THE DISTRIBUTION OF NERVES IN THE UPPER LIMB, WITH REFERENCE TO VARIABILITIES AND THEIR CLINICAL SIGNIFICANCE[1]

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1. INTRODUCTION.

This investigation was undertaken with the following objects:

(1) To assist the clinician, by means of measurements, as to the position of origin of important branches of the nerves of the arm and as to the limits within which he may expect to find variations of these branches;

(2) to give average positions for the entry of muscular nerves into their respective muscles, and also the variabilities to be expected;

(3) to determine the positions at which the larger sensory branches become cutaneous;

(4) to study, as far as dissecting-room subjects will permit, the communications taking place between cutaneous nerves;

(5) to point out any anatomical anomalies and variabilities found in the nerve supply of the upper limb which may be of significance in helping to elucidate various problems presented clinically by soldiers wounded during the war. Clinical investigation and the surgical treatment of the very numerous cases of peripheral nerve injury has shown that a more precise knowledge than is to be found in the standard anatomical textbooks was required about the above points.

For this reason 26 adult and eight foetal limbs have been examined. The method employed has been to take measurements accurate to ·5 cm. between convenient bony points of the limbs examined. The bony points used were the tip of the acromion process and the tip of the external condyle of the humerus for upper arm measurements, and the tip of the external condyle and the tip of the styloid process of the radius for measurements in the forearm, the limb being always adducted to the side with the forearm supinated. The level at which the branch of the nerve under examination arose from its parent trunk, entered a muscle, became cutaneous, etc., was marked off on a vertical scale stretching between the two bony points used. For example, if the distance in an upper arm was found to be 30·0 cms. between the tip of the acromion process and the tip of the external condyle of the humerus and the branch of the musculo-cutaneous to the biceps was found to enter this muscle at the

[1] This thesis was submitted for the degree of M.D. at Manchester in May 1920, and was awarded commendation.

level of 15·5 cms. along this scale, that measurement was noted under that limb as $\frac{15{\cdot}5}{30{\cdot}0}$. This fraction expressed as a decimal or ratio is ·52. From a series of such ratios obtained by the measurement of numerous limbs an average ratio can be obtained, as shown in column 3 of the Tables in section 11. This average ratio is a constant for all limbs. The average length of the upper arm is found to be 30·5 cms. and so the application of this figure to the constant, or average ratio, gives an average distance in centimetres for the entry of the nerve to the biceps in an upper arm of average length. In correcting the distance for any particular arm under examination, e.g. for one 33·5 cms. long, all that is required is an application of the constant to this figure, ·52 × 33·5. This, within slight limits of variability to be described later, will give a definite position at which the clinician may confidently expect to find the branch of the musculo-cutaneous nerve entering the biceps.

It is to be carefully noted that all measurements refer to horizontal *levels* and bear no relation to the actual length of the nerve unless, between two measurements, the nerve happens to pass vertically down the limb and in one vertical plane.

The dissections of foetal limbs have not been included in this series of measurements. The average ratio or constant was found to correspond with that of the adult series, but the great disparity of length between foetal and adult limbs so lowered the average length measurements as seriously to affect the average readings of the positions taken.

The foetal limbs have however been of value, particularly in studying the brachial plexus and the distribution of cutaneous nerves.

The application of this principle to about forty important definite points in the course of the nerves of the upper limb has resulted:

(1) in a series of average measurements from which the course of the various nerves can be accurately mapped out, and

(2) in a series of average ratios or constants (column 3, Tables, section 11) from which the clinician can obtain the above series of average measurements in any limb he is investigating provided he knows the length of that limb.

In the subsequent descriptions the brachial plexus will first be dealt with and then will follow an account of each of its branches of distribution to the limb with the exception of the lesser internal cutaneous, which did not seem to be of sufficient clinical importance to warrant its inclusion.

The gross anatomy of the parts will not be considered except where it is necessary in order to explain any points of interest or anomalous conditions which may require description. Anomalies will be described under the various nerves in the course of which they occur. Variabilities in position of branches of distribution will also be considered under their respective nerves and these variabilities will be given in their corrected form. To explain this the nerve supply to the biceps may be again taken as an example. Let us suppose that

the muscle-entry of this nerve is found to vary between 12·0 and 18·0 cms. in various arms. This may be termed *gross variability* and would be inaccurate as the upper arm giving the first measurement was found to be 28·0 cms. long, and that giving the second 34·0 cms. The ratios in these cases were therefore $\frac{12{\cdot}0}{28{\cdot}0}$ and $\frac{18{\cdot}0}{34{\cdot}0}$ or ·42 and ·53. This therefore reduces the variability to ·11, which, taking the average upper arm as 30·03 cms. in length, is 3·3 cms. The *corrected variability* of this branch would therefore be 3·3 cms.

The figures used in this example are not accurate, but they will serve to explain the principle of these measurements. The subject will be referred to again when the actual figures are considered.

2. BRACHIAL PLEXUS

The gross anatomy of the formation of the trunks and cords of the brachial plexus has been found to correspond so accurately with the description in the textbooks that it need not be mentioned here.

The branches of the brachial plexus are generally divided into a supraclavicular and an infraclavicular set. This is indefinite and inaccurate, and is consequently of little clinical value. To substantiate this statement the position of origin of the external and internal anterior thoracic nerves has been observed with some care. These branches are described as infraclavicular in origin. In the fully abducted position of the limb, when the outer end of the clavicle is considerably raised with reference to its level in the orthodox "anatomical position," the external anterior thoracic is found to arise distinctly above the clavicle and the internal anterior thoracic has at least a postclavicular if not a supraclavicular origin. In the anatomical position, therefore, with the arm adducted to the side, these branches must be even more supraclavicular in origin due to the dropping of the outer end of the clavicle. In view of this inaccuracy and of the lack of definition in using the clavicle as a line of subdivision on account of the considerable excursion of this bone with motion of the limb, it has seemed advisable to look for some definite line by which may be effected a subdivision which is not dependent on the vagaries of the moving clavicle (1).

In the fully abducted position of the limb, the trunks, cords and their terminal divisions, may be described as passing horizontally from the root of the neck into the limb. It is found that the point of junction of the three posterior divisions of the trunks to form the posterior cord is constant. If now a vertical line be drawn through the plexus cutting this point, a definite line of division of the plexus is obtained which is constant for all limbs, showing only very slight variations proportionate with the dimensions of the individual subject. A series of measurements of 21 limbs has established this line as being on an average 7·75 cms. from the lateral border of the lower cervical vertebral bodies (fig. 1). In the living, the pulsations of the common carotid artery will form a better landmark and 6·75 cms. horizontally outwards from the

lateral border of the common carotid at the root of the neck will give the same line of division. This line, where it cuts the plexus, is definitely distal to the clavicle.

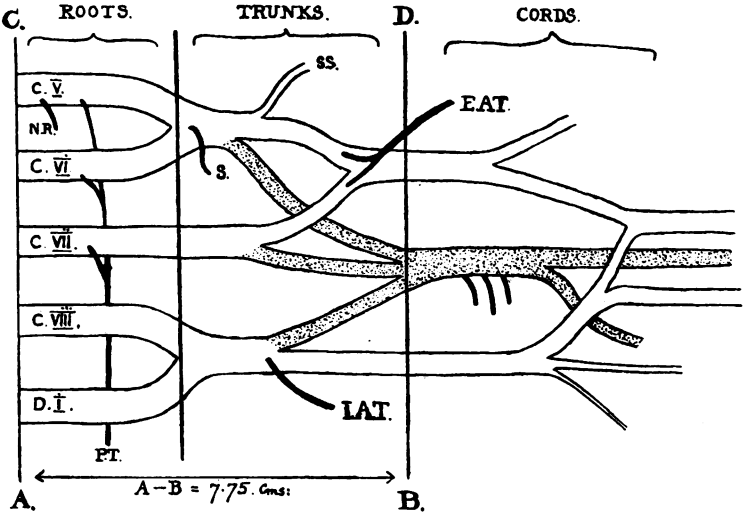

Fig. 1. Brachial plexus (left).

C.A. = line of lateral borders of bodies of lower cervical vertebrae.
D.B. = subdivisional line separating trunks from cords.
S.S. = suprascapular nerve.
S. = nerve to subclavius.
N.R = nerve to rhomboids.
P.T. = posterior thoracic nerve.
E.A.T. = external anterior thoracic nerve.
I.A.T. = internal anterior thoracic nerve.

The use of this line should simplify the nomenclature of the branches of the plexus, besides eliminating the clavicle from consideration in this respect. The branches would be classified as

(*a*) branches of the roots,
(*b*) branches of the trunks,
(*c*) branches of the cords.

The line would divide the trunks from the cords. The branches of the roots would remain as before, as would those of the cords. The trunk branches as at present described are two, the suprascapular and nerve to the subclavius, both from the upper trunk. To these would have to be added the two anterior thoracic nerves and such an addition appears to be justifiable. An examination of the origins of these nerves in 25 subjects (including foetuses) shows the following points.

Internal anterior thoracic nerve. This nerve arises from the plexus at a higher level than is compatible with its origin from the inner cord. Gray (2) recognises this high origin by describing it as a posterior relation of the first

part of the axillary artery, which portion of the vessel is always considered as an inferior relation of the three trunks of the plexus. The actual origin of the nerve is occasionally directly from the anterior aspect of the lower trunk. Generally, however, it arises from the anterior aspect of the trunk immediately distal to the origin of its posterior division which is going to assist in the formation of the posterior cord. It is customary to say that the lower trunk divides into an anterior and posterior division but the anterior division is not considered as a separate entity, in other words the inner cord is described as beginning immediately the posterior division of the lower trunk has arisen. It would seem better to give the anterior division of the lower trunk a definite length and to consider it as extending downwards to the dividing line described (*BD*, fig. 1), distal to which line it could justifiably be called the inner cord. The internal anterior thoracic nerve does therefore belong definitely to the trunk branches and should be considered as arising from the anterior division of the lower trunk.

External anterior thoracic nerve. This should also be considered as a branch of the brachial nerve trunks. Observations on the origin of this nerve have been taken in a series of 21 adult and four foetal limbs. The nerve has been found to arise either by two separate roots from the anterior divisions of the upper and middle trunks, or by a single root placed exactly at the angle where these two anterior divisions join to form the outer cord. In 60 per cent. the origin was by two roots from the anterior divisions of the trunks, and in the remainder the single root origin so obviously came from these two divisions, immediately after their union, that only technically could the nerve be considered as a branch of the outer cord.

When the anterior divisions of the upper and middle trunks join they are classically considered as forming the outer cord immediately. If, now, we consider this cord as being formed at the level of the dividing line, *BD* in fig. 1 as suggested, the external anterior thoracic will, in any case, be included as a trunk branch and will be rightly described as arising from the anterior divisions of the upper and middle trunks.

The anterior thoracic nerves should therefore be considered, from both anatomical and clinical points of view, as branches of the brachial nerve trunks, and not as branches of the outer and inner cords as usually described. The dividing line here suggested will place them both in this category.

Passing now to the segmental constitution of the cords, a variability has been observed which has not been sufficiently emphasised in English text-books, but which is of very considerable clinical significance.

The inner cord is generally described as drawing its fibres solely from the eighth cervical and first dorsal roots. In a very considerable proportion of cases the seventh cervical root also gives fibres to the inner cord in the following manner:

The outer head of the median contains fibres from the sixth and seventh cervical roots. This nerve bundle joins the inner head of the median to form the median trunk.

Frequently, however, a considerable bundle of fibres from the inner aspect of the outer head of the median becomes separated off immediately above the formation of the median trunk. This bundle, consisting of seventh cervical fibres, runs obliquely downwards and inwards behind the inner head of the median to enter the ulnar nerve. Hence the ulnar nerve frequently contains fibres from the seventh cervical root in addition to its eighth cervical and first dorsal fibres (fig. 2). The significance of this distribution of fibres will be discussed when dealing with the ulnar nerve.

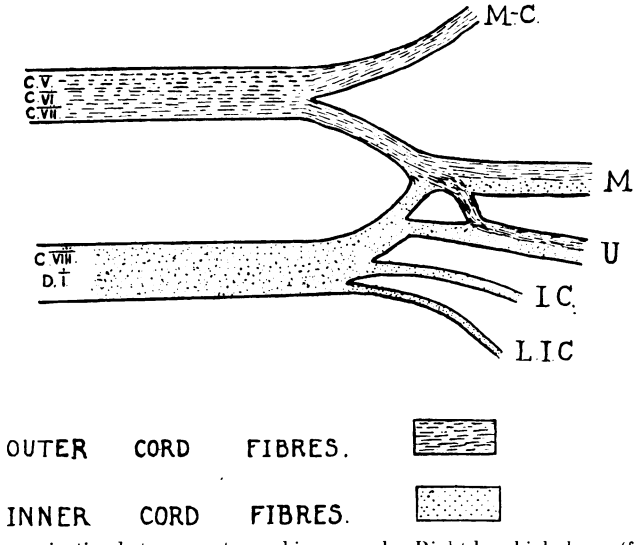

Fig. 2. Communication between outer and inner cords. Right brachial plexus (from behind).
M.C. = musculo-cutaneous nerve.
M. = median nerve.
U. = ulnar nerve.
I.C. = internal cutaneous nerve.
L.I.C. = lesser internal cutaneous nerve.

This interchange of fibres between the outer and inner cords has been looked for in 21 foetal and adult subjects and has been found to be present in 57 per cent.

Wilfred Harris (3) in his paper on the true form of the brachial plexus gives a positive result in 86 per cent. of the 30 subjects examined. He includes in this percentage a number of cases in which, by careful dissection of excised brachial plexuses removed at postmortems, he was able to trace a bundle of fibres down the outer head of the median, up its inner head and thence down again into the ulnar nerve.

Whatever the exact percentage may be, my estimate of 57 per cent., in which the condition was quite obvious without minute dissection, may be taken as a minimum. This variability is consequently well worthy of emphasis in textbooks, especially in view of its clinical significance in helping to explain variabilities in the cutaneous distribution of the ulnar nerve.

3. MUSCULO-CUTANEOUS NERVE

Origin. This nerve shows considerable variability in its origin from the outer cord.

In four out of the 26 cases the outer cord did not split into two divisions and the muscular branches of the musculo-cutaneous arose direct from the lateral aspect of the outer cord. The cutaneous division of the nerve was separated from the cord about the junction of the middle and lower thirds of the arm, from which point it proceeded downwards and outwards between the biceps and brachialis anticus to its normal distribution. This anomalous origin of muscular branches did not affect the average level at which the coraco-brachialis, biceps and brachialis anticus are normally supplied.

Another anomaly occasionally found in this region was a musculo-cutaneous trunk containing fibres destined to join the median. These fibres were given off in a bundle to join the median trunk at a variable distance down the upper arm. The size of this anomalous nerve bundle, which has been noted by several other workers, varies inversely with the size of the outer head of the median, and this bundle appears to consist merely of a variable number of "median" fibres which have descended for a short distance in the trunk of the musculo-cutaneous nerve.

Distribution. In describing the distribution of the nerves the numbers given will refer to horizontal levels down the average upper arm or average forearm.

The average upper arm is found to measure 30·5 cms. from the tip of the acromion process to the tip of the external condyle of the humerus. The average forearm, measured from the latter bony point to the tip of the styloid process of the radius, is 24·04 cms. long. These two numbers should, therefore, be borne in mind throughout the subsequent description of the individual nerves.

I. Muscular distribution

In such an average upper arm (30·5 cms.) the levels at which muscular branches arise from the musculo-cutaneous nerve trunk and enter their respective muscles will be shown by the following figures:

Nerve to coraco-brachialis	arises	4·76	cms.	(·156)
,, ,,	enters	7·35	,,	(·241)
Nerve to biceps	arises	12·99	,,	(·426)
,,	enters	15·28	,,	(·501)
Nerve to brachialis anticus	arises	17·32	,,	(·568)
,, ,,	enters	20·27	,,	(·665)

Nerve to coraco-brachialis. A slender bundle of fibres arising from the lateral aspect of the nerve trunk high up in the upper arm. After a course of about 2·5 cms. it ends by entering the medial aspect of the muscle just above the point at which the coraco-brachialis is pierced by the main musculo-cutaneous trunk.

Nerve to biceps. A stout branch arising from the nerve trunk as this is proceeding obliquely distally and laterally between biceps and brachialis anticus. After a short course distally and forward it divides into two branches, one entering the deep surface of each belly of the muscle at the same horizontal level. The above figures bring out two points. First, the nerve to the biceps is very short and secondly it enters the muscle immediately below the middle of the brachium $\left(\frac{15{\cdot}28}{30{\cdot}50}\right)$.

Nerve to brachialis anticus. This nerve arises from the inferior aspect of the main trunk while it is lying between biceps and brachialis anticus. Its extra-muscular course is longer than that of the nerve to the biceps and it ends by breaking up into four or five large branches which penetrate the anterior aspect of the muscle over a considerable area. From the measurements it will be observed that this branch arises only about 2 cms. below the middle of the upper arm and that it enters the muscle approximately at the junction of the middle and lower thirds of the brachium.

From these points it follows (i) that a lesion of the musculo-cutaneous trunk below 17·32 cms. of the upper arm will result in an anaesthesia of the musculo-cutaneous area uncomplicated by any muscular paralysis, and (ii) that however extensive any lesion of the upper arm may be, provided its upper limit is distal to 20·27 cms., the branch to the brachialis anticus will be uninjured and consequently a simple sensory lesion will again be the result in so far as the musculo-cutaneous nerve is concerned.

II. Cutaneous distribution

It will be noticed that the musculo-cutaneous gives off its last motor fibres higher up in the arm than is generally realised, 17·32 cms. This is of interest in view of the fact that a lesion of the musculo-cutaneous trunk a very short distance below the middle of the brachium will result in an uncomplicated sensory lesion. Stopford states that an uncomplicated sensory lesion of this nerve is five times as common as a mixed lesion.

Of the two cutaneous divisions of this nerve the anterior is the larger. The posterior division seldom reaches to the wrist, generally ending on the back of the lower part of the forearm. Occasionally this division ends by anastomosing with the lower external cutaneous branch of the musculo-spiral (fig. 4).

The anterior division can always be traced beyond the wrist and terminates by supplying a variable portion of skin over the thenar eminence. This division is in close relation with the radial nerve, which is becoming cutaneous in the lower part of the forearm by appearing behind the supinator longus tendon. In this region, therefore, there is frequently a communication between the musculo-cutaneous and radial nerves, which is a matter of clinical importance as probably explaining the slightness or absence of sensory disturbance in cases of section of the radial nerve above the lower third of the forearm (4). An

attempt has consequently been made to find how often this anastomosis occurs, but there have been obvious difficulties in studying limbs dissected by students who do not reverence cutaneous nerves. In only seven limbs was it possible to be certain whether or not this anastomosis occurred, and these seven gave five positive results. In the other two no trace of a communication could be found, although the dissection was carefully performed. Two of these anastomoses are shown in figs. 3 and 4. It will be seen from these figures

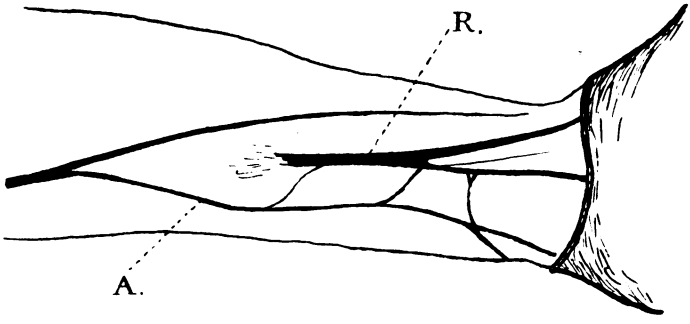

Fig. 3. Communication between musculo-cutaneous and radial nerves.
R = radial nerve.
A = anterior division of musculo-cutaneous nerve.

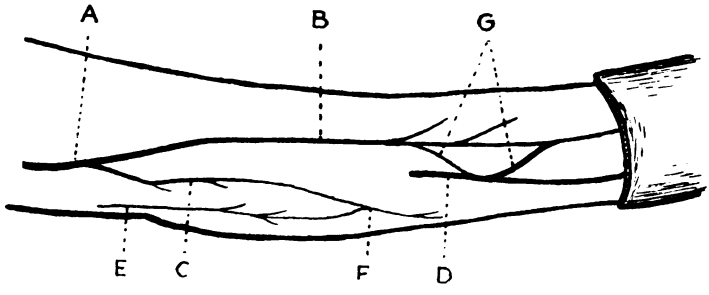

Fig. 4. Communications between musculo-cutaneous, musculo spiral and radial nerves.
A = musculo-cutaneous nerve trunk.
B = anterior division of musculo-cutaneous.
C = posterior division of musculo-cutaneous.
D = radial nerve.
E = lower ext. cut. branch of musculo-spiral.
F = communication between lower ext. cut. branch of musculo-spiral and post. div. of musculo-cutaneous.
G = communication between ant. div. of musculo-cutaneous and radial nerves.

that the size and complexity of the anastomosis vary greatly. In fig. 3 two large bundles of fibres are seen entering the radial nerve, whereas in fig. 4 the anastomosis consists only of two small filaments and the latter is the condition more frequently met with.

An attempt to find this communication in foetuses was unsuccessful, the filaments being too minute to trace with any accuracy in these small limbs.

The interchanged fibres become inextricably bound up with the radial nerve and are presumably distributed in the branches of the latter.

It is of some clinical importance to remember that this communication may not be present.

4. MEDIAN NERVE

The median trunk is normally formed to the lateral side of the proximal part of the brachial artery by the union of its outer and inner heads, the outer head being slightly the larger.

This origin is subject to some variation. The fibres composing the inner head are constant, but those forming the outer head may be partially, or completely, carried down in the musculo-cutaneous trunk to be given off from that trunk to the inner head, and thus form the median nerve, at variable distances down the upper arm. This low origin was found in three of my cases. In one of these the nerve was only formed at the junction of the fourth and lowest fifth of the upper arm. Occasionally only some of the fibres of the outer head join the inner head in the normal position, the remainder joining it, *via* the musculo-cutaneous trunk, at a lower level. On both sides of one body the median nerve passed deep to the brachial artery to get from its lateral to its medial side.

Distribution

Muscular. The multiple muscular branches of the median immediately distal to the elbow show such tremendous variability and come off so close together that estimations of their average levels must be only approximate. The nerve to the pronator radii teres can be distinguished as a separate branch but the supplies of flexor carpi radialis, palmaris longus and flexor sublimis digitorum have been classed as one nerve bundle. In the average forearm 24·04 cms. long the

Nerve to pronator radii teres arises 1·0–2·0 cms. approx.
" " enters 1·5–2·0 " approx.
Nerve bundle to the common flexor mass, upper limit of origin = 2·08 cms. (·086)
" " upper limit of entry = 2·76 " (·115)
" " lower limit of entry = 5·05 " (·210)
Anterior interosseous nerve arises 5·24 cms. (·218)

Nerve to pronator radii teres. This is the first branch of distribution of the median. Although its origin may be given as approximately 1·0–2·0 cms. below the tip of the external condyle this point varies greatly in both directions. As a general rule it arises below the external condyle, but it has been found coming from the trunk as much as 4 cms. above this bony point. Its direction is medially and slightly distally. As it approaches the muscle it commonly divides into an anterior and a posterior branch, the anterior entering the lateral aspect of the condylar head of the muscle and the posterior supplying the coronoid head at its origin from the ulna. The level of the entry to the muscle is approximately from 1·5–2·0 cms., therefore its direction is practically

horizontal, the posterior branch descending a little to gain the coronoid head. Occasionally the nerve to the coronoid head of the muscle arises by a separate branch just below that for the condylar head, and in one case such a branch entered the coronoid head as low as 6·0 cms. down the forearm. It is therefore anatomically possible to have paralysis of either of the heads of the muscle alone in lesions of the anterior or posterior branches when these arise from a common trunk. When these branches arise independently, section of the median between their points of origin will paralyse the coronoid head leaving the condylar head intact. It is doubtful whether this point is of clinical value as the coronoid head of pronator radii teres is generally very small and its reactions cannot be tested clinically apart from those of the condylar head.

Frequently the nerve supply to the condylar head arises by two distinct roots.

Bundle to the common flexor mass. A large bundle of fibres arising from the antero-medial aspect of the nerve trunk at about 2·0 cms. down the forearm. This bundle proceeds forwards and medially towards the muscles it supplies, expanding as it goes into a triangular sheet of fibres. The highest fibres are directed medially and a little distally to reach the flexor carpi radialis. The lower fibres descend more and more obliquely to reach the palmaris longus and flexor sublimis digitorum. The expanded base of this triangular sheet of fibres is formed where they enter the muscles, the upper limit of entry being 2·75 cms. and corresponding to their entry into flexor carpi radialis and the lower limit, or point of entry into palmaris longus and flexor sublimis digitorum being a little more than 5 cms. down the forearm. The base of this triangle has therefore a vertical length of nearly an inch. In accordance with this increasing obliquity of nerve fibres a lesion involving the supply to the flexor sublimis digitorum is more likely to injure the median trunk than is damage to the nerve to flexor carpi radialis.

The flexor sublimis digitorum does not, however, receive all its nerve fibres in this situation. In 11 cases out of this series of 24 I was able to find a branch of the median mentioned by Quain (5), which arises in the lower part of the forearm, while the nerve is lying between the superficial and deep flexor muscles, and which proceeds practically horizontally forwards with a slight inclination distally to end in the posterior aspect of the index or occasionally of the medius belly, of the flexor sublimis digitorum. The level at which this branch arises is not sufficiently constant to give anything of a reliable average measurement. Its height of origin in my cases varies between 9·0 cms. and 22·5 cms. down the forearm, but in the majority of cases it was below 12·0 cms. It entered the muscle belly, on an average, 1·0 cm. below its origin. The paralysis of this branch may help to explain weakness of flexion confined to the index finger in median injuries in the second quarter of the forearm.

Clinically this branch seems to have been very constant. Professor Stopford tells me that in all of nine patients in whom complete division of the median in the middle of the forearm was verified at operation, the belly of the flexor

sublimis digitorum to the index finger was paralysed. This nerve may, then, be the sole supply of the index belly of the muscle.

Anterior interosseous nerve. This is the next distinct branch of the median. It arises 5·24 cms. down the forearm and proceeds distally and dorsally to reach the interosseous membrane and lie between the flexor profundus digitorum and flexor longus pollicis. Just before it reaches the interosseous membrane it gives a branch from its medial side to the lateral portion of the flexor profundus digitorum and, at about the same level, one from its lateral side, which enters the upper extremity of the flexor longus pollicis. In the proximal part of its course on the interosseous membrane it supplies a few additional twigs to the upper ends of these muscles and then, greatly reduced in size, runs vertically downwards. At the junction of the third and lowest quarters of the forearm it disappears under the pronator quadratus, which muscle it supplies on its deep aspect.

This completes the muscular distribution of the median in the forearm, as the branch to the index belly of the flexor sublimis digitorum has been described in connection with that muscle.

Muscular distribution in hand

The median nerve is classically described as supplying abductor pollicis, opponens pollicis and the superficial head of flexor brevis pollicis. It has been found clinically, however, that the superficial head of flexor brevis pollicis may react well to faradic stimulation in cases of median paralysis, although the abductor and opponens pollicis do not respond. The difficulty, as Wood-Jones (6) points out, appears to be principally one of nomenclature, and the problem resolves itself into the answer to the question "What exactly is the superficial head of flexor brevis pollicis?" If the answer to this question is "That portion of flexor brevis pollicis which obtains insertion to the radial sesamoid and to the radial side of the base of the proximal phalanx of the thumb" an electrical response will be obtained from this "superficial head." Wood-Jones shows that this slip of muscle attached to the radial side of the first phalanx of the thumb is divisible into a superficial and deep portion. The superficial portion, which arises practically entirely from the anterior annular ligament, is supplied by the median nerve. The deeper portion gets its nerve supply from the ulnar and it is this portion of the "superficial head" of flexor brevis pollicis which reacts to stimulation when the median nerve is paralysed.

Cutaneous distribution

Palmar cutaneous. A minute twig arising a variable, and generally considerable, distance proximal to the wrist-joint. It runs down on the anterior surface of the main trunk to appear at the wrist-joint between palmaris longus and flexor carpi radialis. Then, running over the anterior annular ligament, it terminates by supplying a small area of skin over the middle of the proximal part of the palm.

Cutaneous supply to fingers. This supply varies inversely with variations in the palmar digital distribution of the ulnar nerve, and to save re-duplication of description the nerve supply of the fingers will be discussed when dealing with the ulnar nerve.

5. CIRCUMFLEX NERVE

This branch of the brachial plexus arises from the posterior cord as this is lying on the subscapularis muscle. The nerve runs distally to the lower border of this muscle when it turns backwards through the quadrilateral space. In this situation it is a somewhat intimate relation of the inferior aspect of the capsule of the shoulder-joint and it gives an articular branch upwards to penetrate this aspect of the capsule. Immediately behind the quadrilateral space it ends by dividing into an anterior and posterior division. The level of this division is 6·98 cms. down the arm.

The *anterior division* runs horizontally round the surgical neck of the humerus in contact with the deep aspect of the deltoid muscle. It is exhausted in supplying numerous short twigs of supply to this muscle and ends just short of its anterior border. The terminal twigs described as perforating the muscle to have a cutaneous distribution were not seen.

The *posterior division.* This division takes up a definitely lower level than the anterior one. It gives off, close to its origin, a short stout branch which proceeds upwards and medially to sink into the teres minor muscle. The remaining fibres then wind round the posterior border of the deltoid muscle and immediately pierce the deep fascia to become cutaneous. This division takes a horizontal course on the superficial surface of the deltoid similar to, but at a somewhat lower level than, that of the anterior division on its deep surface. By means of ascending and descending branches it supplies the skin over the distal half or more of the deltoid and cannot be traced further forwards than the anterior border of this muscle.

6. ULNAR NERVE

The ulnar is the lowest nerve-trunk split off from the medial aspect of the inner cord of the brachial plexus. It is constant in its level of origin in front of the teres major muscle, lying immediately medial to the termination of the axillary artery and separating this structure from its accompanying venae comites.

In describing the brachial plexus it has been observed that the ulnar nerve obtains fibres from the seventh cervical root, in at least 57 per cent. of cases, by means of a communication established between it and the outer head of the median nerve.

The course of the ulnar follows very constantly the accepted description in the textbooks. It leaves the brachial artery at the middle of the brachium by dipping backwards into the posterior muscular compartment. Here it runs distally in contact with the posterior aspect of the internal inter-muscular

septum to the interval between the olecranon and internal condyle of the humerus. Entering the forearm between the two heads of flexor carpi ulnaris it comes to lie on the flexor profundus digitorum, and this deep relation it maintains to the wrist-joint. Passing superficial to the anterior annular ligament the nerve ends at the lower border of this ligament under cover of palmaris brevis muscle by dividing into a superficial and a deep division.

The ulnar has no branches of distribution until it arrives in the region of the elbow-joint. In one case a communicating filament from the internal cutaneous nerve trunk was observed to join the ulnar about the middle of the arm. The first branch of distribution of the ulnar is an *articular branch* to the posterior aspect of the elbow-joint. This is a twig of considerable size, variable in its origin, but seldom coming off higher than 1 cm. proximal to the tip of the external condyle. In one anomalous case this nerve arose as high as the junction of the middle and lower thirds of the arm, and ran distally along with the main trunk for a length of about 12 cms. to reach its distribution to the elbow-joint. Generally, however, this nerve was extremely short and ran practically horizontally outwards to its distribution.

The next series of branches of the ulnar trunk are for the supply of the flexor carpi ulnaris and flexor profundus digitorum.

Nerves to flexor carpi ulnaris. There are, as a rule, two distinct nerves to this muscle, but frequently three and occasionally four separate branches may be seen.

I and II. The two primary and almost constant branches arise from the main trunk, one immediately below the other, and just before the ulnar trunk disappears between the two heads of flexor carpi ulnaris. The level of origin of these two branches was, in this series, ·90 cm. and 1·62 cms. distal to the tip of the external condyle. In two cases (which are not included in this average) the levels of origin of the highest muscular branch were 1·0 cm. and ·5 cm. respectively, proximal to the external condyle. It is exceptional, therefore, for any muscular branch to arise from the ulnar above the elbow-joint or, more accurately, above the tip of the external condyle.

These two primary branches run distally. The upper one is the shorter and ends 2·08 cms. down the forearm by piercing the inner aspect of the olecranon head. The lower branch enters the lateral aspect of the condylar head at 2·99 cms. down the forearm. Tabulated, the measurements of these two nerves are as follows:

Nerve to olecranon head arises ...	... ·90 cm.	(·037)
,, ,, enters ...	... 2·08 cms.	(·087)
Primary nerve to condylar head arises	1·62 ,,	(·067)
,, ,, enters	2·99 ,,	(·125)

III. The next branch, which is not constant but is frequently present, may be spoken of as the secondary nerve to the condylar head. The average measurements are:

Secondary nerve to condylar head arises	2·25 cms.	(·093)
,, ,, ,, enters	4·88 ,,	(·203)

This secondary nerve will be seen from these figures to arise a little more than ·5 cm. below the primary branch to this head of the muscle. It will also be observed to have a much longer extra-muscular course than either of the preceding branches. It arises from the medial aspect of the ulnar trunk, runs down with this trunk between the two heads of the muscle and then proceeds obliquely distally and medially on the deep surface of the condylar head to enter the anterior surface of this head at its medial border after an extra-muscular course of over an inch (2·63 cms.).

Poirier and Charpy(7) describe this branch as having an extremely long extra-muscular course and state that it enters the muscle in the lower third of the forearm. Nothing comparable with this length of course was found in any of this series.

IV. The fourth nerve to the flexor carpi ulnaris is a short, inconstant twig which arises from the ulnar after it has disappeared between the two heads of the muscle. It runs forward to enter the deep aspect of the muscle at approximately the same level of entry as the secondary branch to the condylar head.

It has seemed of value to describe this nerve supply fully as the books are vague on the subject, and it is one of clinical importance since injuries to the ulnar nerve in the region of the elbow have been encountered so frequently and displacement of the nerve trunk in front of the internal condyle of the humerus is now a fairly common surgical manœuvre, which permits end-to-end suture to be performed, even when a large defect is found. The freeing of the nerve trunk necessary to allow of this anterior displacement can generally be performed without sacrifice of any of the branches to the flexor carpi ulnaris. The articular branch to the elbow-joint has, however, to be cut as a rule.

To summarise: Four distinct branches may be found arising from the ulnar to supply the flexor carpi ulnaris. In their order of origin these are:

(i) Nerve to olecranon head.
(ii) Primary nerve to condylar head.
(iii) Secondary nerve to condylar head.
(iv) Branch entering muscle immediately below the junction of its two heads.

An analysis of 23 limbs showed the following:

2	cases had	4	branches	(i), (ii), (iii) and (iv).
3	,,	3	,,	(i), (ii) and (iii).
12	,,	2	,,	(i) and (ii).
6	,,	1	branch.	

(i) and (ii). 17 out of 23 subjects, therefore, had these two branches so that this seems to be the usual method of nerve supply to the muscle.

(iii). Five cases showed this additional branch to the condylar head. This branch, although only present in approximately 20 per cent., is of importance for two reasons. First, on account of the length of its extra-muscular course and secondly, because it may, exceptionally, be the only branch to the

condylar head of the muscle. In one case this nerve entered as low as 8·0 cms. down the forearm.

(iv). The fourth branch is obviously exceptional.

The six cases, in which only one branch was found, showed this branch entering at the junction of the two heads. Its filaments were not traced into the muscle.

The last point to notice in connection with this nerve supply is that the ulnar gives off the first three of these nerves between the average horizontal levels of ·9 cm. and 2·25 cms. down the forearm.

Nerve to flexor profundus digitorum. This branch arises high in the forearm, a short distance below the origin of the lowest nerve to the preceding muscle. The following are its average measurements:

Origin 3·07 cms. (·127),
Entry 5·54 cms. (·230).

The nerve arises from the ulnar trunk while this is lying on the upper fibres of flexor profundus digitorum deep to flexor carpi ulnaris. It is a stout bundle of fibres which runs down on the anterior surface of its muscle for nearly an inch before entering it.

The remaining branches of distribution of the ulnar nerve in the forearm are two, both of which are probably entirely sensory in function.

Dorsal cutaneous branch of ulnar. Two measurements have been taken to fix this branch:

(*a*) its position of origin, 17·06 cms. (·709);

(*b*) the level at which it becomes cutaneous by appearing at the mesial border of the flexor carpi ulnaris muscle, 20·95 cms. (·871).

The measurement of the level of origin shows very marked variation (see Tables, section 11). From its average level of 17·06 cms. the nerve runs distally and very obliquely inwards under flexor carpi ulnaris to gain its second fixation point at the medial border of this muscle. Here it becomes cutaneous at an average level of 20·95 cms. down the forearm and this measurement showed little variability. In the average forearm of 24·04 cms. length the dorsal branch of the ulnar may therefore be considered to become cutaneous a little over 3 cms. proximal to the tip of the styloid process of the radius, and this is therefore a measurement of importance for purposes of localisation in connection with injuries in the neighbourhood of the ulnar side of the wrist-joint.

This is a lower level than is usually given in textbooks. Fig. 5 shows this branch winding round the wrist below the styloid process of the ulna. This is anomalous and is therefore not included in these estimates.

The distribution of this nerve to the dorsum of the hand and fingers has been carefully worked out and will be considered later.

Palmar cutaneous branch. This, the last branch of the ulnar trunk, is a slender twig arising in the lower third of the forearm. It runs down on the

anterior aspect of its parent trunk superficial to the annular ligament to be distributed to the skin over the hypothenar eminence.

The ulnar nerve ends at the distal border of the anterior annular ligament under cover of the palmaris brevis muscle, by dividing into a superficial and a deep division.

The *deep division* dips down between abductor minimi digiti and flexor brevis minimi digiti to supply all the intrinsic muscles of the hand, except those which are innervated by the median and have already been considered.

The superficial division. This is a purely sensory nerve supplying branches to the skin of the ulnar half of the palm and then dividing into terminal

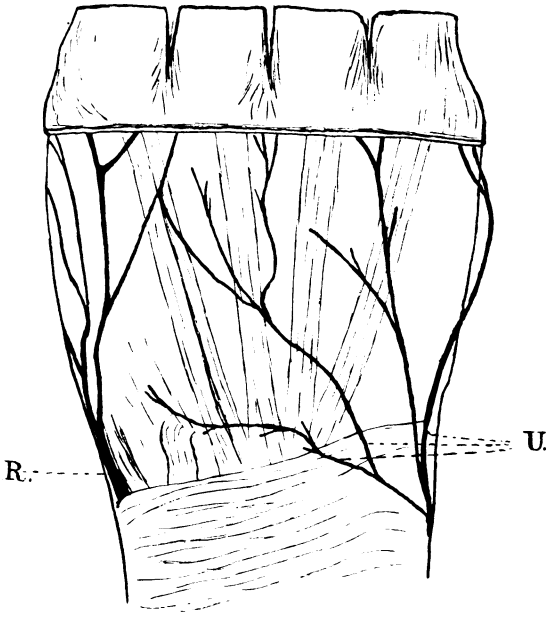

Fig. 5. Dorsal digital distribution of ulnar nerve (Rt).
U. = dorsal cutaneous branch of ulnar nerve.
R. = radial nerve.

branches for the palmar aspect of the ulnar digits. The exact distribution of this nerve will now be considered.

Digital cutaneous distribution of ulnar nerve. The ulnar nerve is usually described as supplying the fifth and the ulnar half of the fourth digit on their palmar and dorsal aspects. Anomalies found clinically have called in question the accuracy of this classical description.

Consequently I have attempted in a series of dissections to arrive at some conclusions as to the variabilities which may be expected to be met with in the cutaneous supply to the fingers.

The ulnar nerve has been taken as the basis in these dissections as, from a complete display of this nerve, it has been considered justifiable to deduce

the digital supply of the median to the palmar aspect and of the radial to the dorsal aspect of the remaining fingers.

In order to supplement observations on dissecting-room subjects a careful dissection of eight foetal ulnar nerves has been performed.

In all, 36 observations have been made—20 on the palmar digital and 16 on the dorsal digital distribution of the nerve.

Palmar digital distribution of ulnar nerve. In the 20 cases of this series, 16 showed the classical supply to the little finger and the ulnar side of the ring finger. Of the remaining four, one supplied the whole of the two ulnar digits and the remaining three had an additional distribution to the ulnar side of the middle finger.

Dorsal digital distribution of ulnar nerve. Of 16 cases, only two showed the classically described distribution to the little finger and the inner half of the ring finger. In eleven cases the distribution was to the little, ring and the ulnar half of the middle fingers. Of the remaining three, one supplied the fingers as far laterally as the ulnar side of the index and two supplied both sides of the two ulnar fingers.

Counting from the ulnar margin of the hand these results may be put in a concise form as follows:

Palmar Digital Distribution

$1\frac{1}{2}$	fingers in	16 cases	= 80 %
$2\frac{1}{2}$	,,	3 ,,	= 15 %
2	,,	1 case	= 5 %
		20	100 %

Dorsal Digital Distribution

$1\frac{1}{2}$	fingers in	2 cases	= 12·5 %
2	,,	2 ,,	= 12·5 %
$2\frac{1}{2}$	,,	11 ,,	= 68·75 %
$3\frac{1}{2}$	,,	1 case	= 6·25 %
		16	100 %

These figures show, therefore, that, while the palmar digital distribution corresponds with the description in the textbooks, the branches of the dorsal cutaneous branch of the ulnar very frequently supply the whole of the inner two fingers and the ulnar side of the middle finger (fig. 5). Stopford from clinical data comes to the conclusion that "the radial nerve only rarely appears to supply the extensive area of skin usually described, as in about 70 per cent. it does not extend medially beyond the second metacarpal bone (4)."

The dorsal digital branches of the ulnar nerve cannot be traced distally beyond the head of the first phalanx.

In connection with this distribution of the dorsal cutaneous branch of the ulnar it is of interest to remember, as again suggested by Stopford, that the middle is the axial finger of the limb. The seventh cervical is the axial nerve root of the limb. In discussing the brachial plexus the ulnar nerve was found

to obtain fibres from the seventh cervical root by a communication from the outer head of the median in at least 57 per cent. of cases. The dorsal branch of the ulnar supplies the middle finger in 75 per cent. (68·75 per cent. + 6·25 per cent.) of cases. The seventh cervical fibres may be then distributed as a whole, or in part, in this nerve to supply the middle or axial finger.

7. INTERNAL CUTANEOUS NERVE

With the exception of the lesser internal cutaneous this is the highest branch given off from the inner cord of the brachial plexus. It may be considered as arising immediately distal to the lower border of pectoralis minor. It takes up a position on the anterior aspect of the third part of the axillary and the proximal part of the brachial arteries. As a general rule the nerve divides into anterior and posterior divisions in the upper third of the arm.

These divisions run down and pierce the deep fascia close together about the middle of the antero-medial aspect of the arm. Immediately after piercing the fascia the anterior division supplies a constant branch which runs transversely outwards and divides into ascending and descending twigs to supply the skin over the biceps, the descending twigs being traceable as far as the elbow-joint. In two of my cases the internal cutaneous did not divide until it reached the lower third of the arm and, in these, the supply to the skin over the biceps came from the main trunk.

In one case there was a considerable communication between the anterior division and the ulnar in the lower third of the arm.

The anterior division is somewhat larger than the posterior. At the elbow-joint it is an anterior relation to the bicipital fascia and thus to the termination of the brachial artery. It is distributed as low as the lower third of the forearm.

The posterior division diverges from the anterior in the superficial fascia to gain the internal condyle in front of, or occasionally behind, which it proceeds to gain the lateral and posterior aspect of the forearm. It is the smaller of the divisions and can seldom be traced below the middle of the forearm.

The communication described (2) between the internal cutaneous and ulnar nerves at the wrist-joint was never found in this series of cases, and neither of the divisions appeared to get far enough down the forearm to make such an exchange of fibres possible.

As has just been noted a communication may occur between these two nerves in the upper arm and this may be of clinical value.

8. MUSCULO-SPIRAL NERVE

This is the largest of the terminal branches of the brachial plexus. It is best considered as a continuation into the arm of the posterior cord of the plexus. The lowest branch of the posterior cord, the circumflex, arises as the cord is lying upon the subscapularis, and the musculo-spiral may therefore

be said to start immediately below this point. From this point of origin, which was found to be very constant, the nerve proceeds vertically downwards in front of the lower fibres of subscapularis, the latissimus dorsi and teres major muscles to leave the axilla and enter the arm, where it is first placed in front of long head of triceps. It now inclines posteriorly and laterally between the long and inner heads of triceps to gain the musculo-spiral groove. Here it lies directly in contact with the bone and is covered by the outer head of the triceps and a fibrous arch thrown over the groove from the deep aponeurosis of this head. The musculo-spiral groove conducts the nerve obliquely distally and laterally to the external inter-muscular septum, which it pierces at the junction of the middle and lower thirds of the arm to appear between the supinator longus and brachialis anticus muscles. A vertical course thence, deeply between the supinator longus and extensor carpi radialis longior on its outer and the brachialis anticus on its inner side, carries it to its termination, which shows very considerable variation. In 23 measurements the variability of termination of this nerve was from 4·5 cms. above to 4·0 cms. below the tip of the external condyle. In nine cases it was above this point and in eleven below it. In the remaining three the nerve split into its two terminal divisions immediately in front of the tip of the external condyle.

This bony landmark therefore gives a good average position of termination of this nerve(2), but it should be remembered that it has a variability of approximately 4 cms. above and below this point.

Distribution

Muscular. Up to the point where the musculo-spiral pierces the external inter-muscular septum, i.e. in the upper two-thirds of the arm, the muscular branches of distribution are those to the triceps and anconeous muscles.

Nerve supply of triceps (fig. 6). The triceps is supplied by four distinct bundles of nerve fibres from the musculo-spiral and their average positions will be seen from the following table:

I.	Nerve to long head arises	7·11 cms.	(·233)
	,, ,, enters	11·30 ,,	(·370)
II.	Ulnar collateral arises	9·53 ,,	(·312)
	,, ,, enters	18·17 ,,	(·595)
III.	Nerve to outer head arises	10·13 ,,	(·332)
	,, ,, enters	14·62 ,,	(·479)
IV.	Nerve to inner head arises	11·21 ,,	(·368)
	,, ,, enters	18·26 ,,	(·599)

There is one general point about the branches of the musculo-spiral which will be most conveniently referred to here. The nerve bundles are arranged and receive their individual sheaths of perineurium a considerable distance above the point where they are given off as branches. These branches are bound to the main trunk merely by the epineurium and are consequently easily split up from the nerve to some distance above their normal point of origin. This discretion of nerve bundles in the main trunk was observed to some extent

in all the nerves but it is so marked in the case of the musculo-spiral as to deserve special mention. The dissection was carried out to avoid this splitting up as far as possible, as the object of these measurements is to show where the nerve actually leaves the main trunk, but its recognition is of practical importance particularly

(1) in the operation of fascicular suture,

(2) in explaining certain dissociated paralyses.

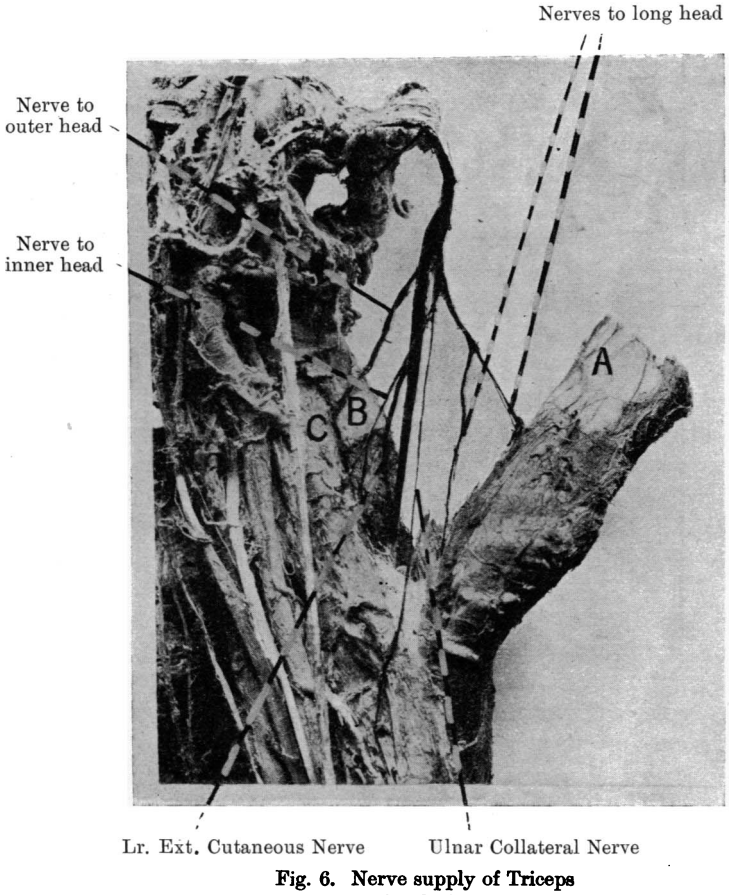

Fig. 6. Nerve supply of Triceps
A = long head of Triceps.
B = outer head of Triceps.
C = inner head of Triceps.

Nerve to the long head of triceps. This bundle of fibres is the first branch of the musculo-spiral. It arises while the main trunk is still in contact with the posterior axillary wall at 7·11 cms. After a course of over 4 cms. distally and medially it ends by piercing the anterior surface and lateral border of the long head of the muscle at 11·3 cms. A point to emphasise is the height of its origin. The internal cutaneous branch of the musculo-spiral generally arises in common with this muscular bundle. The bundle splits into numerous branches some

distance before it gains the muscle and these terminal branches enter the long head over a considerable area, the highest at least a centimetre above the lowest. The figure of entry, 11·3 cms., is a mean measurement.

Ulnar collateral nerve. This branch arises at 9·53 cms., which corresponds approximately to the lower border of teres major. It is the inner and smaller nerve to the inner head of the triceps. It has a long extra-muscular course distally and slightly medially, first resting on the ulnar nerve and then on the internal inter-muscular septum which it pierces about 18·0 cms. down the arm to sink immediately into the inner head of triceps. It has the longest extra-muscular course of any of the branches to the triceps. This nerve is therefore sometimes injured in lesions of the ulnar nerve, but it has not been found clinically to be of importance as a nerve supply of this head of triceps (Stopford).

Nerve to the outer head of triceps. A bundle of fibres arising about half a centimetre below the ulnar collateral and the last of the branches coming off definitely on the medial side of the arm. Its general direction is laterally with an inclination distally. As it approaches the muscle it divides into numerous subdivisions which enter the medial aspect of the outer head of the muscle over an area with a vertical depth of half to one centimetre. The mean level of its entry is 14·62 cms.

Frequently this nerve arises by a large common trunk, which includes the nerve to the inner head of triceps and the lower external cutaneous branch of the musculo-spiral.

Nerve to the inner head of triceps. This is a branch of considerable size arising just as the main trunk is entering the musculo-spiral groove at an average level of 11·21 cms. It proceeds distally and very slightly laterally and, after an extra-muscular course of 7·0 cms., it enters the fibres of the inner head of the triceps. The terminal filaments of this nerve run through the triceps to supply the greater part of the anconeous muscle. This nerve is definitely larger than the ulnar collateral so that, although a few of its fibres end in the anconeous, it is probably the more important nerve of supply to the inner head of triceps. This observation seems to get confirmation from clinical evidence of lesions of the ulnar collateral nerve.

As previously mentioned this bundle of fibres sometimes arises by a common trunk with the fibres destined for the outer head of the muscle and, more frequently, with those which eventually go to form the lower external cutaneous branch.

In connection with the nerve supply of the triceps there are certain points of special significance. The musculo-spiral is most vulnerable while it lies in the musculo-spiral groove. The musculo-spiral groove corresponds in vertical length with the middle third of the upper arm. All the nerves to the triceps except the nerve to the inner head arise in the upper third of the arm, i.e. above the musculo-spiral groove. The nerve to the inner head arises just at the upper limit of the groove. No other muscular branches arise while the main trunk is in the groove. Consequently (i) an uncomplicated lesion of the trunk in the

musculo-spiral groove is very unlikely to affect the nerve supply of the triceps, and (ii) when the surgeon is operating on the musculo-spiral in the groove there are no important muscular branches for him to look for and establish the integrity of. The only important branch which generally arises definitely in the groove is the lower external cutaneous. A piece of clinical evidence confirming these anatomical facts is found in the statement that in 25 cases of injury to the musculo-spiral in the middle third of the brachium, in which complete division of the main musculo-spiral trunk was proved at operation, there was no paralysis of any head of triceps (Stopford).

The remaining muscular branches arise well within the lower third of the upper arm after the trunk has pierced the external inter-muscular septum. They are distributed to brachialis anticus, supinator longus and extensor carpi radialis longior in that order proximo-distally.

Nerve to the brachialis anticus. This branch is by no means constant. When present it arises about 24·0 cms. down the upper arm. It has a very short course running transversely inwards, sometimes with an inclination upwards, to enter the superficial aspect and lateral border of the muscle. Electrical stimulation of this branch on the operating table has shown no effect on the muscle, from which it is considered probable that this nerve is an afferent nerve-path (H. Platt).

Nerve to the supinator longus.

Arises 25·23 cms. (·827).
Enters 28·26 ,, (·927).

This branch arises from the anterior aspect of the musculo-spiral and, after proceeding vertical downwards for about 3 cms., terminates in the inner surface of its muscle. This branch is frequently duplicated. In two of my cases it entered the muscle as low as the tip of the external condyle (30·5).

Nerve to the extensor carpi radialis longior. This nerve was extremely constant in its origin at an average of 26·79 cms. down the arm, roughly 1½ cms. below the origin of the nerve to supinator longus. It proceeds distally and slightly laterally, somewhat deep to the preceding nerve, to enter the medial border of its muscle. As an average level of entry into its muscle a point should be taken immediately above the tip of the external condyle. In 22 measurements the nerve entered the muscle, in the upper arm in 11, in the forearm in seven and directly opposite the tip of the external condyle in four cases. The highest level of entry noted was 2 cms. above, and the lowest, 2·5 cms. below the condyle. These figures exclude an anomalous case in which the nerve arose from the posterior interosseous trunk and entered the muscle as low as 5·5 cms. below the external condyle.

Cutaneous. Three cutaneous nerves are generally described as arising from the musculo-spiral trunk:

(i) Internal cutaneous.
(ii) Upper external cutaneous.
(iii) Lower external cutaneous.

Internal cutaneous. This branch arises in the axilla, generally from one of the muscular branches to the long head of triceps (7·11 cms.). After effecting communications with the intercosto-humeral nerve and the lesser internal cutaneous it winds round the medial border of the long head of triceps to gain the back of the brachium. It runs vertically downwards in the superficial fascia of the posterior aspect of the arm and its terminal filaments can generally be traced as far as the olecranon.

Upper external cutaneous. This nerve though described in the textbooks was very seldom found, and it was not considered of sufficient importance to warrant any records being taken of it.

Lower external cutaneous. Arises 13·95 cms. (·457). (Fig. 6.)

A large nerve trunk, of interest as being the only branch of importance arising from the musculo-spiral trunk in the musculo-spiral groove. Its point of origin is so extremely variable (7·11 cms.–28·87 cms.) that the average is of little value. This variability is largely due to the fact that this nerve is the branch of the musculo-spiral most easily "split up" from the main trunk. Probably the nerve fibres are arranged in their own sheath of perineurium in the axilla in all cases. This bundle has frequently been observed to arise in common with the nerve to the outer or inner heads of triceps or even in common with both these branches.

From its origin it proceeds down the musculo-spiral groove in company with the main trunk, and at the lower end of the groove it turns outwards to pierce the deep fascia immediately behind the external inter-muscular septum. Exceptionally it becomes cutaneous by piercing the lower and outer fibres of the triceps. After piercing the deep fascia it runs obliquely distally and medially to gain the middle of the posterior aspect of the forearm. It then runs vertically down the forearm and can be traced as far as the posterior aspect of the wrist-joint. The position of the nerve on the posterior aspect of the forearm varies between the radial border and the axial line. The nearer it runs to the radial border of the forearm the more likely it is to communicate with the posterior division of the musculo-cutaneous (see fig. 4).

9. RADIAL NERVE

This is the smaller of the two terminal divisions of the musculo-spiral and arises, therefore, where this nerve terminates on the anterior aspect of the outer side of the elbow on an average horizontal level with the tip of the external condyle. It runs down the forearm along a line continuous with that of the terminal portion of the musculo-spiral trunk. Just below its origin it is in intimate relation with the front of the elbow-joint and the head of the radius. From its origin it lies under the supinator longus muscle, which relation it maintains to a point ·5 cm. above the junction of middle and lower thirds of the forearm. There, on account of the slight lateral obliquity of its course, it appears behind the posterior border of the supinator longus tendon and

almost immediately afterwards pierces the deep fascia. It then proceeds vertically downwards in the superficial fascia to its cutaneous termination in the hand and fingers. This cutaneous distribution has been considered in the description of the sensory supply of hand and fingers when the ulnar nerve was dealt with.

Some interesting anomalies were found in connection with this nerve:

(*a*) On both sides of one body the radial was completely absent.

(*b*) In another case the supinator longus muscle was inseparably fused with the extensor carpi radialis longior and the tendon of the combined muscles was inserted into the base of the second metacarpal bone. Here it was noticed that the nerve pierced the fused tendons marking off the portion of the tendon corresponding to the supinator longus superficially from that portion corresponding to the extensor carpi radialis longior deep to the nerve.

(*c*) In three cases the motor branch to the extensor carpi radialis brevior arose from the radial trunk.

(*d*) One radial nerve was observed to wind round the mesial margin of supinator longus opposite the elbow-joint and to pass down the forearm superficial to this muscle.

The most important point, for practical purposes, in the course of this nerve is that at which it becomes cutaneous by appearing from under the tendon of the supinator longus. This point was found to average 15·53 cms. down the average forearm of 24·04 cms. length, i.e. 8·5 cms. above the tip of the radial styloid process, which will be seen to be just above the junction of middle and lower thirds of the forearm. This point varied between 12·52 cms. and 18·28 cms.

The communications of the radial nerve at the wrist-joint have been discussed in section 3, when describing the musculo-cutaneous nerve.

10. POSTERIOR INTEROSSEOUS NERVE

This nerve normally contains all the motor fibres remaining in the musculospiral nerve when it divides in front of the external condyle of the humerus. These fibres are distributed by the posterior interosseous nerve to all the muscles on the back of the forearm, except in the anomalous cases mentioned, in which the radial supplies extensor carpi radialis brevior.

The following measurements have been taken to fix the course of this nerve:

In the average forearm of 24·04 cms., posterior interosseous arises 0·0 (average)

Nerve to extensor carpi radialis brevior arises	1·82	cms.	(·076)
„ „ enters	6·10	„	(·254)
Posterior interosseous enters supinator brevis	4·05	„	(·169)
„ leaves „	7·09	„	(·295)
Dips below extensor longus pollicis	13·69	„	(·570)

Two minor anomalies of this nerve are worthy of mention:

(1) In three cases the motor fibres to the extensor carpi radialis brevior

were carried down in the radial nerve for a short distance before being given off to the muscle.

(2) In three cases the posterior interosseous, in its course down the back of the forearm, crossed the superficial aspect of the extensor longus pollicis instead of dipping down normally at the upper border of this muscle to reach its deep aspect.

Nerve to the extensor carpi radialis brevior. This is the first branch of the posterior interosseous nerve and the only one arising on the front of the forearm. As just mentioned, this nerve may occasionally come from the radial trunk. It arises 1·82 cms. down the forearm and proceeds distally and very obliquely laterally. Just before it reaches the muscle it splits into numerous bundles of fibres which enter the anterior border of the muscle along a vertical line of considerable extent. The horizontal level of this point of entry is 6·10 cms.

Nerves to the supinator brevis. These are numerous short branches which arise while the posterior interosseous trunk is in relation to the anterior, lateral and posterior aspects of the neck and upper part of shaft of the radius. The nerve trunk takes this course amidst the fibres of the supinator brevis, thus dividing this muscle into a superficial and a deep portion.

The posterior interosseous leaves the supinator brevis on the back of the forearm a considerable distance above the lower border of that muscle. Its exit is bounded above by the lower margin of a well-defined tendinous arch which is developed on the posterior surface of the supinator brevis.

The course of this nerve through the supinator brevis muscle is of clinical importance. It is firmly bound down in this region to the neck and upper part of the shaft of the radius by the superficial fibres of supinator brevis and consequently can hardly escape injury in fracture of this portion of the radius. This relationship to bone is maintained from the point where the nerve enters the muscle on the anterior aspect of the forearm to the point where it leaves it on the posterior aspect. The vertical distance between these two points is over 3 cms. and so the posterior interosseous nerve is extremely vulnerable in lesions of the radius anywhere between 4·04 and 7·09 cms. down the forearm.

The posterior interosseous leaves the supinator brevis 7·09 cms. down the forearm as a flat band of nerve fibres of considerable width. Almost immediately after its appearance this band gives off the majority of its fibres as a bundle which runs horizontally backwards to sink into the deep aspect of the superficial extensor muscles.

This large posterior leash of nerve fibres may therefore be considered as arising 7·5 cms. down the forearm. Before it reaches its muscles it breaks up into at least four distinct branches. Two of these sink immediately into extensor communis digitorum. One, slightly longer than its companions, has a short oblique course downwards and medially to end in extensor minimi digiti. The last of the four constant branches has a short but distinct course practically horizontally inwards to end in extensor carpi ulnaris. Very inconstantly a fifth branch may be traced still further inwards to terminate

in the lower fibres of the anconeous muscle. On account of their practically horizontal direction backwards these branches are very short and their level of entry to their muscles practically corresponds with their level of origin as a bundle from the main trunk (7·5 cms.). As an exception to this general rule, the nerve to the extensor minimi digiti, by the obliquity of its direction, enters its muscle at a slightly lower level.

The main trunk of the nerve, reduced to less than half its size, now runs vertically down the forearm between the superficial and deep extensor muscles as far as the upper border of the extensor longus pollicis. It lies in this portion of its course well to the radial side of the axial plane of the forearm and rests from above downwards on the lower fibres of the supinator brevis, extensor ossis metacarpi pollicis and extensor brevis pollicis.

Nerves to the extensor ossis metacarpi pollicis. These are generally two short stout branches which arise from the main trunk as it is lying on the muscle, and consequently they have practically no extra-muscular course.

Nerve to the extensor brevis pollicis. A fine filament arising from the main trunk as it lies on the muscle, which sinks into the muscle immediately.

The main trunk reaches the upper border of extensor longus pollicis 13·69 cms. down the forearm and normally dips below this muscle to gain the interosseous membrane. It has already been mentioned that in three of the dissections it continued its downward course superficial to this muscle.

Nerve to the extensor longus pollicis. This is a bundle of fibres of some size, which arises just before the nerve passes deep to the muscle. The branch breaks up into two or three filaments which enter the upper (or lateral) border of the muscle over an area of considerable vertical extent.

Nerve to the extensor indicis proprius. This muscle is supplied by a slender filament which arises from the posterior interosseous nerve whilst this trunk descends on the interosseous membrane. This branch runs backwards to enter the deep surface of its muscle. The nerve to the extensor indicis proprius is always described as the last muscular branch of the posterior interosseous, but the posterior interosseous may occasionally have still another muscle to supply. In three cases of this series a muscle has been observed which may be called the extensor medii proprius. This muscle when present receives the last motor fibres of the posterior interosseous nerve and, on account of its size and its possible clinical significance, seems worthy of description.

Extensor medii digiti proprius muscle (fig. 7). This muscle has been found in three out of the 26 adult limbs examined in this work.

It arises from the posterior and lateral surfaces of the ulna below the extensor indicis proprius and from the inter-muscular septum separating it from the extensor carpi ulnaris. In one case its fleshy belly of origin was partially fused with that of extensor indicis, but in the other two it was quite distinct. The fleshy belly gives place to a tendon which runs under the posterior annular ligament in company with the extensor communis and extensor indicis tendons. The tendon then passes obliquely over the dorsum of the hand medial to that of extensor indicis and deep to the extensor communis tendons,

and gains its insertion by joining the ulnar side of the dorsal expansion of the long extensor tendon to the middle finger.

This muscle, judging from the description of its insertion, is the musculus Manieux described by Le Double(8), but this author described its origin as from the back of the carpus and in no description have I read of its possible origin from the ulna.

It is of morphological interest, since it may be considered either (1) as the reappearance of an atavistic short extensor of the middle finger, or

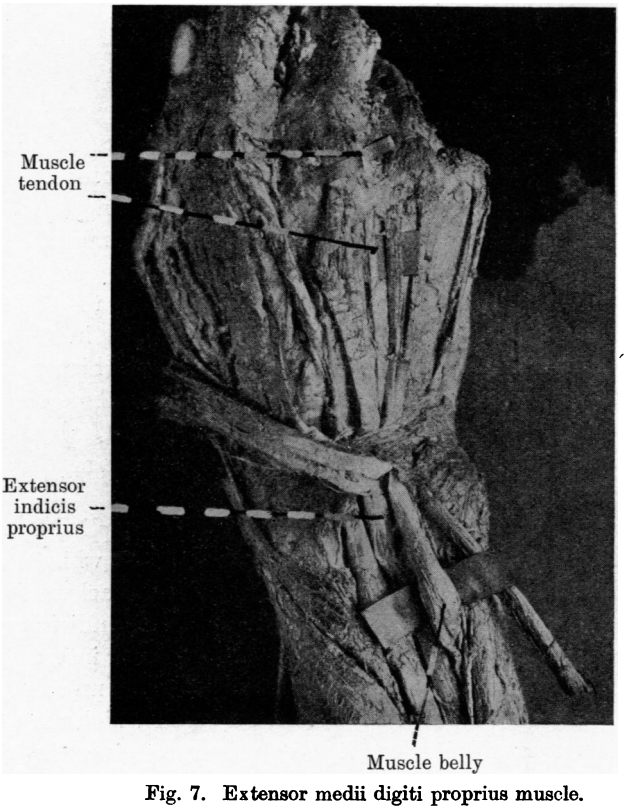

Fig. 7. Extensor medii digiti proprius muscle.

(2) as an example of what Wood-Jones(6) describes under the term of "progressive variabilities." A quadruped, such as the cat, has a special short extensor to each of the digits of its forelimb and these are used as muscles of progression. In bipedal man the forelimb is not used for progression and therefore these short extensors lose their function. Those to the middle and ring fingers disappear and the remaining three are retained and modified to subserve other uses. The medius is probably the next in importance to the thumb, index and little fingers and would therefore be the next most likely to require an individual short extensor. It is just possible then, that the reappearance of this special short extensor of the medius may be a progressive

stage in the development of the human hand. The well-defined appearance of this muscle three times in 26 cases seemed to me a somewhat excessive percentage for a pure atavism.

The posterior interosseous nerve terminates on the dorsum of the carpus in a swollen extremity from which appear small filaments for the supply of the carpal joints.

Tables of Measurements

It is hoped that these Tables may prove of clinical value. They are compiled from over 700 measurements of 25 adult limbs. Extreme anomalies, which would invalidate the ratios, have been excluded.

The principle of these measurements has been explained in the introduction and little more remains to be said.

Two vertical measurements have been taken. One, from the tip of the acromion process to the tip of the external condyle of the humerus, for nerves of the upper arm, may conveniently be spoken of as the "A measurement"; the second, from the tip of the external condyle to the tip of the styloid process of the radius, which may be called the "B measurement," and is for nerves in the forearm.

In the 25 limbs under consideration

The average length of A measurement = 30·5 cms.

" " B " = 24·04 "

Column 3 gives the average ratio of the total A or B measurement where the important point on the nerve is situated. Column 1, which gives the horizontal level of this point down the average arm or forearm, is obtained, therefore, by multiplying column 3 by 30·5 or 24·04 as the case may be.

Columns 4 and 5 give the maximum proximal and distal variabilities found of the average ratio, column 3.

The clinical value of these tables can best be shown by an example.

The clinician may wish to know as accurately as possible where the nerve to the supinator longus arises. He measures the upper arm of his patient and gets an "A measurement" of 32·0 cms. He multiplies this by the average ratio, ·827 in this case,

$$\cdot 827 \times 32 = 26 \cdot 46 \text{ cms.}$$

Therefore, he will expect to find the nerve to the supinator longus arising in this patient at a horizontal level 26·46 cms. vertically below the tip of the acromion process.

He has however to take into account the variabilities of this origin. Applying his A measurement to the maximum proximal and distal variabilities he gets

$$\cdot 742 \times 32 = 23 \cdot 74 \text{ cms.}$$

$$\cdot 900 \times 32 = 28 \cdot 80 \text{ cms.}$$

The variability in this case is, therefore, 5·06 cms. or approximately 2 inches.

Before leaving this section I wish to acknowledge the great assistance I have obtained from Mr Burnet, a student of Engineering at the University of Manchester. His work of averaging and checking the mass of figures, which the compilation of these tables entailed, has been very helpful.

11. TABLES OF AVERAGE MEASUREMENTS AND THEIR VARIABILITIES

	Average distance in cms.	Arm (A) or fore-arm (B)	Average ratio	Variability of ratio From	Variability of ratio To
I. *Musculo-cutaneous Nerve:*					
Nerve to coraco brachialis ... ... arises	4·76	A	·156	0·0	·283
„ „ „ ... ... enters	7·35	A	·241	·096	·410
Nerve to biceps ... ... arises	12·99	A	·426	·357	·533
„ „ ... ... enters	15·28	A	·501	·426	·616
Nerve to brachialis anticus ... ... arises	17·32	A	·568	·400	·650
„ „ „ ... ... enters	20·27	A	·665	·616	·746
Cutaneous division ... ... arises	17·32	A	·568	·400	·650
II. *Median Nerve:*					
Nerve to pronator radii teres ... ... arises	1·0–2·0	B	Variability too great to give reliable ratios. See text		
„ „ „ ... ... enters	1·5–2·0	B			
Nerve bundle to common flexor mass:					
Upper limit of origin	2·08	B	·086	0·0 (B)	·213
„ „ entry	2·76	B	·115	·037	·340
Lower limit of entry	5·05	B	·210	·143	·425
Branch to index belly flexor sublimis digitorum arises	12·0 +	B		See text	
Anterior interosseous ... ... arises	5·24	B	·218	·130	·314
III. *Circumflex Nerve:*					
Supplies deltoid	6·98	A	·229	·161	·290
IV. *Ulnar Nerve:*					
Branches to flexor carpi ulnaris:					
(i) Nerve to olecranon head ... ... arises	·90	B	·037	0·0 (B)	·115
„ „ ... ... enters	2·08	B	·087	·020	·200
(ii) Primary nerve to condylar head ... arises	1·62	B	·067	·020	·120
„ „ „ ... enters	2·99	B	·125	·060	·204
(iii) Secondary nerve to condylar head ... arises	2·25	B	·093	·087	·100
„ „ „ ... enters	4·88	B	·203	·193	·213
Nerve to flexor profundus digitorum ... ... arises	3·07	B	·127	·040	·225
„ „ „ ... ... enters	5·54	B	·230	·128	·311
Dorsal cutaneous nerve ... ... arises	17·06	B	·709	·420	·854
„ „ ... Appears behind flexor carpi ulnaris	20·95	B	·871	·700	·960
V. *Musculo-spiral Nerve:*					
Branches to triceps:					
(i) Nerve to long head ... ... arises	7·11	A	·233	·161	·333
„ „ ... ... enters	11·30	A	·370	·308	·441
(ii) Ulnar collateral ... ... arises	9·53	A	·312	·179	·419
„ „ ... ... enters	18·17	A	·595	·431	·800
(iii) Nerve to outer head ... ... arises	10·13	A	·332	·293	·393
„ „ ... ... enters	14·62	A	·479	·342	·643
(iv) Nerve to inner head ... ... arises	11·21	A	·368	·300	·467
„ „ ... ... enters	18·26	A	·599	·517	·800
Lower external cutaneous nerve ... ... arises	13·95	A	·457	·233	·750
				See text	
Nerve to supinator longus ... ... arises	25·23	A	·827	·742	·900
„ „ ... ... enters	28·26	A	·927	·855	0·0 (B)
Nerve to extensor carpi radialis longior ... arises	26·79	A	·878	·786	·935
„ „ „ ... enters	Average immediately proximal to tip of external condyle. See text				
Musculo-spiral nerve ... ... ends	Average level is tip of external condyle. See text				
VI. *Radial Nerve:*					
Appears from under tendon of supinator longus	15·53	B	·646	·521	·761
VII. *Posterior Interosseous Nerve:*					
Nerve to extensor carpi radialis brevior ... arises	1·82	B	·076	0·0	·130
„ „ „ ... enters	6·10	B	·254	·160	·339
Posterior interosseous trunk enters supinator brevis	4·05	B	·169	·120	·245
Posterior interosseous trunk leaves supinator brevis	7·09	B	·295	·240	·358
Trunk dips below extensor longus pollicis ...	13·69	B	·570	·456	·667

12. SUMMARY AND CONCLUSION

An attempt has been made in the text of this paper to emphasise points of clinical importance in the distribution of the nerves of the upper limb. In many cases it has been possible to support the anatomical findings by analyses of clinical groups of cases kindly given me by Prof. J. S. B. Stopford. Most of these analyses have been referred to in the text, so that it is only necessary to give a very brief tabulated summary of the main conclusions arrived at from these observations.

I. Variability of Distribution of Nerve Branches

As the nerve branches show such marked individual variability in their distribution no rules can be laid down. Each branch of each nerve must be taken separately and its variability worked out from the Tables before any accurate conclusion can be arrived at as to its variability. It is interesting to note that the minimum variability of any branch is 4·5 to 5·0 cms., which represents approximately a variation between an inch above and an inch below the point obtained for the average ratio. Variations so extreme as to fall under the heading of anomalies have been excluded from the Tables.

A clinical matter of importance, in which these measurements should be of assistance, deals with the question of prognosis in nerve injuries. It is often difficult to judge by clinical examination before operation as to the length of nerve involved in and devitalised by callus or scar tissue, etc. Upon the length of nerve which will require to be resected at operation depends the important question as to whether or not end-to-end suture will be possible. Reference to the Tables will, in many cases, give the surgeon a definite idea in centimetres of the length of nerve likely to require removal.

II. Subdivision of the Brachial Plexus

The brachial plexus may be subdivided by a vertical line drawn 7·75 cms. from the lateral borders of the lower cervical vertebral bodies or by a similar vertical line 6·75 cms. lateral to the common carotid artery at the root of the neck. Such a line, where it cuts the plexus, divides the trunks from the cords with certain modifications of the usual nomenclature as described in the text. This line has the great advantage of excluding the clavicle as a basis of subdivision.

III. Anterior Thoracic Nerves

Both these nerves have a very high origin from the brachial plexus and should be considered anatomically and clinically, as branches of the nerve trunks and not of the nerve cords.

IV. Communication between the outer and inner cords

In at least 57 per cent. of cases the ulnar nerve obtains fibres from the seventh cervical root by means of a communication which it receives from the inner aspect of the outer head of the median.

V. Anomalies of Musculo-cutaneous Nerve

In a small proportion of cases the branches of this nerve arise direct from an undivided outer cord.

VI. Muscular Distribution of the Musculo-cutaneous

This is completed in the upper two-thirds of the brachium. A lesion of the main trunk distal to 2·0 cms. below the middle of the upper arm will cause no paralysis. Clinical evidence shows that a sensory lesion of the musculo-cutaneous is five times as common as a mixed lesion.

VII. Communication between Musculo-cutaneous and Radial Nerves at the Wrist-Joint

This was absent in two out of seven cases and was seen to vary extremely in size when found. The interchanged fibres are presumably distributed in the branches of the radial nerve.

VIII. Anomalies of Origin of Median Nerve

The position at which the outer head joins the inner head of this nerve shows marked variability but, generally, at least a number of the fibres of the outer head join the inner head at the normal level.

IX. Nerve to pronator radii teres

This nerve seldom arises proximal to the elbow-joint.

X. Nerve to index belly of flexor sublimis digitorum

A branch, frequently present, which arises in the lower half of the forearm and sinks into the deep aspect of this belly. Occasionally it supplies the medius belly of the muscle.

XI. Muscular Distribution of Median Nerve in the hand

Besides supplying the abductor and the opponens pollicis muscles this nerve also supplies the superficial slip of that portion of flexor brevis pollicis which is inserted into the radial sesamoid bone and the radial side of the base of the first phalanx of the thumb.

XII. Circumflex Nerve

The most constant nerve of the upper limb in origin, course and distribution. Its anterior terminal division is purely motor to the deltoid. The posterior division takes up a lower horizontal level than that maintained by the anterior division.

XIII. Nerves to flexor carpi ulnaris

These vary from two to four in number. They all enter the muscle high up in the forearm, the point of entry of the lowest being 4·88 cms. Only occasionally does the highest of these branches arise in the upper arm, but this infrequent

high origin will account for those exceptional cases in which the flexor carpi ulnaris is only paretic after an injury to the ulnar nerve trunk, where it lies between the olecranon process and the internal condyle.

XIV. Nerve to flexor profundus digitorum

A single stout trunk, with an extra-muscular course of about an inch, and not the two distinct bundles of fibres, one for each ulnar belly of the muscle, as described by Poirier (7).

XV. Dorsal Cutaneous Branch of Ulnar Nerve

Origin very variable. Point where it becomes cutaneous at the medial border of the flexor carpi ulnaris reasonably constant and just over an inch proximal to the tip of the styloid process of the radius, i.e. approximately half an inch above the styloid process of the ulna.

XVI. Digital Cutaneous Distribution of Ulnar Nerve

On the palmar aspect the ulnar nerve gives the classical supply of $1\frac{1}{2}$ fingers in 80 per cent. of cases.

The dorsal cutaneous branch of the ulnar supplies $2\frac{1}{2}$ fingers in 75 per cent. of cases.

XVII. Communication between Ulnar and Internal Cutaneous Nerves

These nerves have been seen to communicate in the upper arm but not in the region of the wrist-joint.

XVIII. Termination of Musculo-spiral

Variability from approximately 4 cms. above to 4 cms. below the tip of the external condyle. This bony point gives a good average level of termination.

XIX. Nerve-supply of triceps

This muscle has four distinct bundles of fibres from the musculo-spiral nerve. For practical purposes they all arise in the upper third of the arm before the main trunk enters the musculo-spiral groove. The two nerves for the inner head have the longest extra-muscular course.

XX. Discretion of bundles of Nerve fibres in the Musculo-spiral

The individual bundles of fibres of this nerve are arranged and receive their own sheaths of perineurium in the lower part of the axilla. Consequently the branches of the musculo-spiral are very easily split up from the main trunk, and suture of individual bundles ought to be easily practicable.

XXI. Ulnar Collateral Nerve

This is the smaller and less important branch to the inner head of the triceps.

XXII. Branch of Musculo-spiral to Brachialis Anticus

Probably an afferent nerve-path.

XXIII. Cutaneous Branches of Musculo-spiral

Internal cutaneous branch generally arises from one of the nerves to the long head of triceps.

Upper external cutaneous branch was very seldom found.

Lower external cutaneous branch supplies the skin of the back of the forearm as far as the wrist. It occasionally communicates with the musculo-cutaneous. It is the branch of the musculo-spiral most easily split up from the main trunk.

XXIV. Radial Nerve

This becomes cutaneous as a rule just above the junction of middle and lower thirds of the forearm, approximately $3\frac{1}{2}$ inches proximal to the tip of the radial styloid process.

XXV. Nerve to the Extensor Carpi Radialis Brevior

Occasionally this motor nerve arises from the radial trunk.

XXVI. Relation of the Posterior Interosseous Nerve to Radius

The posterior interosseous nerve is an intimate relation of this bone throughout its course through the supinator brevis muscle. As its relation to the muscle has a vertical extent of over 3 cms. it can hardly escape injury in fracture of this portion of the radius.

XXVII. Extensor Medii Digiti Proprius Muscle

A well-defined muscle-belly present in three out of 26 cases.

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