Hydraulic pressure drives urine concentration too

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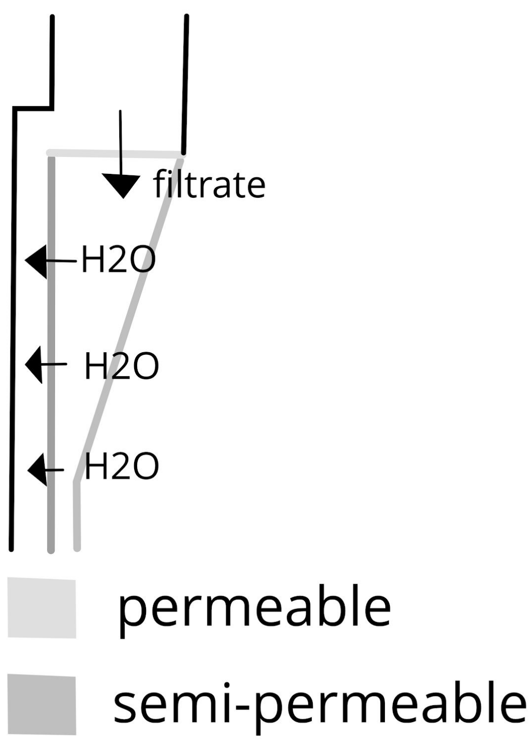
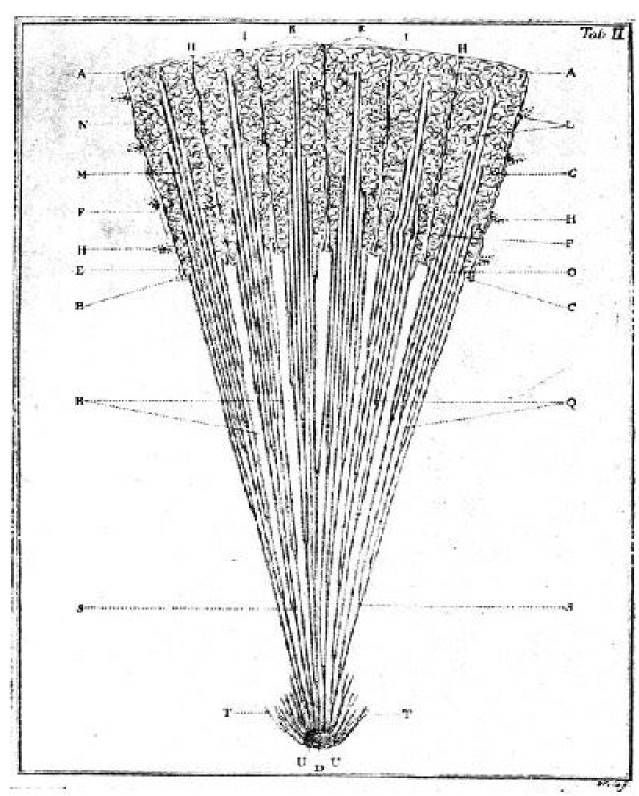
> *"I thought it was a kind of interstitial connective tissue, but emphasized its resemblance to the elements of organic muscle tissue. Virchow declared them to be muscle fiber cells; Frerichs left their origins uncertain" - Jakob Henle, Zur Anatomie der Niere, 1862*

ABSTRACT: The kidney has connected filtration and reabsorption in series down a pressure gradient and both rely on pressure generated by the heart as a pump.

Synthesis

Hydraulic pressure drops in the kidney blood supply from 90 mmhg to 45mm hg in the glomeruli, and from 45 mmhg to 20 mmhg across the efferent arteriole, hydraulic energy is consumed to force filtrate into the renal tubules. In a similar manner, pressure drops within the renal tubules at the thin segment, that in juxtamedullary nephrons dives deep in the medulla forming the loop of Henle, and, in the inner medullary collecting ducts (Gilmer, 2018). This drop in pressure represents the loss of volume from water being reabsorbed, just like the pressure drop in the blood vessels during filtration.



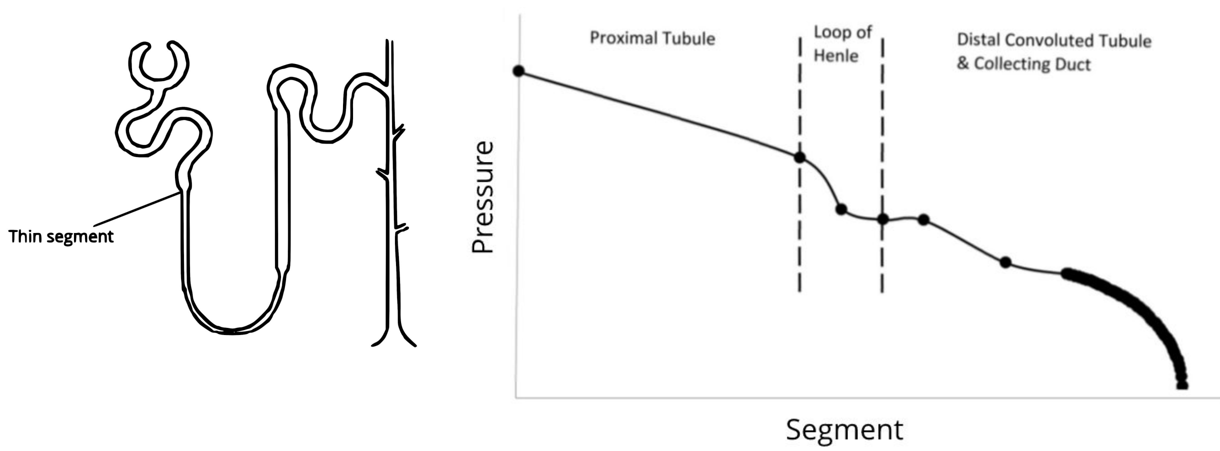


Renal interstitial medullary cells (RMIC) have been shown to be contractile, a response that has been suggested to be involved in regulating urine concentration (Hughes, 1995; Hughes, 2006). Vasopressin, first identified for its ability to contract blood vessels, has been shown to contract these interstitial cells (Hughes, 2006), also suggested to have a role in the anti-diuretic response of vasopressin (Huges, 2006).

The steep pressure drop observed in the inner medullary collecting ducts is due to the convergent structure of the tubules, which channels flow into fewer and fewer tubules toward the papillary tip (Gilmer, 2018). Vasopressin-induced contraction of renal interstitial medullary cells (RMIC) will decrease the diameter of these tubules, increasing flow resistance. The water reabsorption that results, generating anti-diuresis, is equivalent to ultrafiltration in the glomeruli, filtration and reabsorption rely on the same hydraulic pressure source, the heart, and are connected in series.

Hydraulic single effect

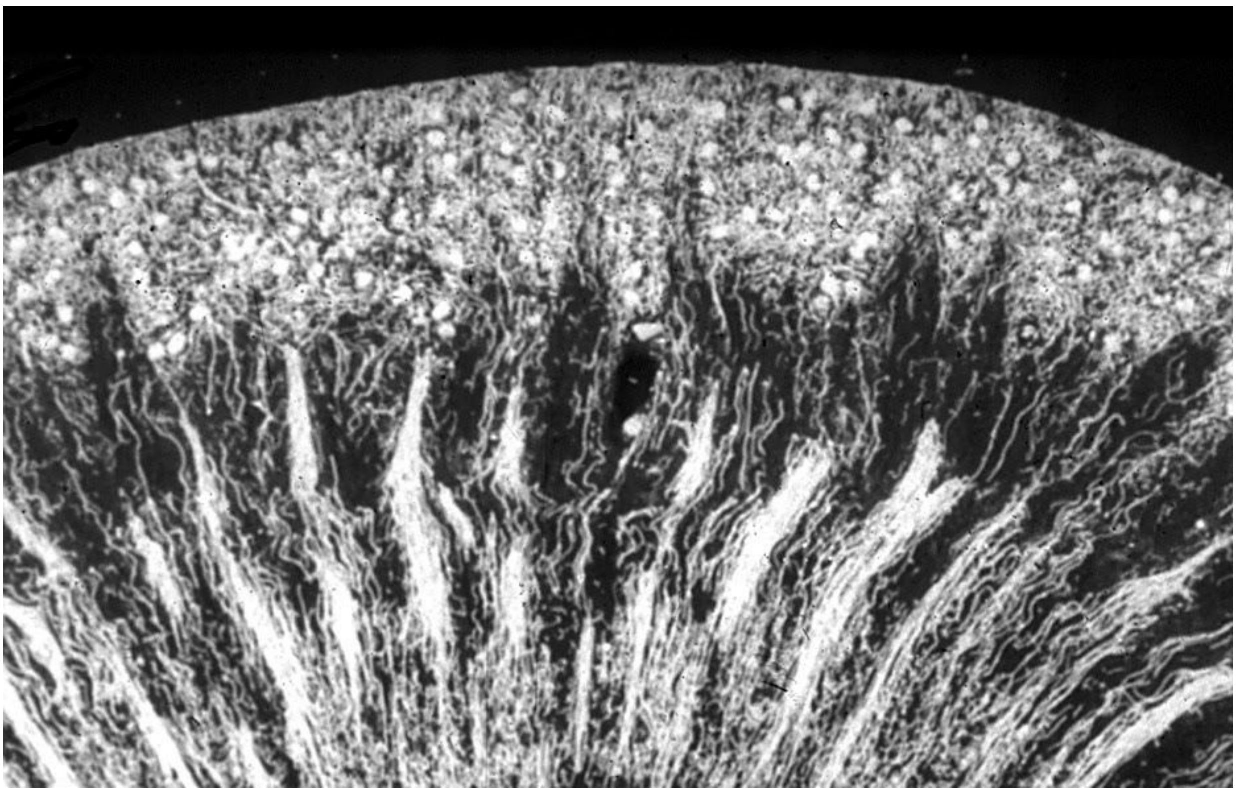
The thin limbs of Henle and the inner medullary collecting ducts are the major sites of flow resistance along the renal tubule (Gilmer, 2018), generating water reabsorption in the proximal tubule and down the length of the collective duct tree. Flow resistance in the collecting ducts concentrates urine, and resistance in the loops of Henle deposits concentrated filtrate into the medulla (Berliner, 1958), a passive “single effect” that is the basis for the axial osmolality gradient in the medulla.



Evolution of the metanephros

The evolution of the metanephros now becomes clear. Since the terrestrial animals had to filter large volumes of blood to begin with, to take over the role of the gills in nitrogen excretion, the mesonephros was multiplied into thousands of copies, packed side by side and forming the cortex of the metanephros.

The systemic circulatory pressure that was put into these filtration units, could be co-opted to also manage the uncertain water availability in the terrestrial world. This was achieved by pumping the filtrate through a convergent structure of tubules, that drain into fewer and fewer tubules toward the papillary tip. The same pressure could also be used to generate an osmotic reabsorption mechanism, simply by co-opting the thin segments of the pronephros and mesonephros for the loops of Henle, providing a passive “single effect” for osmotic multiplication as concentrated filtrate is deposited into the interstitium through the thin segments that dive deep into the medulla.



The metanephros showing the multiplication of individual mesonephros units, packed side by side. These individual units all drain into the same root at the area cribrosa in the papilla, an evolutionarily parsimonious way to generate water reabsorption. Image from Bankir et al.

References

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