

## THE SITE OF SWELLING IN MUSCLE

E. J. HARRIS. From the Biophysics Department, University College, London

Skeletal muscle responds to hypotonicity by swelling; the same effect is caused if part or all of the sodium salt in the normal solution is replaced by a potassium salt so long as chloride or another penetrating anion is present. In the latter case the KCl acts as a penetrating salt and it

sides. Work on isolated subcellular particles has shown that these respond to osmotic changes (Palade and Siekevitz, 1956; Tedeschi and Harris, 1955; Jackson and Pace, 1956; Tedeschi, 1959). The rate of volume change depends upon the solute as well as other factors; Jackson and

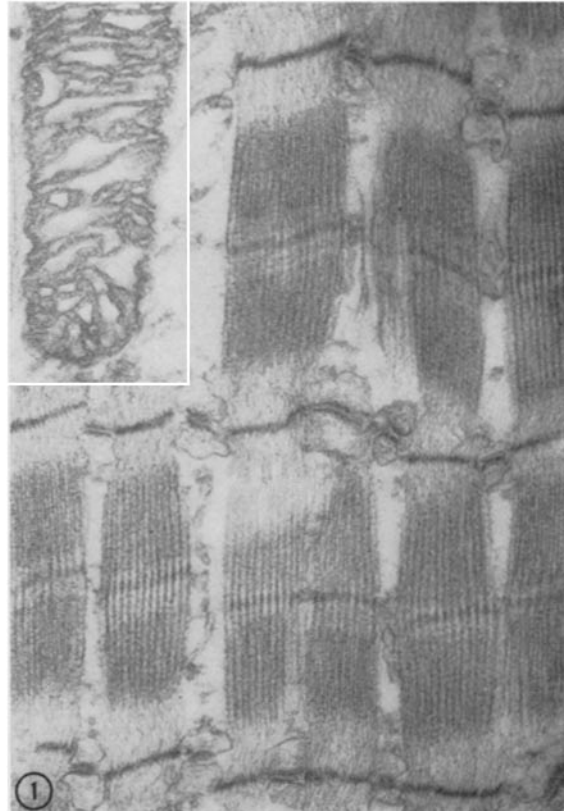


FIGURE 1

Section of swollen muscle and a mitochondrion taken from another part of the field. Before fixation the saline solution had been diluted with  $\frac{1}{2}$  its own volume of water which caused the tissue to swell to 1.2 times its original weight.  $\times 24,000$ .

fails to balance the internal non-penetrating solutes of the muscle cell. The swelling of the whole tissue which occurs with uptake of KCl and water has been discussed by Boyle and Conway (1941). It is important to know where in the muscle cell the osmotically active material re-

Pace observed that KCl or NaCl enters rat liver mitochondria much more rapidly than does sucrose. Mitochondrial volume changes occurring when the particles are still within the cell have been described (Zollinger, 1948). The present observations made with the electron microscope



FIGURE 2

Section of swollen muscle and a mitochondrion from another part of the field. The saline mixture used had 50 mM KCl replacing 50 mM NaCl and when fixed the tissue had swollen to 1.25 times its original weight.  $\times 25,000$ .

of normal and swollen frog sartorius muscle show changes in both mitochondria and reticular elements whose swelling is consistent with their acting as osmometers permeable to KCl.

Micrographs of muscle sections were taken after fixing by adding an equal volume of cold 2 per cent  $\text{OsO}_4$  to the particular solution bathing the tissue at  $0^\circ\text{C}$ . Controls were prepared either (a) using normal saline to which 1 per cent procaine had been added to reduce excitability or (b) using a mixture of 50 mM potassium methyl sulfate with 45 mM sodium methyl sulfate and 20 mM sodium bicarbonate. The muscles do not swell in the latter mixture because the methyl sulfate anion cannot penetrate and the

appearance of the micrographs from the solutions was indistinguishable.

Swollen muscles having about 1.2 times the fresh weight were prepared by 1 hour exposure to hypotonic saline solution having  $\frac{1}{3}$  part water added to the normal solution. Fig. 1 shows that the reticular material is swollen and that the fibrils are separated by areas including unstained material. A portion of a mitochondrion (inset) shows an expansion of the material included between the dark-stained invaginating bands (cristae) which would be consistent with the proposal that the cristae become part of the surface of the swollen particle (Tedeschi, 1959).

Muscles prepared by a 2 hour exposure to a

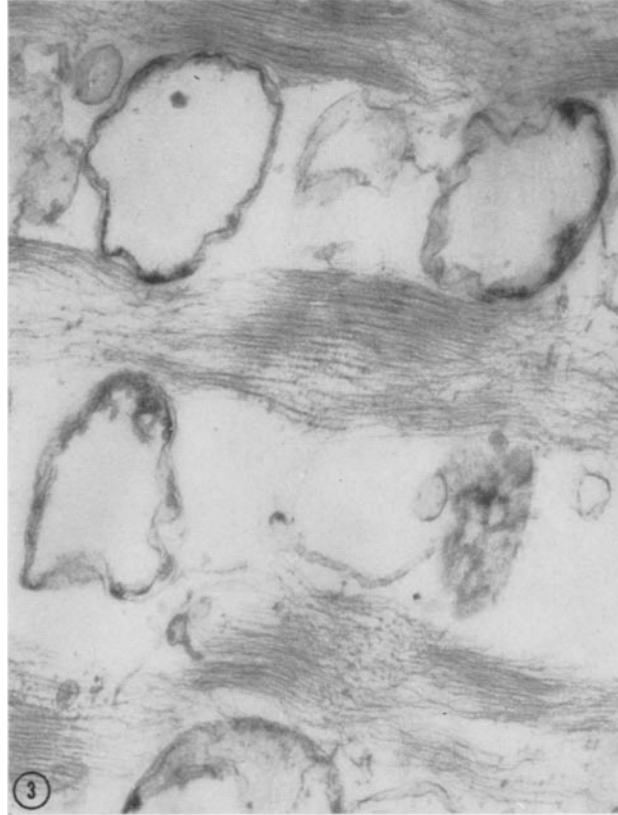


FIGURE 3

Section of swollen muscle fixed after exposure to distilled water.  $\times 24,000$ .

saline mixture having 50 mM KCl replacing its equivalent of NaCl were swollen to 1.25 times the fresh weight; sections from these (Fig. 2) resemble those obtained in the hypotonic medium. From this it is inferred that KCl readily penetrates both the reticulum and the mitochondria.

Muscles subjected to pure water show a disorganisation of their contractile elements in addition to grossly swollen material between the fibrils (Fig. 3). The fibrils seem most disorganised at the positions where normally the Z lines would be seen and in these positions occur the outlines of what were presumably the triads. Since the swelling persists after some hours' exposure, which would be expected to leach out internal salts, it could be due in part to a gel whose volume responds to salt concentration. The volumes of the subcellular elements certainly follow changes of tonicity, as found by the authors cited in the first paragraph, and it appears that the volume of the whole muscle cell responds to the behaviour of

some of its internal elements, others of which are unaffected by tonicity.

I am indebted to Miss P. Y. Dyer, working under the supervision of Dr. H. E. Huxley, F. R. S., for preparing the sections and micrographs.

Received for publication, October 3, 1960.

#### REFERENCES

- BOYLE, P. J. and CONWAY, E. J., 1941, *J. Physiol.*, **100**, 1.  
 JACKSON, K. L., and PACE, N., 1956, *J. Gen. Physiol.*, **40**, 47.  
 PALADE, G. E., and SIEKEVITZ, P., 1956, *J. Biophysic. and Biochem. Cytol.*, **2**, 171.  
 TEDESCHI, H., 1959, *J. Biophysic. and Biochem. Cytol.*, **6**, 241.  
 TEDESCHI, H., and HARRIS, D. L., 1955, *Arch. Biochem. and Biophysics*, **58**, 52.  
 ZOLLINGER, H., 1948, *Experientia*, **4**, 312.