EXPERIMENTAL BIOLOGY

REGENERATION OF KIDNEYS IN MAMMALS

COMMUNICATION III. CHANGES IN THE FINE STRUCTURE OF KIDNEY DURING ITS REGENERATION

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We have shown that resection of 1/5 to 1/3 of the surviving kidney of a unilaterally nephrectomized rat is followed by an increase in the size and weight of the remaining part of the kidney, in which the structural relations are largely restored to those characteristic of the kidneys of control animals.

Of what do the changes proceeding in the injured organ, affecting its weight and dimensions, consist? The regenerative processes occurring in the injured kidney are located in the zone of injury, on the one hand, and in the residual parenchyma, not directly affected by the injury, on the other hand. These latter processes are the more pronounced, for which reason we gave priority to the elucidation of their nature and extent. With this object, we performed a detailed morphological study of the changes taking place in a rat's surviving kidney at different times after partial nephrotomy.

The results presented in the Table characterize the changes taking place in a number of structural indices of the operated kidney. All the parameters relate to transverse median sections of the kidney. So as to facilitate comparison of our results with the normal values, the first two horizontal rows of figures, given at the top of the Table, represent the results obtained on control animals at the beginning of the experiment (initial control), and at its end (terminal control).

As is evident from the Table, the number of renal corpuscles rose during the experiment, although not to the initial figure, and the relative number of renal corpuscles per mm^2 of surface was similarly not restored.

Since at the end of the experiment the total number of renal corpuscles had increased, it may be supposed that new ones had been formed. The difference between the total number of renal corpuscles on the 17th and the 89th day of the experiment is statistically significant. A certain rise in the number of renal corpuscles takes place, according to our findings, in normal rats during their growth; this is contrary to the views of some authors (Vashetko).

The mean surface area of a renal corpuscle was increased over the whole period of observation, and considerably exceeded that found in the terminal control animals, e.g., by 42% on the 89th day (Fig. 1). Hence the total surface of the renal corpuscles was found to approach closely the value found for the terminal control, over the whole period of observation. On the 89th day it exceeded this value by 9%. Although increase in the dimensions of the renal corpuscles was found from the very beginning of the experiment, and persisted throughout its duration, it is not impossible that variations in either direction may have been present at different times after the operation, but that this increase was associated with stable morphological changes in structural elements toward the end of the experiment.

Measurements of the maximum dimension of renal corpuscles showed that it had increased from 3.9 μ for normal animals to an average of 8.2 μ on the 89th day after operation.

Changes in the Structure of the Kidneys of Operated Rats

Time after operation	Number of renal corpuscles: absolute	Number of renal corpuscles: relative (per mm² of area of the cortical zone)	Surface area of renal corpuscles (in μ²): of a single corpuscle	Surface area of renal corpuscles (in μ²): total	Ratio of the surface area of the renal corpuscles to that of the cortex (as %): of a single corpuscle	Ratio of the surface area of the renal corpuscles to that of the cortex (as %): all corpuscles	Dimensions of the convoluted tubules (in μ): diameter of the tubules	Dimensions of the convoluted tubules (in μ): height of the cells	Dimensions of the convoluted tubules (in μ): lumen
Initial control (normal)									
	152	5.6	3741	569 697	0.014	2.10	32.4	11.3	11.4
Terminal control (normal)									
	183	4,5	4 338	793 724	0.011	1.92	35.7	10.2	11.6
Experimental									
12 hours	131	4.1	5 770	752 730	0.018	2.37	37.7	11.6	16.9
24 hours	108	3.4	5 491	565 420	0.017	1.73	38.7	12.2	15.7
2 days	143	2.7	5 685	808 680	0.011	1.55	39.8	11.9	18.5
5 "	145	2.3	5 606	817 806	0.009	1.26	40.3	11.8	16.5
11 "	136	3.4	5 127	698 238	0.012	1.68	38.8	13.2	11.2
17 "	115	2.6	6 502	746 911	0.015	1.72	44.5	12.2	17.7
23 "	126	2.4	5 984	755 712	0.012	1.46	41.0	11.9	13.8
35 "	123	2.6	5 999	735 134	0.013	1.56	42.5	11.7	19.2
47 "	123	2.5	5 742	713 274	0.012	1.47	42.0	12.6	14.3
59 "	135	2.4	5 427	728 851	0.01	1.28	40.9	11.6	15.4
71 "	140	3.0	5 482	758 351	0.012	1.65	41.6	11.5	19.6
83 "	146	2.9	5 547	806 460	0.011	1.60	46.7	12.3	18.3
89 "	139	2.8	6 178	862 285	0.012	1.71	46.5	11.6	21.9
217 "	147	2.2	6 563	950 013	0.01	1.45	42.6	12.0	19.0

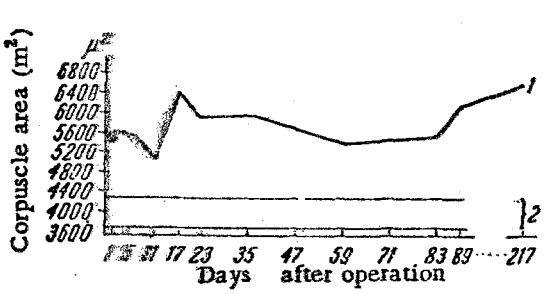

Fig. 1. Changes in the area of the renal corpuscles. Abscissae: days after operation; ordinates: surface area of the corpuscles, in square microns.
1) Operated rats; 2) initial and terminal control rats.

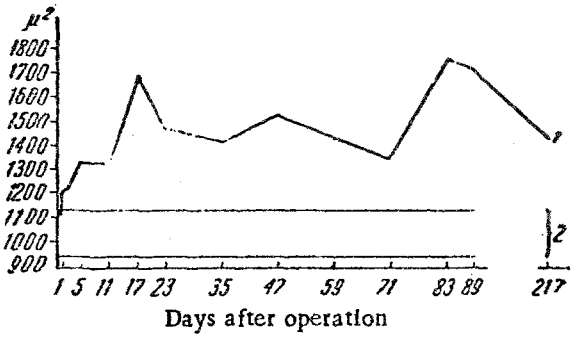

Fig. 2. Changes in the area of the wall of the convoluted tubule.
Explanation of diagram as for Fig. 1.

We counted the number of nuclei in the outer layer of the capsule of Shumlianskii, in order to ascertain whether the increase in the dimensions of this capsule was due only to hypertrophy of the cells, or to their hyperplasia.

We found that on the 89th postoperative day the capsule contained an average of 18.6 nuclei, as compared with 11.5 for normal controls. The increase in the size of the capsule can hence be ascribed to increase in the number of its constituent cells.

We also measured the distance between nuclei in the outer layer of the capsule of Shumlianskii. On the 89th postoperative day this distance amounted on the average to 13.1 μ, as compared with 8.6 μ in normal controls. It follows that not only does the number of constituent cells rise during increase in size of the capsule, but that there is also an increase in their size, i.e., they are hypertrophied.

The diameter of the cross section of the convoluted tubules rose within 12 hours of the operation, when it already exceeded that found in the terminal control. It remained higher than in the terminal control throughout the experiment, being greatest on the 83rd day (31% greater than the terminal control figure).

The height of the cells seen in cross sections of the convoluted tubules was also increased within 12 hours of the operation, and remained at a high level thereafter. It was maximum on the 11th day (29% greater than in the terminal control). This increase in height of cells is statistically significant.

The size of the lumen of the convoluted tubules was increased from the very beginning (47% greater than the control 12 hours after the operation). It was maximum on the 89th day (90% greater than the control value).

We measured the area occupied by cells on the cross section of the convoluted tubules, by subtracting from the overall cross section that part of it representing the lumen. We found that this area increased gradually from the very beginning of the experiment, and that it remained at a high level throughout. It was maximum on the 83rd day, 56% greater than for the terminal control (Fig. 1).

A count of the number of nuclei present on a cross section of a convoluted tubule showed that the figure had increased by 60% on the 89th day.

We also measured the distances between nuclei in cross sections of the convoluted tubules, so as to ascertain whether any changes had taken place in the size of the cells. On the 89th day after the operation the average distance was 9.4 μ, as compared with 7.9 μ for the control (Fig. 2), showing that cell hypertrophy had taken place here, too.

Thus, during the postoperational period dilation of the tubules had taken place, associated with increase in the number of cells and in their size.

We also studied the changes in the dimensions of the collecting tubules, in both the cortical and the medullary zones.

We found that the diameter of the collecting tubules of the cortex (as seen in cross section) had increased from the normal value of 26.7 μ to 35.4 μ on the 89th day. The diameter of the lumen had risen from 13.9 to 22.8 μ. The part of the cross sections occupied by cells had risen from 521.6 to 709.1 μ^2. The height of the cells had increased from 6.6 to 7.6 μ, but this difference is not statistically significant. The number of nuclei had risen from 5.1 to 7.6. The distance between nuclei had increased from 5.5 to 8.4 μ. This difference is of a random nature.

It thus appears that not only had dilation of the collecting tubules of the cortical zone taken place during the experimental period, but that the number of cells lining the tubules had risen. There was no significant change in the dimensions of the cells.

The diameter of the collecting tubules of the medullary zone, as seen in cross section, rose from the normal value of 25 μ to 29.7 μ on the 89th day after the operation. The lumen had increased in size from 15.1 to 18.1 μ. The area occupied by cells in the cross section had risen from 398.7 to 551.8 μ^2. The number of nuclei had risen from 4.3 to 5.4. There were no changes in the height of the cells or in the distance between nuclei. Thus the dilation of the medullary collecting tubules was associated with an increase in the number of cells lining the tubules.

As is evident from the above findings, the process of regeneration of the kidney is a complex one. The changes taking place, which affect the whole of the renal parenchyma, involve increase in the dimensions of the structural elements of the kidney (corpuscles and tubules), due chiefly to cell hyperplasia, and partly to cell hypertrophy.

Although we observed the presence of well developed regenerative processes in the damaged kidney, we wish to record that full regeneration was not achieved under the conditions of our experiment.

The normal structure of the kidney was not fully restored in our experiments. Instead, we found an increase in the dimensions of the nephrons and of their constituent parts, due chiefly to cell hyperplasia, and partly to cell hypertrophy. In addition, there was an increase in the dimensions of the intercellular spaces, in particular in the lumen of the tubules and in the volume of the corpuscles.

SUMMARY

Experiments were performed on rats. A detailed morphological analysis was carried out of changes which take place in residual part of the kidney at various periods following operation of ablation of one kidney and partial resection of the other.

The changes involve the whole parenchyma of the kidney and consist in increase of the size of the structural elements of the kidney (tubules and Malpighian bodies) caused mostly by cellular hyperplasia with their partial hypertrophy. Besides, the intercellular spaces are enlarged, particularly the tubular lumen and the cavity of Malpighian bodies.

LITERATURE CITED

N. P. Vashetko, Kharkov Med. Journal, 18, Nos. 7-11 (1914).