also feeds on bottom dwelling crabs and other crustacea. The distribution of prey governs the movement of pollock[7]. Experiments on fish kept in captivity at Woods Hole have shown that pollocks capture their food more by keen sight than by scent[5].

The behavior patterns of these fishes are obviously different. The yellowtail and hake are sluggish swimmers and are bottom dwellers in adult life. The pollock, in contrast, may be found in any part of the water column using its keen sight to actively pursue its prey. We conclude that the function of these triple cones cannot be deduced based on the behavioral patterns of these 3 fishes. It is, however, intriguing that many fishes in the Woods Hole area possess this unusual photoreceptor structure.

1 We wish to thank Kathleen French for her advice and criticism in the preparation of this paper.

2 M.A. Ali and M. Anctil, Retina of Fishes, An Atlas. Springer-Verlag, Berlin, Heidelberg and New York 1976.
3 R.D. Allen, G.B. David and G. Nomarski, Z. wiss. Mikrosk. *69*, 193 (1968).
4 H.B. Bigelow and W.C. Schroeder, Fishery Bull. Fish Wildl. Serv. U.S. *53*, 249 (1953).
5 C.J. Herrick, Bull. U.S. Fish Commn *22*, 258 (1904).
6 H.B. Bigelow and W.C. Schroeder, Fishery Bull. Fish Wildl. Serv. U.S. *53*, 221 (1953).
7 H.B. Bigelow and W.C. Schroeder, Fishery Bull. Fish Wildl. Serv. U.S. *53*, 213 (1953).

Ultrastructure of muscle spindles in C57BL/6J dy^{2J}/dy^{2J} dystrophic mice[1]

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Summary. The sensory organs of skeletal muscles, the muscle spindles, were examined using electron microscopy in dy^{2J}/dy^{2J} dystrophic mice. Despite widespread damage to the extrafusal (skeletomotor) fibres the intrafusal (spindle) fibres appeared normal and seemed resistant to the aetiological factors for murine dystrophy.

Muscular dystrophy is a term used to describe a variety of inherited progressive diseases of skeletal muscle. In the mouse, there exists a muscular dystrophy caused by an autosomal recessive gene (denoted *dy*). This well known muscular dystrophy has been extensively studied as it has been considered a model for human Duchenne[2,3] and extraocular[4] muscular dystrophies because of the similarities in muscle histology. More recently, a 2nd progressive hereditary mouse myopathy has been discovered in which neurological abnormalities are also present[5-7]. This disease is caused by a 2nd allele (denoted dy^{2J}) at the *dy* locus. Histochemical and morphological studies of extrafusal muscle fibres in dy^{2J}/dy^{2J} mice have recently been described[8,9].

Although the pathological changes in murine muscular dystrophy are commonly attributed to a primary abnormality of the muscle fibres, there is evidence to suggest that muscular dystrophy could be attributable to neuronal abnormalities[7,10-12] particularly in dy^{2J}/dy^{2J} mice. This became known as the 'neurogenic hypothesis'. Electron microscopical studies of the richly innervated sensory organs of skeletal muscles, the muscle spindles, in 129 ReJ *dy/dy* dystrophic mice have shown that, contrary to expectation, they appear normal. Consequently, partial rejection or modification of the neurogenic hypothesis was proposed[13].

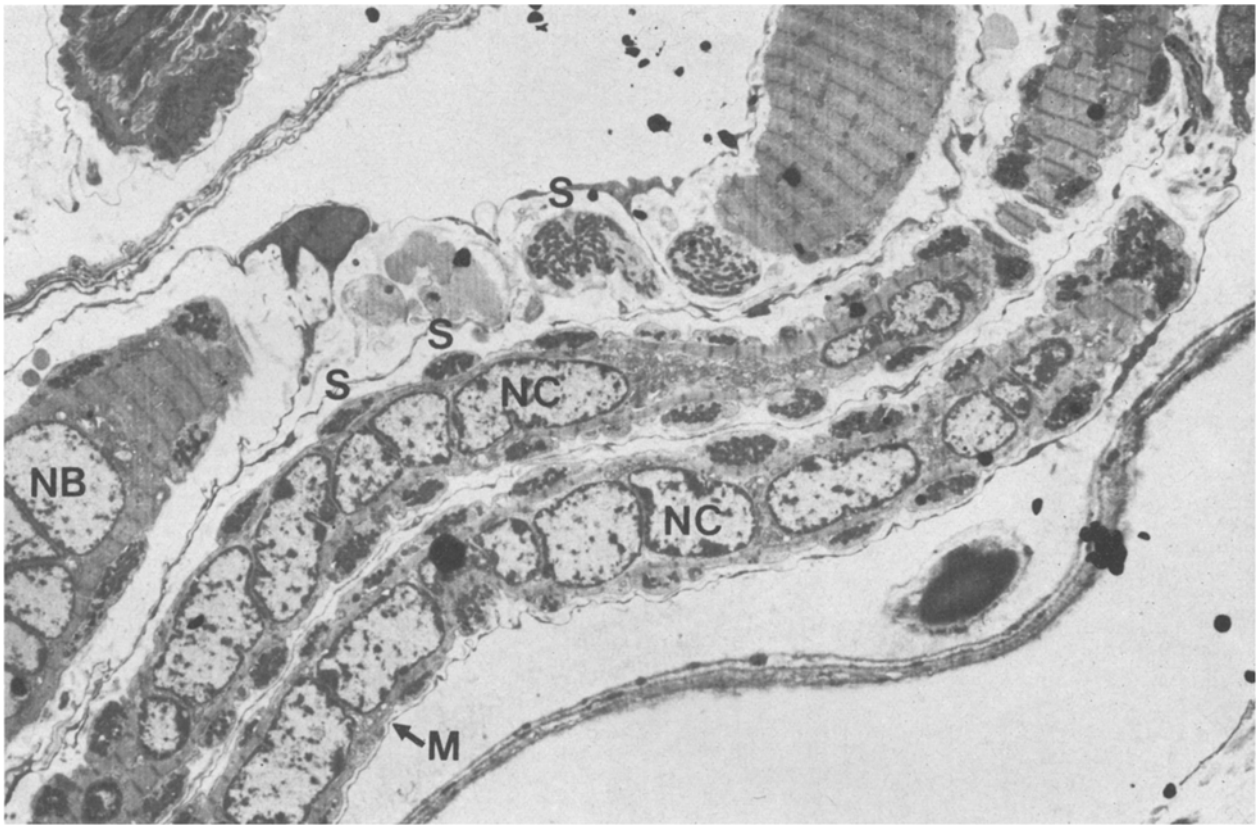
The present study was undertaken to establish whether there are any ultrastructural changes detectable in the intrafusal fibres in muscle spindles of dy^{2J}/dy^{2J} dystrophic mice. Any evidence suggesting that intrafusal muscle fibres are capable of resisting the pathological processes that induce changes in the extrafusal fibres would be of considerable interest.

Specimens of extensor digitorum longus muscles were obtained from 6 clinically affected dy^{2J}/dy^{2J} dystrophic mice at 3 months of age and from 6 non-littermate controls and prepared for electron microscopy as described previously[13,14]. 15 spindles were found in dystrophic muscle. Ultrathin sections were cut from the spindles at intervals along most of their lengths. Some spindles were also examined in longitudinally-cut sections.

The dystrophic spindles contained an average of 4 intrafusal fibres ranging from 3 to 7 fibres. Nuclear bag fibres contained up to 3 nuclei and a peripheral rim of myofilaments in each equatorial cross section and could be clearly differentiated from the narrower and shorter nuclear chain fibres which contained singly occurring central nuclei. Both the major types of intrafusal fibre contained numerous myofilaments in their polar regions. Nuclear bag fibres tended to contain confluent masses of myofilaments interspaced with relatively infrequently occurring mitochondria of variable size. In a few nuclear bag fibres the mitochondria were of more regular size and more evenly dispersed throughout the fibre cross sections. These 2 types of nuclear bag fibre correspond to those previously designated as types 2 and 3 respectively[13,15]. Nuclear chain fibres contained groups of myofilaments which formed relatively discrete myofibrils often separated by numerous mitochondria. In both nuclear bag and nuclear chain fibres the number of myofilaments was markedly reduced in their equatorial regions compared with their polar regions. Numerous dilated terminal cisternae of triads typical of those previously reported in the mouse[12] and in other species[16] were also found.

Satellite cells were found lying between the basement membrane of the intrafusal fibres and their plasma membranes. They seemed inactive because their relatively small amounts of cytoplasm contained few ribosomes and little rough endoplasmic reticulum. All intrafusal fibres examined received a direct sensory innervation without intervening basement membrane.

Each spindle was seen to possess a prominent periaxial space containing a characteristic flocculent precipitate. Typically, aggregations of the precipitate could be found close to inner capsule cells on the side facing the intrafusal fibre. The periaxial space was bounded by a capsule consisting of up to 5 or 6 layers of perineural epithelial



Longitudinal section of equatorial region of a muscle spindle in a clinically dystrophic mouse. 2 major types of intrafusal fibre can be differentiated. Nuclear bag fibres (NB) are relatively broad and contain relatively few mitochondria. Nuclear chain fibres (NC) are relatively narrow and contain more numerous mitochondria particularly along their central axes. Primary sensory endings (S) contain numerous mitochondria and encircle all intrafusal fibres. The equatorial reduction in myofilament (M) content when compared with polar region as in typical normal spindles is clearly seen. × 1950.

cells. Each of these cells contained numerous pinocytic vesicles. The capsule of each spindle enclosed the muscle fibres for most of their lenghts except close to their insertions into perimysium. Capillaries were never seen to penetrate the capsule and enter the periaxial space.

None of the spindles in dy^{2J}/dy^{2J} dystrophic muscles contained any ultrastructural abnormality and did not appear to differ qualitatively from normal spindles. Quantitative differences between dystrophic and normal spindles in their organelle content could exist but they could only be detected using stereological techniques specially derived for anisotropic tissue[17].

These findings have important implications for the aetiology of murine dystrophy and for the properties of intrafusal muscle fibres. If the neurogenic hypothesis is true then abnormal features of the richly innervated intrafusal fibres would be expected. In their demonstrable absence, however, partial rejection or modification of the hypothesis is necessary. For example, either the sensory or the γ-motor supply of the spindle must be selectively spared from the neurogenic process or the intrafusal fibres may be resistant to the supposed neurogenic influence. Should future investigation reveal that mouse muscle spindles receive significant additional β-innervation in which single axons innervate both intrafusal and extrafusal fibres, then further support for the notion of intrafusal resistance to neurogenic influences might be forthcoming. Alternatively, if a myogenic process is responsible for the observed pathological changes then intrafusal fibres clearly have some mechanism by which they escape damage. Further studies on these 2 possibilities seem worthwhile. The findings may be relevant to many human diseases in which the intrafusal fibres seem relatively unaffected, at least when using light microscopical techniques[18,19].

1 This work was supported by grants from the Medical Research Council and the Science Research Council of Great Britain.
2 A.M. Michelson, E.S. Russell and R.J. Harmon, Proc. natl Acad. Sci. *41*, 1079 (1955).
3 B.Q. Banker, J. Neuropath. exp. Neurol. *26*, 259 (1967).
4 B.R. Pachter, J. Davidowitz and G.M. Breinin, Invest. Ophthal. *11*, 715 (1972).
5 M. Kuno, in: Amytrophic Lateral Selerosis: Recent Research Trends, p. 135. Academic Press, New York 1977.
6 H. Meier and J.L. Southard, Life Sci. *9*, 137 (1970).
7 R. Parson, Nature *251*, 621 (1974).
8 L.B. Dribin and S.B. Simpson, Exp. Neurol. *56*, 480 (1977).
9 J. Butler and E. Cosmos, Exp. Neurol. *57*, 666 (1977).
10 A.N. McComas, Nature *251*, 569 (1974).
11 C.A. Stirling, J. Anat. *120*, 169 (1975).
12 A.C. Peterson, Nature *248*, 561 (1974).
13 N.T. James and G.A. Meek, Nature *254*, 612 (1975).
14 N.T. James and G.A. Meek, J. Ultrastruct. Res. *43*, 193 (1973).
15 N.T. James, Histochem. J. *3*, 456 (1971).
16 N.T. James and G.A. Meek, J. Anat. *116*, 219 (1973).
17 N.T. James, in: Analytical and Quantitative Methods in Microscopy, p. 1. Ed. G.A. Meek and H.Y. Elder. California University Press, 1977.
18 G. Cazzato and J. Walton, J. neurol. Sci. *7*, 15 (1968).
19 A. Patel, V. Lalitha and D. Dastur, Brain *91*, 737 (1968).