Ultrastructural Manifestation of Compensatory and Destructive Processes of the Cell Surface of Endotheliocytes in Trauma of the Skeletal Muscle

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In trauma of the skeletal muscle the activation of the cell surface of endotheliocytes acquires a pathological pattern. Enhanced microvilli formation and clasmatosis lead to the formation of free emboli, which results in complete occlusion of the lumen of some vessels. Enhanced formation of microvilli leads to depletion of endotheliocytes, formation of transcellular channels, and necrosis of the vascular wall.

Key Words: *endothelium; clasmatosis; cell surface; trauma of skeletal muscle*

The formation of lacunar invaginations, microvilli, and marginal folds [3,6], which is interpreted by many researchers as an increase in the functional activity of endotheliocytes [1,4-6], is known to be one of the earliest reactions of the membrane in microvessel endothelium in different functional states of an organ or during the development of pathological processes.

In some pathological states marginal folds and microvilli may attain a considerable size. Meanwhile, membrane complexes, which sometimes completely occlude the lumen, are frequently encountered in intact vessels. Signs of tissue destruction are often observed around such vessels. The genesis of such formations is still unclear [2,5], highlighting the need for an ultrastructural analysis of transformations of the cell surface of endotheliocytes in response to a damaging factor.

In this study we investigated reactive changes of endothelium in the crushed skeletal muscle 1, 5, 10, and 30 days and 8 months after trauma.

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MATERIALS AND METHODS

Albino outbred rats weighing 300-360 g were used in the investigation. The muscles of the locomotor apparatus were traumatized after Cannon. Specimens were studied 1, 5, 10, and 30 days and 8 months after trauma. Pieces of the median head of the gastrocnemius muscle were successively fixed in a cool formol-sucrose solution and in 1% buffered osmium tetroxide and embedded in Araldite. Ultrathin sections were examined under a JEM-7A electron microscope.

RESULTS

A study of endothelium of the capillaries of the skeletal muscle in the zone adjacent to necrosis demonstrated that on day 1 after trauma, along with lacunar invaginations of the cell surface, the microvessel endothelium developed long microvilli and marginal folds. In the lumen of some capillaries they formed a thick network of anastomosed folds (Fig. 1, *a*, *c*, and *e*). Although in this case the lumens of the capillaries were markedly diminished, such a reaction of the cell surface may be

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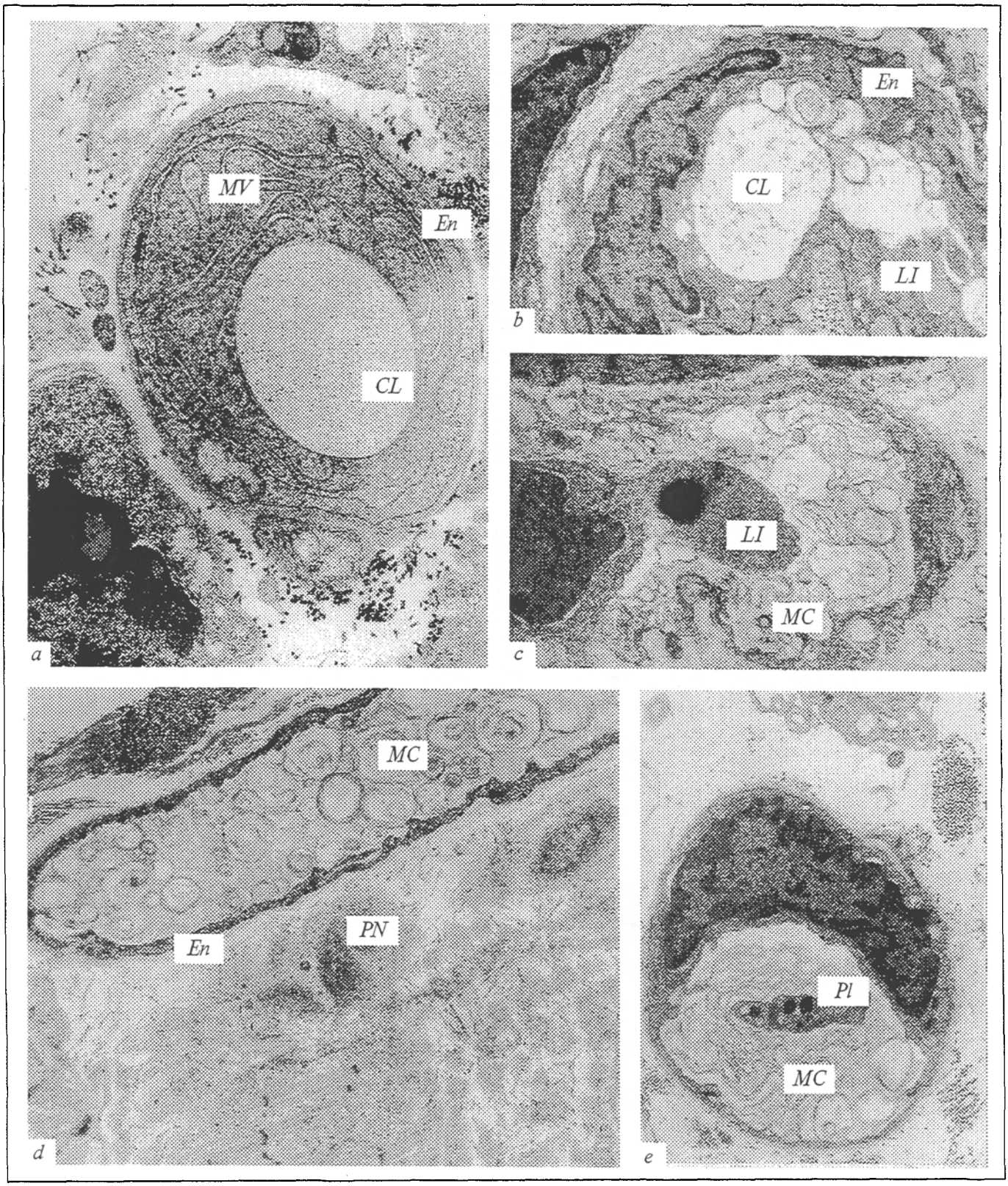

Fig. 1. Transformation of endothelial surface of capillary. *a*) enlargement of endothelial surface of capillary, ×17,000; *b* and *c*) degenerating microvilli and membrane complexes in the capillary lumen, ×10,500; *d*) vessel embolization with membrane complexes, ×10,500; *e*) degenerating membrane complexes, ×11,600. Here and in Figs. 2 and 3: *MV*: microvilli; *CL*: capillary lumen; *En*: endothelium; *LI*: lacunar invaginations; *MC*: membrane complexes; *PN*: perivascular necrosis; *Pl*: platelets.

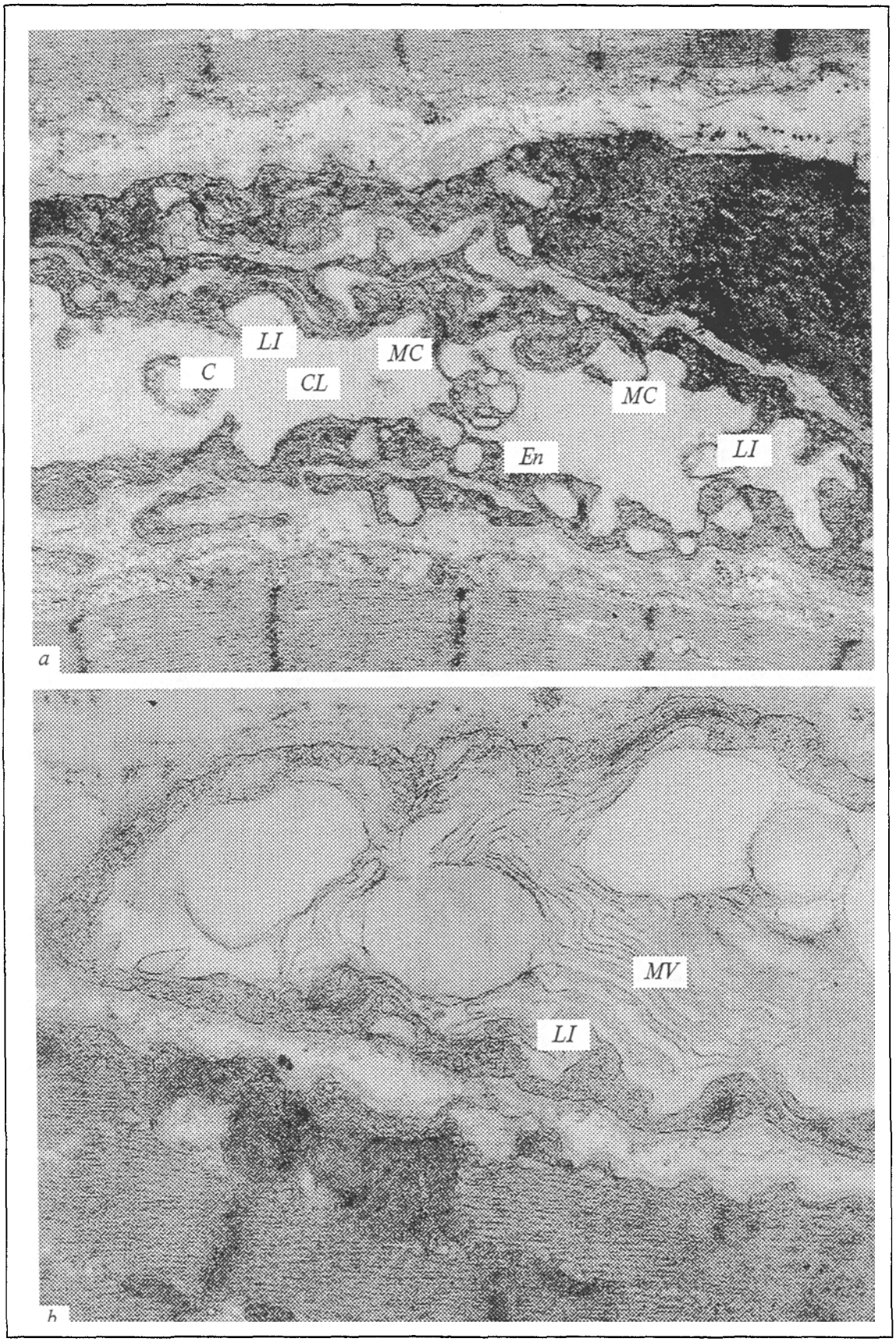

Fig. 2. Reactive changes in endothelial surface of capillary 10 (*a*) and 30 (*b*) days after trauma of skeletal muscle, ×10,500 and ×11,200, respectively. *MF*: marginal folds. Here and in Fig. 3: *C*: clasmatosis.

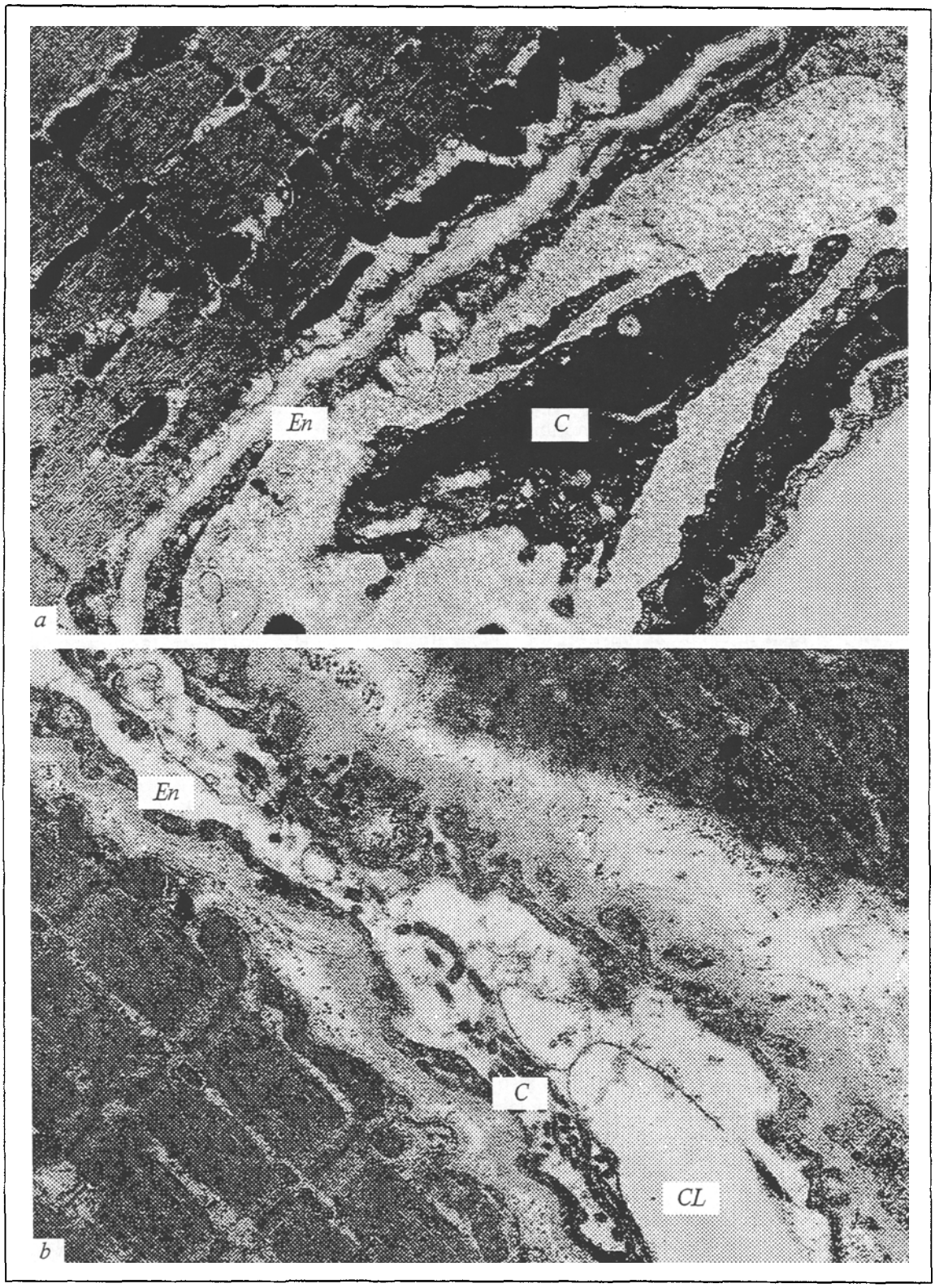

Fig. 3. Transformation of endothelial surface and necrosis of wall of microvessel at later stages after trauma, ×17,000. *a*) microvilli in the capillary lumen and clear nuclear–plasmatic area of endotheliocyte (8 months after replantation); *b*) microvilli proliferation and clasmatosis; necrosis of wall of microvessel.

regarded as a compensatory response aimed at enlarging the exchange surface of the microvessel. In the early stages after trauma the microvilli contained individual cell organelles typical of endothelium: vesicles, ribosomes, and mitochondria (Figs. 1, *a* and 2, *a*). After 7, 10, and 30 days

we observed transformation of microvilli, which gradually lost the cytoplasmic matrix and became converted into empty channels with fine-dispersed contents bounded by elementary membranes (Figs. 1, *e* and 2, *b*). Later, as the cytoplasmic matrix of microvilli washed out, they became transformed into twisted membrane complexes. In some vessels we observed junctions between the membrane complexes and endothelial cell surface (Fig. 2, *b*). In the lumen of such capillaries solitary formed elements of blood were encountered in the thick network of microvilli (Fig. 1, *e*), this being indicative of the capillary bed permeability.

It should be mentioned that such an enlargement of the cell surface was attended by depletion of the vesicular apparatus of endotheliocytes, which is also known to be a reserve of cell membranes. Whereas there were 110-120 vesicles (luminal, basal, and free) per unit area of endothelium in the norm, during microvilli formation their number sharply dropped, and in some capillaries they became solitary (30-40 vesicles per unit area of the vessel). Microvilli and membrane complexes underwent degenerative changes (Fig. 1, *c*), detaching into the capillary lumen and becoming transformed into free emboli (Fig. 3, *b*). At the later stages after trauma (8 months) free membrane emboli could be found in satisfactorily preserved microvessels. Such a vessel is presented in Fig. 1, *d*. The lumen of this capillary is occluded by membrane complexes circulating in the vessels. Perivascular necrosis and sclerosis were frequently noted around such vessels.

The described ultrastructural changes of the endothelial surface of microvessels were persistent and embraced some microvessels. Evidently, they were a result of damaging circulating factors: products of tissue necrosis, PAF (platelet activating factor), and other components released into the blood flow after an extensive injury to the skeletal muscle. Although at the later stages after trauma the described ultrastructural changes were still progressing, the number of injured vessels did not exceed 20% of the total number of the capillary profiles examined. It should be emphasized that we observed at the later stages both initial ultrastructural changes of the endothelial surface (microvilli formation and clasmatosis and detachment of entire nuclear-plasmatic areas of endotheliocytes) (Fig. 3, *a*), and grosser changes, when microvilli growth and clasmatosis resulted in depletion and destruction of the endothelial lining of the microvessels, culminating in some of them in the formation of wide transendothelial channels and ports and in necrosis of the endothelium (Fig. 3, *b*).

Thus, an ultrastructural analysis of the state of the cell surface of endotheliocytes showed that at the initial stages lacunar invaginations, marginal folds, and microvilli formation are, undoubtedly, a manifestation of the activation of the cell surface, and are compensatory in nature. Later, excessive "growth" of the cell surface overcomes and destroys the wall of the microvessel. In this case pinched-off fragments of endothelial cells and twisted membrane complexes are transformed into emboli.

Hence, in assessing the damage-induced response of the cell surface in the endothelium of microvessels, we can recognize compensatory phenomena in the form of lacunar invaginations, marginal folds, and microvilli growth on the cell surface, attesting to increased functional activity of endotheliocytes. Under conditions of trauma of the skeletal muscle changes of the cell surface develop, assume a pathological nature, and lead to the obliteration of some vessels with membrane complexes and to necrosis of the microvessel wall.

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