A CONTRIBUTION TO NEUROMUSCULAR SPINDLES IN SOME EXTRA-OCULAR MUSCLES IN MAN

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INTRODUCTION

Much work was carried out on muscle spindles as sensory end organs in the various skeletal muscles of the body. Sherrington (1894) was one of the pioneers who gave a detailed description of their structure as well as their role in maintaining the body position and coordination of muscle movements.

The presence of muscle spindles in the extra-ocular muscles was the subject of many investigations in various animal species where they were found in the ox by Crevatin (1900) and Dogiel (1906) as well as in the sheep by Cilimbarais (1910). Their detection in man was denied by Woollard (1931), Irvine (1934), Marson (1941), Adler (1945) and Cogan (1948) who believed that the extra-ocular muscles lack proprioceptive innervation. Furthermore, Cooper et al (1955) failed to notice such spindles in the extra-ocular muscles of macaque monkey in spite of the fact that they recorded reflex activities after their stimulation. However, Daniel (1946) examined transverse sections in human extra-ocular muscles and was able to observe groups of muscle fibres enclosed in connective tissue capsule which he described as small muscle spindles.

Several attempts have been made to count muscle spindles in the extra-ocular muscles of man and animals. Cooper and Daniel (1949) counted 47 spindles in the inferior rectus muscle of man while Marillees et al (1950) succeeded to find as many as 71 spindles in one of the human extra-ocular muscles. Cooper et al (1951) recorded 120 spindles in one of the extra-ocular muscles of the goat but Green and Jampel (1966) found only 6 spindles in one of the extra-ocular muscles in the macaque monkey. Harker (1972) and Browne (1975) pointed out that the extra-ocular muscles of the sheep were richly supplied with muscle spindles.

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Spindles in the extra-ocular muscles were found by Cooper and Daniel (1949) to be mainly aggregated close to the muscle origin while they were fewer in number near the insertion and none at the middle zone of the muscle belly.

Muscle spindles in the extra-ocular muscles have been noticed to possess special structure. They are small with a very thin delicate capsule of two to three lamellae which is more easily seen in transverse sections at the central zone of the spindle (Cooper and Daniel. 1949). These authors stated that the intrafusal muscle fibres extended through the whole length of the spindle with no bags of clear nuclei as those found in the lumbrical muscles. In their human specimens, they counted 2-10 intrafusal muscle fibres having nearly the same diameter as that of the nearby extrafusal fibres. Similar description was also given by Green and Jampel (1966) in the macaque monkey. As regards the nuclear bag fibres and nuclear chain fibres they were only demonstrated by Harker (1972) in the sheep.

The apparent controversy seen in the previous review as regards the presence or absence of spindles in the extra-ocular muscles in different species stimulated the present workers to further investigate muscle spindles in the human eye muscles. In this work, it was attempted to clarify the structure and distribution of muscle spindles in relation to the point of nerve entry in both the lateral and medial recti. These muscles were particularly selected because of their simple and opposing actions and therefore, the relationship between the number of spindles and the muscle function may be inferred.

MATERIAL AND METHODS

The specimens used for this investigation included 8 medial recti and 8 lateral recti muscles taken from four newly born infants in addition to one human lumbrical muscle taken for comparison. The total length of the lateral and the medial recti was measured from their origin to their insertion. The nerve supply of these muscles was traced and the distance between the points of nerve entry and the origin of the muscle was measured. Serial sections of the muscles were cut either transversely or longitudinally at 10 *u* thickness and were stained with haematoxylin and eosin, van Geison or with silver nitrate impregnation. The sections were examined serially for the presence of muscle spindles or any other free nerve endings. Spindles found were counted and their structure was studied. The connective tissue content of the muscles was compared with that found in the lumbrical muscle examined and the nerve bundles and nerve trunks were all noticed.

RESULTS

Muscle spindles are found in the examined lateral and medial recti muscles of man. They are short, having a length ranging from 30-50u in the lateral rectus and from 30-60u in the medial rectus. These spindles have a thin capsule which is clearly seen as a rounded ring in the transverse sections taken at the middle zone but becomes less apparent towards its poles (fig. 1). It consists of 2-3 lamellae of fibrous tissue with flat nucleated cells and is crossed by connective tissue trabeculae, nerve filaments and blood vessels. The intrafusal muscle fibres are nearly equal in diameter to the extrafusal muscle fibres and showing transverse striations (fig. 1). Their number ranges from 2 - 8 with the majority of spindles (mode) having three intrafusal fibres. Their nuclei are peripherally placed and neither bags nor chains can be detected in any of the spindles found.

The number of spindles in the lateral rectus muscle ranges from 20 to 37 spindles while those in the medial rectus ranges from17 to 34. Most of the spindles are situated near the origin of the muscle while few are found near the insertion in the eye globe. The middle zone of the muscle is devoid of muscle spindles in all the specimens examined except in one case (4%) where one spindle is noticed in the central belly of the muscle. Spindles are placed near the outer surfaces (in contact with the orbital walls) of both the lateral and medial recti.

Spiral nerve endings have been noticed winding around some of the individual extrafusal muscle fibres in silver preparations (fig. 2).

In the specimens examined, the nerve is seen to enter the muscle at the junction of its posterior and middle thirds. The length of the medial rectus ranges from 2.4 to 3.5cm with the points of nerve entry ranging from0.8to1.4cm from the muscle origin while the length of the lateral rectus ranges from 3.1 to 3.8cm and the points of nerve entry ranging from 0.9 to 12.cm from the muscle origin.

The nerves supplying the extra-ocular muscles are relatively thick in diameter as compared with the size of the muscle particularly in the lateral rectus (fig. 3). These nerves show profuse branchings amidst the muscle fibres.

A very striking feature of the extra-ocular muscles examined in man is that they are surrounded by a very thick capsule of connective tissue in addition to the presence of a dense network of connective tissue among the individual muscle fibres (figs. 4 & 5). Sections of the human lumbrical muscles taken for comparison show that the connective tissue forms septa that surround the muscle bundles rather than the individual muscle fibres.

DISCUSSION

The exact role of muscle spindles as sensory nerve endings inside the skeletal muscles is not yet established. The available literature is devoid of definite evidence supporting any correlation between the number and structure of the spindles and the muscle function. The ambiguity in our knowledge about the presence and importance of muscle spindles was manifested mainly in some muscles such as the lateral pterygoid, mylohyoid and the extra ocular muscles.

It appears that there is species variation in the spindle content of the extra-ocular muscles where some animals as the ox, sheep and goat are richly supplied with these sensory end organs (Crevatin, 1900; Dogiel, 1906; Cilimbaris, 1910 and Cooper and Daniel, 1949), while others like rabbit, Macaque monkey, horse and man are endowed with few spindles or even lack them completely (Cilimbaris, 1910; Hines, 1931 and Woollard, 1931).

The extra-ocular muscles of man, as examined in this Work show peculiar types of muscle spindles which are of short length with thin capsule and containing on the average, three intrafusal muscle fibres. They are clustered near the bony attachement and do not show bag or chain fibres. Such findings have been also reported by Cooper and Daniel (1949) who pointed out that muscle spindles in the extra-ocular muscles did not resemble, in every detail, those present in other somatic muscles. One of the outstanding differences stated by these authors was that the spindles in the extra-ocular muscle had very thin capsule as compared with those in the lumbricals. The delicacy of the capsule may be one of the factors responsible for missing their detection by some previous authors (Woollard, 1931; Irvine, 1934; Marson, 1941; Adler, 1945 and Cogan, 1948). Some explanations have been given in connection with the peculiar thickness of the capsule. Cooper and Daniel (1949) believed that the presence of these muscles within the orbit, which acts as a protective bony shield, makes their muscle spindles not in need for the thick capsules. In addition, the thinness is a functional necessity to help rapid and easy recording of delicate stimuli. In the opinion of the present workers, the presence of a large amount of connective tissue in between the muscle bundles acts as an additional protective factor for both the intrafusal and extrafusal muscle fibres.

It is well known that the intrafusal muscle fibres are markedly smaller in diameter than the extrafusal fibres as far as the limb muscles are concerned (Cooper 1960). However, such difference is not marked in the present study on the extra-ocular muscles of infants. This observation is in agreement with what has been found by Cooper and Daniel (1949) in human adult eye muscles. The finding of minor difference between the intra and extrafusal muscle fibres in the adult human extra-ocular muscles by Cooper and Danial (1949) indicates that the relation in size between the two types of fibres does not change by age. This is not the case with other somatic muscles of the body such as the interossei or lumbricals. In these muscles, the difference in size between the intra and extrafusal fibres increased by age due to a greater increase in the size of the extrafusal fibres (Forster, 1902 and Cooper and Daniel, 1963). It is worthmentioning that the extra-ocular muscles possess extrafusal fibres which are smaller in size than those of most of the other somatic muscles of the body (Wohlfart, 1935 and Voss, 1935).

The muscle spindles are noticed to lie mainly near the bony origin where the nerve enters the muscle. They are scarce at the attachment in the fibrous sclera and practically absent in the central belly of the muscle. Similar observations on the extra-ocular muscles have been previously recorded by Cooper and Daniel (1949). This is in conformity with the general observation that the muscle spindles are usually concentrated in the region where the nerve enters the muscle belly (Cooper, 1960).

The count of the spindles in both the lateral and medial recti muscles shows that the range of difference between the two sides is from 4 to12 spindles. The available evidence obtained from most cases examined in this work refers to the preponderance of muscle spindles in the lateral rectus on the right side while the reverse is true as regards the opposite eye where the medial rectus, except in one case, contains larger number of spindles. In the available literature, there is no detailed counts of the spindles in the human extra-ocular muscles except for the inferior rectus (Cooper and Daniel, 1949).

In the present work, the extra-ocular muscles are noticed to contain a large amount of connective tissue stroma condensed in between fine muscle bundles. This finding has been also observed by Schiefferdecker (1941) who assumed that the function of the connective tissue is to bring the muscle back to its resting length after contraction of its antagonist, a mechanism that takes the place of a stretch reflex initiated by proprioceptors. Stretch of a healthy muscle is believed by Clemessen (1951) to be resisted by the presence of connective tissue ensheathing the muscle fibres as well as by the active tone of the neuromuscular spindles. It is possible to assume a further role for the firm connective tissue, surrounding the muscle as a whole and intermingling between its bundles, to act as an amplifier for the impulses originating in the muscle spindles by increasing the tension inside the muscle.

The extra-ocular muscles, in general, are highly active muscles, therefore, they should be endowed with a highly active neuromuscular mechanism. The presence of muscle spindles with their thin capsules together with the dense connective tissue and the finding of too much nerve fibres inside the muscle may be the responsible structural elements in such mechanism.

SUMMARY

Serial sections of lateral and medial recti muscles taken from four human infants were studied. The neuromuscular spindles found were not typical in structure as they were of short length with a very thin capsule and possessing a few number of intrafusal muscle fibres. Neither bags nor chains were observed in the intrafusal muscle fibres. Most of the spindles were present in the posterior third of the muscle where the nerve supply was found entering.

The connective tissue content of the extra-ocular muscles was excessive as it was found to form a very thick capsule around the muscle and a very dense network inside it. It is believed that this connective tissue in addition to its protective role for both the intra and the extrafusal muscle fibres, amplifies the impulse originating from the muscle spindles by increasing the tension inside the muscles.

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LEGENDS

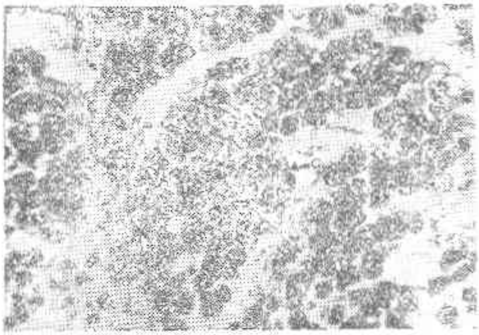
Fig. (1) : T.S. in a human lateral rectus muscle showing a muscle spindle with a very thin capsule (C). The intrafusal fibres are nearly of the same size as the extrafusal fibres. A nerve trunk (N) is seen beside the muscle spindle.
(Hx. & E. . . . X 600).

Fig. (2) : L. S. in the medial rectus muscle showing a spiral nerve ending (sp.). (Modified Glee's silver impregnation method . . . . X 600).

Fig. (3) : L. S. in the lateral rectus showing a large number of nerve bundles (N) intermingling with the small muscle bundles (M).
(Hx. & E. . . . X 60).

Fig. (4) : L.S. in the medial rectus showing a very thick capsule (C) of connective tissue surrounding the muscle.
(Hx. & E . . . . X 25).

Fig. (5) : L. S. in the medial rectus showing dense network of connective tissue (C. T.) separating fine muscle bundles.
(Hx. & E . . . . X 300).



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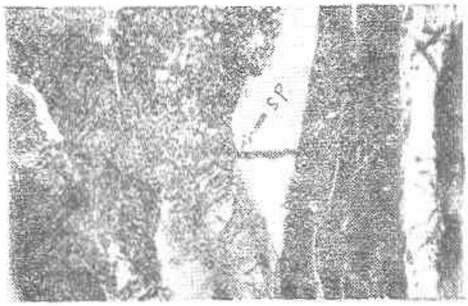

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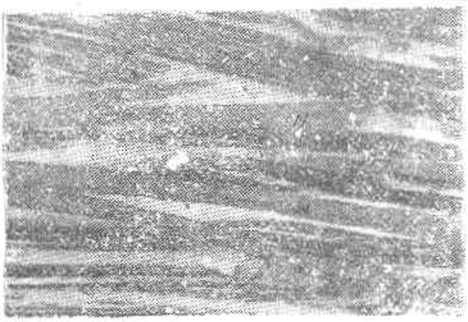

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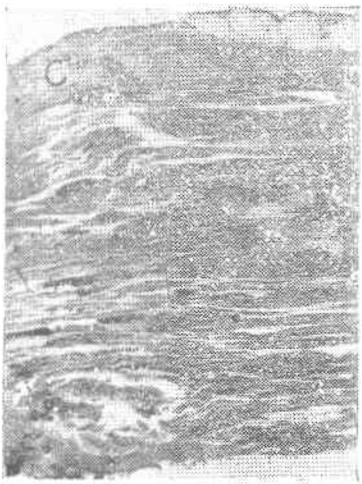

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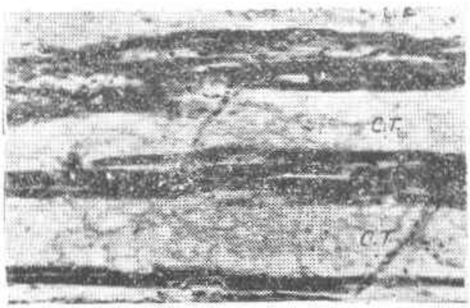

Fig. (5)