NEURO-VASCULAR HILA OF LIMB MUSCLES

BY

JAMES COUPER BRASH

M.C., M.A., M.D., D.Sc., LL.D., F.R.C.S.(Ed.), F.R.S.E.

Professor Emeritus of Anatomy, University of Edinburgh

AN ATLAS

WITH THIRTY COLOURED PLATES

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INTRODUCTION

As mentioned in the Preface, while the primary object of the study on which this Atlas is based was the determination of the incidence of distinct neuro-vascular hila in the Limb Muscles, it incidentally and necessarily implied a series of new observations on the points of nerve-entry. Some account of the history of previous observations is therefore desirable.

Duchenne, whose later work (1867) on the " Movements of Muscles " is well known, appears to have been the first to call attention to the practical utility of knowledge of the " motor points " of muscles. One of his early figures illustrating faradic stimulation of muscles shows an electrode placed approximately on the " motor point " of the extensor muscles in the upper part of the back of the forearm. It occurs in his book *L'Électrisation localisée* (1855)—the origin of part of what we are now accustomed to call " physio-therapy ". Such " motor points ", not necessarily over the exact point of entry of its nerve into a muscle, Duchenne apparently discovered by trial and error.

Schwalbe (1879) was the first to consider in any detail the question of a principle that might govern the sites of entry of nerves into muscles. He quoted current ideas: (1) The simple, rather vague notion that the nerve enters the " middle " of the muscle; (2) Langer's statement that it enters at the " proximal end of the fleshy belly "; and (3) Krause's more precise statement that the point of entry is in the " proximal third of a muscle near its junction with the middle third ". None of these, Schwalbe says, is generally applicable, though they may be true for individual elongated muscles. The same criticism applies to Chassaignac's later statement (quoted by Eisler, 1912) in the negative form that the nerve never enters in the proximal fourth or the distal half; which seems by exclusion to place the point of entry in the second quarter from the proximal end and therefore approximately in the same region as stated by Krause.

Schwalbe himself, with characteristic German thoroughness, then proceeded to analyse the form of muscles (excluding tendons) and arrived at his " Law of Muscle-Nerve-Entry " (Gesetz des Muskelnerveneintritts)—that the nerve always enters at what he calls the " Geometric Centre " of the muscle. This seems to have been in relation to the actual site of entry on the surface of the muscle; and Roux (1895) modified Schwalbe's statement to " in the direction of the geometric centre ".

To illustrate his thesis, Schwalbe described three main types of muscles with notes on the mode of entry of their nerves: (1) Muscles, equally broad and thick, with parallel fibres and the nerve of supply entering at the " middle "; of these, there are two varieties—(*a*) very long muscles, the nerve of supply breaking up into several branches which enter along a " nervenlinie " parallel to the muscle-bundles, *e.g.*, Sartorius, and (*b*) very broad muscles in which the " nervenlinie " is at right angles to the muscle-bundles and half-way between the ends of the muscles, *e.g.*,

Gluteus maximus; (2) Three-sided muscles, the nerve entering at the " convergence point ", *e.g.,* Pectoralis major and Adductors of thigh; (3) Spindle-shaped muscles, the nerve entering at the middle of the belly, *e.g.,* Semitendinosus, Long head of Biceps femoris. From this point of view, Schwalbe would analyse compound muscles into component types; and it should be noted that in effect his " geometric centre " appears to be at the " middle " of each muscle.

Bardeleben & Frohse (1897), on the other hand, asserted that the nerve-entry is seldom at the middle or geometric centre, seldom quite proximal, never quite distal and usually about the junction of proximal and middle thirds of a muscle. The nerves of supply may enter either the superficial or the deep surface of muscles and, in the case of some, may have a marginal entry. Eisler (1912), in his extended discussion of this question, adds the points (1) that the nerve of supply usually divides into several branches before entering, but that there is variation in this respect even in the same muscle; (2) that the majority of muscles receive their nerves on the deep (skeletal) surface and some (*e.g.,* Adductor magnus and Soleus) have nerves on both surfaces; and (3) that there is no general rule for surface or location, nor for the relation of the point of nerve-entry to the length of a muscle, though there is little variation in that respect in individual muscles. The variations of the location of nerve-entry from muscle to muscle, as seen in the illustrations in this Atlas, do seem to provide examples that correspond in general with all these varying statements.

Schwalbe (1879) made no reference to the entry of blood-vessels into muscles, but Frohse (1898), in his incidental references to this question, used the term " Muskelhilus ", coined by Mays (1884) in relation to the muscles of the frog. " In many cases," said Frohse, " the vessels have a common entrance with the nerves, or enter near them; and one can speak of a ' Muskelhilus ' with the reservation that this does not mean a single point but rather a location "—the German word is *Hof*—" in effect, an *area nervo-vasculosa.*" This seems to be the origin of the idea of a " neuro-vascular hilum ", further developed by Eisler (1908) in Bardeleben's *Handbuch,* though not so named. The expression in this form was used by T. H. Bryce in the 11th edition of *Quain's Anatomy* (1923), where it is in fact attributed to Frohse.

Frohse, however, was principally concerned with a re-examination of Schwalbe's " Gesetz des Muskelnerveneintritts ", for which purpose he made elaborate dissections of individual muscles, tracing the intramuscular course of the nerves and describing various types of intramuscular nerve-plexuses which he claimed as characteristic for each muscle. In the Sections of Bardeleben's *Handbuch* (1908) on the Muscles of the Limbs, Frohse & Fränkel give many detailed descriptions of the sites of entry of nerves and there are elaborate illustrations of intramuscular plexuses; but there is little or no reference to the blood-vessels of individual muscles in the text, and only an occasional indication in the figures. Frohse & Fränkel's illustrations provide, therefore, a complementary contrast to those here presented.

Special attention should now be called to three contributions made in this country to knowledge of the mode and levels of nerve-entry into limb-muscles, data

from which are given for comparative purposes in the text corresponding to each of our illustrations. They were all due to practical problems presented by nerve-injuries during the 1914-18 War and date from the post-war period, as this contribution, with many others, has arisen out of similar problems during the 1939/45 War.

R. W. Reid (1920), with the object of improving the basis of " electrical methods employed in the diagnosis and treatment of the results of peripheral nerve lesions ", made a special dissection of a single, male muscular subject. Although Reid's data were derived from a single subject—as in the case of Cappell's contribution (see below)—he made a special note that " by comparison with cadavera which were being dissected in the course of ordinary practical anatomy work, I find that they are not subject to more variation than might be considered normal ". The paper consists in effect of a table " showing the number of the principal nerve branches entering each muscle together with the approximate places of entry into each muscle ", and nine photographic Plates. The " approximate places of entry " are expressed mainly in relation to the division of muscle-bellies into thirds and are therefore not directly comparable with the data of Linell and Cappell. The " motor points " of the several muscles were marked on the surface of a cast previously made of one half of the subject, and they were then transferred by proportionate measurement to another cast from a living muscular male. The Plates illustrate the completed cast, of which copies also were placed on the market.

E. A. Linell (1921)—then in Manchester, now Professor of Neuropathology in the University of Toronto—investigated the whole distribution of nerves in the Upper Limb with reference to common variations and their general clinical significance. His principal objects were (1) " To assist the clinician, by means of measurement, as to the position of origin of the nerves of the arm and as to the limits within which he may expect to find variation of these branches," and (2) " To give average positions for the entry of muscular nerves into their respective muscles, and also the variabilities to be expected.".

Linell dissected twenty-six (26) Upper Limbs of adult subjects and eight (8) foetal limbs and, among other observations, he noted the levels of the points of entry into muscles with reference to vertical scales based on convenient bony points. He also devised ratios, on the basis of some seven hundred (700) measurements and the average dimensions of the adult limbs dissected, by means of which the probable position, with maximal proximal and distal range, of the point of nerve-entry to any muscle in limbs of varying dimensions could be calculated. His paper contains also much detailed information of great value, *e.g.*, the average position of origin of important branches from the main nerves; and it includes a Table of all his measurements and ratios. The intrinsic muscles of the hand are not included; and it is unfortunate that Linell did not have the opportunity to extend his observations to the Lower Limb.

In 1918 D. F. Cappell—now Professor of Pathology in the University of Glasgow, where he was then a student—made for the late Professor T. H. Bryce a complete dissection of a single subject with the same objects in view as Linell.

His observations, including descriptions of the mode of nerve-entry into muscles and detailed vertical measurements from bony points, were not published separately but were utilised with some of Linell's similar data by Bryce in the preparation of the new volume of *Quain's Anatomy* on *Myology* (11th edition, 1923).* Owing to this circumstance, the data mainly due to Cappell are quoted in the text in relation to each illustration as from " Cappell/Bryce ".

In addition to these three basic contributions, B. Feinstein (1943), continuing the work of W. B. Highet in the Department of Human Anatomy, University of Oxford, made a series of similar observations on selected muscles of both limbs. These observations have not been published separately in detail, but are given in the paper by Seddon, Medawar & Smith (1943) on " Rate of regeneration of peripheral nerves in Man ". The number of observations is not stated, but the authors of that paper comment that both Highet and Feinstein " found considerable variation in levels of entry of branches, even between the two sides of the same subject, and there was no relation between the levels of entry and the length of limbs in subjects of different adult stature ".

Information in varying detail about the course and sites of entry of motor nerves in the limbs is to be found in several of the larger text-books in addition to *Quain's Anatomy*. Selected data from two representative works, German and French respectively, are included in the notes on " Previous Observations " in relation to each illustration.

The contributions of F. Frohse and M. Fränkel (1908) to *Bardeleben's Handbuch* (to which reference has been made above) are the standard German accounts of the Muscles of the Limbs. They include elaborate descriptions of the branchings of the motor nerves, of their intramuscular course and the formation of intramuscular plexuses.† A. Hovelacque (1927), in his great work on the Peripheral Nervous System, gives an excellent detailed account of the variations and mode of entry of motor nerves. He quotes numerous authors, including Linell for the Upper Limb. It should be noted that the standard source of information on variations of the muscles themselves is the treatise on that subject of Le Double (1897).

ILLUSTRATIONS.—All the illustrations have been made on a common plan. They are based on outlines taken from radiographs of living limbs with a punched lead strip as nearly as possible in the plane of the bones to provide a scale, the distances being checked by direct measurements on the living subject. In order to accommodate the drawings to a uniform size of page—with a scale that actually measures 20 cm. in each case—the following are the reductions that have been necessary: Forearm and Gluteal Region 2/3; Upper Arm 4/7; Thigh 2/5; Leg 1/2. The actual dimensions are indicated, of course, by the varying subdivisions of the scales. The measurements between the bony points selected for the scales are given in the Tables in the Appendix for comparison with average measurements recorded by others. Additional scales have been added to Plates I and II for

* I have had the advantage of seeing Cappell's original notes which Professor Bryce and he kindly placed at my disposal.

† I have to acknowledge the valuable assistance of Dr. G. V. Born in the preparation of translated abstracts from this work.

Humerus and Brachialis; similar additional scales for muscles or bones, *e.g.*, for the Fibula in the illustrations of the Leg, can be easily added to other Plates if desired.

All the muscles and main nerves have been drawn direct from special dissections prepared for the purpose and, where necessary, owing to considerable deviations in the particular dissection from what appears to be the average arrangement, points of origin and of entrance of motor nerves have been adjusted in accordance with the detailed data available. Minor variations in detail in some of the dissections used, however, have been retained as an indication of the type of arrangement that may be expected. In effect, the illustrations are a combination of diagram and exact representation. It should be noted that all nerves and arteries entering the deep surfaces of the muscles are shown in the illustrations by dotted lines.

The average levels of origin of motor nerves from main trunks and of their entry into muscles in the series may be read off from the scales in relation to the bony landmarks selected. The average levels of the points of entry are stated also in the comparative Tables in the Appendix which provide a comparison with the data of other authors. Notes of the dimensions of the limbs to which these data refer, as indicated already, are included, and in some cases direct comparison of the stated levels of nerve-entry is possible. For example, the Acromion/Lateral Epicondyle measurement used in this series is 30 cm.; Cappell's measurement was 30·1 cm.; and Linell's average was 30·5 cm.

Some of the illustrations show single muscles, but in general it has been found more convenient to represent the muscles in groups in relation to the main nerves, but bringing out in each picture only those muscles (sometimes single) of which the nerves and arteries might be shown clearly without danger of confusion from overlapping. The illustrations have indeed been reduced to the simplest terms, and it has not been thought necessary to introduce any labelling of the drawings themselves—easily added by users of the Atlas if they so desire. Each Plate faces its corresponding text-page, headed by the name of the main nerve or nerves with serial numbers and the names of the muscle or muscles represented. The data for some muscles, *e.g.*, pectoralis major, were not sufficiently exact to warrant their inclusion; nor has it seemed worth while, from the particular point of view, to attempt to treat the short muscles of hand and foot in the same manner.

EXPLANATORY TEXT-PAGES.—After a general note on the preparation of the corresponding drawing, these pages give a summary of the observations made on each muscle, followed by a selected summary of previous observations.

Position of Nerve-Entry.—The statement indicates the frequency with which the position as shown in the drawing may be expected to occur, and in most cases the range of variation. In general, the level of nerve-entry represented in the illustration corresponds to the most frequent rather than the average level, *e.g.*, in 50 per cent. of the Biceps brachii the entry was half-way between acromion and lateral epicondyle; 19 per cent. were slightly above and 31 per cent. slightly below—not a great deal of variation. Taking account of variations, and with some exceptions, the levels agree in general with the previous data of Cappell, of Feinstein and

Highet, and of Linell for the Upper Limb; and they are in reasonable conformity with the less detailed statements of Reid.

The mode of entry to individual muscles agrees with Schwalbe's original statement (1879), with examples, that this depends on the form and dimensions of each muscle; but the variations in level of entry and in its situation in relation to the muscle as a whole make it doubtful whether his " Gesetz des Muskelnerveneintritts ", *i.e.*, that the nerve enters at the " geometric centre " of the muscle, is more than generally applicable, perhaps in the sense of Roux's (1895) modification. In general, the situation of nerve-entry, or the intramuscular subdivision of the motor nerve after its entry, appears to depend upon facility of even distribution rather than on avoidance of drag during contractions and movement, though the two things may well be associated. The same principles appear to govern the entry of the main blood-vessels of a muscle and in many cases therefore, though by no means invariably, these do have a common entrance with the nerve or enter very near it.

Neuro-Vascular Hilum.—The statement under this head shows the percentage in which the principal blood-supply of the muscle was observed to enter with the main motor nerve. It is a minimum percentage, since positive statements were lacking in some of the records; and it should be noted that in the case of the Upper Limb the number of the observations on which the frequency of distinct neuro-vascular hila is based is greater in all cases than those used for the position of nerve-entry. Some records, in which the position of nerve-entry could not be adequately checked, have been used only for the occurrence of a distinct neuro-vascular hilum. This difficulty did not arise with the records of the Lower Limbs.

A definite neuro-vascular hilum is shown in the illustration of each muscle in which it has been recorded in approximately 50 per cent. or over, with some minor exceptions, *e.g.*, in the Brachio-radialis, in which there may be a double nerve-entry, one branch accompanied by an artery, a single neuro-vascular hilum was recorded in less than 50 per cent. The principal artery enters with the nerve much more frequently in some muscles than in others; in many the neuro-vascular hilum has been recorded in well over 50 per cent.; in some it is over 80 per cent.; and in at least three muscles (Biceps brachii, Latissimus dorsi, Gastrocnemius) it has been recorded in over 90 per cent. and may therefore be considered constant.

In most of the muscles there are subsidiary arteries, usually related to the periphery of the muscular substance, close to bony attachments or tendinous endings; but there is much variation from limb to limb in the pattern of subsidiary blood-supply. The points of entry of these subsidiary vessels, indicated in the drawings, have been taken from actual dissections; and it has not been thought necessary to name the main vessels from which these, or the main muscular branches entering at hila, take their origin.

Two main varieties of neuro-vascular hilum have been named—interfascicular and transfascicular (F. W. Fyfe). These correspond to the arrangements of a " nervenlinie " described by Schwalbe—parallel to the muscle-bundles in long muscles, *e.g.*, Sartorius, and at right angles to the muscle-bundles in broad muscles, *e.g.*, Gluteus maximus. Intermediate forms are naturally to be found, *e.g.*, the

" double interfascicular hilum " of Flexor carpi ulnaris and the " multiple interfascicular hilum " of Flexor digitorum profundus in Plate VII.

PREVIOUS OBSERVATIONS.—The notes under this head vary greatly in the amount of detail available. Reid's statements of the sites of nerve-entry are approximate only; Hovelacque and Frohse & Fränkel give more descriptive detail; only Linell (for Upper Limb), Cappell/Bryce and Feinstein & Highet (for selected muscles in both limbs) state levels of nerve-entry by measurements from bony landmarks. Linell's figures, averaged from the whole series of his observations, appear too precise, and his mm. fractions are omitted in the Appendix Table.

INTRAMUSCULAR ANASTOMOSIS.—The presence of a principal artery entering at a neuro-vascular hilum and its relation to the number and situation of subsidiary vessels in any individual muscle must have a bearing on the efficiency of its blood-supply in view of the inadequacy of intramuscular anastomoses shown experimentally by Le Gros Clark and Blomfield (1945). Examples are not wanting of total infarction of a muscle, *e.g.*, one of the heads of Biceps brachii or Gastrocnemius, as a result of injury to its principal artery of supply. The probability of such a result doubtless is related roughly to the proportionate occurrence of a definite neuro-vascular hilum in any individual muscle. Le Gros Clark and Blomfield have shown that the efficiency of intramuscular anastomoses varies in different muscles; and it seems that interruption even of one of the smaller arteries may lead to a circumscribed area of degeneration.

Campbell and Pennefather (1919) quoted other examples of infarction of muscles, and they classified the muscles from the point of view of their blood-supply as follows: (1) Numerous sources of blood-supply with good potential anastomoses, *e.g.*, Pectoralis major, Deltoid, Vastus lateralis; (2) Two or three arteries of supply, potential anastomoses relatively few, *e.g.*, Sartorius, Rectus femoris, Hamstrings; (3) Single artery of supply with practical absence of collateral channels, with almost total ischaemia if the artery is interrupted, *e.g.*, Gastrocnemius, Gracilis, Vastus intermedius.

Blomfield (1945) has developed these ideas still further in relation to the variety of intramuscular vascular patterns of which he recognises five main types: (1) Longitudinal anastomotic chain formed by separate vessels entering throughout length of muscle, *e.g.*, Soleus, Peroneus longus; (2) Longitudinal pattern of vessels derived from single group of arteries arising from common stem and entering one end of the muscle, *e.g.*, Gastrocnemius; (3) Radiating pattern of collaterals arising from single vessel entering the middle of a muscle, *e.g.*, Biceps brachii; (4) Anastomotic loops throughout the length of a muscle and derived from succession of entering vessels, *e.g.*, Tibialis anterior, Extensor digitorum longus; (5) Open quadrilateral pattern with sparse anastomotic connexions, *e.g.*, Extensor hallucis longus. Blomfield further suggests that the " relative vulnerability of muscles to necrosis and clostridial infections " is related to several vascular factors including the intramuscular pattern of its vessels—the site of entry and source of the main nutrient arteries; the *number* of arteries derived from independent sources; the efficiency of

the intramuscular anastomoses; and the relation between the *size* of the main nutrient vessels and the size of its anastomotic connexions.

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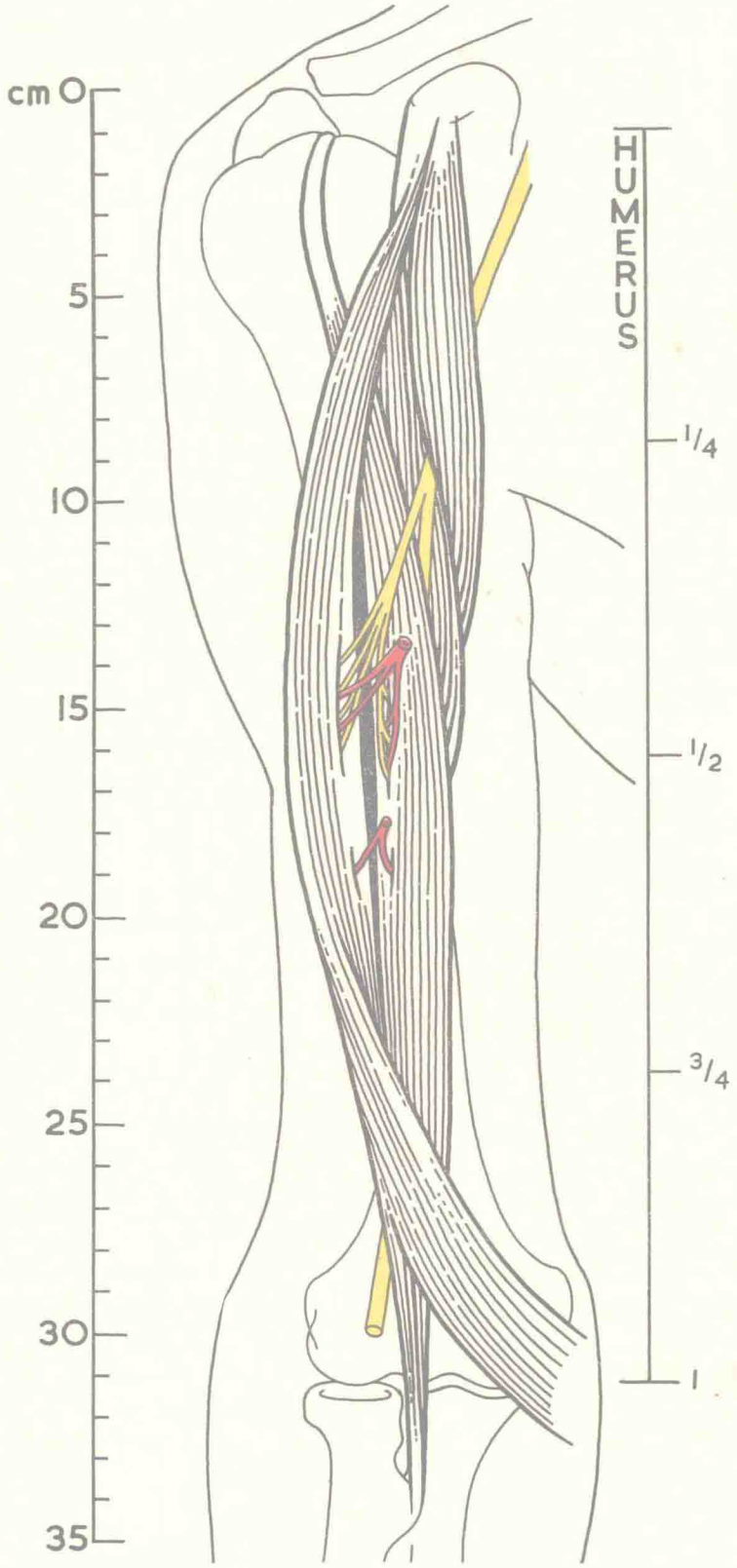
NEURO-VASCULAR HILA OF LIMB MUSCLES

UPPER LIMB

PLATE I
× 4/7



MUSCULO-CUTANEOUS NERVE (1)

CORACO-BRACHIALIS: BICEPS BRACHII

In addition to the acromio-epicondylar scale, a scale with reference to the Humerus has been introduced.

CORACO-BRACHIALIS

For details, see MUSCULO-CUTANEOUS NERVE (2), PLATE II.

BICEPS BRACHII

Both bellies have been turned over laterally to expose the neuro-vascular hila. The nerve to the Biceps arises from the Musculo-Cutaneous N. as it emerges from the Coraco-Brachialis; the branches of the nerve, each dividing into three or four twigs, enter an interfascicular hilum on the deep surface of each belly close to their contiguous borders. The hilum of the Long Head is usually situated a little lower than that of the Short Head; this point has been specially noted in some 50 per cent. of the dissections, but the proportion is certainly greater.

There is some variation in the level of origin of the nerve to Biceps and in its relation to Coraco-Brachialis; and the branches to the two heads may occasionally arise independently. Communications between Musculo-Cutaneous and Median Nerves are well known to be frequent, and the reciprocal variations of these nerves affect the origin of the nerve to Biceps. Two examples of varieties of "fusion of musculo-cutaneous and median" were observed in this series.

Position of Nerve-Entry

Above	"middle of arm"	8/42 = 19·0 per cent.
About	do.	21/42 = 50·0 per cent.
Below	do.	13/42 = 31·0 per cent.

Neuro-Vascular Hila as Shown

63/67 = 94·3 per cent.

Previous Observations

REID.—5 points of nerve-entry in middle third of deep surface.

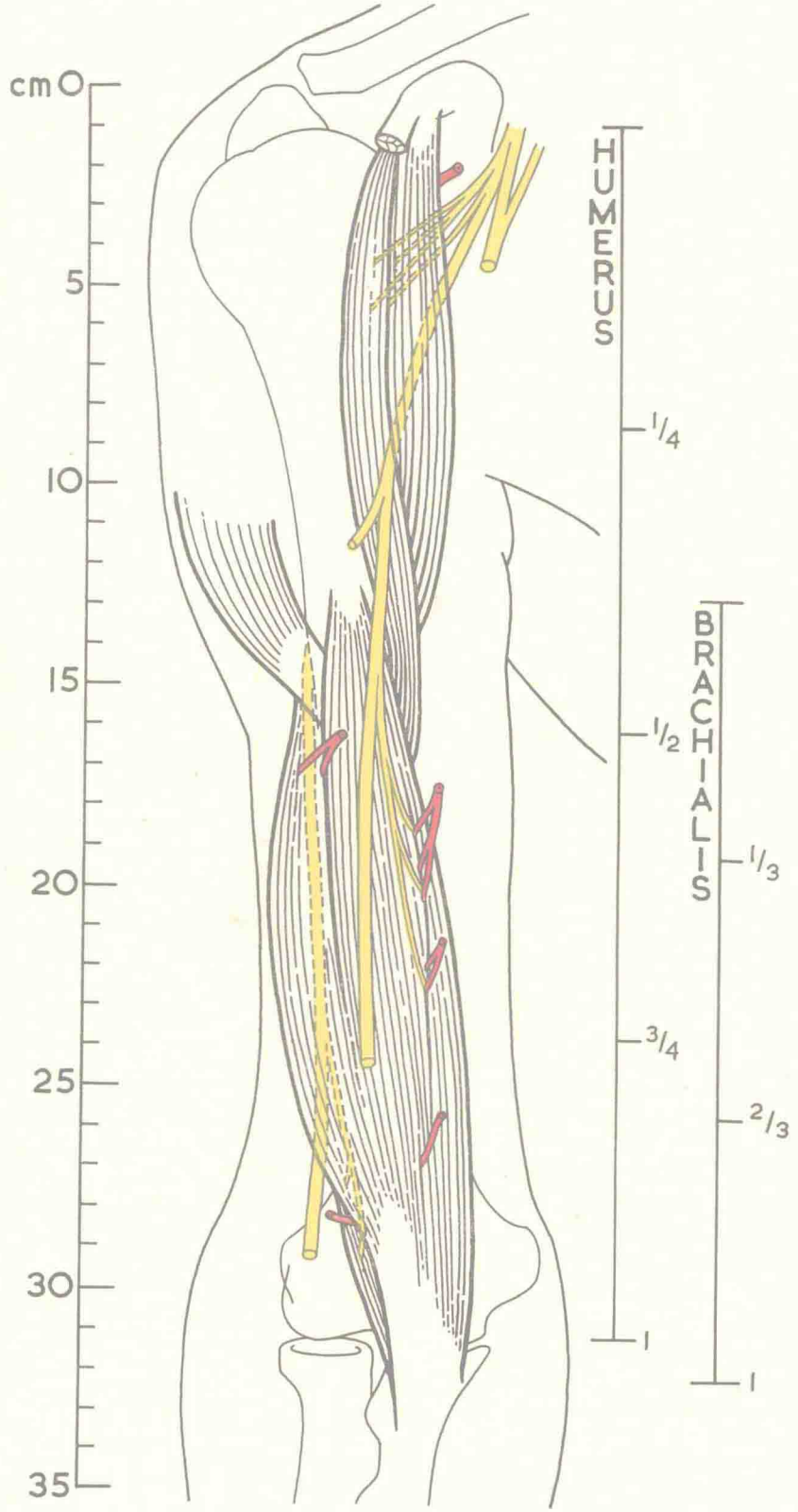
LINELL.—Single, short, stout branch divides into two and one branch enters deep surface of each belly at same horizontal level "immediately below middle of brachium". The nerve arises 12·99 cm. and enters 15·28 cm. below level of Acromion.

CAPPELL/BRYCE.—One large branch, from lateral side of Musculo-Cutaneous N. just before it emerged from Coraco-Brachialis, divided into two main branches, one to each head.
SHORT HEAD. Two main twigs, with series of small branches and one branch to Long Head, entered 15·6 to 20 cm. below level of Acromion.
LONG HEAD. Three main twigs, with series of branches, entered 15·8 to 18·3 cm. below level of Acromion.

HOVELACQUE.—The nerves of supply arise from a common trunk, the Musculo-Cutaneous N. appearing to bifurcate (Cruveilhier). The trunk has a very short oblique course and divides into two branches, sometimes connected by plexus of fine filaments, one entering deep surface of each head on horizontal plane immediately below middle of arm (Linell). Variations are noted.

FROHSE & FRÄNKEL.—One nerve plexus which can be separated artificially into several constituents; there is often interchange between the branches to the two heads.

PLATE II
× 4/7



MUSCULO-CUTANEOUS NERVE (2)

CORACO-BRACHIALIS: BRACHIALIS

The passage of the Musculo-Cutaneous Nerve through the Coraco-Brachialis and of the Radial Nerve behind the Brachialis, and portions of their branches to these muscles, are indicated by dotted lines. In addition to the acromio-epicondylar scale, scales for the Humerus and the Brachialis muscle have been introduced.

CORACO-BRACHIALIS

The arrangement of the nerves of supply was not specially recorded in this series. The drawing was made from a single dissection which showed separate but not independent supply to the two heads (deep = coraco-brachialis medius; superficial = coraco-brachialis inferior or longus).

Previous Observations

REID.—2 points of nerve-entry in proximal third of deep surface.

LINELL.—The nerve of supply arises from lateral side of Musculo-Cutaneous N. high up in arm and enters the medial side of the muscle, after a course of 2·5 cm., just above the point of entrance of the Musculo-Cutaneous N. itself. The nerve arises 4·76 cm. and enters 7·35 cm. below the level of Acromion.

CAPPELL/BRYCE.—There were three main branches of supply: proximal and middle to deep surface of deep head, with twig from proximal branch to superficial head supplied also by distal branch arising from Musculo-Cutaneous N. during its passage through the muscle. The nerves entered from 7·2 to 9·3 below level of Acromion.

HOVELACQUE.—The main nerve of supply has a high origin and enters above the canal for Musculo-Cutaneous N; it may be double or have 3 - 4 branches. Proximal branches supply antero-lateral head, distal branches the postero-medial head. There may be two or three accessory branches in the canal.

FROHSE & FRÄNKEL.—The nerve of supply arises from lateral cord of brachial plexus above origin of Musculo-Cutaneous N.; there are several branches, not entirely independent, to superficial and deep parts of the muscle.

BRACHIALIS

The single nerve of supply divides into several branches which enter an elongated interfascicular hilum, the position of which is very constant near the border of the thick medial portion of the muscle. In only one of the present series has a branch been noted running obliquely across the muscle to enter near its lateral border. The inconstant branch of the Radial N. is shown entering the deep lateral portion of the muscle which is always overlapped by the main belly.