Physiology. — *District formation, mixing or fusion of myotomic derivates in dimeric mammalian muscles? Uni- or biradicular innervation?* [1]) By G. VAN RIJNBERK and L. KAISER.

(Communicated at the meeting of September 29, 1928).

Introduction.

Whether muscle fibres from different myotomes remain separated in the muscle, or, on the other hand, become mixed or even amalgamated, this is already an old problem.

Usually it has been tried to solve this question by investigating the way of innervation taken by the motor nerve fibres springing from the ventral spinal roots. Concerning conditions in mammals the following data are laid down in literature.

KRAUSE (1865) [2]) cut one innervating root at a time and determined microscopically the distribution of degenerated nerve fibres in the muscle. He concluded that each pluriradicular and therefore plurisegmental muscle consists of more or less distinct neuromuscular radicular territories. Each muscle fibre from such a territory therefore receives nerve fibres from one spinal root only; the radicular (segmental) territories remain separated.

FORGUE and LANNEGRACE (1885) [3]) believed to have demonstrated that stimulating one of the spinal roots of a plurisegmental muscle results in contraction of the whole muscle. Therefore they concluded that district formation (so-called "cantonnement"), i.g. division in separate radicular territories, does not exist.

EXNER (1885) [4]) failed to find degeneration in the cricothyreoid muscle of the rabbit after cutting the N. Laryngeus sup. and med.; also the

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[1]) After research carried out in the Physiological Laboratory of the University of Amsterdam.

[2]) W. KRAUSE. Beitr. zur Neurologie der oberen Extremität. 1865.

[3]) E. FORGUE et W. LANNEGRACE. Distribution des racines motrices dans les muscles du membre supérieur, etc. Comptes rendus de l'Académie des Sciences. Tome **98**. p. 685, 829, 1068.

[4]) S. EXNER. Notiz zu der Frage von der Faservertheilung mehrerer Nerven in einem Muskel. Pflüger's Archiv. **36**. S. 572.

gastrocnemius muscle did not show any degeneration after cutting the larger of the three plexus stems from which the muscle receives its innervation.

SHERRINGTON (1892) [1]) and VAN RIJNBERK (1911) [2]) on the other hand confirmed KRAUSE's opinion by means of electrical stimulation of the spinal roots; each root innervates a seperate district of the pluri-radicular muscle in the innervation of which it partakes. However the remark must be made that both investigators worked with long muscles consisting of segmental or radicular parts one situated after the other, i.g. the M. Sartorius (Sh.) and the M. Iliocost. (V.R.)

LEDERER and LEMBERGER (1907) [3]) tried to solve the contradictory results obtained by EXNER with rabbit and frog and by GAD [4]) (1882) with frogs, by mammal experiments, in which the cricothyreoid muscle of the rabbit was stimulated. Those experiments yielded the conclusion that part of the muscle fibres received their innervation from one innervating nerve, partly from the other. Analogous experiments with the M. Flexor digt. comm. prof. and subl., both innervated by C VIII and Th I gave opposite results; it appeared that all or at least the majority of muscle fibres are innervated by nerve fibres originating from both roots.

After those researches the question remained untouched for some time till E. AGDUHR [5]) took it up again in 1917—19.

The outcome of stimulating the median and ulnar nerve of the pig gave him the impression that the muscle fibres of the M. Flexor digit. comm. receive a double innervation at the same time from median fibres (C VIII) and from ulnar fibres (Th. I). His extensive anatomical control work on the cat, by means of the degeneration method, confirmed this conclusion.

More recent investigators worked with frogs exclusively. (We mention FULTON 1925, DE BOER 1925, SAMOILOFF 1926). None of those could confirm the results of AGDUHR; all found that muscle fibres of polymer

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1) C. S. SHERRINGTON. Notes on the arrangement of some motor fibres in the lumbo-sacral plexus. Journal of Physiology. Vol. **13**, p. 621.

2) G. VAN RIJNBERK. Ueber die Segmental-Innervation polymerer Muskeln. Ein Beitrag zur Cantonnementfrage. Folia Neuro-biologica. V. **7**. blz. 767.

3) R. LEDERER und F. LEMBERGER. Zur Frage der doppelten Innervation von Muskeln des Warmblüters. Pflüger's Archiv. **119**. S. 95.

4) J. GAD. Ueber einige Beziehungen zwischen Nerv, Muskel und Zentrum. Festschrift z. Feier des 300-jahrigen Bestehens der Julius Max. Univ. zu Würzburg.

5) E. AGDUHR. Anatomische, statistische und experimentelle Untersuchungen über den N. ulnaris und N. medianus. Anat. Hefte. **52**. H. 158.

Morphologischer Beweis der doppelten (plurisegmentalen) motorischen Innervation der einzelnen quergestreiften Muskelfasern bei den Säugetieren. Anat. Anzeiger. **49**. S. 1.

Ueber die plurisegmentelle Innervation der einzelnen quer-gestreiften Muskelfasern. Anat. Anzeiger. **52**. S. 273.

muscles of the frog are innervated by fibres from one spinal root only, an opinion that was already forwarded by GAD in 1882, therefore no amalgamation of contractile substance originating from different myotoms takes place.

As yet it appears that the problem is by no means solved.

EXPERIMENTAL CONTRIBUTION.

In our inquiry into the segmental structure and radicular innervation of the M. Rectus abdominis of the dog we found that very frequently one and the same muscle district was supplied with nerve fibres from two different roots. Those muscle segments were designated in our terminology as M 4 and M 5, clearly separated by tendinous septa (myosepta, inscriptiones tendinea), and received their innervation from Th 11 and 12 in the first case, from Th 12 and 13 in the second case. We have tried to solve the question of district formation ("cantonnement") by means of such dimeric muscle segments. Those segments consist of muscle fibres of paralel course, have a very simple form (about that of a paralellopipedum) and are easily accessible for inspection and experiment. We used to study the results of stimulating the spinal roots or of the unisegmental peripheral nerve branches.

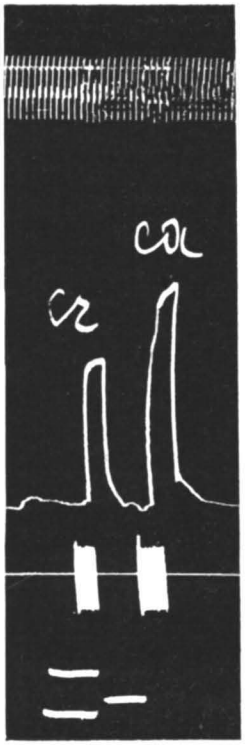

Fig. 1.

1. *Data obtained by simple observation of the contractions of muscle segments innervated by two roots.*

The general result of root or nerve stimulation is increase in bulk and shortening in cranio-caudal direction. But if first the cranial and afterwards the caudal root or segmental branch of the double innervated muscle segment be stimulated and the changes in form are carefully noted, it sometimes will become apparent that the change in both cases is absolutely the same. It is impossible to deduct from the character of deformation of the muscle segment, which of the two roots has been stimulated. Therefore in this case, formation of district does not exist, and amalgamation is possible. But in other cases the deformation of the contracting muscle segment by stimulating one or the other root is quite different. Often the contraction elicited from the cranial nerve is stronger on the medial side. Such facts prove without doubt that in double innervated muscle segments, district formation may occur. But whether in the cases just mentioned a double innervation of the muscle fibres exists is not to be answered by simple observation; if a complete mixing

of simple innervated fibres has taken place without amalgamation, consecutive stimulation of both roots should yield the same result.

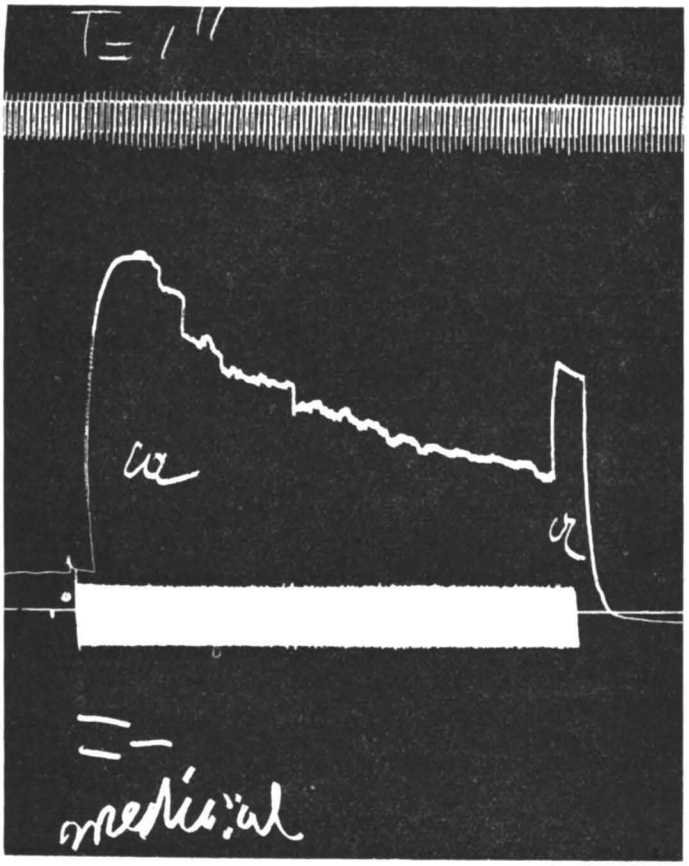

Fig. 2.

2. *Data obtained by graphical method; registration of change in diameter of muscles innervated by two roots.*

In order to answer the question whether the fibres of a muscle innervated by two roots receive a single (uniradicular) or double (biracular) innervation, several procedures are indicated, some of which have been applied by us.

We have registered the change in diameter of a dimeric muscle segment by inserting the part between the legs of a pair of MAREY muscle pincers, the movement being registrated on a smoked drum by means of a tambour worked by air transport. The flat shape of the rectus muscle is well adepted to those experiments. The results are as follows.

A. The tetanic contraction obtained by maximal faradic stimulation of the separate roots or nerves were never of aequal height. (Fig. 1). By

stimulattng one root the apex of contraction is always heigher than by stimulating the other. If amalgamation existed in the derivates of myomers in those muscle segments and the fibres of it receive a double (biradicular) innervation, this fusion could not have been complete, not all muscle fibres are double innervated, for it is clear that one root supplies more fibres than the other.

Fig. 3.

B. When one of the roots or nerves was stimulated for a certain period at a time till the height attained decreased for about $^2/_3$ and the muscle therefore was fatigued, the height would increase again immediately to the normal niveau when the other root or nerve was stimulated. (Fig. 2). This shows that at least in the place where the curve was registrated, each root supplied different muscle fibres and that for certain no considerable number of double innervated fibres could be present. Changing the position of the myograph (median, in the middle, lateral) always gave the same result.

C. When first one root was stimulated for a short time and than the other root or nerve together with the first (also for a short time to avoid fatigue) the height of contraction would increase considerably (Fig. 3) This also proves clearly that muscle fibres innervated by one root are not the same as those innervated by the other root, or at least, that the majority of the fibres receive an uniradicular innervation.

Summary of experimental results.

In some cases biradicular innervated segments of the rectus abdominis muscle show division in districts ("cantonnement"); the medullar roots innervating the muscle parts each supply a distinct territory with fibres. The large majority of the muscle fibres receives in those cases uniradicular innervation.

2. In other cases both spinal roots distribute their fibres throughout the muscle segment. But double innervation does no more exist than in the former case; the majority of muscle fibres receives its innervation from one single medullar root.

Conclusion.

Sometimes the muscle segments of the M. Rectus abdominis of the dog

that are innervated by two spinal roots show district formation; sometimes the territories of the roots are completely mixed. But each fibre is innervated by one root only (uniradicular). If biradicular innervation be present, it occurs as an exception. If those data be applied to the segmental origin of muscle, the following conclusion is justified: sometimes in the rectus abdominal muscle of the dog the contractile substance originating from two myomers remains partly separated (district formation), sometimes intensive mixing may take place. The experimental results do not allow to assume the occurrence of amalgamation of contractile material.

EXPLANATION OF THE FIGURES.

Fig. 1. Tetanic stimulation of short duration, first of the cranial than of the caudal nerve supplying M 4, with the same faradic current. Time in seconds.

Fig. 2. Tetanic stimulation of long duration of caudal nerve supplying M 4. After marked fatigue of the muscle the POHL's switch is turned, enabling the stimulation of the cranial nerve with the same current. Time in seconds.

Fig. 3. Consecutive stimulation of short duration with the same current of cranial and caudal nerve separately. After this a series of stimulation: *A.* of cranial nerve only; *B.* of both nerves simultaniously; *C.* of cranial nerve only. Time in seconds.