ULTRASTRUCTURE OF SMOOTH-MUSCLE CELLS OF THE CAUDAL VENA CAVA OF ALBINO RATS FOLLOWING INCREASED STRETCHING OF ITS WALL

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An electron-microscopic study was made of the smooth-muscle cells of the caudal vena cava of intact albino rats and of rats 14 days after experimental interference with the drainage of blood. After disturbance of the hemodynamics, the smooth-muscle cells showed signs of activation of protein synthesis, an increase in the number of micropinocytotic vesicles, and a decrease in the number of dense particles.

The ultrastructure of the smooth-muscle cells of mammalian blood vessels under normal conditions has been adequately studied [6, 11-13, 15], but the fine structure of these cells after changes in the hemodynamics has received comparatively little attention [3, 5, 7, 8].

In some previous investigations the drainage of blood from the caudal vena cava of albino rats was used as a model for studying hypertrophy of the muscular coat of the blood vessels [1, 2]. The results showed that, starting from the second week after induced stasis of blood, hypertrophy of the nuclei of the smooth-muscle cells and evidence of activation of protein synthesis in them were visible [1, 2]. However, the results required further electron-microscopic confirmation. In particular, it was not clear whether the structure of the contractile system of the smooth-muscle cells is modified as the result of its hypertrophy.

EXPERIMENTAL METHOD

To shed light on the problems which had not been cleared up by the previous investigation, the caudal vena cava was constricted in male Wistar rats weighing 160 g by the standard method [1]. After 14 days under ether anesthesia (two experimental and two control animals), pieces of the caudal vena cava were excised and fixed in buffered OsO_4 solution by the usual method [9] at 4°C. The material was embedded in Araldite-212. Sections were cut on the LKB-4801A ultratome, shadow-cast by Watson's method [17], and examined in the UEMV-100V microscope. In addition, total preparations of the caudal vena cava of these animals were fixed in neutral formalin and stained with Heidenhain's iron hematoxylin for comparison with the electron-microscopic data.

EXPERIMENTAL RESULTS

In sections stained with iron hematoxylin and examined under the light microscope, these smooth-muscle cells of the caudal vena cava were 80-120 μ long and 5-6 μ wide; their nuclei were 20-35 μ long and 2-3 μ wide. These cells appeared spindle-shaped, with a few (one or two) processes leaving the cell body near its middle at an acute angle to its long axis.

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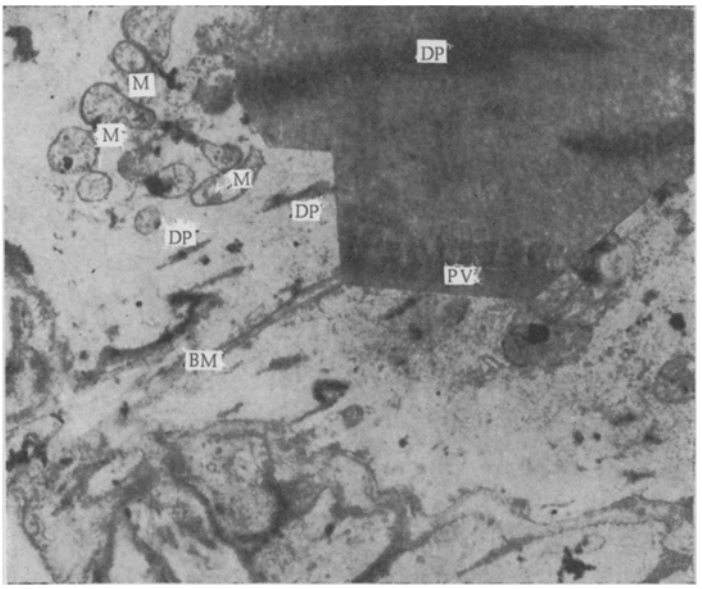

Fig. 1. Smooth-muscle cell of the caudal vena cava of an intact sexually-mature albino rat: large numbers of dense particles are visible (original magnification 4800 ×). Above on the right, detail of the structure: M – mitochondria; DP – dense particles (12,000×); BM – basement membrane; PV – pinocytotic vesicles.

In the electron micrograph the smooth-muscle cells were flattened in shape. Their nucleus was electron-dense and occupied $^1/_4$–$^1/_5$ of the cell, which was usually elongated in shape with deep indentation. The nucleus was surrounded completely by a double nuclear membrane. The chromatin was uniformly distributed with a slight increase in concentration at the periphery. One or several nucleoli could be seen. The cytoplasm of the smooth-muscle cells of the caudal vena cava had low electron density, and the cell organoids were usually concentrated at the poles of the nucleus. The mitochondria were small, circular or oval in shape, with a few transversely arranged cristae, and they lay in groups (up to 20 in the section) mainly in the central part of the cell. Sometimes mitochondria were seen between the filaments and in the processes. There was a well-developed Golgi apparatus, but the rough endoplasmic reticulum was poorly developed. Free ribosomes and tiny granules of glycogen were observed in the cytoplasm of the smooth-muscle cells, either at their center or at the periphery.

A characteristic feature of the ultrastructure of the smooth-muscle cells was the presence of electron-dense zones in the cytoplasm of the cells and the myofibrils. Electron-dense particles were very numerous (Fig. 1). These were elongated in shape, and some of them were connected to the plasma membrane. Nevertheless, most of them lay freely in the cytoplasm. The myofibrils of the smooth-muscle cells of the caudal vena cava were comparatively short and thin and they did not form bands. They were arranged mainly along the long axis of the cell.

Numerous micropinocytotic vesicles were present in the smooth-muscle cells of the caudal vena cava, and as a rule they were located beneath the sarcolemma, irregularly along the length of the cell. Some micropinocytotic vesicles lay freely in the cytoplasm while others communicated with the intercellular space. The basement membrane surrounding smooth-muscle cells of the caudal vena cava varied considerably in thickness and it was difficult to determine its size. In some places the basement membrane was homogeneous, while in other areas electron-optically dark and light zones were visible.

The place of contact between neighboring smooth-muscle cells (end to end) consisted of long, finger-like processes of cytoplasm surrounded by a basement membrane; many myofibrils and pinocytotic vesicles could be seen in these processes.

The structure of the nucleus was unchanged 14 days after constriction of the caudal vena cava. Often the mitochondria were almost indistinguishable from those in the control, although occasionally their cristae

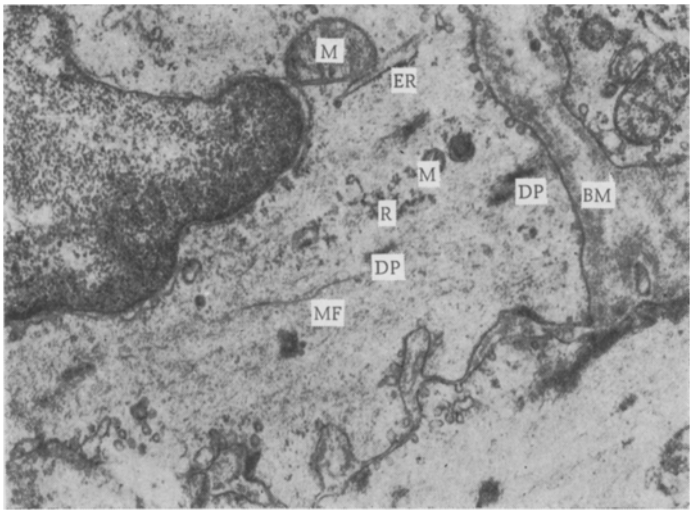

Fig. 2. Smooth-muscle cell of caudal vena cava 14 days after disturbance of blood drainage; slight decrease in number of dense particles, numerous ribosomes, basement membrane not thickened (original magnification 12,000×). ER – endoplasmic reticulum; R – ribosomes; MF – myofibrils. Remainder of legend as in Fig. 1.

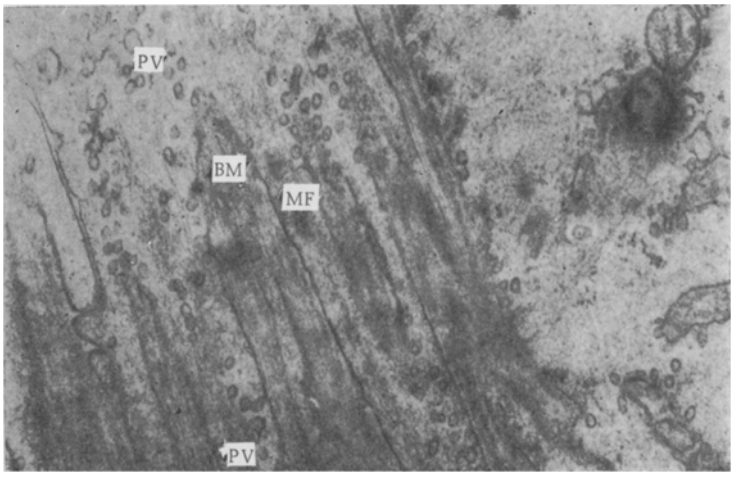

Fig. 3. Place of contact between two smooth-muscle cells of the caudal vena cava of a rat 14 days after interference with the blood drainage (original magnification 12,000×). Legend as in Figs. 1 and 2.

appeared edematous. The number of mitochondria were slightly reduced. The amount of endoplasmic granular reticulum and the number of free ribosomes in the cytoplasm of the cells were increased.

The number and size of the electron-dense particles were considerably reduced (Fig. 2). They were elongated in shape and most of them were located in the sarcoplasm. The myofibrils had a tendency to be grouped into ill-defined bundles, and they were electron-optically denser than in the control. The number of micropinocytotic vesicles was greatly increased (Fig. 3), and in some areas these vesicles formed a chain running into the depth of the cytoplasm, or they were arranged in several rows in the sarcoplasm.

The electron-microscopic findings (an increase in the number of ribosomes, a more powerfully developed, rough endoplasmic reticulum) thus indicate activation of protein synthesis in the smooth-muscle cells of the caudal vena cava after an increase in stretching and hypertrophy of these cells, in agreement with results obtained by other workers [3, 16] and with the results of the present writers' earlier histochemical studies [2]. An increase in the number of micropinocytotic vesicles was discovered; this was related to the brisk transport of materials and is evidence of an increased intensity of metabolism [4].

At this stage of hypertrophy of the smooth-muscle cells no increase in the number or size of the mitochondria could be detected. However, the possibility is not ruled out that changes of this sort could occur at earlier stages of the process, as has been demonstrated in the case of some form of cardiac hypertrophy [10].

The change in the density of distribution of the myofibrils in the hypertrophied smooth-muscle cells could be due to aggregation of the myosin [14], rather than to changes in the strength of the contractile apparatus. The fact is that thin actin filaments are constantly seen in smooth-muscle cells, whereas myosin is found only during contraction of the cell or at a certain pH value [14]. This fact undoubtedly influenced the observed pattern of the contractile structures.

The same can be said regarding the decrease in number of dense particles which was discovered. These particles are of two types [14]: those of the first type are analogous to the discs of cross-striated muscle cells, while the second type is formed of compounds of actin and myosin. Depending on the state of aggregation of the myosin, the number of particles of the second type may vary, as the results of several investigations have shown [5, 8, 12].

LITERATURE CITED

1. O. Ya. Kaufman, Byull. Éksperim. Biol. i Med., No. 11, 117 (1968).
2. O. Ya. Kaufman, in: Physiology and Pathology of the Circulation [in Russian], Moscow (1969), p. 131.
3. E. N. Albert and D. C. Pease, Am. J. Anat., 123, 165 (1968).
4. A. Bozner, F. Inczinger, and E. Mrena, Folia Morphol. (Warsaw), 14, 400 (1966).
5. G. Conti, B. Haennii, L. Laszt, et al., Angiologica, 1, 119 (1964).
6. D. W. Fawcett, in: S. Reynolds (Editor), The Microcirculation (1959), p. 1.
7. D. L. Gardner, J. Path., 97, 51 (1967).
8. B. P. Lane and M. A. Matthews, J. Cell. Biol., 27, 199 (1965).
9. G. E. Palade, J. Exp. Med., 95, 285 (1952).
10. R. Poche, C. M. de Mello Mattos, H. W. Rembarz, et al., Arch. Path. Anat., 344, 100 (1968).
11. E. Reale and H. Ruska, Angiologica, 2, 314 (1965).
12. J. A. G. Rodin, Physiol. Rev., 42, Suppl. 5, 48 (1962).
13. J. A. G. Rodin, J. Ultrastruct. Res., 18, 181 (1967).
14. A. P. Somlio and A. V. Somlio, Pharmacol. Rev., 20, 197 (1968).
15. M. Spitery, J. Nguyen, H. Anh, et al., Path. et Biol., 14, 348 (1966).
16. G. Waldmann, Exp. Path. (Jena), 2, 360 (1968).
17. M. L. Watson, J. Biophys. Biochem. Cytol., 4, 475 (1958).