine terminal nerve fibrils is produced in order to terminate in relation to the intrafusal muscle fibres of the spindle. In longitudinal sections they may be traced for some distance, as may be seen from figure 47,- a muscle spindle of the cat.



Fig. 47.

(B. 57. S. 10. Sc. 4). (Slide 2).

In the centre of the spindle the black non-medullated nerve terminations come into intimate relationship with the intrafusal muscle fibres which, at this place, are represented by columns of nuclei. The nerve fibres terminate in a spiral manner around the muscle fibre, and there are some ring forms.

Length of Spindle. 0.4 mm.

Breadth of Spindle. 0.1 mm.

Diameter of Nerve Fibrils 0.001 mm.

That/

That the nerve fibrils are close to the sarcolemma of the intrafusal muscle fibres can be well seen in somewhat oblique sections of muscle spindles, such as is shown in Figure 48., which is from the Gastrocnemius muscle of the rabbit.



Fig. 48.

(B. 76..S. 17. Sc. 1). (Slide 14).

Oblique section of a muscle spindle, to show the nerve terminations ramifying alongside the intrafusal muscle fibres.

Diameter of Spindle.	0.04 mm.
	0.08 mm
Muscle Fibres.	0.008mm.
Nerve Terminations.	0.001mm.

When the nerve terminals ultimately come in contact with the intrafusal muscle fibres, the difficulty of accurate description begins, for no two spindles seem to have exactly similar nerve terminations. In the cat the endings are at the same time rather more simple than in most other mammals, and are capable of showing all the typical forms. I have inserted the next photograph, - figure 49, which is from the Gastrocnemius muscle of the cat, to show the typical forms of nerve endings that may be met with.



Fig. 49.

(B. 57. S. 11. Sc. 1). (Slide.1).

At the top of the photograph seven black rings/
rings/

rings are seen; then the nerve fibre is seen to be wound spirally around the muscle fibre, while here and there black nerve fibres are seen to terminate freely in small club-shaped endings. t₂/

It was in the muscle spindles of the cat that Ruffini first recognised three types of ultimate endings, which are shown above.

These are:- Terminations in Rings.

Terminations in Spirals.

Terminations in Flower-like Endings.

The terminations in spirals seem to form the groundwork of the terminal arrangement in all muscle spindles. I am not so sure of the terminations in rings, for even in the above figure where the ring forms appear to be very distinct, fine focussing shows that they are not really rings but that they are joined up on the under surface of the muscle fibre, and that they are, therefore, merely detached portions of spirals. I have frequently seen a nerve fibre go round a muscle fibre for about five-sixths of the circle of the muscle fibre, but there is always a break, which prevents a true ring being formed. The flower-like endings are not distinctive, for a flower-like appearance is obtained whenever a nerve fibre gives off/

off a freely-branching fibril, which ends in swollen club-shaped terminations, without joining on to other terminal nerve fibres.

No matter how much care is taken it is rare to find even in many hundreds of sections any muscle spindles which give more information, than can be gathered from the study of about a dozen muscle spindles. Even in serial sections little can be made out, if the spindles are cut obliquely, and I give figures 50 and 51 to indicate how little can be made out of the relationship of the nerve fibres to the muscle fibres, when the latter are cut in any way except absolutely longitudinally.

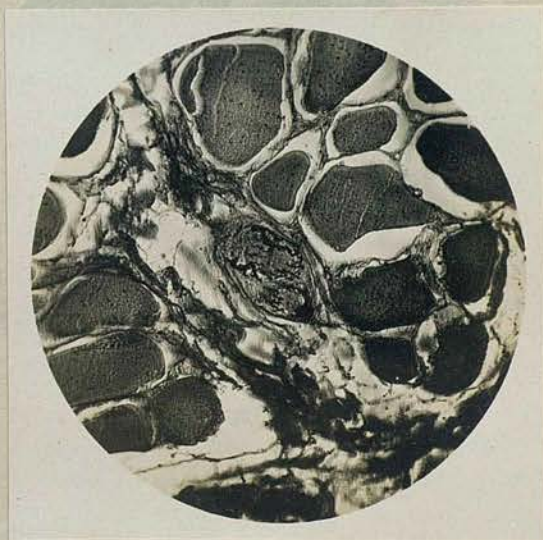


Fig. 50.

(B. 76. S. 11. Sc. 3). (slide 9).

Oblique/

Oblique section through the proximal polar region of a muscle spindle from the rabbit. The black nerves are seen at the sides of the intrafusal muscle fibres. The diameter of these nerve fibres is 0.0026 mm.

Naturally, at the proximal polar region it is not to be expected that there will be much detail of nerve termination, but even, in a similar section to the above, only cut nearer the equator of the spindle little more can be learnt of the mode of termination.



Fig. 51.

(B. 76. S. 6. Sc. 3). (Slide. 7).

Oblique/

Oblique section through a muscle spindle, near the equatorial region. The muscle fibres are cut obliquely and the black margins represent the nerve terminations around them.

Figure 52 is given to indicate how much may be seen of the terminations of the nerves around the muscle fibres. It is also from the muscle of the rabbit.



Fig. 52.

(B. 76. S. 35. Sc. 1). (Slide 21).

Cross section of a muscle spindle, showing an axial core made up of five muscle fibres to/

to which nerve terminations are seen going. The muscle fibre in the centre is quite circular, the others show a large number of nuclei. The black dots are sections of nerve fibres, which, applied to the muscle fibres, happen to be running parallel to the long axis of the spindle. At the right side of the axial core the nerve fibre is almost surrounding the muscle fibre, but not quite: this, in longitudinal section, would probably appear as a ring form.

Diameter of Spindle. 0.12 mm.

Diameter of Axial Core. 0.06 mm.

Diameter of Muscle Fibres. 0.012mm.
0.03 mm.

Diameter of Nerve Termination 0.0015mm.

Even in good longitudinal sections of muscle spindles, stained by Cajal's Silver method it is very difficult if not impossible to recognise any approach to a typical form of nerve termination. The undesirability of trying to generalise, or to dogmatise concerning the mode of ultimate nerve termination, will be admitted after an examination of figure 53.



Fig. 53.

(B. 57. S. 10. Sc. 1). (Slide 2).

The nerve terminations are well shown, but are so intricate, the twisting and turning being so various, that accurate detailed description is almost defied.

In man the striking feature about the nerve terminations is the great compactness in the formation of the terminal plate. Spirals are seen, but are not so common as in, say, the rabbit or cat. The flower-like endings are represented by nerve fibres having little swollen balls at the end of fine stalks, but these/

these, too, are very much pressed together, and are very compact. In man the terminal fibres often run along the spindle for some distance, turn over, or cross the muscle fibre and then run alongside for a further distance, and so on, forming a picture very difficult to describe.

I must not close this section without attempting to indicate what the intra-vitam Methylene Blue method can show. I shall give three photographs of the same muscle spindle, one of the whole spindle under low magnification, a second of the nerve to the muscle spindle under the oil immersion lens, and a third of the ultimate nerve terminations, also under the oil immersion. Where I state that these figures are from teased specimens the reason will be apparent for the indistinctness of the focussing.

Intrinsic plantar muscle of the rabbit,
stained by the intra-vitam methylene blue
method, fixed in Bouin's fixative, and teased.

Projecting out from the teased muscle fibres,
is a muscle spindle with only the
nerve elements stained with methylene blue.

Length of spindle, 0.5 mm.

Breadth of spindle, 0.05 mm.



Fig. 54.

(B. 266. Sc. 3). (Slide 39).

Intrinsic Plantar muscle of the rabbit,
stained by the intra-vitam Methylene Blue
method, fixed in Ammonium Picrate, and tea-
sed.

Projecting out from the teased muscle fi-
bres, is a muscle spindle with only the
nerve elements stained with Methylene Blue.

Length of Spindle. 0.6 mm.

Breadth of Spindle. 0.06 mm.



Fig. 55.

(B. 266. S. 3).

(Slide 39).

Running transversely along the centre of the photograph is seen a darkly stained nerve fibre 0.0034 mm. in diameter. It was traced to end in the muscle spindle seen in figure 54. Above it and below it are several nerve fibres also running transversely, but indistinctly shown as they are on a different plane. They are motor nerve fibres and measure only 0.0017 mm. in diameter.



Fig. 56.

(B. 266. S. 3).

(Slide 39).

This represents the ultimate terminations of the nerve fibre, shown in figure 55, around the intrafusal muscle fibres of the muscle spindle shown in Fig. 54. The muscle fibres are unstained, and the photograph is indistinct on account of the thickness of the teased preparation. Under the oil immersion lens, however, these nerve terminations are very pretty, and it is/

4. It is possible to follow them for a great distance along the whole length of the spindle by focussing to suit the plane in which the fibre is lying.

Muscle spindles are freely supplied with blood-vessels, so freely that every section of a muscle spindle shows a longitudinal, somewhat distinct arrangement of a rich arterial and venous arrangement. Apart from special injection methods, with which I have had little success, but which usually give the finest results, I have found that, of all the methods used, the method of Singer after maceration and staining gives the best results. The vessels are stained almost as distinctly as the nerve fibres, and apart altogether from special injection methods is of great use in studying the blood-vessels of muscle tissue generally.

From these stained preparations we may note the following points:-

- (1). More than one artery, as a rule, supply a muscle spindle.
- (2). The arterial blood-vessels are of the type of the spiral artery, and are supplied with a rich network of capillaries.
- (3). Arteries and veins are given off from the spiral vessels, and are not, as is generally supposed, the spiral vessels themselves, but are given off from them.

4. THE BLOOD-VESSELS OF MUSCLE SPINDLES.

Muscle spindles are freely supplied with blood-vessels, so freely that every section of a muscle spindle, cross or longitudinal, shows distinct evidence of a rich arterial and venous arrangement. Apart from special injection methods, with which I have had little success, but which usually give the finest results, I have found that, of all the methods used, the method of Sihler after maceration and teasing gives the best results. The vessels are stained almost as distinctly as the nerve fibres, and apart altogether from muscle spindles this method is of great use in studying the blood-vessels of muscular tissue generally.

From these teased preparations we may note the following points:-

- (1). More than one artery goes, as a rule, to each muscle spindle.
- (2). The largest vessels course in and on the capsule of the organ.
- (3). Numerous branches are given off from the capsule vessels, have a spiral course, are not end arteries, but freely/

freely intercommunicate to form a network around the spindle.

- (4). Small twigs are seen in the axial core sharing in the general course being parallel to the long axis of the spindle. They give off small capillary twigs which run in all directions.

Cross sections of muscle spindles stained with Silver according to Cajal's methods show the large vessels in the capsule extremely well.

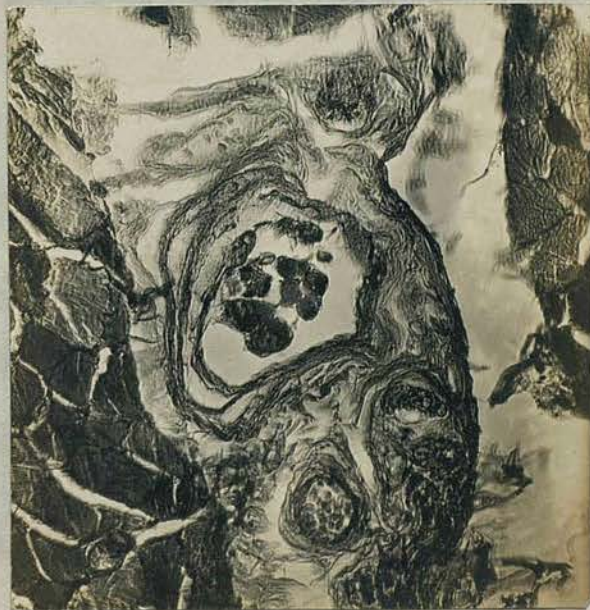


Fig. 57

(B., 161. S. 5. Sc. 1). (Slide 23).

Muscle spindle in cross section from the human Sartorius muscle. Immediately above the spindle a vessel is seen in longitudinal section. Branches were traced from this vessel to end among the muscle fibres of the intrafusal muscle bundle.

Diameter of Spindle.	0.1 mm.
	0.12 mm.
Diameter of Vessel.	0.02 mm.
Diameter of Axial Core.	0.04 mm.
	0.048mm.
Diameter of Muscle Fibres.	0.008mm.
	0.016mm.

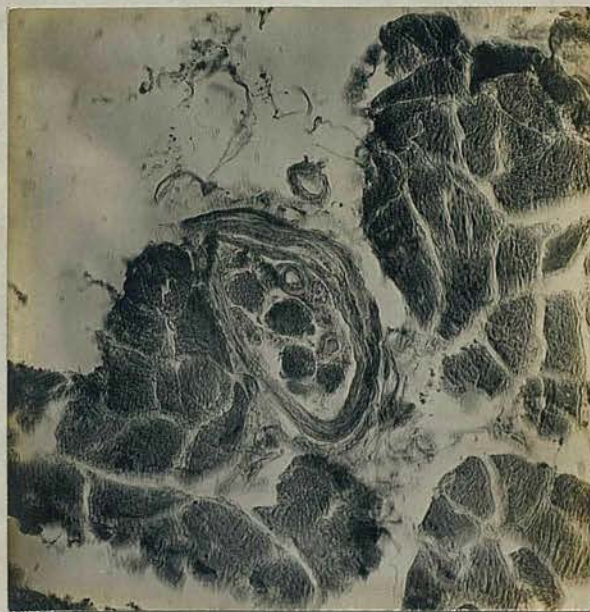


Fig. 58.

(B. 138. S. 1. Sc. 4). (Slide 34).

Cross/

Cross section of a muscle spindle from the human Sartorius muscle. The intrafusal muscle bundle contains six muscle fibres, a medullated nerve fibre and a well marked blood vessel.

Diameter of Spindle.	0.06	mm.
	0.12	mm.
Diameter of Muscle Fibres	0.007	mm.
	0.018	mm.
Diameter of Blood vessel.	0.017	mm.

In pieces of muscle tissue cut in serial section, it is often possible to trace from some distance blood-vessels to terminate in the muscle spindles.

The next two figures were taken from the same muscle spindle and show how the blood vessels can be traced out.



Fig. 59.

Fig. 59.

(B. 161. S. 16. Sc. 2) (Slide 30).

Cross section of a human muscle spindle.

At the top right hand corner there is a large nerve trunk, with a very wide sheath; just above the nerve is seen a blood vessel, not yet within in the confines of the spindle.



Fig. 60.

(B. 161. S. 15. Sc. 5) (Slide 29).

In this section the vessel is just making its way into the capsule of the muscle spindle at the/

the right hand top corner.

5. THE LYMPHATICS AND LYMPH SPACES.

Lymphatic vessels can be detected in muscle spindles in teased specimens, but the course is difficult to make out clearly.

The PERIAXIAL LYMPH SPACE has already been referred to as well as the fact that the space has been injected by injecting the lymphatics of the leg.

In a muscle spindle measuring a tenth of a millimeter across, fully one half may be accounted for by the lymph space, the axial core and the capsule making up the other half.

At the proximal polar region the periaxial lymph/

lymph space appears as a mere cleft and it is the gradual increase in this cleft that makes the observation of cross serial sections of muscle spindles so interesting and almost, I might say, entertaining.

In the photographs of the silver sections it will be seen that the space appears as such, or filled up with coagulated proteid material (lymph) showing as a light granular debris. In sections stained with Van Gieson stain the space appears filled up in parts by a homogenous almost glistening material, and from its outline, obviously a fluid substance which has been precipitated by the fixing fluid. With this stain, too, the occasional lymphocytes show up well.

6. SYMPATHETIC NERVES IN THE MUSCLE SPINDLES.

There can be no doubt that sympathetic nerves exist in muscle spindles. They have been figured by Huber whose diagrams I reproduce on that account, for in my own sections, although I have noted the existence of very fine non-medullated nerve fibrils in close proximity to blood-vessels I have never yet been able to observe the actual termination of these fine fibrils in and around the walls of the vessels/

vessels. They are probably the vaso-motor fibres of the spindle vessels, for Sherrington has shown that after extirpation of the spinal ganglion together with section of the ventral spinal roots all myelinate nerve fibres to the muscle spindles and the Golgi's tendon-organs degenerate and disappear. He concludes that neither the muscle spindles nor the tendon organs receive any myelinate fibres from the sympathetic system.

THE FUNCTION OF THE MUSCLE SPINDLES.

During the last 60 years various theories have been held as to the function of the muscle spindles. At the present time it is only necessary to state that the muscle spindles are sensory nervous in nature, and that they form the terminations of the sensory nerves in voluntary muscle, - definite terminal organs subserving the MUSCULAR SENSE.

The other theories that have been held at various times are best considered under the heading of the History of Muscle Spindles, for they are now only of value from the historical point of view.

It may be well to briefly summarise the points that have been gathered from time to time in favour of the sensory nerve theory. The points may be conveniently grouped thus:-

A. GENERALITIES.

- (1). Constant presence in nearly all the muscles.
- (2). Constant general morphological characters in all the animals, except, perhaps, in the Reptiles.
- (3). Constant form and structure at all ages in the foetus, new-born child, and adult.
- (4). Greater number in muscles where a fine muscle sense is required.

B. RESEMBLANCE TO OTHER SENSORY NERVE TERMINATIONS.

- (1). Resemblance to Pacinian Corpuscles especially the surrounding capsular layers.
- (2). Resemblance to the Golgi Tendon Organ.
 - a. Both are fusiform.
 - b. Both are innervated by a special nerve fibre terminating in it.
 - c. Occasional ending of the same nerve in the two organs.
 - d. The two organs have similar sheaths.
 - e. The two have one extremity very similar in appearance (the tendinous extremity of the tendon organ and the small tendon of the spindle).
- (3). Resemblance to the End Bulbs, in the presence of nuclear groups devoid of mitosis.
- (4). Resemblance to certain other nerve endings in Joints, conjunctivae, etc.

C. DETAILS OF STRUCTURE.

- (1). The muscles, modified to help in the formation of the spindles, possess at some distance the usual motor nerve endings.
- (2). Nerve fibres have been traced into the organs.
- (3). The nerve fibre divides more like a sensory than a motor nerve.
- (4). The nerve supply is abundant, far above the amount the muscle fibres require.
- (5). Presence of true nerve end plates absolutely specific and characteristic.
- (6). The spindle nerve is differentiated from the motor nerve by its thickness and its wide sheath.

(7)./

- (7). Nerve fibres proved to be the axis cylinders of nerve cells lying in the posterior root-ganglion.

D. ANATOMICAL STRUCTURE.

- (1). The structure of these organs is in keeping with the sensory function. Every pressure exerted by the contracting and thickening muscle will be diffused into the lymph space, and exert pressure upon and influence the nerve terminations.
- (2). The stimulus to which these organs are adapted is evidently mechanical.
- (3). That mere mechanical stimulus exists is hinted at by the facts that simply stretching a passive muscle causes a discharge of afferent impulses, and that similar centripetal impulses are obtained from electrical stimulation of the motor fibres only.

E. DEFINITE EXPERIMENTAL PROOF.

This proof was supplied by Sherrington in 1894. The experiments demonstrate "that the muscle spindle is supplied with nerve fibres arising in the cells of the spinal root-ganglion. In muscles from which all motor fibres have been entirely removed by degeneration, I have never in a single instance failed to find every spindle met within the muscle still possessed of perfectly sound myelinate nerve fibres. These myelinate nerve fibres are traceable from the sensory roots, and penetrate into the spindles, and terminate within them. The muscle spindle proves therefore to be a sensorial organ as argued by Kerschner and as indicated by the histological analysis of the nerve-ending of Ruffini".

THE MUSCLE SPINDLE IN DISEASE.

It is not within the scope of this paper to consider the muscle spindle in disease, but, in passing, I may note that from time to time the muscle spindles have been seen and examined in the following conditions:-

NERVOUS DISEASES.

(1).	Progressive muscular atrophy.	Erb	1891
		Forster	1894
		Spiller	1897
		Batten	1897
(2).	Myopathy.	Santesson.	1890
		Batten	1897
(3).	Amyotrophic lateral sclerosis.	Pilliet	1890
(4).	Pseudohypertrophic muscular paralysis.	Westphal	1887
		Gruenbaum	1897
(5).	Infantile spinal paralysis.	Eisenlohr	1876
		Batten	1897
(6).	Alcoholic paraplegia.	Pilliet	1890
(7).	Bulbar paralysis.	Forster	1894
(8).	Acute and chronic myelitis.	Babinski	1884
		Forster	1894
(9).	Poliomyelitis.	Blocq & Marinesco	1890
(10).	Alcoholic and other neuritis.	Eichhorst	1888
		Gudden	1896
		Blocq & Marinesco	1890
		Santesson	1890
		Batten	1897
(11).	Diphtheritic paralysis.	Volkmann	1893
(12).	Gumma of base of brain.	Siemerling	1888
(13).	Injury to nerves of arm.	Volkmann	1893
		Batten	1897

Apart from nervous diseases the condition of the muscle spindles has been noted in Phthisis, Rheumatism, Phosphorus poisoning, and other conditions, but nothing of any importance has been recorded.

I have found perfectly normal muscle spindles lying in muscular tissue which was in an advanced stage of atrophy, and where, indeed, the muscular fibres inside the muscle spindles were the only healthy muscle fibres to be seen in the muscle.

In one case of peripheral neuritis healthy muscle spindles could be found lying in fat which had entirely replaced the ordinary muscle fibres. In all the conditions of muscular atrophy in which I have had the opportunity of examining the muscle spindles, these structures stand out in the ordinary degenerated muscle tissue as remarkably fresh structures, which seem to enjoy an exemption from the usual degenerative changes in muscles.

While all this is interesting I must refrain from dwelling upon this point for it would be out of place in this Thesis.

HISTORY OF THE MUSCLE SPINDLES.

The History of the Muscle Spindles forms one of the most interesting aspects of this subject. I have found a peculiar fascination in trying to become familiar with what has been written on this subject. I do not wish to make too much of this aspect, but there is something very delightful, I might almost say enticing, about the historical review of this work when an attempt is made to understand the thoughts and appreciate the theories of men who worked more than half a century ago. At times there creeps in a certain feeling of amusement at the mistakes that have been made, when they are viewed in the light of our present knowledge, but this tendency is readily overcome when we quietly contemplate each worker's contribution and judge it in the light of the knowledge in possession of the workers at the time the contribution was written.

As a rule credit is given to Weismann for first describing muscle spindles, but a more exact description was given by Kölliker about fifty years ago./

ago. But nearly seventy years ago there are figures to be found which indicate that muscle spindles must have been observed although the importance of them was not recognised. Thus as far back as 1843 Miescher described in the abdominal muscles of a house-mouse bodies to which he gave the name "Schläüchen". He expressed the opinion that they were either pathological or parasitic, but this view was negatived ten years later by Siebold who found the same structures in the muscles of the rat.

To give a chronological review of all the work after this fashion would become hopelessly tiresome. The most instructive way to consider the History of the Muscle Spindles is under the headings of the various theories that have been held and to arrange the various observers according to the views they held.

In the following pages, then, mention will be made of the work of most of the inquirers into this subject, but although I have become familiar with all that I shall mention, I will refrain from criticising an article unless I have personally perused it.

The THEORIES regarding the Muscle Spindles are:-

- (1). That They are Parasitic in nature.

Date/

Date 1843.

- (2). That they form a Protection to the Nerve Ending.

Date 1888.

- (3). That they are connected with the Lymphatic System.

Date 1888.

- (4). That they are a stage in the Development of Muscle.

Date 1861 to 1892.

- (5). That they are Pathological Structures.

Date 1876 to 1890.

- (6). That they are Sensory Nervous in nature.

Date Hinted at in 1874.

Definitely stated in 1888.

Definitely proved in 1894.

Continued to present day.

The first three theories can be dismissed in a word.

PARASITIC THEORY.

In 1843, as previously stated, ^{B 1.} Miescher found what he called "Schläuchen" in the abdominal muscles of the house-mouse. He thought they might be parasitic in nature, but merely expressed the opinion. In 1853

^{B 2.}
Siebold/

Siebold found these same bodies in the muscles of the rat, and denied the parasitic theory.

PROTECTION TO NERVE-ENDING THEORY.

^{B 24a.}
In 1888 Kerschner suggested that the muscle spindles had protection of the nerve-ending as their function. This should not properly speaking be looked upon as a theory and it will not be mentioned again.

LYMPHATIC THEORY.

^{B 14.}
In 1888 Golgi defined the muscle spindles as "Bundles of incompletely developed muscle fibres surrounded by a special sheath, and to be found in the muscles at every period of growth." He suggested that they had some special connection with the lymphatic system of the muscle. The other three theories must be discussed in full, they are the Developmental, the Pathological and the Sensory Terminal.

THE DEVELOPMENTAL THEORY.

About a dozen authors have supported this view and much has been written for and against the theory. The supporters include:- Weismann, 1861; Kölliker, 1862 and 1889; Beale, 1862 and 1865; Kuhne, 1863 and/

and 1864; Peremeschko, 1863; Bom, 1873; Bremer, 1883; Felix, 1888 and 1888; Von Franque, 1890; Trinchese, 1891; Thanhoffer, 1892 and 1894; Volkmann, 1893;

B 3.

WEISMANN (1861), when working at the muscle of the frog noticed some very fine fibres "flat and band-like and not cylindrical". He found it difficult to give exact measurements but stated that one fibre had a maximum measurement of 0'0040''' and a minimum of 0'0005'''. "These fine fibres," he states, "are almost never single but lie with 2, 3, 4, 6, 8, 10, or more together." After giving further details as to the size of the fibres he continues, "Now it not seldom happens that such groups of fine fibres are bound together by a cord at the middle of their length for a longer or shorter distance, and they appear to be wrapped round by a dull granular substance, through which the individual fibres cannot very clearly be followed. Small nuclei are not infrequently seen lying within the interior of the fibres of the group at these places." He then notes that these fibres have all the same length and run from tendon to tendon.

"At places peculiar splittings appear, from which the formation of new fibres takes place (fig./

(fig. H. 1.) In a thin muscle fibre a longitudinal splitting occurs in such a way that there remains between the split and the edge of the fibre a long thin portion of muscle fibre containing isolated nuclei. This happens as a rule at several places in the muscle fibre at the same time, so that we have the separation of long thin nucleated muscle fibres, -fibres as long as the muscle fibres from which they took their origin. The splitting does not always take place at the same spot. At times at the tendon end the splitting off is quite complete while in the neighbourhood very short split-off portions are seen. At other times a young fibre is split off from the mother fibre and is connected to it only by a very short bridge of tissue. Others are split off completely in the middle portion but are still joined on at the tendon ends of the group. Very often I have seen several splittings near one another, while in one case there was a single fibre with four or five fibres completely split off, each of which contained isolated nuclei arranged in rows. When freed they could be floated quite free from each other and from the mother fibre." Weismann's findings may be summarised as follows:-

(1). Fine fibre in bundles. 6, 8, or 10.

(2)./

- (2). Bound together by a cord in the middle.
- (3). Wrapped round by a granular substance, through which one can but indistinctly trace each fibre.
- (4). Fibres possess closely-set, double triple or quadruple rows of nuclei.

He looked upon the whole muscle spindle with its contained intrafusal muscle fibres, as one single "mother" fibre, from which the "daughter" fibres were split off. Weismann thought that he certainly had to do with "New Formation" and concluded that the muscle spindles were "Theilungerscheinungen der quergestreiften Muskeln".

I give a photograph of one of his diagrams.

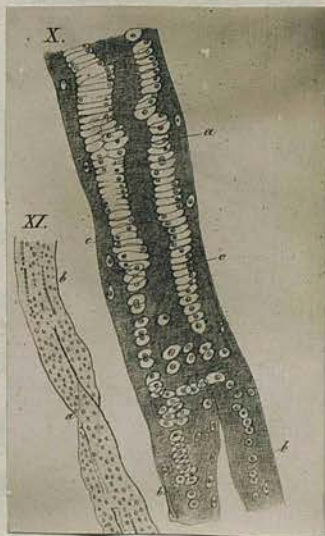


Fig. H. (1).

Weismann/

Weismann (1861) Part of a Primitive Bundle from the gastrocnemius muscle of a frog. The splitting is seen at places.

(a) Mother fibre; (b) Daughter fibre; (c) Rows of nuclei, frequently seen to be double.

^{B 4a.}
 KÖLLIKER described bodies in the muscle of the frog. He thought at first that they were very like tactile corpuscles or terminal end buds but concluded that they were not really of that nature. He described them as "nodular swellings marked by a profusion of rather roundish nuclei, and receiving a thick single nerve fibre loosely surrounded by its comparatively wide membranous sheath. The nerve on reaching the nodules of the muscle, is wound up into a coil, and after repeated division may be seen to enter the muscle fibre". He noted that the apparently single muscle fibre is in reality composed of from three to seven fine fibres and that the nerve fibres passed between them. Simultaneously with the increase of the terminal fibres, Kölliker noted that the nerve fibre increased in thickness, and that it was invariably much larger than the nerve fibres proceeding to the other muscular fibres.

Kölliker noted the resemblance of the structures to the "Weismann fibre" of embryonic muscle/

muscle, and interpreting them as similar centres of growth persisting in the adult muscle named the bundles in keeping with that view, "MUSKEL-KNOSPEN".

In 1889 Kölliker still held to the same view as to the nature of the muscle spindles, although he had become acquainted with, and had discussed the various other views held. He gave, what is the first account of the muscle spindles in man, for up to this date all the authors had studied these structures only in animals.

^{B 5.}
BEALE gave a detailed description of the muscle spindles in 1862 and after noting that the muscle fibres were supplied with nerve throughout their entire length, he came to the conclusion that the bodies were "muscle and nerve in the course of development". In his paper in 1865 he appears to agree with the view held by Kölliker. The development of the muscular fibres according to Beale takes place from the nuclei while Kölliker thought that it was division of the parent fibre that was responsible for the production of new fibres.

^{B 6.}
KUHNE (1863 and 1864).

When Kühne was working on the nerve endings in the white rat he came across a "peculiar form of nerve ending". In his first paper he is content/

content with merely noting the existence of the body and giving the figure that I have photographed, (Fig. H. (2)), but it evidently stimulated him to look for them alone for in his next paper he states that "I have now found them in most of the muscles of the house-mouse."



Fig.H. (2).

^{B 6a.}
Kühne (1863). A muscle fibre from psoas muscle of white rat.

N.- Portion of a very thick nerve; a.a.-passage of nerve into the muscle fibre; b.b- nucleated body in a fine granular substance; c.- clear globular bodies; d.d.- globular granular bodies; e.e.- granular mass in the axis of the muscle fibre; f.- muscle nuclei.

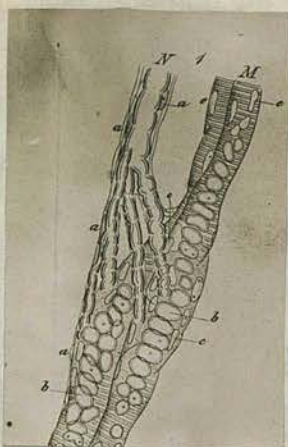


Fig.H. (3).

Kühne (1863). "When two muscle spindles lie close together, then four nerve fibres come off the main nerve stem to supply them". B 6b.

In his third paper he figures a muscle spindle and gives a drawing of the spindle from mammalian muscle. I have photographed it. (Fig.H. (4)). In that paper too he asks about the muscle spindles, "Are they an apparatus with a peculiar, still unknown physiological function, or do they form a stage in the development of muscle?"

B 6c.

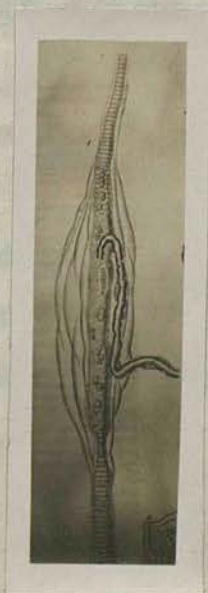


Fig. H. (4).

Fig. H.(4).

Kühne (1864). A mammalian muscle spindle.

Magnified 400 times.

"Kühne's findings may be summarised as follows:-

(1). Noted spindle shaped swellings on the muscle fibres, and designated them, in virtue of their shape, "MUSKELSPINDLEN".

(2). Occur about 1 in 100 ordinary muscle fibres.

(3). Muscle fibres in the muscle spindles had the following characteristics. -

Smaller than neighbours.

Striation well marked at ends.

Striation broader than in larger fibres.

Striation disappears at centre.

(4). Noted the existence of groups of nuclei in a granular material with round transparent bodies.

(5). With regard to nerves noted:-

More than one forked nerve ran to each spindle.

Nerve four times as large as motor nerve.

Nerve has a well-developed loose sheath, "weit abstehende Scheide".

"Kühne concludes that "A knowledge of the muscle spindles/

spindles is important in understanding the development, regeneration, and growth of muscles and their nerves".

B 7.
PEREMESCHKO (1863) tried to prove that the results obtained by Kühne were due to the reagents employed, he denied that any nerve fibre ran to the spindles, and agreed with Kölliker in calling them Muskelknospen.

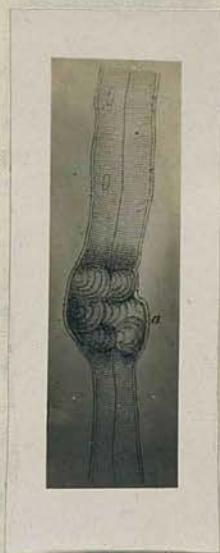


Fig. H. (5).

Peremeschko (1863). "A bundle of muscle fibres lying in a sheath. The sheath widens and at that place the bundle is thickened."

B 8.
BOM (1873) held view of Kölliker.

B 16.
BREMER (1883) traced the various stages in the development of the muscle and nerves, gave a detailed description of the muscle spindles and held the view of Weismann and Kölliker.

B 22a.
FELIX/

B 22a.

FELIX (1888-9) published some work which is of importance since he studied the muscle spindles at different stages of foetal life. In a long article where he refers to the opinions of over forty authors on the "Weismann fibre", he describes a muscle spindle at the various foetal months. In the muscle spindles he traced in cross section what he thought was the complete development of the muscle fibres. The main points in his paper are these:-

- (1). Detailed arrangement of nuclei in rows.
- (2). To the centre of the spindle, where the nuclei are richest in amount, he relegates the greatest divisional activity "Wachstumsenergie"
- (3). The rich supply of nuclei to the sheath distinguishes it from the ordinary sarcolemma.
- (4). One only seldom sees a nerve in connection with the fibres under consideration.
- (5). Great stress is laid upon the number of the muscles in the spindles at the different ages.

In adult muscle spindle---3-6 muscle fibres.

In foetal muscle spindle --20 muscle fibres.

I give two of his drawings.



Fig. H. (6).

Felix. Weismann's fibre. A nerve with a wide sheath in connection with the muscle at the place of greatest richness of nuclei. (of nuclear activity.)

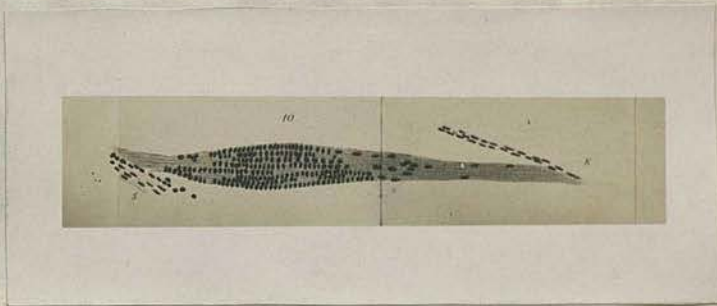


Fig. H. (7).

Felix. Bundle of muscle fibres from the forearm of a two and a half months embryo.

K. - Periosteum. S. - Tendon.

B. 29.

VON FRANQUE (1890) upheld the developmental theory.

B. 33.

TRINCHESE/

B 33.

TRINCHESE (1891) described the nerve ending in the nucleated part of the muscle fibre, but although he held this view he concluded as follows, "One has not yet demonstrated the truth of the statement of Bremer that the spindles are fibres or bundles of muscle fibres in course of development. The theory seems to be very probable but until the phase of transition is found between the adult muscle fibres and the spindles one cannot affirm anything with certainty concerning the nature of these organs."

B 36.

VOLKMANN (1893) studied the muscle spindles in various abnormal as well as normal conditions and stated that they had to do with growth of muscle but not with regeneration of muscle.

B 35.

THANHOFFER (1892-4) did some very elaborate work upon the nerve endings in muscle, working mostly with the gold methods. Thanhoffer seems to look upon the pale nerve fibres in muscle as the sensory ones but states that "It is really difficult to be sure which is sensory and which is motor in the chaos of thick and thin nerve fibrils running throughout the muscle". He looks upon the muscle spindle essentially as a "product of post-embryonic development". Thanhoffer's diagrams are very elaborate and form really accurate representations of the muscle spindles, especially with/

with regard to the actual nerve terminations in them. It is interesting to note in passing how it was that he misinterpreted the appearances for he seemed to have excellent material to work from. He comes to the conclusion that muscle spindles are "nothing else than complex bodies of muscle fibre and nerve met with in the course of development, for which they form the building material." From his paper three diagrams may be taken to illustrate how he considered the muscle spindles formed the "building material":-

(1). The first, which he calls an endplate showing an early stage of development, may be recognised as the grape-like "Terminaison en grappe" or the "Enddolde" of Bremer. (Proved to be motorial).



Fig. H. (8).

Thanhoffer (1894). Doldeform nerve ending in lizard's muscle. (g). (motor end plate in development).

Thanhoffer looked upon this as the earliest stage in the development of muscle and nerve. This has later been/

been proved to be a motor nerve ending.

(2). In the second a granular dark-staining substance lies around the nerve terminations like a cap. Thanhoffer looks upon this as a later stage of development than the grape-like endings.



Fig. H. (9).

Thanhoffer (1894). Here and there is a protoplasmic substance stained dark with the gold.

(3). In the third there is in addition a substance, (staining a deep black like the detail structure of the motor nerve endings), which is seen forming a cap around the nerve terminations and to this ending a medullated nerve may be traced.

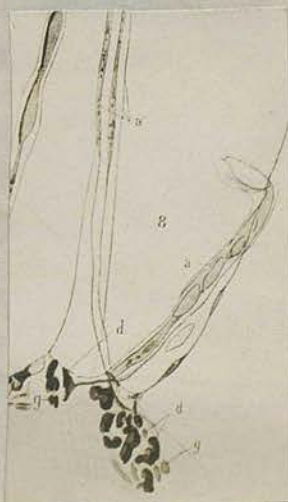


Fig. H. (10).

Fig. H. (10).

Thanhoffer (1894). Muscle of lizard. It is to be noted that in one of the nerve endplates the granular substance, forming the under part of the endplate, is already formed.

To this ending a pale fibre (a'), and a medullated nerve (a) can be seen going.

I have given photographs of these three diagrams to illustrate how Thanhoffer traced the growth of muscle and nerve and how he arrived at his conclusions. In his paper we also find:-

- a. Proof that "Enddolge of Bremer" are motorial.
- b. Evidence that the muscle fibres of the muscle spindles are supplied with motor nerve endings.

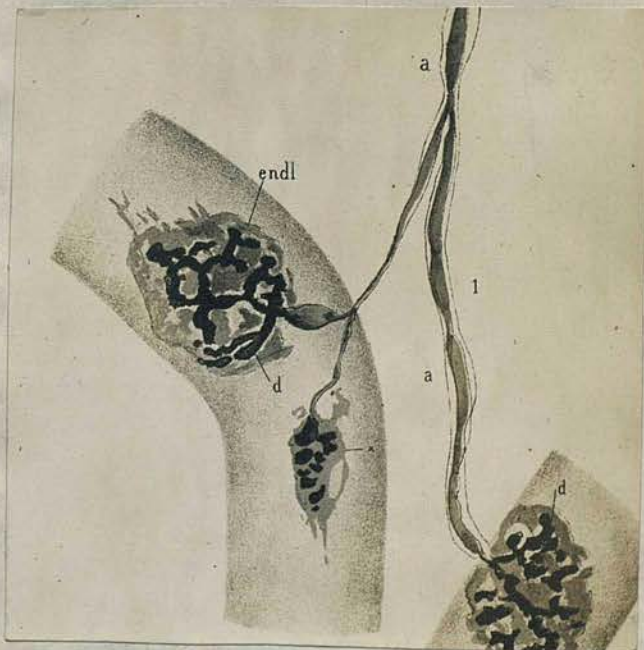


Fig. H. (11).

Fig. H. (11).

Thanhoffer (1894). Lizard's muscle. Gold method.

This representation of a muscle fibre shows a common motor nerve ending, and in addition "a doldeform so-called sensory" nerve ending. (x). "It shows that the latter has no connection with any sensory fibre whatever, but it is actually supplied by a branch of the same nerve fibre as supplies the motor nerve ending, a branch which comes off after the axis cyclinder has left its myelin sheath."

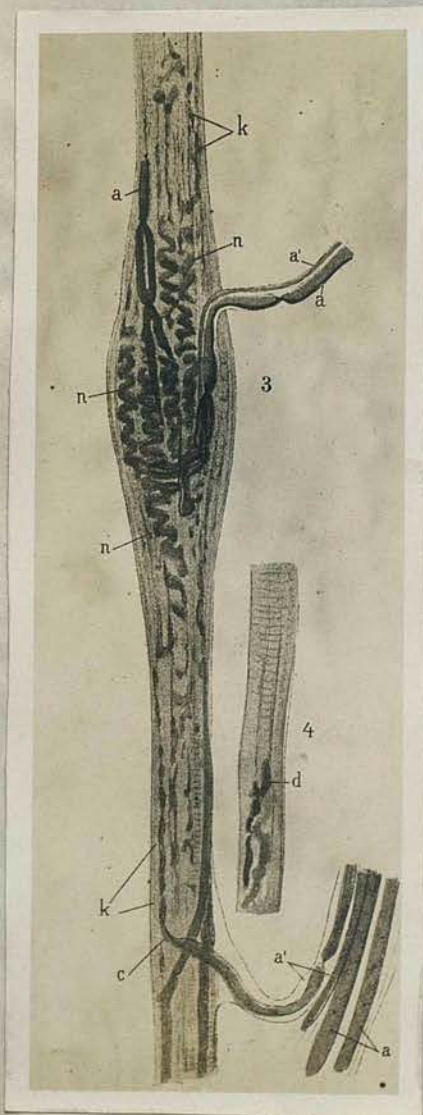


Fig. H. (12).

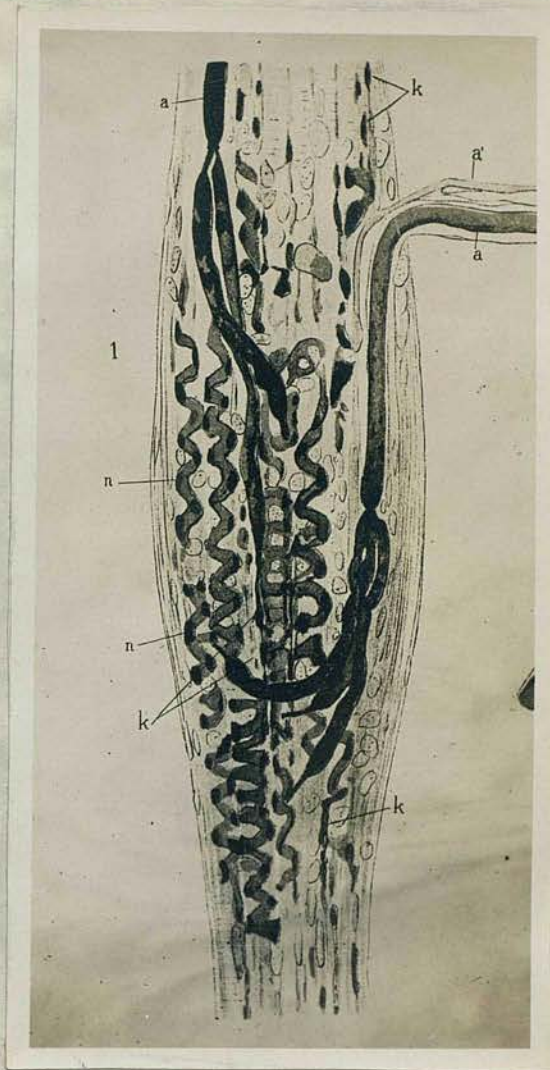


Fig. H. (13).

Thanhoffer (1894). Developing muscle spindle of a mouse, in which several nerves enter. The inner part of the spindle is composed of the spindle shaped swelling of four muscle fibres and these are not yet separated from one another at/

at the ends.

Fig. H. (13). is the enlarged middle part of the muscle spindle in Fig. H. (12).

The sensory nerve fibre can be seen entering the spindle at (a'), and Thanhoffer also figures what he calls a motor nerve fibre at (a).

One of the separated ends is seen enlarged at four in Fig. H. (12) and this muscle column "shows the beginning of a motor nerve ending".

These figures can be recognised as excellent representations of normal muscle spindles, but Thanhoffer looked upon them as "building material" for the development of muscle fibre and nerve. I give these photographs to show the nature of the nerve endings described by Thanhoffer.

THE PATHOLOGICAL THEORY.

Several authors, when examining the muscles from various diseases, found muscle spindles more or less in a state of preservation, some recognising them as muscle spindles but looking upon them as foci of inflammatory degeneration and others looking upon them as entirely pathological structures peculiar to the condition they happened to be examining. These include:- Eisenlohr, 1876; Fraenkel, 1878; Millbacher, 1882; Babinski, 1884; Eichhorst, 1888; Santesson, 1890.

To show that these writers were dealing with muscle spindles I give photographs of the drawings of Fraenkel. To indicate how they fell into error I give photographs of the diagrams of Eichhorst. The others I shall dismiss very shortly.

B 10.
EISENLOHR (1876) found in the atrophied muscle from cases of infantile spinal paralysis a number of well preserved fibres arranged within a sheath which they incompletely filled. He looked upon them as pathological and did not seem to recognise them as muscle/

muscle spindles.

R 11.
 FRAENKEL (1878). In a third of all his preparations taken from the muscles of phthisical patients Fraenkel found what are undoubtedly muscle spindles, but called them, "UMSCHNURTE BUNDEL". He never found them in the muscles of the eye or in the muscle fibres of the masseter or diaphragm. He looked upon the spindles as pathological formations. I give photographs of his diagrams, - cross sections of normal muscle spindles.

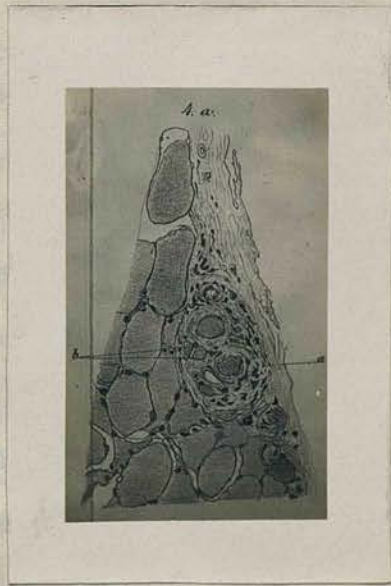


Fig. H. (14).

Fraenkel (1878). Cross section of muscle of back showing "Umschnürten Bündel".



Fig. H. (15).

Fraenkel (1878). Cross section of muscle of ball of thumb, showing "Umschnürten Bündel".

(a).- in both sections is the nucleated sheath,
 (b).- is the small primitive bundles cut in cross section; (c).- cross sections of the "secondary bundles".

Fraenkel thought that the "secondary muscle fibres" outside the muscle spindle were derived from the "primitive muscle fibres" inside the spindle.

B 13.
MILBACHER (1882). examined the muscles from various acute and chronic diseases and found the "umschnürte Bündel". in all of them except the eye and diaphragm. He stated that they had a vascular origin and gave a drawing to prove their source from the blood vessels. Millbacher described three forms of "umschnürte Bündel/

Bündel" as follows:-

1. Unvollständig umschnürte Bündel.
2. Vollständig umschnürte Bündel. (containing muscle fibres).
3. Vollständig umschnürte Bündel (containing atrophied muscle fibres).

These of course can be recognised as cross sections of muscle spindles at the various regions.

Millbacher found muscle spindles in normal muscle also but was doubtful of their significance.

B 18a.

BABINSKI (1884) described circular rings, having atrophied muscle fibres in their centre, in a case of chronic myelitis. He considered them pathological at first, but in 1886 did not think them pathological but was doubtful of real meaning.

B 21.

EICHHORST (1888). I have selected the work of Eichhorst to indicate how error was made interpreting the presence of normal muscle spindles in pathological muscle. He was working at a case of alcoholic muscular paralysis and was examining the muscle far more carefully than he had evidently examined normal muscle, and came across a small intramuscular nerve twig with an advanced degree of atrophic change and increase of endo- and perineural/

neural tissue.

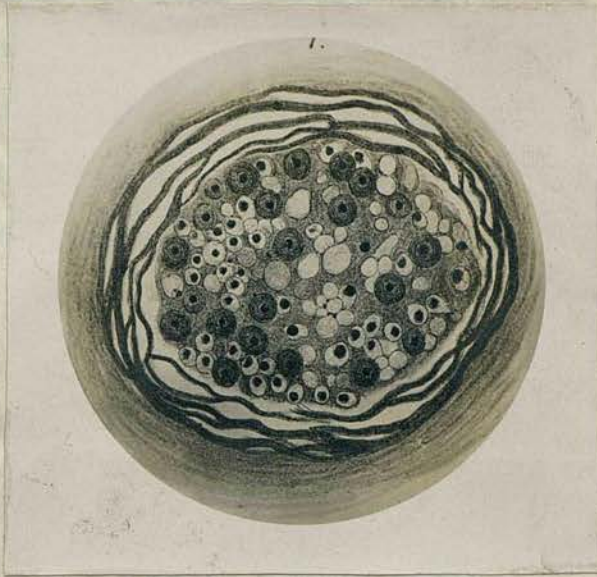


Fig. H. (16).

Eichherst (1888). "Neuritis Fascians". Cross section of a muscle nerve showing thickened perineurium. Magnified 275 times.

Then later he figured isolated primitive muscle bundles affected in such a peculiar manner that he chose the name "Neuritis Fascians" for the pathological condition present.



Fig. H. (17).

Fig. H. (17).

Eichhorst (1888). Cross section of the right extensor communis muscle. Magnified 60 times. This can be recognised as a normal muscle spindle. In another of his diagrams he shows the lamellae derived from the epineural sheath growing round the primitive muscle bundles, compressing them, and leading to pressure atrophy, so that only a small remnant is left.



Fig. H. (18).

Eichhorst (1888). Cross section from the right extensor communis digitorum muscle showing the muscle bound round by thickened perineurium.

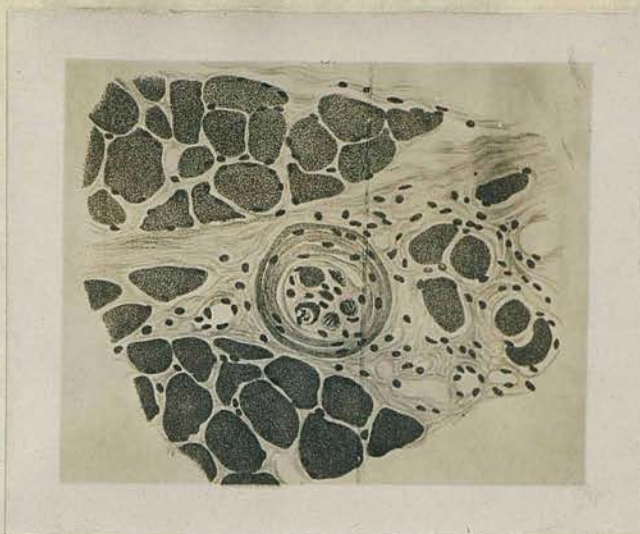


Fig. H. (19).

Eichhorst (1888). Same as preceding picture to show increase of connective tissue.

Eichhorst definitely held to the opinion that the "umschnürung der Muskelbündeln" was undoubtedly developed from the neurillemma of the muscle nerves. He further maintained that what he described as "neuritis fascians" was quite specific of alcoholic paralysis.

I give his drawings to illustrate these points, and to show that he was dealing with muscle spindles.

^{B 27.}
SANTESSÓN. (1890). described muscle spindles in myopathy and regarded them as pathological in nature.

SENSORY TERMINAL THEORY.

The sensory nature of the muscle spindles was hinted at in 1874 by Sachs, definitely stated in 1888 by Kerschner, and conclusively proved in 1894 by Sherrington. A large number of authors have supported this, - the correct view, - some adding little, some adding much to further the opinion. They include:- Sachs, 1874; Ranvier, 1878; Mays, 1884, 1892; Roth, 1887; Kerschner, 1888, 1892; Cattaneo, 1888; Dogiel, 1890; Ciaccio, 1891; Christomanos and Strössner, 1891; V. Ebner, 1892; Ruffini, 1893, 1897; Forster, 1894; Sherrington, 1894; Sihler, 1895; Weiss & Dutil, 1896; Batten, 1897; Spiller, 1897; Horsley, 1899; Grunbaum, 1897; Huber, 1898, 1900.

B 9.
SACHS (1874) found medullated nerves not degenerated in frogs muscle after division of the anterior roots, and noted that the ending was entirely different from that of a motor nerve. The nerve ended in a spindle-shaped body, twisting round the muscle fibre in a spiral manner.

After/

After cutting the posterior roots peripherally to the ganglion he noted:-

(1). Degeneration of sensory muscle nerves takes place very slowly.

(2). After six weeks appearance is not striking.

B 12.

RANVIER (1878) noted that the nerve penetrated the sheath, divided into two, some fibres passing between layers of sheath, others curling spirally round the muscle fibres. After noting the resemblance to the sheath of a Pacinian corpuscle, Ranvier concluded that muscle spindles formed a definite physiological apparatus, "having a special relation to the nervous system".

B 17.

MAYS (1884, 1892). stated his belief in the fact that the muscle spindles were "in connection with the sensory nerve fibres".

B 20.

ROTH (1887). supported Ranvier in disputing the developmental and the pathological theories, and described the muscle spindles under the name of "NEURO-MUSCULAERE STAMMCHEN". He found the spindles in atrophied and normal muscle and looked upon them as physiological organs.

B 24.

KERSCHNER (1888, 1892, 1893). was the first to definitely state that the muscle spindles were sensory/

sensory terminal organs and suggested that they served the function of muscle sense. The points he put forward in favour of the sensory nature were as follows:-

- (1). Abundant nerve supply, far above number of muscle fibres.
- (2). Division of nerve fibre after a type which reminds one more of a sensory than of a motor nerve ending.
- (3). Presence of nuclear groups like those of end bulbs.
- (4). Frequent ending of part of the same nerve in a tendon organ.
- (5). Analogy with a Golgi tendon organ:
 - a Supply from same nerve.
 - b Similar sheath.
- (6). Constant presence: number and appearance in many muscles in which fine muscle sense is needed.

Kerschner concluded that the muscle spindles were "Complicirte Organe, welche dem Muskelsinne dienen dürften".

B 25.

CATTANEO (1888) proved by experiment that the tendon organs of Golgi were sensory terminal organs probably serving muscle sense, and from the analogy between those organs and muscle spindles strengthened the sensory theory.

B 30.

DOGIEL (1890) was the first to use methylene blue as a staining agent in the study of the nerves of the muscle spindles. Supported the sensory theory.

B 34.

GIACCIO (1891) studied more the musculo-tendinous organs, of which he gave excellent plates, than the muscle spindles. He corroborated the sensory view of muscle spindles.

B 32.

CHRISTOMANOS and STRÖSSNER (1891) examined the muscle spindles at various periods of life, considered them to be sensory organs and noted that the difference in size at the different ages depended mostly upon the thickness of the walls of the muscle spindles.

B 24c.

V. EBNER (1892) supported the sensory terminal theory, and showed, for Kerschner, specimens of the nerve endings in muscle spindles stained with gold chloride.

B 37.

RUFFINI (1893, 1897.) gave a very accurate description of the nerve endings in the muscle spindles of the cat. He divided the termination into three main types:-

1. Terminaisons à anneaux.
2. Terminaisons à spirales.
3. Terminaisons à fleurs.

He found rings and spirals alongside one another/

another in one and the same fibre and termed this kind of ending "Terminaison annulo-spiralée", and as the axis-cylinders were in the form of a "ruban" the termination may be more exactly called "Terminaison à rubans annulo-spiralés". He compared these results with what he found in the human muscle. In his paper in 1897 he added little to what he had described in his earlier work, but distinguished;— Spindles with complex endings, spindles with simpler ending, spindles with simplest ending, according to the combinations they possessed of the three types recognised in his first paper.

Ruffini looked upon the muscle spindles "as particular nervous terminal organs" and gave the points on which he based his opinion.

B 38.
FORSTER (1894) examined the condition of the muscle spindles in certain diseases of the spinal cord, and concluded that their "trophic centre lies not in the cells of the anterior horn, -- and certainly not in the spinal cord at all. The nerve fibres in relation to the spindles are the axis-cylinders of the ganglion cells which are situated outside the cord altogether".

He stated that "Probably the consideration of the anatomical structure is the most likely direction in which/

which to search for the physiological signification of the muscle spindles. Supposing one represents one of these structures, -- a long narrow spindle, hollow in the inside, open at the two ends, but these openings presenting vessels and connective tissue arranged in such a way as to a certain extent shut off the space inside, while in the lymph, which fills the broad middle part of the spindle, muscle fibres and nerves are found in larger numbers than at the ends; every pressure which is exerted from the outside or from the inside, by the contracting and thickening muscle, will be diffused into the space inside by the lymph of the spindle and exert pressure upon, and influence from all sides the nerves and muscles contained therein. In addition we have in this an apparatus which can indicate the degree of contraction". I give two of his drawings.



Fig. H. (20).

Fig. H. (20).

Forster (1894). In the spindle there is a broad muscle fibre (a), and a small oblique muscle fibre cut in cross section: near the large fibre there are two medullated nerves (c). Further cut there is a third nerve (c) near a capillary (d). In the sheath of the spindle a large bundle of nerve fibres is seen, also an isolated nerve bundle and an artery (d).



Fig. H. (21).

Forster (1894). A muscle spindle from the atrophied muscle of a case of transverse myelitis. Beside the muscle fibres (a) are eight medullated nerves (b), and a capillary (c).

In/

In the sheath is a little group with two nerve fibres (d).

B39

SHERRINGTON (1894) in one of his classical contributions upon "Nerves of Skeletal Muscles" gave the final absolute proof that the muscle spindles were sensory nervous in nature. He cut the anterior roots of the cord and also the posterior roots proximal to the ganglia. Thus the only nerve fibres remaining undegenerated after the experiments were nerve fibres which had their nerve cells in the posterior root ganglia. On examining the muscles he found that the muscle spindles were supplied, after the section of the roots as above described, with perfectly normal nerve fibres. He said, (and this paragraph is now very frequently quoted),- "My own experiments have been suitable for examining the effect of degeneration of the motor spinal roots upon the nerve fibres supplying the muscle spindles; they demonstrate that the muscle spindle is supplied with nerve fibres arising in the cells of the spinal root-ganglion. In muscles from which all motor fibres have been entirely removed by degeneration I have never in a single instance failed to find every spindle met within the muscle still possessed of perfectly sound myelinate nerve-fibres. These myelinate/

myelinate fibres are traceable from the sensory roots, and penetrate into the spindles and terminate within them. The muscle spindle proves therefore to be a sensorial organ as argued by Kerschner and as indicated by the historical analysis of the nerve-ending by Ruffini". I have reproduced five of Sherrington's diagrams as they contain the proof of the sensory nature of the muscle spindles.



Fig. H. (22).

Sherrington (1894). Flexor brevis digitorum muscle (cat); root ganglion fibres only remaining. Thirty-five days degeneration. Small intramuscular nerve twigs in cross section; from the smaller of these (purely motor) all myelinate fibres have disappeared, from the larger/

larger all but two. To the right and above is the commencement of a "muscle spindle", into the capsule of which the large fibre seen in the middle of figure was traceable in the series of sections made.



Fig. H. (23).

Sherrington (1894). Gracilis muscle, monkey. Root ganglion fibres only remaining. Muscle spindle containing eight muscle fibres: near it a spindle nerve containing five myelinate nerve fibres: also a motor nerve from which all myelinate fibres have disappeared.

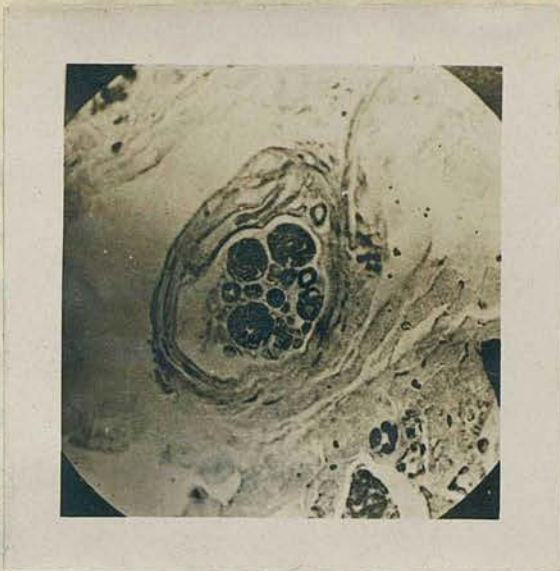


Fig. H. (24).

Sherrington (1894). Vastus medialis muscle (cat). Root ganglion fibres only remaining; sixty days degeneration.

Muscle spindle containing three large and six small muscle fibres. A large root ganglion fibre lies in the outer part of the capsule of the organ, and a small myelinate fibre lies close to the muscle fibres in the core of the organ.

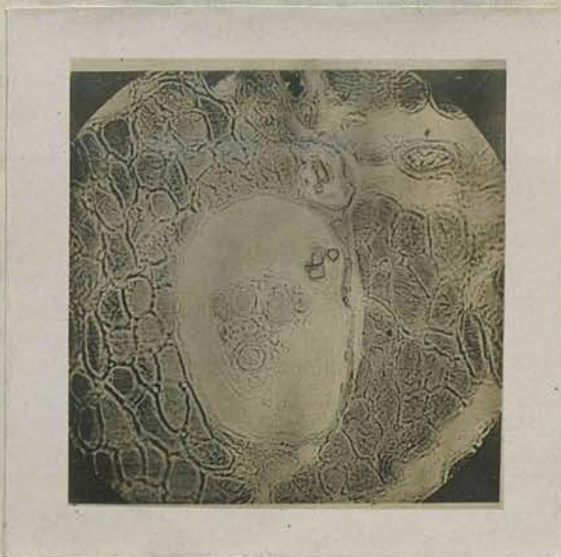


Fig. H. (25).

Fig. H. (25).

Sherrington (1894). Semi-membranosus muscle, (monkey). Root ganglion fibres only remaining; fifty days allowed for degeneration.

A muscle spindle in cross section through the equatorial region. Two myelinate nerve fibres cut obliquely in the thickness of the capsule of the spindle: three cut fairly transversely just within the periaxial lymph space. Six muscle fibres and two non-muelinate nerve fibres cut transversely within the core of the organ.

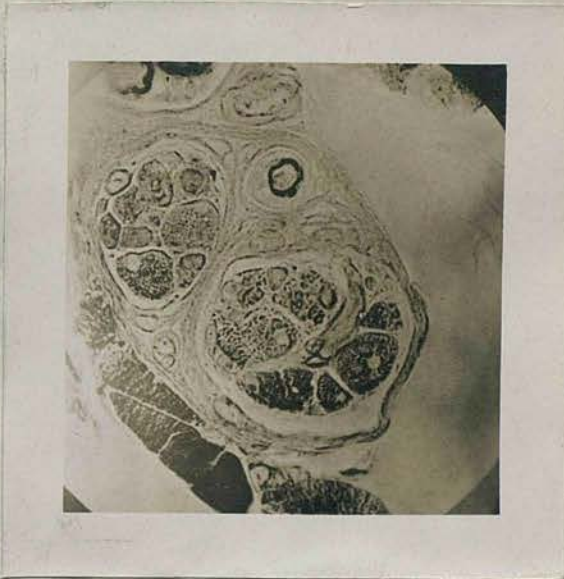


Fig. H. (26).

Sherrington (1894). Intercossecus plantar muscle (cat). Compound muscle spindle, one division containing eight muscle fibres, and the/

the other nine muscle fibres. In the smaller division a myelinate fibre is seen in transverse section, in the larger a myelinate fibre curves across from the centre to the periphery of the intrafusal muscle bundle. At one side of the spindle lies a solitary "spindle-nerve" fibre enclosed in a well-developed loosely-fitting sheath of Henle.

This work of Sherrington's is probably the most important, the most perfect, and the most exhaustive, and decisive that has been done on the muscle spindles. I offer no excuse for giving so many of his diagrams and for dwelling somewhat fully upon his results, which, however, speak for themselves.

⁴⁰

SIHLER (1895) after giving a detailed account of the muscle spindles, concluded that they were sensory in nature. He introduced a new method of staining the nerve endings, - one that I have found of great use in studying the gross arrangement of the nerve fibres. It is a macerating and teasing process and gives very good low power views. It is, however, not nearly so good as the intra-vitam methylene blue method for staining the fine terminations. Batten used this method a great deal and found it very useful. Beyond the method there is nothing new in the articles/

articles of Sihler.

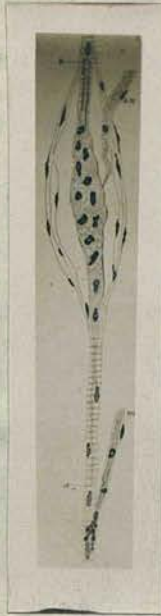


Fig. H. (27).

Sihler (1895). A muscle spindle, - somewhat diagrammatic - prepared by Sihler's process.

SN. - nerve to muscle spindle; M. - nerve going to motor nerve ending.

B 41.

WEISS and DUTIL (1896) worked with Ranvier's gold chloride method, using rabbits and cats for their investigations. They described three modes of nerve termination within the muscle spindle:-

(1). Two fine branches, one passing above, and the other below a nucleus.

(2). A small eminence on the sarcolemma, where there is a group of two or three nuclei.

This/

This ending is generally found towards the pole of a spindle.

- (3). Fibres spread themselves on the surface of the muscular bundles in tree-like form, deprived of all nuclear elements.

B 43.
 BATTEN (1897) gave an account of the muscle spindle under certain pathological conditions, but failed to find any very marked change except in some cases of Tabes, but that is of no interest to us in the present paper although it is of great interest in view of the fact that the muscle spindles remain quite healthy in many cases of advanced muscular atrophy from many causes. Batten described the muscle spindles in man, but only as a preliminary to his study of them in various pathological conditions.



Fig. H. (28).

Batten (1897). Normal spindle from abductor pollicis of foot (Man).

A nerve (N) can be seen entering the equatorial region of the spindle. Another nerve (N) enters the spindle/

spindle at the opposite pole. An artery (A) and a vein (V) can also be seen giving branches to the spindle. Teased specimen, with Sihler's method.



Fig. H. (29).

Batten (1897). Normal spindle in longitudinal section. To show the intramuscular nuclei, the nerve passing to this portion of the spindle is seen at (N).

In this, as in most of Batten's longitudinal sections, it is rather difficult to recognise at once that a muscle spindle is being represented. His cross sections are much better.



Fig. H. (30).

Fig. H. (30).

Batten (1897). Normal spindle in longitudinal section.

This is under a high magnification to show the nature of the nerve ending within the muscle spindle. The importance of Batten's article, however, is that in it he figured muscle spindles from the various pathological conditions in which he was able to investigate them. This is beyond the scope of the present contribution, but I give the next photograph to indicate the nature of Batten's work.



Fig. H. (31).

Batten (1897). Spindle from a case of myopathy. The sheath is well shown, the intrinsic muscle fibres, those inside the spindle, are equal in size to the extrinsic. (Outside the/

the spindle).

One of the cases that Batten investigated is important from the surgical aspect. It was a case of injury to the brachial plexus, and in it Batten found the muscle fibres somewhat shrunken. Below is his representation of the spindle in cross section.



Fig. H. (32).

Batten (1897). Muscle spindle from a case of injury to the brachial plexus, from the hypothenar muscles. Transverse section. Two spindles are seen in transverse section lying in areas where extensive atrophy has taken place. The muscle fibres are smaller than normal and appear shrunken.

B. 44. B. 46. B. 45.
 SPILLER, HORSLEY, and GRUNBAUM (1897) investigated the condition of the muscle spindles in muscular atrophies, and the last mentioned described a definite change in the spindles in Pseudohypertrophic Muscular/

Muscular Paralysis. Horsley noted the condition of the spindles after section of the sciatic nerves in the cat: (that will be referred to later;) but I wish to insert at this place photographs of their diagrams.



Fig. H. (33).

Horsley (1897). Gastrocnemius muscle of cat seventeen days after section of the sciatic nerve. Note the shrinkage of the muscle spindles.

Horsley divided the sciatic nerve of cat and dog, and allowed a period for degeneration of from three days to one year. As a rule by the seventeenth day there was apparently a shrinkage of the spindles, a shrinkage parallel to the general shrinkage which the/

the atrophy of the muscle gradually undergoes as a whole. The muscle fibres are unaltered in character. Grunbaum gives the following two diagrams:-



Fig. H. (34)

Grunbaum (1897). Muscle spindle in unaffected portion of muscle.



Fig. H. (35).

Fig. H. (35).

Grunbaum (1897). The same with affected fibre. In case of Pseudo-hypertrophic Paralysis, Grunbaum found diminution in size of an intrafusal fibre with a deposit of hyaline substance around.

B 47.
 HUBER (1890, 1900) did some very beautiful work upon the nerve endings in muscle. He used the intravital method of staining with Methylene Blue, and was able to corroborate, and in some instances correct, the results obtained with the gold methods. His work is of the utmost value throughout, but special mention must be made of the excellent descriptive detail given of the ultimate nerve terminations. I reproduce some of his diagrams illustrating the mode of entrance of the nerves into the muscle spindles, and other points.

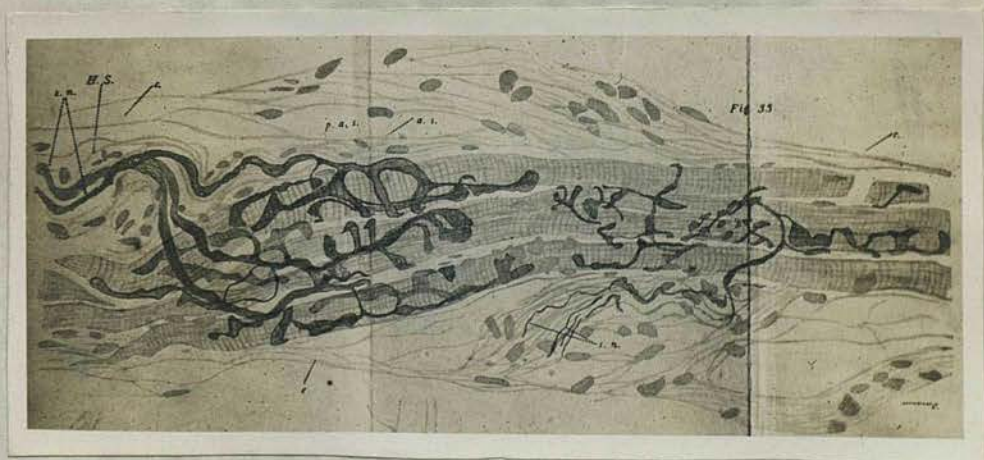


Fig. H. (36).

Fig. H. (36).

Huber Longitudinal section of the compound muscle spindle from the intrinsic plantar muscle of the rabbit.

This is given to show the nature of the ultimate nerve endings described by Huber.

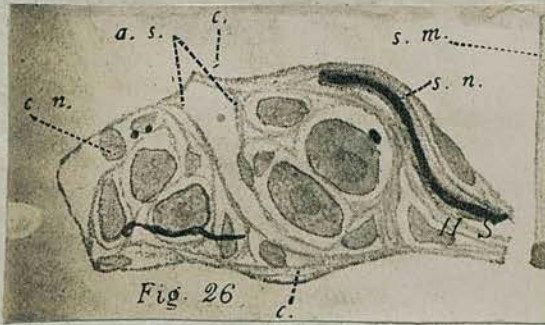


Fig. H. (37).

Huber. Cross section of a muscle spindle at the place of entrance of a spindle-nerve. (Amphibia).

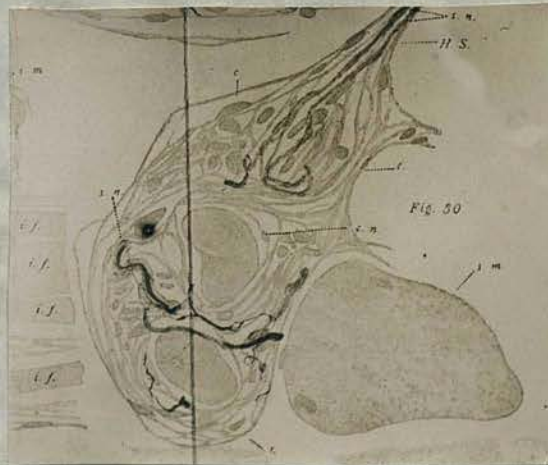


Fig. H. (38).

Fig. H. (38).

Huber. Cross section of muscle spindle through place of entrance of spindle-nerves. (Tortoise).

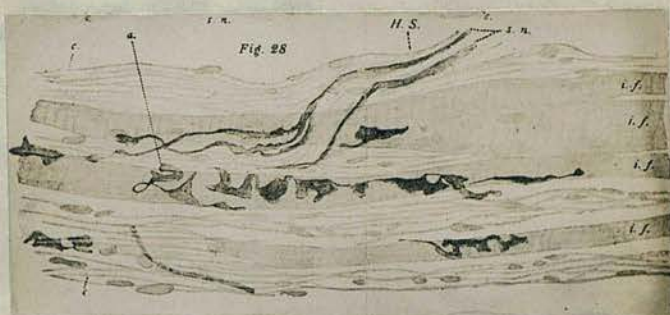


Fig. H. (39).

Huber. Longitudinal section through the equatorial region, showing entrance of spindle-nerve. (Tortoise).

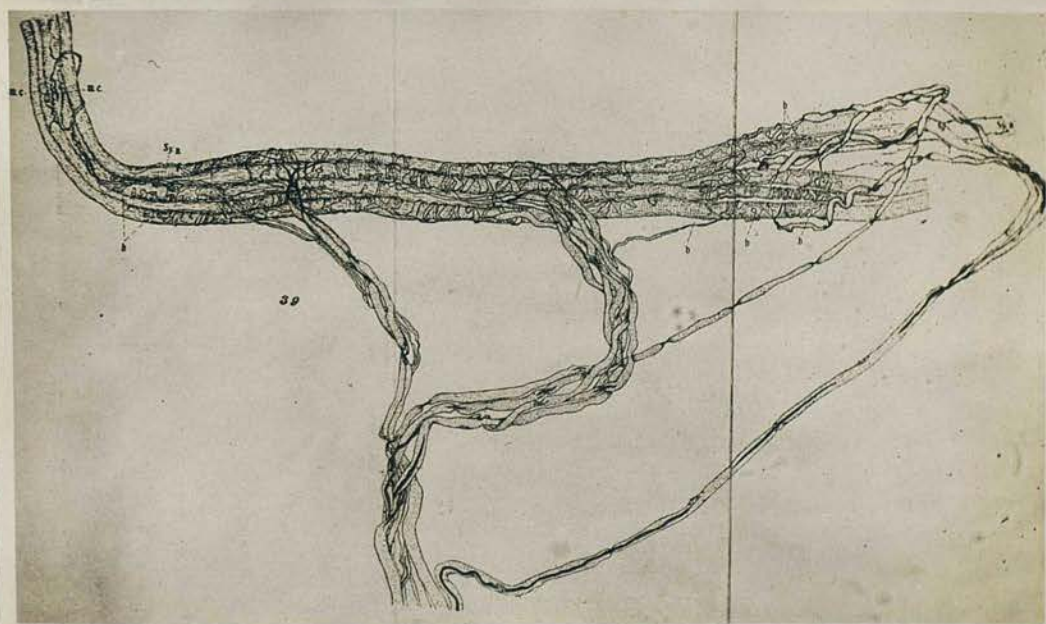


Fig. H. (40).

Fig. H. (40).

Huber. Compound muscle spindle from the intrinsic plantar muscles of a dog, showing three areas of nerve distribution.

This diagram is from a teased specimen, and shows that the muscle fibres of the muscle spindles have motorial nerve endings. (m.e.).



Fig. H. (41).

Huber. Cross section of muscle spindle from the intrinsic plantar muscle of a cat.

This diagram, cut somewhat obliquely, shows the nerve fibre being distributed to several of the muscle fibres inside the muscle spindle. At the right bottom corner a sympathetic nerve is seen ending around a blood-vessel. (Sy.n.).

The letters in Huber's diagrams have the following meanings:- c.-capsule; a.s.-axial sheath; c.n.-connective tissue sheath; i.f.-intrafusal fibre/

fibre; p.a.s.-periaxial space; s.n.-medullated spindle-nerve; H.S.-Henle's sheath; s.m.-striated muscle fibre from muscle, given to show the relative size of intrafusal and the other striated muscle fibres; Sy.n.-sympathetic nerve fibre; bl.v.-blood-vessel.

1. ...
 2. ...
 3. ...
 4. ...
 5. ...
 6. ...

(c)

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THE GOLGI TENDON ORGAN.

The Golgi Tendon organs are the sensory nerve terminations in tendon.

In 1880 Golgi described spindle shaped bodies in the tendons of man and other vertebrates, and traced nerves to them. Marchi found similar structures in the eye muscles in 1882, while in 1888 Cattaneo's classical paper appeared. Cattaneo showed that, after cutting the anterior spinal nerve roots, the nerves to the tendon spindles remained intact. He described these organs in the guinea-pig, rabbit, cat and dog, and lastly in man. His experiments included not only cutting of the anterior roots, but also section of the sciatic nerves. Ciaccio followed in 1891, giving an excellent series of plates to illustrate his work. Huber in 1898, employing the intravital methylene blue method corrected certain details but corroborated in the main the findings of the previous observers.

While working at the muscle spindles in the various animals and in man I have naturally come across numerous nerve endings in tendon, but I have not done any work upon these structures and therefore

I think that I would not be justified in considering them here. I will not refer to the Golgi Tendon Organ again, and only mention it here as it forms one of the modes of termination of sensory nerve in muscle.

By "other" sensory nerve terminations is meant, sensory nerve terminations in muscle "other than" :-

- (1). The muscle spindle.
- (2). The Golgi tendon organ.

These other sensory nerve terminations are :-

- (1). CORPUSCLES OF PACINI.
- (2). OTHER END BULBS.

In the tendons of certain muscles of the upper and lower extremities of man Golgi found, besides the tendon organs, "divers formes de Corpuscles de Pacini", which he called "Pelotes". He gave figures of these, and the larger of these, as pointed out by Clesio, resembles very closely in appearance the typical Pacinian Corpuscle found in the mesentery of the cat. The difference is that in the ordinary Pacinian Corpuscle the nerve ends in a definite part, whereas in the Pacinian Corpuscle, as found in muscle, the nerve generally ends by winding or rolling round the central core.

The smaller of the two bodies figured by Golgi resembles, on the other hand, the Corpuscles of

OTHER SENSORY NERVE TERMINATIONS
IN MUSCLE.

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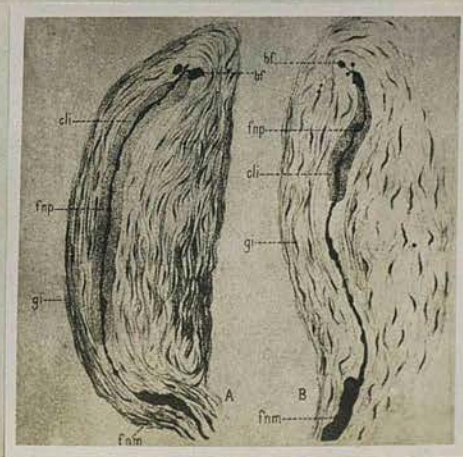
The smaller of the two bodies figured by Golgi resembles, on the other hand, the Corpuscles of Herbst/

Herbst or the cylindrical or spherical End Bulbs of Krause, but does not show the distinctly regular investing capsule, nor the double row of nuclei possessed by the typical Herbst's Corpuscle.

As far back as 1883 Horsley noted not only Tactile Corpuscles, but also Pacinian Corpuscles in the nerve trunks and later, in 1897 gave a short note describing Pacinian Corpuscles in the gastrocnemium muscle of the cat. I have reproduced his Photographs. This was confirmed by Huber.

Cattaneo in 1888 showed the relation of the Pacinian Corpuscle to the Golgi tendon organ and this relationship was further studied by Ruffini in 1892 by the aid of serial cross sections. His results were confirmed, in part at least, by Sherrington.

I have reproduced the representation given by Cattaneo of nervous terminal corpuscles which he found in the white rat, in close relation to the tendon organs.



Cattaneo/

Fig. 61.

Fig. 61

Gattaneo (1888). Two nervous terminal corpuscles closely resembling in some of their characters a Pacinian Corpuscle. From the White rat.



Fig. 62.

Horsley (1897). Pacinian Corpuscle found in the gastrocnemius muscle of the cat. Organ has a diameter of from 100 to 144 micromil. in transverse section.



Fig. 63.

Fig. 63.

Horsley (1897). Tactile body in normal muscle, from the gastrocnemius muscle of cat.

I have been rather interested in these sensory nerve terminations and have been fortunate in finding them not only in the tendons of animals, but also in human muscle and not always in normal muscle. We may note in passing a few points in regard to their Situation and Characters.

SITUATION.

The situation of these bodies in tendon and in muscle may be shortly summarised thus:-

A. In Tendon.

The Pacinian Corpuscle may lie:

- (1). In close proximity to the tendon organ.
- (2). Connected with the tendon organ by the nerve fibre coming from a common nerve bundle.
- (3). On the surface of the tendon organ.
- (4). Embedded in the substance of the tendon organ.
- (5). Near either the muscular or the tendinous extremity of the organ.

B. In Muscle.

The Pacinian Corpuscle may lie:

- (1). Near a nerve trunk in the muscle.
- (2). Near a bloodvessel in the muscle.
- (3)./-

- (3). Near the lining aponeurosis.
- (4). Near a fibrous tissue septum.
- (5). Actually embedded in the muscle tissue in relation to the perimysium.

In animals I have frequently seen Pacinian Corpuscles in relation to the tendon organ, but in the human muscle I have only so far seen the end corpuscles once in close proximity to a nerve trunk and once in the muscle tissue very near to a small artery.

CHARACTERS.

The Pacinian Corpuscle as found in muscle is essentially small, ellipsoidal on cross section, and commonly measuring about a tenth of a millimeter in diameter. It is elongated and shows a capsule possessed of only 6 or 8 lamellae, while the axial portion is thick. Only one medullated nerve fibre goes to the organ as a rule, but it does not usually end in a definite bud.

DEGENERATION.

When the sciatic nerve of the cat is cut and a sufficiently long time allowed to elapse to permit of degeneration taking place, the Pacinian Corpuscles remain quite healthy in appearance, as was shown by Hersley, although the surrounding muscle fibres are extremely/

extremely atrophied. I have seen, and am able to give a photograph of a perfectly healthy Pacinian Corpuscle lying in the muscle of a case of Peripheral Neuritis where the muscle tissue was almost entirely replaced and represented by fat. In another case I found a healthy End Corpuscle lying near a nerve in a muscle where the muscle fibres were distinctly atrophied and surrounded by great increase of the interstitial fibrous tissue, as a result of pressure on the nerve by a tumour.

These facts are undoubtedly of interest in the consideration of the site of the nutritional centre of these End Corpuscles but do not of themselves help us to get very much further on. Nevertheless together with the fact that a Pacinian Corpuscle so often derives its nerve fibre from a nerve trunk common to it and to a Golgi tendon organ, (I have never seen a nerve fibre divide to supply both a Pacinian Corpuscle and a Golgi tendon organ). one more and more gathers the impression that, the function of a nerve depends less upon its different mode of origin (which determines more if the fibre is motor or sensory) than upon its different mode of termination.



Fig. 64.

Pacinian Corpuscle found, in close relationship to a vessel, lying in muscle tissue from a case of Penipheral Neuritis.

Length 1.2 m.m.

Breadth 0.8 m.m.

Central Core 0.026 m.m.



Fig. 65.

End Corpuscle found in the atrophied human muscle,
in close relation to the Ulnar Nerve.

Length 0.5 m.m.

Breadth 0.3 m.m.

Central Core. 0.07m.m.

CHAPTER III. THE EFFECT OF THE
RESECTION OF THE SPINAL NERVE

For this investigation the sciatic nerve of the mouse was used. Twenty-four mice had the sciatic nerve cut, and were allowed to live for a period of ten days up to twenty-three days. The mice were killed every day up to ten days and then every other day up to twenty-three days.

PART III.
EXPERIMENTAL INVESTIGATIONS.

After the resection of the sciatic nerve the mouse was allowed to live for a period of ten days up to twenty-three days. The mice were killed every day up to ten days and then every other day up to twenty-three days.

After the resection of the sciatic nerve the mouse was allowed to live for a period of ten days up to twenty-three days. The mice were killed every day up to ten days and then every other day up to twenty-three days.

It was found that if the nerve were cut

CHANGES RESULTING FROM NERVE SECTION

AT THE SEAT OF SECTION.

For this investigation the sciatic nerve of the mouse was used. Twenty-four mice had the sciatic nerve cut, and were allowed to live for a varying period from one up to twenty-three days. One animal was killed every day up to ten days and then one every other day up to twenty-three days.

OPERATION.

After the animal was anaesthetised the popliteal space was opened up, due aseptic precautions being taken. The sciatic nerve was exposed and a millimetre of its length excised. The wound was then stitched up and in every case healed by first intention.

LATER PROCEDURES.

After having been allowed to live for a certain time the animal was killed, the wound was opened up, and the region of the nerve section exposed. The upper cut end was removed and the lower cut end was removed along with any fat or other tissue adhering to them, care being taken not to take hold of or in any way damage the part of the nerve fibre nearest to the area of section.

It was found that if the nerves were then
put /

put into fixing fluid they were apt to curl up and accurate cross sectioning later was very difficult. To avoid this, the nerves were placed in the fixing fluid after being placed on a small piece of wood with a little groove to contain the piece of nerve fibre. When taken out of the fixing fluid the small nerve fibres were absolutely straight and the later handling of the nerves was simplified, and it became comparatively easy to obtain absolutely transverse sections. The nerve fibres were carried through as detailed under the details of the routine examination of muscle and nerve. The sections after being fixed on albuminised slides were stained with Van Gieson's stain.

Over three thousand sections were stained in order to determine the changes in the nerve fibre and in the surrounding tissues, principally fat, of the popliteal space.

The appearances which were seen under the various days will now be described in detail under the headings of :- Changes in Nerves.

Changes in Fat.

(1.) Eighteen Hours.

Changes in Nerve.

The nerve shows swelling of the myeline sheath /

sheath, while in parts the axis cylinder is retained, staining more faintly than normal. In other parts the axis cylinder and myeline sheath are becoming fused together and stain a pinkish-yellow with Van Gieson.

Fibrin clot is seen around the nerve bundle enclosing many red cells and a few polymorphonuclear leucocytes. Here and there are small accumulations of cells (chiefly polymorphs) and nuclear debris. Only one or two lymphocytes are recognizable.

(2.) Thirty-six Hours.

Changes in Nerve.

The axis cylinder is becoming merged with the myelin sheath into a swollen, homogenous pinkish-yellow mass within the pink-stained neurilemma sheath. (This is probably a result of inflammatory oedema.) The nerve sheath is surrounded by a layer of closely applied cells and nuclear debris. The cells are chiefly small lymphocytes with commencing enlargement of the cell body and clearing up of the nuclear framework with indentation of the nucleus.

Changes in Fat.

The fat meshes surrounding the nerve fibre are occupied by numerous cells. Many of these cells /

cells are polymorphs but most of them are cells with round nucleus, possibly mononucleated emigrated cells, or possibly connective tissue cells, endothelial cells.

(3.) Forty-eight Hours.

Changes in Fat.

The septa between the fat lobules show very marked increase in the cellular elements; Numerous polymorphs are still found, but the cells are chiefly mononucleated cells, which look like polyblasts, (Maximow). Others are more distinctly proliferated connective tissue cells and endothelial cells.

Between the individual fat cells there is increase of the cellular elements of the same type as above. Some fat cells show a complete replacement of the large fat cell by small round cells, (Polyblasts,) the contour of the fat cell being frequently retained. Other fat cells showing a breaking up of the fat into smaller globules are seen, giving the characteristic vacuolated "foam-cell." This has been by some authors described as an "endogenous cell-formation," by others as an invasion of the fat cell by emigrated cells from the vessels.

(4.) Three Days.

Changes /

Changes in Nerve.

The nerve here is cut somewhat obliquely, but shows in places advanced swelling of the myelin. There is, however, chiefly a disappearance of axis cylinder and myelin. It is difficult to say whether there is a neurilemma nuclear increase or not.

Changes in Connective Tissue.

There is distinct softening of the connective tissue cells and bundles, and the nuclei of the connective tissue cells are seen lying in clear spaces. There is possibly a proliferation of the connective tissue cells as well.

(5.) Four Days.Changes in Nerve.

Very few nerve fibres show definite axis cylinders, and nearly all the nerve fibres outlined by neurilemma sheath are empty or occupied by a diffuse swollen, yellow mass.

There is considerable increase in the number of nuclei within the nerve bundle, pointing to proliferation of the neurilemma nuclei and the connective tissue cells.

In the surrounding tissues there are traces of cell-accumulations, mostly small polyblasts.

(6.) Five /

(6.) Five Days.Changes in Nerve.

There is congestion in and around the nerve fibre, and some of the vessels show marked hyaline change. Haemorrhages, probably accidental, are seen in and around the nerve fibre.

Swelling and disappearance of the myelin are to be noted and the ghostly outlines of the axis cylinders are very striking. The nuclei within the nerve bundle are very distinctly increased.

(7.) Six Days.Changes in Surrounding Tissues.

The fat cells show little trace of the so-called "endogenous cell-formation," but there is marked breaking up of the fat globule into several droplets, and granular appearance of the periphery of the fat cell.

Proliferation of the connective tissue cells between the individual fat cells and in the septa is to be noted especially around the vessels, several of which are hyaline.

(8.) Seven Days.Changes in Nerve.

Here, for the first time thickening of the sheath of the nerve may be observed, while the increase of the neurilemma nuclei is very evident.

Very /

Very beautifully shown is the finely-fibrillated interstitial change of early fibrosis. Some little twigs of nerve fibre show a further stage with the fibrillar network more marked.

Swelling of the myelin and axis cylinder and gradual replacement of the nerve elements are the other changes recognisable at this stage.

The Fat is, here, largely replaced in parts by proliferated connective tissue and cellular elements.

(9.) Eight Days.

The nerve shows the same fibrillar, interstitial change as the nerve at seven days section, while the proliferation of the connective tissue cells between the fat cells is advancing.

(10.) Nine Days.

Changes in Nerve.

At this stage there is marked cellular infiltration of the nerve from proliferation of the neurilemma nuclei, connective tissue cells, and possibly from cells that have penetrated from the outside.

There is complete disintegration of the nerve elements which are replaced by the cellular elements /

elements of the fibrous tissue.

Changes in Fat.

There are very marked changes in the fat, chiefly in the direction of connective tissue cell proliferation between the fat cells; in addition well marked granular degeneration of the fat cells and also the alteration of the fat cell into the "foam-cell" form, make themselves evident.

(11.) Thirteen Days.

There is marked cellular replacement of the nerve elements, but the nerve elements are not so completely disorganised as some of the sections of the nerve, which had been cut only nine days, show. Here also the fat is replaced by cellular fibrous tissue.

(12.) Seventeen Days.

Beyond fibrosis of the nerve fibre, part of which is cut in longitudinal section, there is nothing striking about the nerve fibre at this stage.

In the Fat, areas of chronic inflammation can be seen as well as replacement of fat by cellular fibrous tissue. In some areas the fat is almost unchanged, while in others the characteristic "foam" cells appear.

(13.) Nineteen /

(13.) Nineteen Days.

In these preparations the nerve tissue, the fat tissue, the connective tissue, and the surrounding muscle tissue are all inextricably mixed up, the whole showing chronic inflammatory changes with cellular fibrous tissue replacing the nerve tissue, fat and muscle fibres.

(14.) Twenty-two Days.

It is extremely difficult, or even impossible to identify any nerve tissue here at all.

In the fat, in addition to the presence of the "foam-cell", mention must be made of the beautiful demonstration of the granular degeneration of the periphery of the fat cells, which may here be observed.

In order to illustrate the changes in the cut nerves and in the surrounding tissues, I have taken photographs of fourteen selected sections, nine to show the changes in the nerve fibre, and five to show the changes in the fat and surrounding tissues.

It will be advisable to arrange the illustrations firstly under the heading of "Changes in Nerve", and secondly under the heading of "Changes in Surrounding Tissues", so as not to group them under the various days of section, as was done in the first part of this chapter.



Fig. 66.

(B.186 S.3 Row 2). (Slide 53).

Cross/

Cross section of a normal sciatic nerve of a mouse. The fibre is somewhat broken up, but it is inserted to show the size and appearance of the normal nerve fibre with its axis cylinder and myelin sheath. The number of neurilemma nuclei and the amount of interstitial fibrous tissue may be noted in passing.



Fig. 67.

(B. 169. S.2 Row 1). (Slide 54).

Eighteen hours section.

Swelling of myelin sheath..

Axis cylinder and myelin sheath are becoming fused. In parts axis cylinder is retained but stains more faintly than normal. Fibrin clot around./

around.

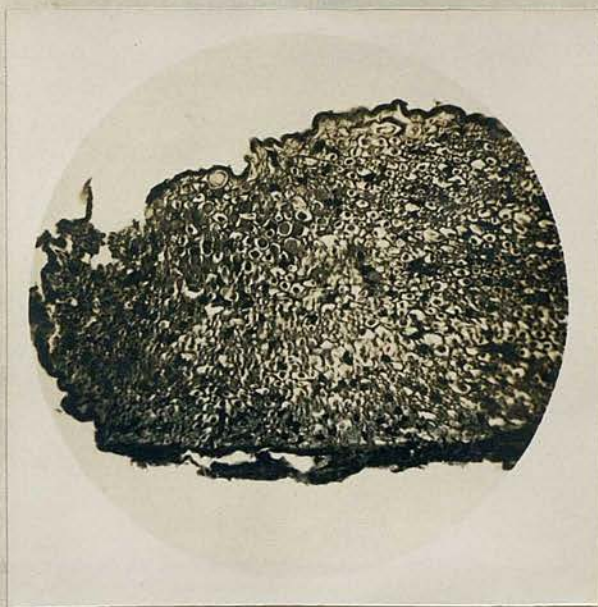


Fig. 68.

(B.170 S.2 Row 2).

(Slide 55).

Thirty-six hours section.

Axis cylinder merged with myelin sheath into a swollen, homogenous, pinkish-yellow mass, within the pink-stained neurilemma sheath.



Fig. 69.

(B.180. S.2 Row 3). (Slide 56).

Four days section.

Few nerve fibres show a definite axis cylinder. Neurilemmal outlines of fibres are empty, or occupied by a diffuse swollen mass. Increase of nuclei within the nerve bundle.



Fig. 70.

(B.187. S.2. Row 5). (Slide 57).

Five days section.

Congestion of vessels in, and around, the nerve.

Marked hyaline change in a small vessel.

Haemorrhages, probably accidental.

Increase of nuclear elements.

Swelling of myelin.

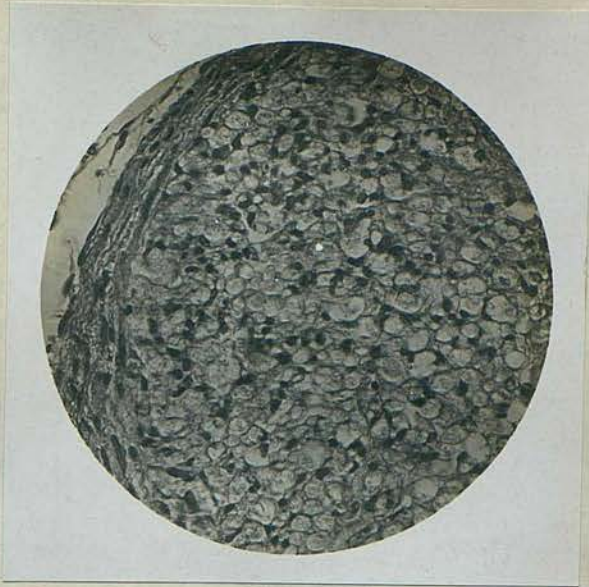


Fig. 71.

(B. 200. S.7. Row 2). (Slide 58).

Seven days section.

Thickening of sheath of nerve.

Increase of neurilemma nuclei.

Fibrillar interstitial change of early fibrosis.

Gradual replacement of nerve elements.

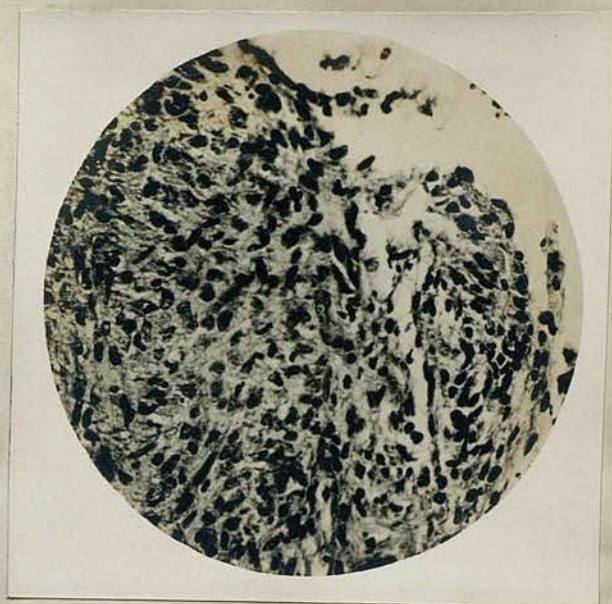


Fig. 72.

(B.213. S.5. Row 1). (Slide 59).

Nine days section.

Marked cellular infiltration of nerve from proliferation of nuclei of neurilemma, connective tissue cells, and possibly penetrated cells.

Complete disorganisation of nerve elements, replaced by cellular fibrous tissue.



Fig. 73.

(B.217. S.7. Row 2). (Slide 60).Thirteen days section.

Marked cellular replacement of nerve elements. Not so completely disorganised as figure 72, which was nerve of nine days section. But then, this section is from the upper cut end of the nerve while all the others are from the lower cut end of the nerve.



Fig. 74.

(B.241. S.3. Row 3). (Slide 61).Nineteen days section.

Nerve, muscle, fat, and connective tissue are all inextricably mixed up into a common mass, which shows chronic inflammatory changes with cellular fibrous tissue replacing the nerve, fat, and muscle tissue.

CHANGES IN SURROUNDING TISSUES.

As the sciatic nerve was cut in the popliteal space, the tissues "surrounding" the nerve are, naturally, /

naturally, mostly, the fat of the popliteal space.

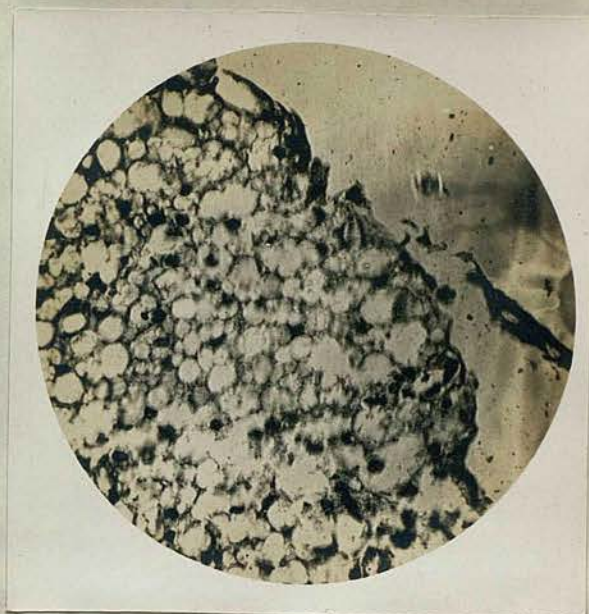


Fig. 75.

(B. 176. S.5. Row 3). (Slide 62).

Forty-eight hours section.

Increase in cellular elements in the septa between the fat lobules.

The cells look like Polyblasts.

Cells also seen between individual fat cells.

Replacement of large fat cells by small round cells, - polyblasts, - the so-called "endogenous cell formation".

Other cells show breaking up of fat into smaller globules/

globules, - "foam-cells".



Fig. 76.

(B. 178. S.1. Row.2). (slide 63).

Three days section.

Softening of connective tissue cells.

Nuclei of connective tissue cells are lying in
clear spaces.

Also slight proliferation of connective tissue
cells.

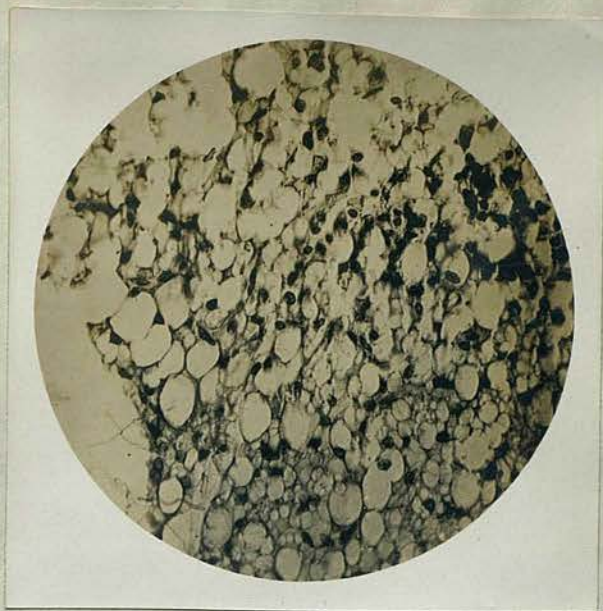


Fig. 77.

(B.198. S.5. Row 3.). (Slide 64).

Six days section.

Marked breaking up of fat cells into several droplets.

Proliferation of connective tissue cells between the individual fat cells.

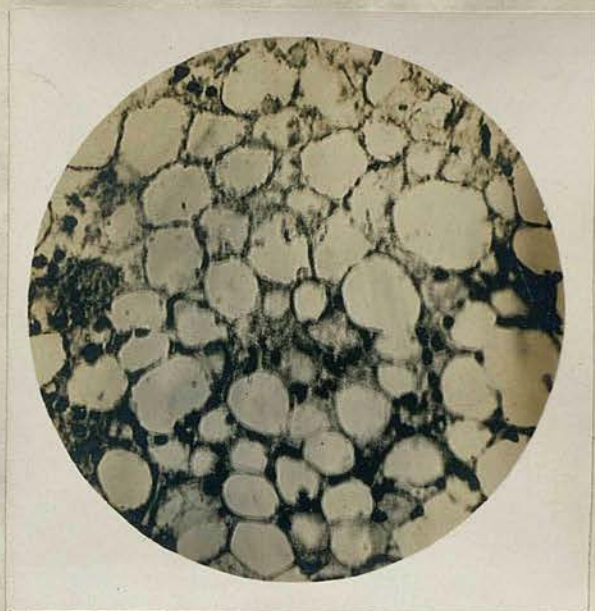


Fig. 78.

(B. 213. S.5. Row 2). (Slide 54)

Nine days section.

Marked proliferation of connective tissue cells
between the fat cells.

Also "foam-cell" formation, here and there.

Granular degeneration of fat cells.



Fig. 79.

(B. 254. S.5. Row 1). (Slide 65).

Twenty-two days section.

Beautiful "foam-cells".

Granular degeneration of periphery of fat cells.

Some fat cells are quite healthy.

CHANGES RESULTING FROM NERVE SECTION
IN NERVE TRUNK BELOW SECTION.

The sciatic nerve and its branches are so small in the mouse, that difficulty was experienced in handling the tissues. Therefore, for this series of experiments the rabbit was used instead of the mouse. Exactly the same procedure was gone through, but a centimetre was removed from the sciatic nerve instead of a millimetre as was done in the mouse. Five rabbits were operated upon and, the wounds all healing by first intention, the animals were allowed to live for a varying number of days.

It was decided to use only the Marchi method in this part of the investigation, so the animals were killed on the sixth, ninth, eleventh, thirteenth, and fifteenth days.

Distinct Marchi degeneration was found on all of these days, and many interesting preparations were obtained. I will, here, only refer to some of the main points, as I think it would be better to place the twenty-eight illustrative photographs in Volume II. (See Volume II. page 26).

My object in carrying out this series of experiments was not so much to obtain information about/

about the changes in the nerve demonstrated by the Marchi method, as to answer the following questions:-

- (A). What evidence is there of the work of cells taking up and removing the fat débris from degenerating peripheral nerve trunk?
- (B). Along what paths do the compound granular corpuscles, or other fat-scavenger cells, travel, as they, loaded with the products of degeneration, travel along and leave the degenerating nerve fibre?.
- (C). When do these fat-carrying cells first make their appearance in the paths along which they travel?.

These questions may be answered at once by the following photographs.



Fig. / 80

X

Fig. 80

(B. 210. S.1)

(Slide 66).

Low power view of a transverse section of the normal sciatic nerve of the rabbit, stained by Marchi's method.

Two large and two small nerve bundles are seen but none of them show any dark points.



Fig. 81.

(B. 210. S.1.)

(Slide 66.)

High power view of the same nerve as is seen in figure 80.

The important point to note is that, in the normal sciatic nerve there is no fat, shown by Marchi staining, inside the confines of the/
the/

the perineural sheath, and there are no fat globules in the septa between the various nerve bundles.



Fig. 82.

(B. 210. S.2.)

(Slide 67).

Low power view of a longitudinal section of the normal sciatic nerve of the rabbit stained with Marchi's method.

There are no black dots in rows. Vessels are seen between and outside the nerve fibres, but there is no fat around them.



Fig. 83.

(B. 210. S.2.)

(Slide 67).

High power view of the same nerve fibre.
No Marchi degeneration, and there is no evidence of fat in the perivascular lymphatic spaces.

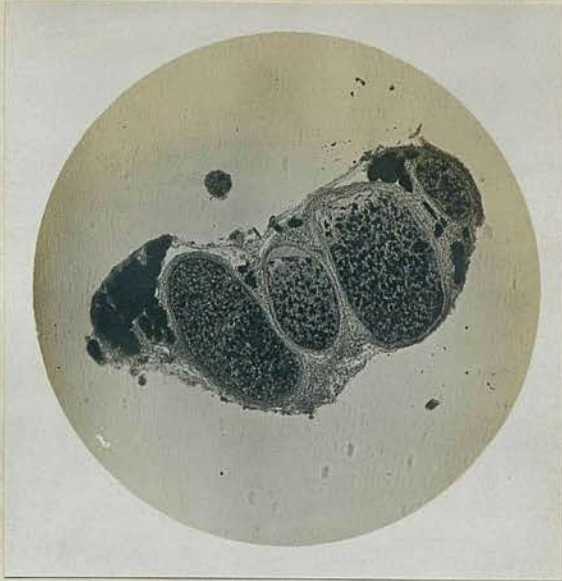


Fig. 84.

(B. 326. S.1.)

Slide 74).

Eleven days section.

Low power view of cross section of degenerated nerve fibre. The Marchi degeneration is obvious, in the four nerve bundles. To the right side there is a large amount of fat inside the perineural sheath. There is also fat in the septum between the smallest and largest nerve bundle. All the fat is in relation to vessels.



Fig. 85.

(B. 226. S.1.)

(Slide 74).

Eleven days section.

High power view of the above nerve. With this magnification it is quite clear that the fat is lying in the perivascular lymphatics. This is, however, better seen in longitudinal sections.



Fig. 86.

(B. 226. S.2.)

Slide 75).

Eleven days section.

Low power view of longitudinal section of degenerated nerve. The true Marchi degeneration requires no comment. At the foot left hand side and further to the right, between two degenerated nerve fibres, are several black masses of fat. These latter consist of seven in a row, and two and three in a row. These black masses will be shown in the next photograph, under a higher magnification.

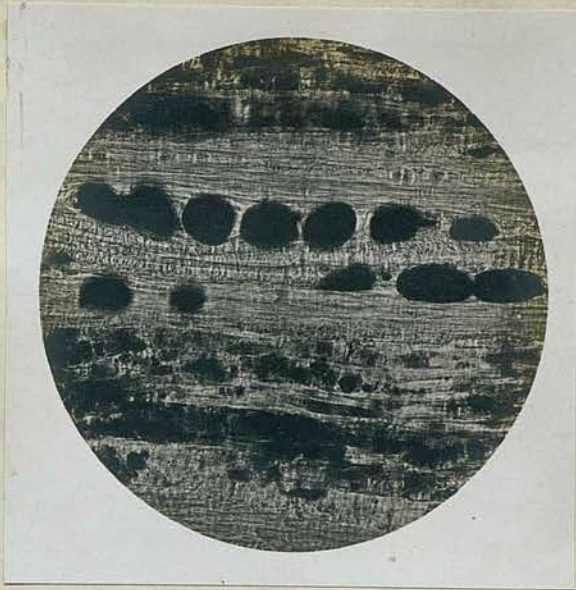


Fig. 87.

(B. 226. S.2.)

(Slide 75).

It will now be seen that the black dots above referred to are in close relation to the small vessels cut in longitudinal section. They are, indeed, fat cells loaded with fat debris, making their way up the perivascular lymphatics.

Now as to the time when the cells are first seen in the perivascular lymphatics. In this series of experiments they first showed themselves in the lymphatics on the eleventh day. They are certainly there on the eleventh/

eleventh day as the above photographs indicate. There is no evidence in any of the earlier sections of any fat whatsoever in the lymphatics of the degenerating nerve, and in a second branch of the same sciatic nerve cut eleven days previously, there is no sign of any fat in the septa or inside the limits of the perineurium, except inside the nerve bundles themselves.

The other photographs of the series will be found in Volume II.

CHANGES IN THE MUSCLE SPINDLES AFTER
NERVE SECTION.

It has been shown that if the sciatic nerve be divided there are no striking changes in the muscles spindles even for as long a period as five months, the muscle fibres inside the muscle spindles being almost the only muscle fibres, not completely atrophied at that time.

In this series of experiments I have cut the sciatic nerves of mice and of rabbits, and have studied the changes in the nerve terminations in the muscle spindles, every day from one up to twenty-three days. This investigation has required the preparation of over six thousand sections, stained by Cajal's Silver Nitrate method.

With the intra-vitam Methylene Blue method Huber has given an account of the early changes in the nerves of the muscle spindles after nerve section, and although I have been working with a different method I shall refrain from discussing the changes in the nerves during the first few days. But Huber has confessed that the Methylene Blue method is of little use in studying the changes in the nerves of the/

the muscle spindles after a period of four or five days, saying the further changes in the nerves could not be made out with the Methylene Blue method.

Long descriptions of microscopical preparations are extremely tiresome to write and still more tiresome to read, so I shall content myself by giving a few photographs of selected sections and describing the appearances to be seen at six days, nine days, eleven days, thirteen days, and fifteen days after section of the nerve.

Naturally when such a capricious stain as Silver Nitrate is being used, the question as to whether in a given section the method has worked properly or not, is very pertinent. In order to make sure that in a single section or series of sections the silver process has been properly carried out, it is well in every case to examine some other structure than the ones in which changes are expected. The ordinary muscle fibres themselves give in muscle after section little help as to whether the method of staining has been successful or not, as they undergo changes as a result of the nerve section.

But the bloodvessels to the muscle have, in the operation not been damaged, and ought to be in a state of more or less good preservation. The inner coat/

coat of an artery is probably as healthy a structure as is to be found in the degenerating muscle after nerve section, and it stains with the Silver.



Fig. 88.

(B. 221. S. 11. Sc. 1)

(slide 80.)

Six days section.

Cross section of a vessel from the muscle of the rabbit, eleven days after section. Note the successful staining of the inner coat.

In this investigation I have only used sections which have some proof as above that the silver method has attained the muscle efficiently.



Fig. 89.

(B. 189. S.7 Sc. 6.)

(Slide 81.).

Six days section.

Cross section of a nerve trunk. Note the swollen neurilemmal sheaths the majority of which contain very much altered axis cylinders, some of which appear as single black spots, others, the more numerous, - as collection of black dots in a dark grey background.



Fig. 90.

(B. 189. S. 5. Sc. 3.)

(Slide 81)

Six days section.

In the intrafusal muscle bundle towards the top of the axial core high magnification shows that there is, even at this date, a medullated nerve fibre just inside the axial sheath.

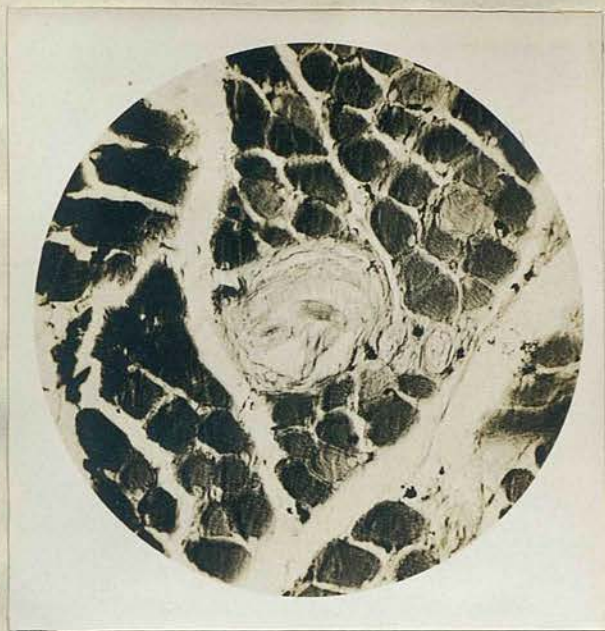


Fig. 91.

(B. 189. S. 5. Sc. 14.)

(Slide 81.)

Six days section.

This is an oblique section of the same muscle spindle as in Figure 90; it shows that at the sixth day there is no evidence of any ultimate nerve terminations in relation to the intra-fusal muscle fibres of the muscle spindles.

Irregular.

At the fibrous joint region where the nerves enter the spindle, the nerves are large and



Fig. 92.

(B. 189. S. 6. Sc. 9).

(Slide 82).

Six days section.

Transverse section of a muscle spindle towards the equatorial region. In the periaxial lymph space on the right side is a medullated nerve. That it is medullated is clear: the axis cylinder is broken up and the outline is very irregular.

At the proximal polar region where the nerves enter the spindle, the nerves are larger and it/

it is to be expected that they will not disappear so early after nerve section as the more delicate nerve terminations in the equatorial region of the spindle. That this is so will be seen from the next figure.



Fig. 93.

(B. 189. S.7. Sc. 10).

(Slide 83.).

Six days section.

Proximal polar region of same spindle as on last figure. To the right side there undoubtedly is a nerve in the capsule. The outline is irregular. Under the oil immersion two nerve/

nerve fibrils can be seen alongside one of the muscle fibres.

That this nerve in the capsule is no artifact or deposit of silver is seen from the next figure which shows in the corresponding position the nerve fibre in cross section.



Fig. 94.

(B. 189. S. 7 Sc. 11.)

Slide 95)

Six days section.

The nerve in the capsule is here shown in cross section. The nerve fibre inside the axial core is more distinct.



Fig. 95.

(B. 189. S. 9. Sc. 7)

(Slide 84).

Six days section.

Cross section of spindle from near the equator. To the right side of the core are two medullated nerves in cross section, they are just recognisable as such and do not stain at all darkly. In the axial core there is, under the oil immersion, an indication of a nerve fibril here and there.



Fig. 96.

(B. 139. S. 9. Sc. 13.)

(Slide 84).

Six days section.

Equatorial region of spindle. Outside the capsule to the right, a single nerve fibre is seen, stained black, with irregular margins. Inside the spindle there are no nerve fibres, recognisable as such, but under the oil immersion lens there is seen at the right margin of the axial sheath a broken up medullated nerve.

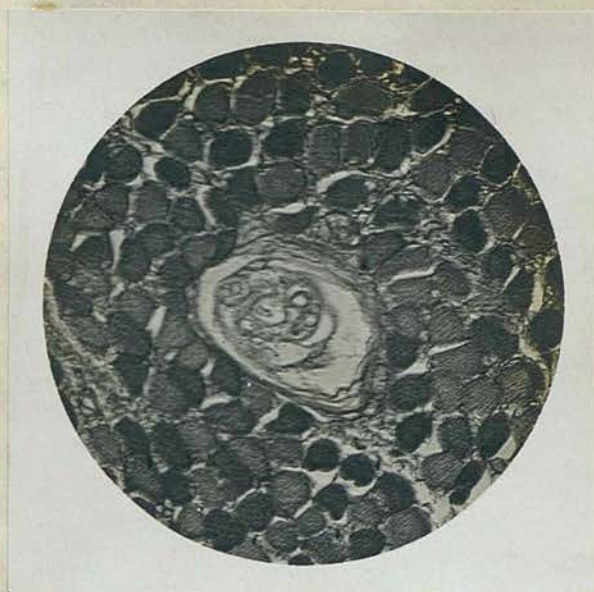


Fig. 97.

(B. 189. S. 15. Sc. 6.)

(Slide 86).

Six days section.

Same muscle spindle as above. There is absolutely no indication of any nerve terminals whatsoever, but at the right hand top corner are the empty nerve sheaths with the smallest possible black fragments inside.



Fig. 98.

(B. 205. S. 1. Sc. 6.)

(Slide 87).

Nine days section.

Muscle nerve in cross and longitudinal section.

In the transverse portion, note the swollen empty neurilemmal sheaths some of which contain minute shrunken black points, - the remains of the axis cylinders.

In the longitudinal portion the nuclei are numerous but there is no indication of properly staining axis cylinders.



Fig. 99.

(B. 205. S. 1. Sc. 3.)

(Slide 97).

Nine days section.

Transverse section of muscle spindle in close relation to the nerve trunk. Note the disposition. Magnified in next figure.

partial view of the right side of the spindle is a bundle of nerve fibers containing all recognizable nerve fibers. The motor fibers branch off from the nerve trunk and in every one of them are small black dots, two or three in each sheath, the whole representing the axons of the



Fig. 100.

(B. 205. S. 1. Sc. 8.) (Slide 87).

Nine days section.

Cross section of muscle spindle and nerve fibre. In the core of the spindle note the absence of any nerve terminations. In the periaxial space to the right side of the core is a bundle of nerve fibres containing six recognisable nerve fibres. The medullary sheaths are swollen and in every one of them are small black dots, two or three in each sheath, the whole representing the broken up axis/

axis cylinders. At the foot of the lymph space is a single nerve with a swollen medullary sheath, and the axis cylinder represented by numerous black dots. In the nerve trunk, the changes are well shown. Some of the nerve sheaths are swollen to three times the normal size and inside many of them is still an indication of an axis cylinder, but the axis cylinders present are swollen, and consist of numerous extremely minute black dots in a granular background, the whole representing the altered axis cylinder. In many fibres there is no indication of any axis cylinder whatsoever and no remains of them.



Fig. 101./

Fig. 101.

(B. 205. S. 2. Sc. 6.)

(Slide 88).

Nine days section.

Same spindle as in last figure, eight sections lower down. At left side of axial core there is a distinctly recognisable medullary nerve fibre: the medullary sheath is quite definite, if less distinct than in normal, the axis cylinder is very minute and irregular in outline.



Fig. 102.

(B. 205. S. 18. Sc. 3.)

(Slide 89).

Nine days section.

Persistence/

Persistence up to this date of recognisable axis cylinder, as a very distorted, swollen, irregularly outlined mass, - is shown by this photograph. There are no nerve terminals.



Fig. 103.

(B. 205. S. 20. Sc. 8) (Slide 90).

Nine days section.

Muscle spindle with no recognisable axis cylinder elements inside the capsule. To the left of the capsule is seen a medullated nerve fibre in longitudinal section. Below the spindle the nerve is seen passing in longitudinal section and here and there the swollen irregular axis cylinders are indicated.

The irregular disposition of the axis cylinder seen in/

in the above photograph explains how a cross section of a nerve fibre at this stage show in some fibres no indication of any axis cylinder, while other fibres show the axis cylinders as black swollen irregularly-shaped masses.

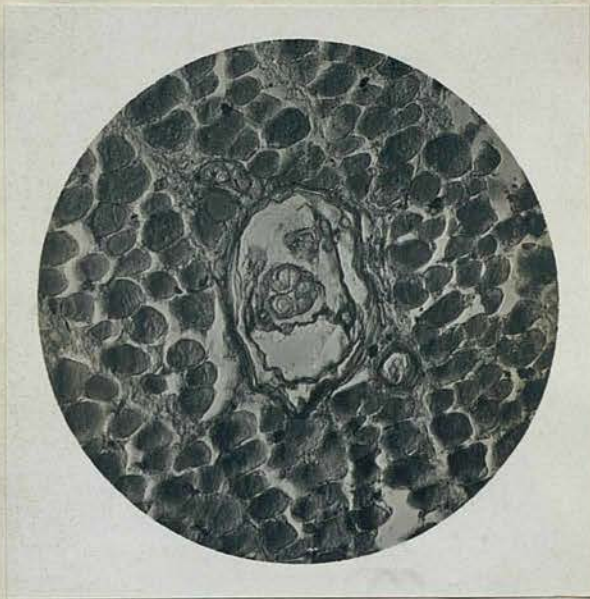


Fig. 104.

(B. 221. S. 1. Sc. 8) (Slide 91).

Eleven Days Section.

Transverse section of muscle spindle. Above the axial core of the spindle is a bundle of nerve fibres in cross section. The outlines of the nerve sheath of the individual nerve fibres are/

are still discernible and one or two of the fibres show very minute black dots - the remains of the axis cylinders.

At the left foot corner of the axial core nerve fibres with their axis cylinders, similarly represented to the above, are shown.

There are no recognisable ultimate nerve terminations in the spindle. The black line below the axial core is the darkly-stained axial sheath.



Fig. 105.

(B. 221. S. 4. Sc. 1) (Slide 92).

Eleven/

Eleven Days Section

Cross section of small intra-muscular nerve twigs with a side branch.

That the nerve elements in the intra-muscular twigs are becoming more and more disorganised and more and more difficult to recognise and interpret correctly will be seen from this last section. (Fig 105).

There is still, however, inside some of the single, much distorted neurilemmal sheaths the remains of axis cylinder elements in the shape of irregular black dots. It will be noticed that these remnants of axis cylinders do not lie in the middle of the space inside the neurilemma, but are always up against one side.

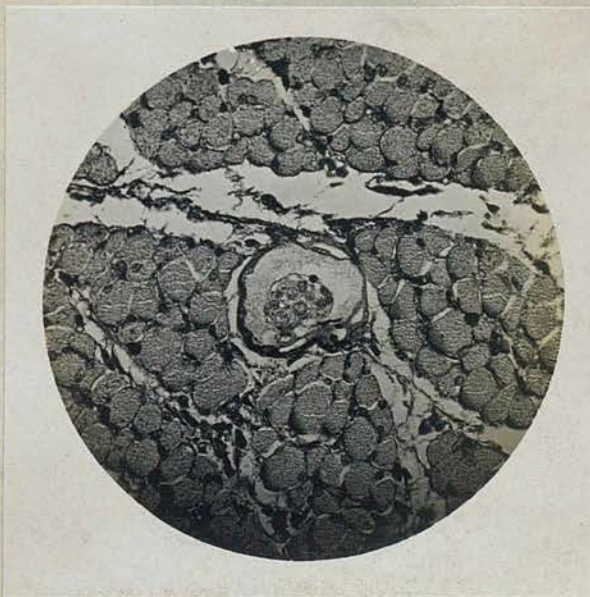


Fig. 106./

Fig. 106.

(B. 233. S. 11. Sc. 14). (Slide 93).

Thirteen days section.

In this muscle spindle there are no recognisable nerve elements.

The whole muscle tissue, stained in silver, has a peculiar appearance and the sections look like as if they had been toned with gold chloride giving them a steel-greyish colour. This is the only section of the series where there is possibly some element to be recognised in the variability of the silver method.



Fig. 107./

Fig. 107.

(B. 246. S. 2. Sc. 1) (Slide 94).

Fifteen days section

Low power view to show the general arrangement of a muscle spindle in the centre, above it and to the left a nerve in cross section and below the nerve is an artery with the inner coat stained black.

This section, here, shows the changes in the ordinary muscle fibres: note the shrinkage of the fibres and the general tendency for the fibres to become circular. The next two figures (108 and 109) are higher magnifications of the nerve and muscle spindle seen in Fig. 107.



Fig. 108/

Fig. 108.

(B. 246. S. 2 Sc. 1) (Slide 94).

Fifteen Days Section.

Cross section of the above nerve twig to show the disorganisation almost beyond recognition of the various nerve elements.

Inside one large neurilemmal sheath note, at one side, the remnants of an altered axis cylinder.

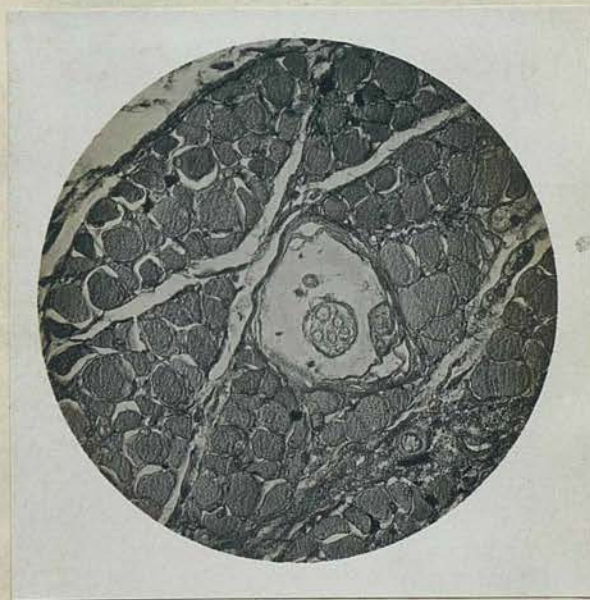


Fig. 109.

(B. 246. S. 2. Sc. 1). (Slide 94).

Fifteen Days Section

Transverse/

Transverse section of the muscle spindle seen in Fig 107.

In the capsule at the right side a distorted, swollen, nerve fibre can be seen. Against the left side of the axial core, what can be recognised, under a higher magnification, as the remains of medullated nerve fibres, showing no sign of any axis cylinder elements. There are no nerve fibres inside the limits of the axial sheath.

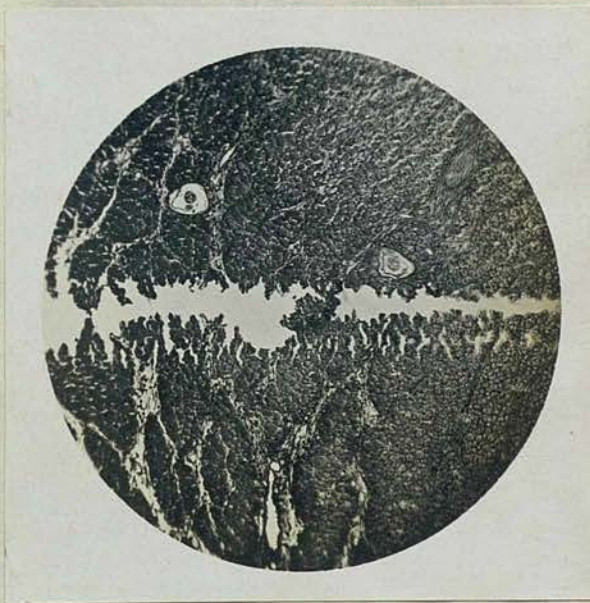


Fig. 110.

(B. 246. S. 3. Sc. 2) (Slide 96).

Fifteen Days Section.

Low power view of muscle to show how two muscle spindles stand out in the shrunken atrophied muscle.

In the section from which this last photograph was taken, six muscle spindles were present in cross section.



Fig. 111.

(B. 246. S. 9 Sc. 9) (Slide 96).

Fifteen Days Section.

In centre of a field is a transverse section of a muscle spindle and above it is a nerve trunk in longitudinal section.

In/

In this last photograph it is interesting to note, that fifteen days after section, there is, even in a comparatively large nerve twig, little if any evidence of axis cylinder processes inside the disorganised, distended, neurilemmal sheaths.

DEGENERATION OF MUSCLE SPINDLES WITH
OF THE SPINAL CORD

This section consists in an account of the
pathological findings in a case of a tubercular
neur. The primary growth was on the dorsal and after
this was removed the tumour, located at a large
growth at the right side of the neck of the body
and came to rest upon the transverse process.

PART IV.

CASE of DEGENERATION of MUSCLE SPINDLES.

The secondary tumour, then, was a small
containing mass at the base of the neck. It measured
three inches from side to side, three and a half in-
ches from before backward and five inches from above
downward. The following is a description of the tu-
mour mass taken after removal from the body. At the
upper end of the mass there is a depression
and beyond that there is a protrusion of the tumour
which presents upon growth and invades the spinal
cavity.

DEGENERATION OF MUSCLE SPINDLE FROM PRESSURE
ON NERVE BY SARCOMA.

This section consists in an account of the Pathological findings in a case of a Sarcomatous Tumour. The primary growth was in the uterus and after this was removed the sarcoma recurred as a large growth at the right side of the root of the neck., and came to press upon the Brachial Plexus.

I did not see the patient before death, and unfortunately there is no available clinical record. This detracts much from the value of the case, but as the case is interesting from the point of view of the muscle spindles I have included it in this Thesis.

The secondary tumour, then, was a large sarcomatous mass at the root of the neck. It measured three inches from side to side, three and a half inches from before backwards, and five inches from above downwards. The following is a photograph of the tumour mass taken after removal from the body. At the upper end of the main mass there is a constriction, and beyond that there is a prolongation of the tumour, which pressed upon, eroded and invaded the spinal column.

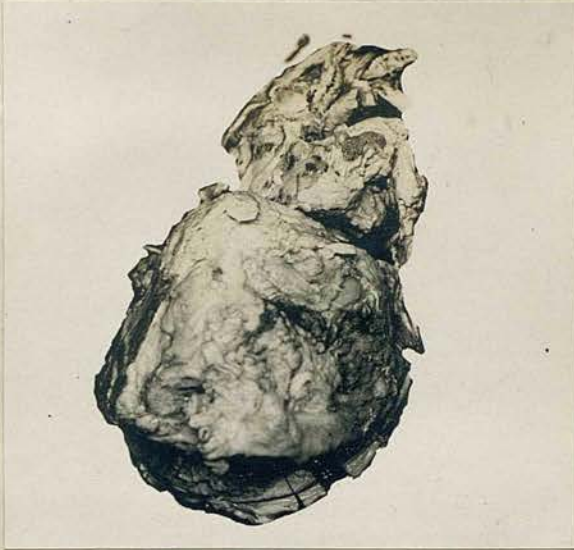


Fig. 112.

The prolongation, which invaded the spinal column, made its way actually into the spinal canal, and invaded the spinal cord.

That it was not a mere pressure upon, and adherency to, the spinal cord, but an actual ingrowth of sarcomatous cells into the structure of the cord, will be seen from the next photograph.

In addition, part of the posterior root fibres were ripped between two portions of the tumour. The root fibres did not stain well and were extremely fibrous.



Fig. 113.

(B. 261. S.1.). (Slide 49).

In this section, above and to the right is seen part of the lateral column of the cord in cross section. This is ^{seen} to be invaded by an ingrowth of the darkly-stained sarcoma cells, which worked their way into the cord along and in the vessels of the cord.

In addition, part of the posterior root fibres were nipped between two portions of the tumour: the root fibres did not stain well and were extremely fibrous.



Fig. 114.

(B. 261. S.2). (Slide 50).

Running across the centre of the field is part of the posterior root fibres, while above them and below them. the sarcomatous growth, which, from pressure, has led to their degeneration, come out well in the photograph.

It is always difficult to dogmatise about the condition of the cells of the posterior root ganglia, for in them pigmentation, slight chromatolysis, and even eccentric position of the nucleus, are not of so much importance as in most other nerve cells. I give a/

a section of the posterior root ganglion in this case, and in it the cells have undoubtedly undergone definite changes.



Fig. 115.

(B. 263. S.1). (Slide 48).

To show the appearance of the cells in the posterior root ganglia.

Up to this stage there is nothing in this case to justify its insertion in this Thesis, but the pressure of the tumour on the Brachial Plexus was so great that it practically corresponds to an injury to a peripheral nerve trunk.

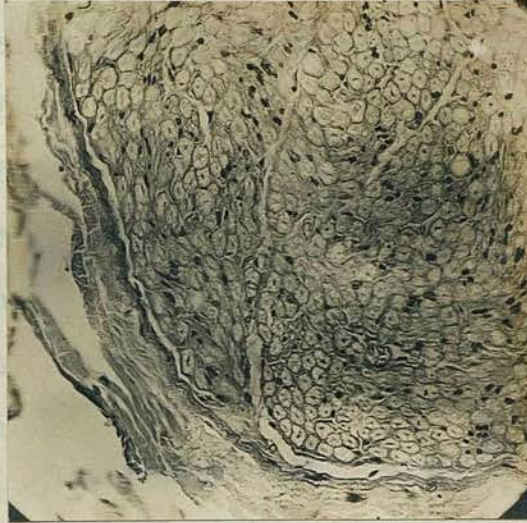


Fig. 116.

(B. 262. Sl.1). (Slide 47).

Cross section of the Median Nerve in the right forearm. Note the great thickening of the perineural sheath, and the increase in fibrous tissue inside the nerve trunk.- a definite interstitial neuritis.

The changes in the nerve trunk, and in the posterior root ganglion, led me to examine the muscles of the right forearm very carefully for the condition of the muscle spindles. Although the pressure of the tumour on the Brachial Plexus had been going on for a long/

long time, how long I have been unable to ascertain,-- I did not expect to find any changes in the muscle fibres inside the muscle spindles, for it has been shown that even five months after section of the sciatic nerve there is no obvious degeneration in the intrafusal muscle fibres of the muscle spindles supplied by the sciatic nerve. I was, however, fortunate enough to find a muscle spindle in the Flexor Longus Digitorum muscle, in which there was a definite degeneration of the intrafusal muscle fibres. The spindle has been accurately represented in the fourth drawing in volume II. (Illustrations). The axial core shows five intrafusal muscle fibres in cross section. The three smallest of these show nuclei in their interior as is often seen in perfectly normal muscle spindles. There is a large muscle fibre measuring 0.026 to 0.052 mm. in diameter, and it is the one which has undergone the degeneration. The greater part of the muscle substance has been replaced by a granular material. A similar degenerative change, not to such an advanced degree, is seen in the intrafusal muscle fibre to the left side of the axial core.

This kind of degeneration is exceedingly rare. The only case I have been able to find with any kind of definite alteration in the muscle of the muscle/

muscle spindles is in a case of Pseudo-hypertrophic Muscular Paralysis described by Grunbaum in 1897.

I have given a photograph of his muscle spindle; it forms Fig.H.35. in the section on the History of the Muscle Spindles. He found diminution in the size of the fibre with a deposit of hyaline material around. The degenerated muscle spindle from the above case is in B. 265. S.3 Sc.1. (Slide 51).

ROUTINE EXAMINATION.

When a fresh piece of muscle was obtained from a newly killed animal or from an operation on the human subject a certain routine was followed out, which when perfected gave a complete examination calculated not to miss the examination of any single structure of interest in the particular piece of muscle to be examined. It was only after some months of experimenting that this routine was found leaving little to be desired. None of the gold processes are included in the list for the silver methods more than make up for the omission of the gold processes. Altogether eight pieces were required for the full examination which revealed, especially stained, the following constituents of the muscle:-

- The muscle fibres.
- The muscle nuclei.
- The elastic fibres.
- The fat.
- The vessels.
- The nerve fibres.
- The nerve terminations.
- The nerve terminal organs.

When fresh muscle was obtained, then, there was placed:

1./

1. 3 Pieces in 10% Formal.
 - (a.) 1 Piece for embedding in Paraffin.
Nuclear plasma stain.
Elastic fibres stain.(Weigert's)
 - (b.) 1 Piece for freezing for Fat.
 - (c.) 1 Piece for Ford Robertson's process for Neurofibrils.
2. 1 Piece in Zenker's Fluid for the fine structures.
3. 1 Piece in Silver Nitrate for Cajal's newest method of staining the nerve termination in muscle.
4. 1 Piece in Nitric Acid for Bethe's Toluidin Blue process.
5. 1 Piece macerating in Sihler's Fluid for examining the gross arrangement of the nerve fibres as well as the muscle spindles and tendon spindles in profile view. Also for the vessels.
6. 1 Piece in Methylene Blue for Ehrlich's or Bethe's process of staining the nerve endings.

If/

If a piece of muscle were put through all these processes it was felt that the examination was complete and that there could be no structure of interest to the present investigation which was not specially stained in one or other of the methods.

When any degeneration or other pathological processes was detected by these methods naturally other more complicated methods were then employed to determine the exact nature of the change.

It may be advisable to give the various methods in detail.

1. Pieces in 10% Formol.

(a.) One Piece for embedding in paraffin.

1. Fix in Formalin . 10%
2. Dehydrate gradually in Alcohol. 40%, 50%, 60%, 70%, 80%, 90%, 98%. each 3 hours.
3. Absolute Alcohol. 12 to 24 hours.
4. Alcohol and Chloroform. 1 day.
5. Chloroform. 1 day.
6. Chloroform and Paraffin.
7. Embed in Paraffin.

Better results were obtained when the alcohol was increased in strength only very gradually as given above. Similarly when the muscle was being changed from the alcohol into the alcohol-chloroform mixture and then from that into chloroform alone, the change was a very gradual one the fluid being/

being added in a few drops at a time during a whole day. Thus at the beginning of a day the muscle might be lying in absolute alcohol, and the chloroform would be added drop by drop during the course of the day, and at night the desired mixture of alcohol and chloroform had been reached but there had been no sudden alteration of the nature of the fluid in which the muscle was lying. In the same way the paraffin was very gradually added to the chloroform in which the specimen lay.

All this trouble was taken because it has been shown that much finer pictures are obtained when the specimen is not changed too suddenly from one fluid into another. It is the sudden alteration of the nature of the fluid in which the specimen is lying that breaks up the finer details of the section.

The Paraffin Sections were used for staining:-

Nuclear Plasma.

Elastic Fibres.

NUCLEAR/

NUCLEAR PLASMA STAIN.

- (1.) Weigert's Iron Haematoxylin. Mix equal parts of solutions (1) and (2.) Mixture stains at once. Differentiation in acid alcohol is not necessary, but is sometimes advisable. Stain for 3 to 5 minutes.
- (2.) Wash in tap water several hours. Not absolutely necessary.
- (3.) Expose to Ammonia. (Drop or two of Liq. Amm. Fort. in bowlful of water.)
- (4.) Stain with Picrofuchsin.
- (5.) Dehydrate in Absolute Alcohol.
- (6.) Clear in Xylol.
- (7.) Mount in Balsam.

As the iron is contained in the staining solution no previous mordanting is necessary.

Solution (1.) Haematoxylin 1 gm.
Alcohol (96%) 100c.c.

Solution (2.) Liq. ferri sesquichl.
(sp. g.- 1.124) 4 c.c.
Hydrochl. acid conc. 1 c.c.
Water. 100 c.c.

I have found this stain specially useful for studying the finer details of the muscle nuclei and of the nerve endings and muscle spindles.

WEIGERT'S STAIN FOR ELASTIC FIBRES.

- (1.) Resorcin-fuchsin mixture. 20 to 30 minutes.
- (2.) Wash rapidly in acid alcohol.
- (3.) Differentiate in ordinary absolute alcohol.
5 to 10 minutes.
- (4.) Wash in water.
- (5.) Safranin 1/10% watery solution. 5 Minutes
- (6.) Wash in water.
- (7.) Blot section with filter paper and rapidly dehydrate with ordinary absolute Alcohol.
- (8.) Clear in Benzole and mount in Canada Balsam.

(B.) One piece for freezing for Fat.

For the demonstration of fat in muscle two stains were

used:- Osmic acid.
Scharlach R.

OSMIC ACID STAIN FOR FAT.

- (1.) Harden in Formalin.. 24 hours.
- (2.) Wash. Freeze and cut on the freezing microtome.
- (3.) Place the section in Flemming's or Marchi's Fluids or in a 1% watery solution of Osmic Acid for 24 hours; or in Marchi's Fluid for 2 to 3 hours at 30 degrees c.
- (4.)/

- (4.) Wash in running or frequently changed water.
4 to 6 hours.
- (5.) Transfer to 80% alcohol for several hours.
- (6.) Wash in water.
- (7.) Place the section flat on a slide; dry it with filter paper, add a drop of warmed and therefore fluid glycerine Gelatine (Grübler;) cover: the medium solidifies rapidly and ringing is unnecessary.

SCHARLACH R STAIN FOR FAT.

- (1.) Harden in Formalin. 24 hours.
- (2.) Prepare sections by freezing microtome.
- (3.) Transfer the sections to 70% Alcohol.
- (4.) Stain in acetone alcoholic solution of Scharlach R. (Fett Ponceau.) for 2 to 3 minutes.
- (5.) Wash in 50 to 70% Alcohol until the ground colour of the section is again more or less white.
- (6.) Transfer to Water.
- (7.) Stain in Ehrlich's or Delafield's Haematoxylin for a short time only and differentiate in acid Alcohol if necessary.
- (8.) Wash in water.
- (9.)/

- (9.) Wash in weak Ammonia.
- (10.) Wash in water.
- (11.) Arrange section on slide: dry with filter paper
- (12.) Mount in Glycerine Gelatine.

The best solution of Scharlach R. is in acetone and Alcohol:—

Alcohol 70%	50 c.c.
Pure Acetone.	50 c.c.

Saturate the mixture with the Scharlach R. Powder.

Filter before use and cover the staining vessel to prevent evaporation and formation of sediment.

(C.) One Piece for Ford Robertson's Method.

FORD ROBERTSON'S SILVER METHOD;
AFTER TONING WITH GOLD OR PLATINUM.

- (1.) Fix in Formalin 10%. Change on 2nd. day.
- (2.) Wash for 3 to 4 hours in tap water.
- (3.) Transfer to an Ammonio-nitrate of Silver solution prepared by adding to a 5% sol. of Silver Nitrate in distilled water, a 5% sol. of Ammonia in distilled water., drop by drop, until the precipitate which forms is nearly but not entirely dissolved, and then filter. The fluid should measure at least 50 times volume of/

of the tissues. Cork tightly and place in the dark. Place the muscle in this solution in the incubator at 37 degrees C. for a week. Then leave in the cold.

- (4.) Place a piece of impregnated tissue in a bowl of water (500 c.c.) to which about 3 c.c. of 5% Ammonia have been added. Renew the fluid after about an hour, and leave the tissue in it for about 3 to 4 hours longer.
- (5.) Transfer to Dextrine solution to which Ammonia has been added in proportion of 10 drops of a 5% sol. to one ounce, immediately before use. Allow to remain in this for from 12 to 24 hours.

Dextrine	140 grammes.
Water	280 grammes.

Dissolve by boiling: filter through cotton wool while still hot. After it has cooled add 1% Carbolic Acid.

- (6.) Cut on freezing microtome: transfer to a bowl of water to which 10 drops of 5% Ammonia have been added. After 5 minutes transfer to another similar bowl and do this a third time.
- (7.) Transfer sections to a bowl of water with 5 to 10 drops of a saturated solution of Citric Acid in water. Allow to remain for 4 to 5 minutes.
- (8.)/

- (8.) Place sections in bowl of tap water and after a few minutes transfer to a second bowl. Now ready for toning.
- (9.) To 10 c.c. of $\frac{1}{4}\%$ sol. of Gold Chloride in distilled water, add a single drop of a 1% sol. of Citric Acid in water, and filter fluid into a flat-bottomed white porcelain dish. Transfer from the water to this toning bath by a glass rod. Allow to remain spread out for from $\frac{1}{2}$ to 1 hour. This is enough to tone about one dozen ordinary slides.
- (10.) Place sections for $\frac{1}{2}$ minute in bowl of tap water, and transfer to bowl of water to which 10 drops of 5% sol. of Ammonia had been added. Allow to remain for 2 to 3 minutes.
- (11.) Transfer to bowl of tap water.
- (12.) Dehydrate sections with Absolute Alcohol, clear in equal parts of Turpentine and Benzole. Remove Turpentine with pure Benzole, mount in Benzole Balsam.

Platinum toning may be used instead of Gold toning.

This is one of the best methods available for the demonstration of neurofibrils, etc., and its author advises its application to other tissues. When applied to the muscle tissue I have found it to be somewhat/

somewhat precarious. It is much more tedious and elaborate than Cajal's methods and is moreover, not so certain and does not give anything like such fine results. Latterly I have quite discontinued its use, at any rate for the investigation of the nerve endings in muscle.

II. 1 Piece in Zenker's Fluid for fine structures.

An almost perfect fixation of tissue can be got by using Zenker's Solution (Mercuric fixation.) But to get the best results the muscular tissue must be taken from the animal in a living contracting state, and the fixing fluid should be heated up to 37 degrees C. and further the fixation should take place in an incubator at body heat.

When all these apparently trivial points are attended to really fine results can be obtained, and one can see that the spaces between the muscle fibres do not really exist although they are shown by the ordinary specimens prepared with the ordinary precautions.

PREPARATION OF SECTIONS AFTER

ZENKER FIXATION.

-
- (1.) Fix in Zenker's Solution at body heat. 24 hours
Zenker's/

Zenker's Solution:-

Mercuric Chloride	5.0 grms.
Sodium Sulphate.	1.0 grms.
Potassium Bichromate.	2.5 grms.
Water	100 c.c.
Glacial Acetic Acid	5 c.c.

Dissolve with heat: add Acetic Acid just before using.

- (2.) Wash in running water 24 hours.
- (3.) Place in graduated Spirit. 50% to 100% spirit with a few drops of Iodine in the Spirit.
- (4.) Place in Methylated Spirit with a few drops of Ammonia. 12 hours.
- (5.) Place in Methylated Spirit. 12 hours.
- (6.) Absolute Alcohol. 12 hours.
- (7.) Alcohol-chloroform, Chloroform, Chloroform-Paraffin: then Paraffin Treatment of Sections.
- (8.) Dissolve out Paraffin with Benzole or Xylol.
- (9.) Place in Spirit.
- (10.) Place in Gram's Iodine for three minutes or so till all the mercuric crystals have disappeared.
- (11.) Place in Methylated Spirit with Ammonia till Iodine colour is out of section.
- (12.) Place in Methylated Spirit.
- (13.) Stain and proceed as desired.

III. 1 Piece in Silver Bitrate for Cajal's method.

From 1900 to 1904 Ramony Cajal published various methods/

methods of nerve staining with Silver Nitrate. The first that he published was for staining the axis cylinders of nerve cells. Then later followed three new methods, the first for myelinated, the second for myelin-free fibres, and the third for the end structures of the nerve fibres. I have given all of these methods an extensive trial, and while they were all extremely satisfactory, they did not give quite such fine results as the last method which appeared.

CAJAL'S METHOD FOR MYELINATED FIBRES.

- (1.) Harden pieces of tissue not thicker than 5 mm. in 96%. 24 hours.
- (2.) Wash in distilled water.
- (3.) Place in 1% to 1½% Silver Nitrate Solution and keep at 30 to 35 degrees. C. for 3 to 5 days.
- (4.) Wash in Distilled Water.
- (5.) Reduce in the following Solution:-

Hydroquinone or Pyrogallol	1-2 grms.
Formol, 40%	5 c.c.
Sodium Sulphite	0.25-0.5 grm.
Distilled Water	100 c.c.
- (6.) Wash in Distilled Water, several seconds.
- (7.) Dehydrate sections in Alcohol; Phenol Xylol; Balsam.

Axis cylinders. red brown.

CAJAL'S METHOD FOR END STRUCTURES
OF NERVE FIBRES.

- (1.) Place small pieces for 24 to 48 hours in
- | | |
|-----------------|-------------|
| Formol | 25 c.c. |
| Ammonia | 100 c.c. |
| Distilled Water | 0.25-1 c.c. |
- (2.) Wash several hours in running water.
- (3.) Place in 1% to 3% Silver Nitrate Solution, and keep at 30 to 35 degrees C. for 3 days.
- (4.) Wash for some seconds in Distilled Water.
- (5.) Reduce in
- | | |
|-----------------|-------------|
| Formol | 5 c.c. |
| Pyrogallol | 2 gms. |
| Distilled Water | 0.25-1 c.c. |
- for 24 hours.
- (6.) Wash in Distilled Water, several seconds.
- (7.) Dehydrate; embed; cut, etc.,
- (8.) Dehydrate sections in Alcohol; Phenol Xylol; Balsam.

The Pericellular plexus and terminating bulbs or clubs of fibrillae, grey or black; nerve cells, yellow.

I was able to obtain many useful preparations with this method. The strength of the Ammonia seems to be a rather important factor in the variability of the results.

RAMON Y CAJAL'S LATEST METHOD.

- (1.) Place thin pieces of tissue, 3 to 4 mm. thick, in a large amount of 1½% to 6% sol. of Silver Nitrate for 4 days or more at 30 to 40 deg. C.
- (2.) Wash in Distilled Water till pieces are brownish yellow in colour. 1 to 2 minutes.
- (3.) Place in

Pyrogallie Acid	1 gm.
Formol (commercial)	5-10 c.c.
Distilled Water	100 c.c. for 24 hours.
- (4.) Wash in Distilled Water, 1 to 2 minutes.
- (5.) Harden in Alcohol, 90%, then 95% then absolute Alcohol.
- (6.) Embed in Collodium, Celloidin, or in Paraffin.
- (7.) Cut fine sections.
- (8.) Treat as usual, mounting in Canada Balsam or Dammar.

For general work with muscle 3% Silver Nitrate was found to be the most useful. The most excellent results were obtained by means of this method. There is certainly nothing to surpass it, in clearness of detail and fineness of outline. The method too is one of comparative simplicity once the necessary want of perfection of technique is got over. The one drawback is that it requires fresh tissue/

tissue to be fixed in Silver Nitrate solution direct without previous immersion in ALCOHOL.

This, of course, is no disadvantage in experimental work, but it is not always possible to have the Silver Nitrate solution at hand when good clinical material can be obtained.

The neurofibrils are dark brown on a yellow background, Nuclei well stained. After some time, in the course of the present investigation, it was discovered that the silver did not enter the tissue at any point at which the tissue was in contact with any object. Thus if the tissue were lying at the bottom of a dish, then the silver penetrated from all sides and from the top, but that no silver entered from the side of the piece of tissue in contact with the vessel. A special glass was therefore constructed to hold a large amount of Silver Nitrate solution, and through the cork a silver wire passed down, presenting a bend on its lower end. A piece of fine silk thread was then tied to a small shred of the tissue and the whole suspended from the bend on the silver wire. The muscle thus hung free in the silver solution and the latter was able to penetrate from all sides quite equally. For uniform results I believe this to be necessary.

IV. 1 piece in Nitric Acid For Bethe's Toluidin

Blue/

Blue process. This method was used in the present investigation but did not yield any useful results. It is quite a good method when applied to the central nervous system but when applied to muscle tissue the staining of the nerve terminations is entirely obscured by certain of the muscular elements taking on the stain.

BETHE'S TOLUIDIN BLUE PROCESS.

- (1.) a. Harden the piece of tissue in 3.5% to 5% sol. Nitric Acid, for 24 hours.
- b. Transfer directly to 95% Alcohol: remain for 12 to 24 hours.
- c. Place the tissue in-

Ammonia (sp. g. .95)	1 part.
Water	3 parts.
Alcohol 96%	8 parts. for 24 hrs.
- d. Place in Alcohol 96% for 12 hours.
- e. Place in:- Hydrochloric Acid 1 part.
Water 3 parts.
Alcohol 96% 10 parts. 12 to 24 hours.
- f. Alcohol 96% 12 to 24 hours.
- g. Water, 2 to 6 hours.
- h. Place in white Ammonium Molybdate 4% Sol. for 24 hours.
- i. Wash rapidly in Water.
- j./

- j. Alcohol 96% dehydrate rapidly in absolute Alcohol; embed in Paraffin: cut; affix section to slide with egg albumin mixture; remove Paraffin; Alcohol; distilled water; (rapidly.)
- (2.) Dry the slide on its under surface; cover the section with water, and place it in an oven at 60 deg. C. for 2 to 10 minutes.
- (3.) Remove the water; wash rapidly in water.
- (4.) Cover the slide and section with a watery Toluidin-blue solution (1 in 3000) and stain at 60 deg. C. for 10 minutes.
- (5.) Wash in Water.
- (6.) Differentiate in 96% Alcohol until clouds cease to be given off from the dye $\frac{3}{4}$ to 2 hours.
- (7.) Dehydrate in absolute Alcohol.
- (8.) Clear in Xylol; mount in Balsam.

V. 1 piece macerating in Sihler's Fluid.

This is a teasing process, the first teasing process to be referred to. Sihler himself got good results with his method but for a long time it did not get the credit it deserved as being one of the methods quite worth employing. Batten came to be very fond of it and with him it worked very well. I have been able to get very pretty pictures by means of its help/

help but I look upon it, not as a rival to a method like that of Cajal, but as an adjunctive. Cajal's method is the better for the fine terminal detail, but this method of Sihler is much the most useful for studying the gross arrangement of the nerves in muscles. It is essentially a preparation for the low power to the microscope and should never be used for anything else. This method of Sihler possesses the additional advantage in that it gives much the best representation of the blood vessels in the muscular tissue. Even the fine terminal capillaries are well shown up. It is a method which deserves to get more support than it has yet had, but its use entails a considerable amount of patience and perseverance.

SIHLER'S MACERATING METHOD.

(1.) Macerate tissue for 18 hours in

Ordinary Acetic Acid	1 part.
Glycerine	1 part.
Chloral Hydrate (1% sol.)	6 parts.

(2.) Transfer to Glycerine for from 1 to 2 hours.

(3.) Unravel somewhat with needles and place for from 3 to 10 days in the staining solution

Ehrlich's Haematoxyline	1 part.
Glycerine	1 part.
Chloral Hydrate (1% sol.)	6 parts.

(4.)//

- (4.) May be kept any desired time in Glycerine, which should be changed several times.
- (5.) Make preparations by dissociation with needles.

VI. 1 Piece in Methylene Blue for Ehrlich's

Method.

- (1.) Place fresh piece of tissue in .2% Methylene Blue in normal saline in an incubator at 37 degrees C. for one to three hours. Expose to air till blue.
- (2.) Place in a saturated watery solution of Ammonium Picrate; ten to fifteen minutes.
- (3.) Transfer directly to a solution of Ammonium Molybdate. Remain for four to twelve hours.

Ammonium Molybdate.	1 gm.
Osmic acid solution. ($\frac{1}{2}\%$)	10 c.c.
Water.	10 c.c.
Off. Hydrochloric acid.	1 drop.

- (4.) Thoroughly wash, dehydrate in cold absolute Alcohol, and imbed in Paraffin or Celloidin.
- (5.) Counterstain, if desirable, with Alum Carmine, pass through absolute Alcohol and Xylol, and mount in Canada Balsam.

Intravital Methylene Blue methods. I

used the intravital methods frequently for studying the fine terminations of the nerves in the muscle spindles.

The Methylene Blue may be injected into a vessel/

vessel of the animal while it is alive, or just immediately after death. Or the stain may be injected into the animal hypodermically, and the injection repeated at intervals until the animal dies. The subsequent treatment of the tissue is the same in either case.

- (1.) Inject the Methylene Blue into the animal as above.
- (2.) Expose to the air till blue.
- (3.) Fix in Ammonium Molybdate solution, which is prepared immediately before injection and which is cooled to zero. For six to twelve hours.

Ammonium Molybdate.	1 gm.
Distilled water.	10 c.c.
Hydrochloric acid.	1 drop.

- (4.) Wash in distilled water, and dehydrate in Alcohol.
- (5.) Embed in Paraffin and cut in serial section.
- (6.) Counterstain with Alum Carmine, and mount in Balsam.

For the study of the nerve endings in the muscle spindles, however, it is often better to make teased preparations, when the following procedure should be carried out.

- (1.) Inject the Methylene Blue into the animal.
- (2.)/

- (2.) Expose to air till blue.
- (3.) Fix in saturated aqueous solution of Ammonium Picrate. Requires about fifteen minutes.
- (4.) Clear in equal parts of Ammonium Picrate and Glycerine.
- (5.) Tease under the dissecting microscope, and mount in Picrate-glycerine jelly.

All the Methylene Blue methods are extremely useful but are, unfortunately, extremely precarious. No matter how carefully the methods are carried out, every now and then absolute failures occur, but when the stain works very beautiful pictures are obtained. It is only from the positive results that any conclusions can be drawn, and no stress can be laid on the fact that a certain nerve does not take on the stain. The fault may be, but is not necessarily, in the nerve, and quite frequently perfectly normal nerves fail to take on the stain at all. The fault is more frequently in the stain. I have not been able to give photographs of my Methylene Blue preparations, because being teased, they are difficult to photograph, and further the blue does not show up so clearly with the camera as does the black stain of the Silver methods.

For/

For examining the degeneration in the nerves of the rabbit experimentally sectioned I have found the following modification of the Marchi give very good results.

- (1.) Place nerve fresh in equal parts of 10% Formaline and Mullers Fluid. One day.
- (2.) Place in 2% Bichromate of Potassium for seven days.
- (3.) Place in a mixture of five parts of Muller's fluid with one part of 1% Osmic Acid for five to seven days. Nerve should be in a well stopped red bottle in a stove kept at 37 deg. C. and solution should be changed frequently. While in the Osmic Acid mixture the nerves should be kept in the dark.
- (4.) Dehydrate in absolute Alcohol, after washing in running water.
- (5.) Change to Alcohol and Ether, and embed in Celloidin.

38 Antl. Tibial muscles. 190.

41 Opponus Pollicis. 59.

42 " " " 190.

43 Muscle of wrist of thumb. 190.

44 Eye Muscles. Fetus. 190.

45 Eye Muscles. Fetus. 190.

46 Digital Muscles. 190.

SCOPE OF WORK.

Under the various figures illustrating the text the following letters are seen:-

e.g. (B. 189. S. 7. Sc. 6) (Slide 102)

B. indicates the block from which the section was cut.

S. indicates the number of the section in the series.

Sc. indicates the number of the section on the slide.

Slide indicates the number of the slide in the box of slides accompanying the Thesis.

—————

The following is a short account of the material used in the investigations.

I. M A N.

—————

<u>Block.</u>		<u>Number of Sections.</u>
32	Anti. Tibial muscles.	100.
41	Opponeus Pollicis.	82.
42	" "	150
43	Muscle of Ball of Thumb.	303
61	Eye Muscles. Foetus.	110.
62	Eye Muscles. Foetus.	192
109	Gluteal Muscles.	140

<u>Block.</u>		<u>Number of Sections.</u>
114	Biceps Flex. Cruris.	120
118	Gluteus Maximus	24.
119	Gluteus Maximus.	42
120	Muscle of Back.	23
137	Sartorius.	144
138	Sartorius.	136
160	Flexor Longus Digitorum.	60
161	Flexor Carpi Ulnaris.	62.
162	Flexor Longus Digitorum.	<u>182.</u>
	<u>TOTAL.</u>	<u>1870.</u>

II. R A B B I T.

<u>Block.</u>		<u>Number of Sections.</u>
63.	Metatarsi.	40
64	Metatarsi.	200
64	Metatarsi.	140
75.	Intrinsic Plantar Muscles.	262
76	Gastrocnemius.	126
77	Gastrocnemius.	185.
85	Biceps Flex. Cruris.	18.
189	Experimental. 5 days.	280
205	" 9 "	
219	" 11 "	
221./		

<u>Block.</u>			<u>Number of Sections.</u>
221	Experimental	11 days.	160
233	"	13 "	180
246	"	15 "	<u>200</u>
		<u>TOTAL.</u>	<u>2438</u>

III. M O U S E.

<u>Block.</u>			<u>Number of Sections.</u>
155	Gastrocnemius.		417
156	"		176
157	"		442
163	"		108
168	"		169
173	"		91.
186, 169, 170, 172,)			
175, 176, 178, 180,)	<u>Nerves.</u>		
181, 187, 188, 198,)	Experimental.		3049
200, 213, 217, 217,)			
218, 231, 241, 244,)			
245, 254, 257.)			
165, 166, 167, 174,)	<u>Muscles.</u>		
179, 182, 199, 214,)	Experimental.		<u>4840.</u>
243, 255.)			
		<u>TOTAL.</u>	<u>9383</u>

IV. F R O G.

<u>Block.</u>		<u>Number of Sections.</u>
1, 6, 7, 15,) 16, 18, 98,)	Gastrocnemius.	720
3, 4,	Sartorius.	23.
19, 23, 95,	Tibialis Anticus.	<u>667.</u>
	<u>TOTAL.</u>	<u>1410</u>

V. C A T.

<u>Block.</u>		<u>Number of Sections.</u>
56	Gastrocnemius.	24.
57	"	102
59	"	236
60	"	<u>112</u>
	<u>TOTAL.</u>	<u>474</u>

VI. G. U I N E A - P I G.

<u>Block.</u>		<u>Number of Sections.</u>
142		<u>130</u>
	<u>TOTAL.</u>	<u>130</u>

VII. ODD SLIDES.

Odd slides not in serial section. 1050.

S U M M A R Y.

I.	MAN.	1870
II.	RABBIT.	2438.
III.	MOUSE.	9383.
IV.	FROG.	1410
V.	CAT.	474.
VI.	GUINEA-PIG.	130.
VII.	ODD SLIDES.	<u>1050.</u>
	<u>TOTAL</u>	<u>16755.</u>

NUMBER OF SECTIONS PREPARED = 16,755.