ULTRASTRUCTURE OF THE APICAL PART OF THE EPITHELIAL CELLS OF THE MUCOUS MEMBRANE OF THE SMALL INTESTINE AFTER EXTENSIVE EXPERIMENTAL ENTERECTOMY

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After extensive enterectomy in dogs, profound ultrastructural changes take place in the epithelial cells of the mucous membrane of the small intestine. The microvilli are reduced in number, considerably shortened, and thickened. Swelling and vacuolation of the mitochondria are observed, the number of mitochondrial cristae is reduced by more than half, and the membranes of the endoplasmic reticulum are swollen and vacuolated.

Insufficient attention has been paid to the study of the morphological characteristics of the intestinal cells after extensive enterectomy, and no reports of electron-microscopic investigations of this type could be found in the accessible literature.

The object of the present investigation was to study the submicroscopic structure of the intestinal epithelium after extensive enterectomy.

EXPERIMENTAL METHOD

Experiments were carried out on four dogs undergoing resection of seven-eighths of the length of the small intestine and subsequent anastomosis of the jejunum to the transverse colon. The mucous membrane of a loop of jejunum was removed for electron-microscopic investigation two months after the operation. An electron-microscopic study was also made of the mucous membrane of the jejunum of four healthy dogs.

The pieces of excised jejunal mucous membrane, measuring 0.5× 1.0 mm, were fixed for 2 h in 2% osmium tetroxide solution in veronal buffer, cooled to 4°C. They were then dehydrated in a series of alcohols of increasing concentration and shadow-cast in 10% phosphotungstic acid solution with the addition of a 2% solution of uranyl acetate in 70° alcohol. The material was embedded in prepolymerized methacrylate. Ultrathin sections were cut on the LKB 8800-A ultramicrotome and examined in the UÉMV-100B electron microscopy with accelerating voltage 75 kV and diaphragm aperture 30 μ. The work was carried out in the laboratory of electron microscopy of L'vov Medical Institute.

EXPERIMENTAL RESULTS

After extensive enterectomy, substantial changes in the structure of the epithelial cells were observed in the mucous membrane of the jejunum. Marked changes were found in the height, arrangement, and structure of the microvilli. As Fig. 1 shows, all the microvilli were deformed, frequently bean-shaped, with a thickening at their base. The ratio between their height and diameter was 7 : 1, compared with 21 : 1 in the control. The number of microvilli per μ^2 surface area of functioning epithelial cell of the mucous membrane was 57 ± 1.7 (control 71 ± 2.5; $P < 0.001$). The surface area of a single microvillus and the surface area of the microvilli per μ^2 of free cell surface also were considerably reduced.

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TABLE 1. Dimensions of Mitochondria and Their Membranes in Apical Part of Epithelial Cell of Jejunal Mucous Membrane of Dog after Extensive Resection of Small Intestine

Parameters of mitochondria	Normal	Two months after resection of small intestine
Length (in μ)	1.0 ± 0.04	1.1 ± 0.04
Diameter (in μ)	0.27 ± 0.006	0.4 ± 0.01
Width of outer membranes (in Å)	168 ± 2.3	239 ± 4.5
Width of inner membranes (in Å)	192 ± 3.4	334 ± 5.9
Number of cristae	27 ± 0.5	13 ± 0.3

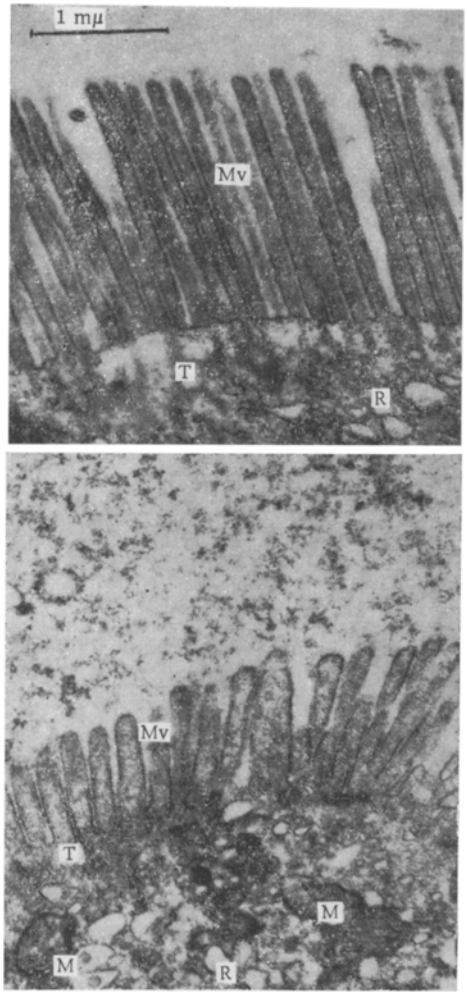

Fig. 1. Longitudinal section through apical part of epithelial cell of jejunal mucous membrane in normal animal (a) and after extensive enterectomy (b). Mv, microvilli; T, terminal network; R, endoplasmic reticulum; 24,000×.

Substantial changes also were found in the mitochondria (Fig. 2A, Table 1). These labile structures were increased in volume in the late postoperative period (2 months), mainly on account of an increase in their diameter (by almost 1.5 times; $P < 0.05$). The number of cristae was reduced by more than half ($P < 0.001$). Besides disappearance of the mitochondrial cristae, an increase in the volume of the central plates (the interiors) of the remaining cristae and a decrease in their length were observed. They were deformed and corrugated in shape (Fig. 2B). The matrix of the mitochondria was clear, it was swollen, and it became increasingly vacuolar in appearance (Fig. 3). The outer and inner membranes were thickened, and ultimately the mitochondria were converted into vesicles, bounded by an outer membrane (Figs. 2B, 3). Meanwhile, the mitochondria distributed around the nucleus (in the basal part) were hypertrophied but showed no signs of disturbance of their fine structure (Fig. 2A).

The ultrastructure or volume of the mitochondria and the activity of the respiratory enzymes have been the subject of repeated parallel investigations which have shown definite correlation between the intensity of respiration and the activity of the respiratory enzymes, on the one hand, and the number of cristae in the mitochondria and the degree of swelling of the mitochondria on the other hand [1, 6, 7, 9]. These changes in the apical part of the epithelial cells of the jejunal mucous membrane can be regarded as reflecting the functional strain on these intracellular structures, whereas the structural changes in the basal part reflect hyperplasia of the organoids in response to the increased functional load [3, 4]. Reconstruction of the damaged mitochondria can take place in the apical part of the cell [2, 3]. Even after loss of their cristae and clearing of their matrix, if the outer membrane remains intact and the pathogenic agent is eliminated, recovery of the damaged mitochondria can evidently take place [3]. When taking note of the profound structural changes in the mitochondria, which evidently reflect regeneration leading to hypertrophy of the residual part of the small intestine, the participation of the endoplasmic reticulum in this process must be borne in mind, for this structure, formed by a complex system of tubules, vacuoles, and cisterns [8], which supplies substrates and materials deficient in the mitochondria, is intimately linked with the mitochondria [1, 5].

It will be clear from Figs. 2B and 3 that marked swelling and vacuolation of the membranes of the endoplasmic reticulum took place in the apical part of the epithelial cells. Initially, the membranes of the endoplasmic reticulum evidently broke up into small vesicles (Fig. 3), filled with amorphous material of low electron density, and these subsequently dilated and were converted into large vacuoles. These ves-

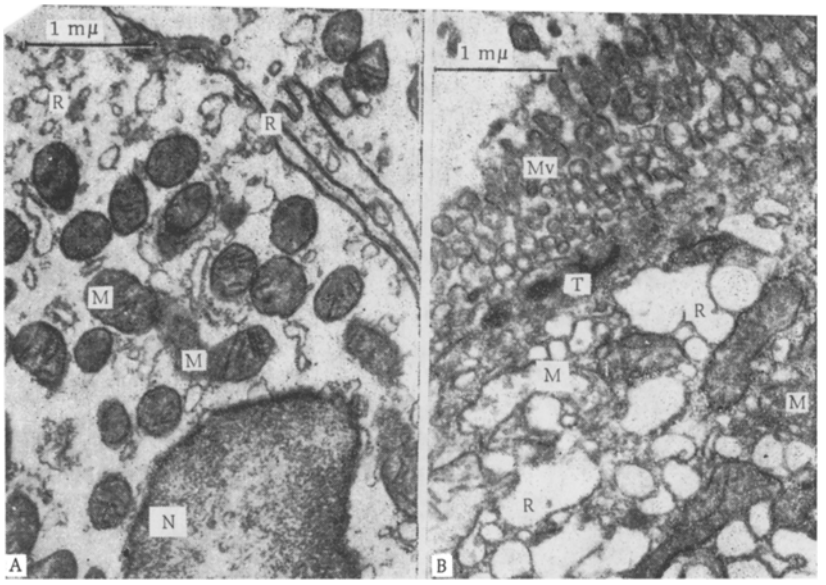

Fig. 2. Electron micrograph of mitochondria and endoplasmic reticulum in apical part of epithelial cell of jejunal mucous membrane of dog after extensive enterectomy: Mv, microvilli; M, mitochondria; T, terminal network; R, endoplasmic reticulum; N, nucleus; C, cell membrane; A) 28,000×, B) 24,000×.

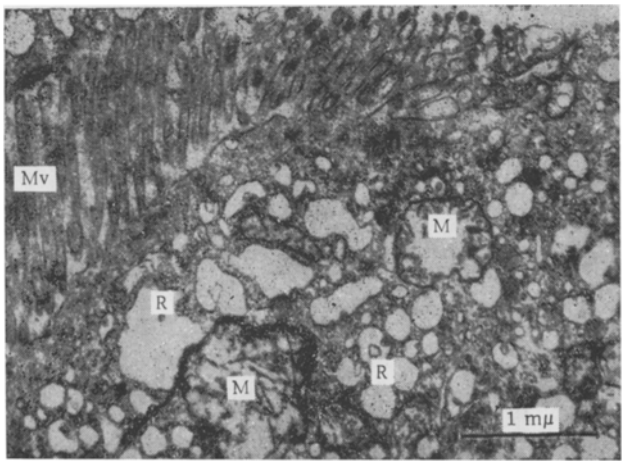

Fig. 3. Swelling and vacuolation of mitochondria and endoplasmic reticulum in apical part of epithelial cell of jejunal mucous membrane of a dog two months after extensive enterectomy: Mv, obliquely divided microvilli; M, mitochondria; R, endoplasmic reticulum, 24,000×.

icles were 0.60-0.75 μ long, 0.50-0.62 μ wide, and they almost completely filled the cytoplasm of the cell. In the basal part and around the nucleus, however, the endoplasmic reticulum showed signs of hyperplasia (mainly near the mitochondria). The changes observed in the endoplasmic reticulum must be considered to be connected with the development of vacuolar degeneration of the cells and also with intracellular compensatory hyperplasia of these ultrastructures of the cells of the intestinal mucous membrane in connection with the increased work load placed on the residual portion of the small intestine.

In this connection, it can be conjectured that by the second month after extensive resection of the small intestine, not only do regressive changes take place in the epithelial cells of the intestinal mucous membrane, but regeneration hypertrophy, in the form of intracellular hyperplasia of the specific ultrastructures also takes place as the result of the increased work load thrown on the remaining part of the small intestine.

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