SATELLITE CELL OF SKELETAL MUSCLE FIBERS

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In the course of an electron microscopic study of the peripheral region of the skeletal muscle fiber of the frog, the presence of certain cells, intimately associated with the muscle fiber, have been observed which we have chosen to call *satellite cells*. Since these cells have not been reported previously and indeed might be of interest to students of muscle histology and furthermore, as we shall suggest, might be pertinent to the vexing problem of skeletal muscle regeneration, a brief communication describing this finding is warranted prior to a more detailed study.

The observations reported here have been made on bundles of fibers dissected from the tibialis anticus muscle of the frog. The material has been fixed by the conventional method with osmium tetroxide, and the embedding has been carried out with methacrylate and with epoxy (epon) resin. In sections that were "stained," the lead hydroxide solution of Watson (1) was used. As seen in the attached electron micrograph of the satellite cell, the striking paucity of cytoplasm relative to its nucleus results in the cell assuming the shape of the nucleus. In fact, it is virtually impossible to discern the cellular nature of this entity in the light microscope, as it appears to be indistinguishable from a peripheral muscle nucleus proper. In electron micrographs the cell is seen "wedged" between the plasma membrane of the muscle fiber and the basement membrane, which invests the fiber throughout its length in close association with the plasma membrane. The intimacy of this satellite cell with respect to the multinucleate muscle cell is further revealed in the fact that, in general, the surface of the muscle fiber is not distorted outward but instead the satellite cell protrudes inward pushing the myofibrils of the muscle cell aside. On the inner surface, the plasma membrane of the satellite cell is in appositon with the plasma membrane of the muscle cell.

Unfortunately, because of the limited observations and the difficulty in acquiring sufficient data readily with electron micrographic techniques, it is not possible at present to estimate the frequency of occurrence of these cells in a typical muscle fiber in our preparation of tibialis anticus muscle. The only generalization warranted at this time is that the peripheral muscle nuclei proper occur much more frequently than the satellite cells.

It is interesting that upon alerting other investigators to these findings, similar cells have been found in electron micrographs of two other muscles of the frog, namely sartorius (2) and ileofibularis (3), and of the sartorius and tongue muscle of the white rat (4). (Though the direct evidence is restricted to these two vertebrates, it seems reasonable to hazard a guess that skeletal muscle fibers of vertebrates in general contain satellite cells.)

It is tempting to speculate about the origin and the role of the satellite cells. Before stating the several possible hypotheses that have figured in our interpretations, it is pertinent to recall a most striking characteristic of regenerating muscle fibers in the least ambiguous case where the sarcolemma-tube remains intact, the myoplasm having undergone hyaline formation and retraction as a result of trauma. Within 48 hours a marked presence of "free cells" is noted in the empty tube, the cells appearing both as "round" and "fusiform" types (5). Moreover, in tissue culture studies of mature skeletal muscle explants, free cells are also seen emanating from the explant. The central question must be asked: what is the origin of these cells? Most cytologists lean toward the interpretation that surviving nuclei in the damaged multinucleate muscle cell give rise to single cells by "gathering up" cytoplasm from the sarcoplasm of the muscle cell—an unusual mechanism, however, for vertebrate systems. If this point of view is taken, the first and immediate hypothesis suggests itself, namely, that in the resting state some cells are being produced at a slow rate by the above mechanism and reside just outside the plasma membrane of the muscle cell, and that upon being stimulated by trauma, *e.g.* ischemia, mechanical compression, toxic agents, etc., the rate of production of such cells is increased.

The second hypothesis, more in keeping with conventional notions of cytology, is that the satellite cells are remnants from the embryonic development of the multinucleate muscle cell which results from the process of fusion of individual myoblasts. Thus the satellite cells are merely dormant myoblasts that failed to fuse with other myoblasts and are ready to recapitulate the embryonic development of skeletal muscle fiber when the main multinucleate cell is damaged. Of course, that both mechanisms might be operating simultaneously as the source of the "free" cells is, indeed, a further possibility since one mechanism need not preclude the other.

A third possibility is that the satellite cells are "wandering" cells that have penetrated the basement membrane and are lying underneath it ready to be mobilized into activity under the proper conditions.

The correct explanation of the origin and role of the satellite cells must await the outcome of further studies.[1]

[1] A thorough search of both Dr. Palade's and Dr. Moore's collection of electron micrographs of cardiac muscle have not revealed either peripheral nuclei or satellite cells. This is consistent with the histological fact that in cardiac cells the nuclei are located only centrally. It is exciting to speculate whether the apparent inability of cardiac muscle cells to regenerate is related to the absence of satellite cells.

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Figure 1

A typical longitudinal view of the satellite cell as it appears in the periphery of the skeletal muscle fiber of the tiabialis anticus of the frog. The extreme poles of the cell are indicated (*sc*). Note that even at the magnification of 10,000 the cell could be dismissed, upon cursory examination, as a peripheral muscle nucleus. The apposing plasma membranes of the satellite cell and the muscle cell can be seen at the inner border of the cell as indicated, by the unmarked arrow. Epon embedding. Unstained. × 10,000.

Figure 2

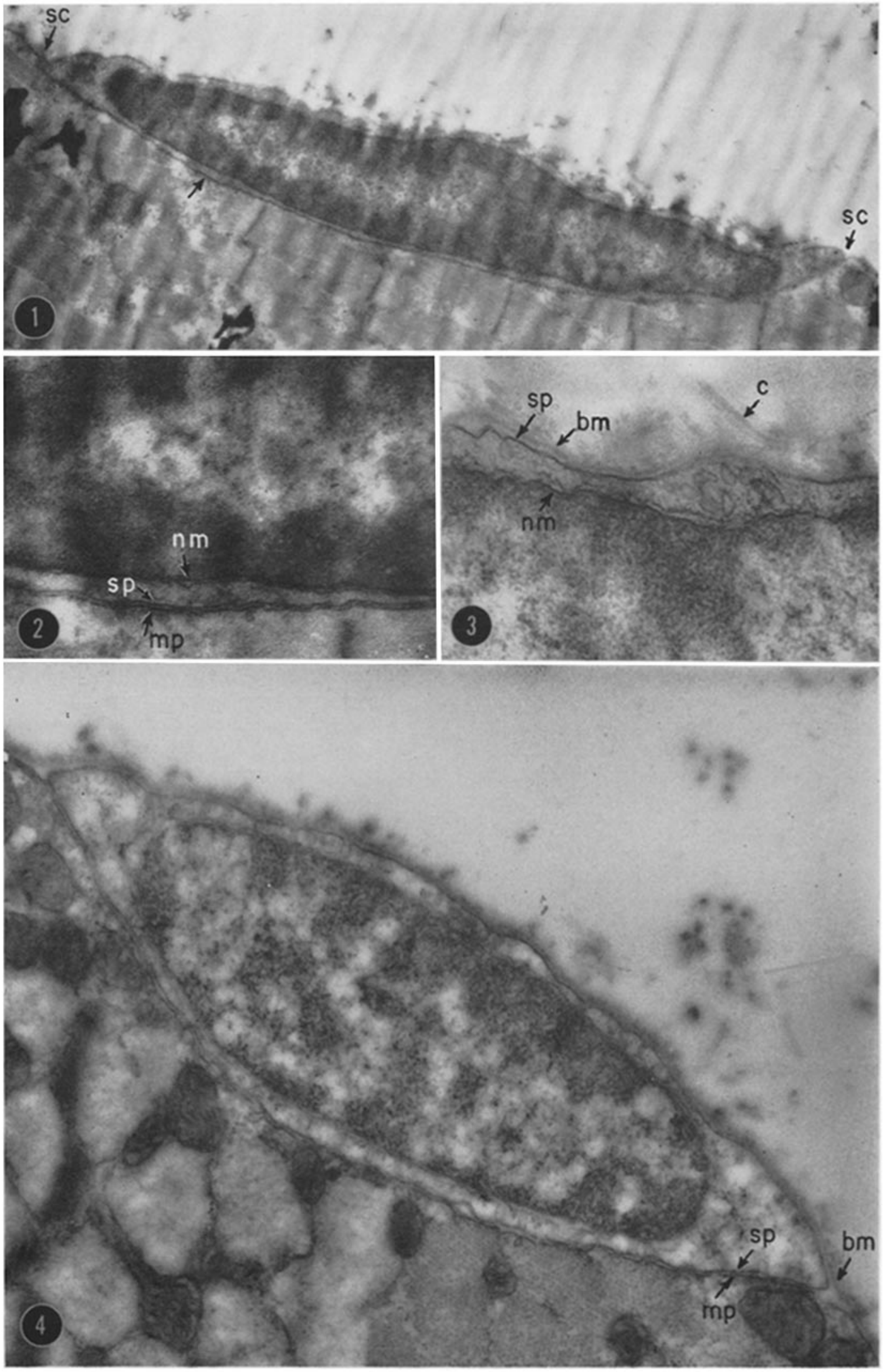
A magnified view of the region indicated by the unmarked arrow in Fig. 1 showing the plasma membrane of the satellite cell (*sp*) and muscle cell (*mp*). The thin layer of cytoplasm between the nuclear envelope (*nm*) and plasma membrane (*sp*) is also seen. × 30,000.

Figure 3

View of another satellite cell showing the outer surface of the cell. The collagen fibrils (*c*) which invest the entire surface of the muscle fiber are seen here in the region of the satellite cell. The basement membrane (*bm*) is seen in close association with the plasma membrane (*sp*) which appears similarly over the entire surface of the muscle cell in association with the plasma membrane of the muscle cell. The cytoplasm of the satellite cell is seen, as in Fig. 2, between the nuclear envelope (*nm*) and the plasma membrane (*sp*). Vesicular components in the cytoplasm, possibly elements of the endoplasmic reticulum, are also seen. Epon embedding. Unstained. × 30,000.

Figure 4

Transverse section of a skeletal muscle fiber from the rat sartorius, furnished by courtesy of Dr. G. Palade. As in Fig. 2, the apposing plasma membranes of the satellite cell (*sp*) and the muscle cell (*mp*) are seen at the inner border of the satellite cell. The basement membrane (*bm*) can be seen extending over the "gap" between the plasma membrane of the muscle cell and the satellite cell. Methacrylate embedding. Stained with PbOH. × 22,000.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