Interrelationships of Renal Hemodynamics, Intrarenal Pressures and Renal Lymph Formation[1] (36089)

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Early investigations by Winton (1) focused attention on intrarenal pressure as a possible factor in determining renal blood flow and urine formation. Subsequent studies by other investigators have revealed that pressures in the intrarenal veins (2) and renal lymphatic vessels (3) may also have effects on renal function and hemodynamics. It is known that renal tissue pressure may be altered by changes in arterial pressure, intrarenal venous pressure (IRVP) (4) and renal vein pressure (5). Similarly, renal lymph pressure is very sensitive to changes in both renal venous pressure and IRVP (6) but not to renal perfusion pressure within the autoregulatory range (7). It thus appears that renal tissue pressure, IRVP, and lymph pressure are related to each other and to renal hemodynamics, but the nature of these relationships is as yet poorly understood.

Methods. Mongrel dogs were anesthetized with sodium pentobarbital (30 mg/kg), and the left kidney was exposed through a flank incision. A length of suture was passed under the renal artery, and sufficient sodium heparin was administered to prevent clotting of blood and lymph. The femoral artery was catheterized for monitoring arterial pressure and obtaining arterial blood samples, and the femoral vein was catheterized to facilitate administration of additional anesthetic.

In lymph collection experiments, either a capsular or hilar lymphatic vessel was catheterized using a length of polyethylene tubing (Clay Adams PE 10). After two control collections of renal lymph, the renal artery was occluded for 5 min. Two additional lymph collections were made upon reestablishment of renal blood flow. Renal lymph was collected under mineral oil in volumes of 0.1 ml, which were obtained in less than 30 min. Arterial blood samples were obtained at the midpoint of each lymph collection period. The protein concentration of renal lymph and arterial blood plasma were determined colorimetrically using a biuret method (8). Values are presented as renal lymph to arterial plasma concentration ratios (L/P).

In fluid dynamic studies, an extracorporeal circuit was established between the renal vein and the external jugular vein. An intrarenal venous pressure catheter was inserted into the kidney using the method and criteria of Hinshaw (4). A capsular lymphatic vessel was then catheterized using polyethylene tubing (Clay Adams PE 60), the tip having been drawn small enough to enter the lumen of the lymphatic vessel. Renal tissue pressure, as estimated by subcapsular pressure, was measured using a wafer-type miniature pressure transducer (Sensotec Model M-7BW) inserted through a small slit in the renal capsule to lie between the capsule and the renal parenchyma (9). Capsular renal lymph pressure, IRVP, and tissue pressure (TP) were continuously recorded using a Sanborn polygraph and resistance bridge transducer. Experimental procedures were begun only after all parameters appeared stable (5–15 min). The renal artery was occluded for 1 min. Recovery of all parameters following reestablishment of renal circulation was observed until relatively constant (usually less than 3 min).

Serial elevations in IRVP were produced by manual compression of the renal vein by-

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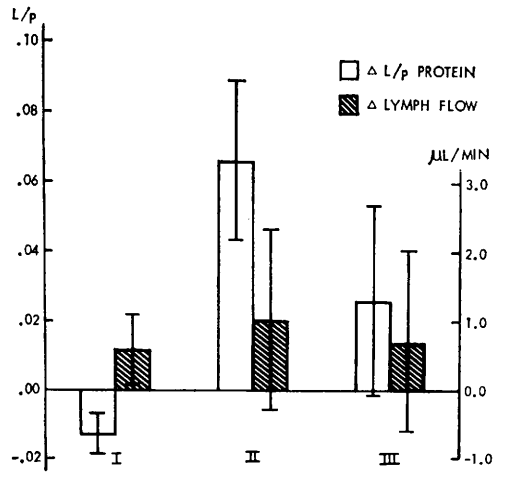

FIG. 1. Changes in L/P ratio for protein and lymph flow during control conditions (Period I) and immediately following release of a 5 min renal artery occlusion (Periods II and III) in seven dogs: Means and standard errors are shown.

pass tubing. Sufficient time was allowed for all parameters to stabilize at their new level (usually 1 min or less) before proceeding to the next increment.

Results. Figure 1 shows changes in lymph flow and protein L/P ratios before (period 1) and after (periods II and III) a 5 minute occlusion of the renal artery. Mean L/P ratio of the first postocclusion sample (period II) was significantly greater ($p<.02$) than that for period I. The L/P values for period III shows a return toward control values. In contrast, the renal artery occlusion did not alter renal lymph flow.

Figure 2 showing the results from 7 dogs, demonstrates that occlusion of the renal artery for 1 min causes a rapid fall in both IRVP and TP. Upon reestablishment of renal blood flow, IRVP returns quickly to the control level, while TP approaches its preocclusion level slowly, requiring at least 60 sec to stabilize. The response of capsular lymph pressure was similar to TP. In contrast, when IRVP is elevated from its resting level in the normally perfused kidney, the corresponding increase in TP and LP occurred rapidly and synchronously. As shown in Figs. 3 and 4, both tissue pressure ($n = 6$) and capsular lymph pressure ($n = 4$) increase as a linear function of IRVP when the latter is experimentally elevated by increasing renal venous outflow resistance. Although the mean values and standard errors fall below the line of identity, neither slope is statistically different from unity.

Discussion. It is known that when venous pressure is elevated to 25 mm Hg or more, lymph production is increased in the leg (10), the liver (11), the rat paw (12), and the kidney (6). Measurement of IRVP in the dog has shown a mean value of 25 mm Hg (13). Thus, it seems probable that the functional kidney is normally in a state of elevated venous pressure maintained by a anatomical constriction of the intrarenal veins (14). This functionally elevated venous pressure may be an immediate determinant of lymph formation as well as interstitial fluid pressure in the kidney.

Renal lymph flow has been shown to increase following increments in IRVP while lymph protein concentration was unchanged (15). Lymph formation in the kidney thus differs from that in the leg where lymph protein concentration is inversely related to lymph flow (10). The independence of protein concentration and flow rate suggests that renal lymph is primarily derived from a

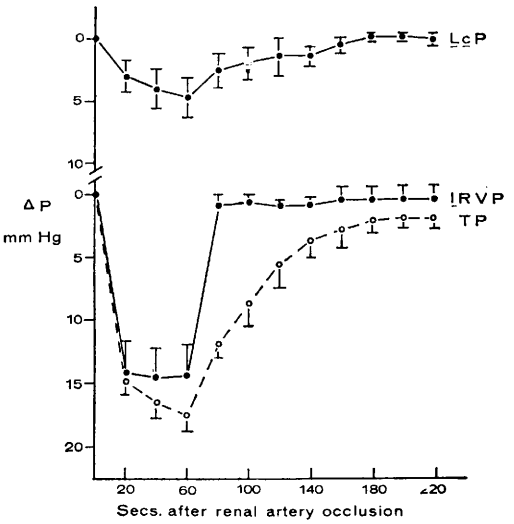

FIG. 2. Changes in capsular lymph pressure (LCP), intrarenal venous pressure (IRVP) and tissue pressure (TP) before, during, and after a 60 sec renal artery occlusion: Means and standard errors are shown.

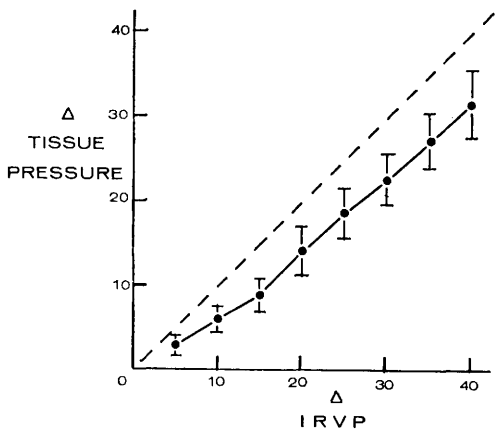

FIG. 3. Changes in tissue pressure (TP) (mm Hg), which accompany increases in intrarenal venous pressure (IRVP) above resting levels: Means and standard errors are shown, as well as the line of identity (- -).

vascular structure in which the net transmural pressure gradient favors filtration only. In the present studies, with cessation of RBF, IRVP falls to low levels reversing the direction of the net pressure gradient. The findings suggest that, under these conditions, protein free fluid from the renal interstitium returns to the vasculature leaving a more concentrated protein solution behind. This protein-rich fluid then becomes a part of the first lymph sample to be collected after reinstatement of renal blood flow. Renal lymph flow was unchanged after reinstatement of blood flow suggesting that permeability changes were not probable factors in the results obtained.

Swann *et al.* (16) have shown that, after the renal artery is occluded, a fluid resembling renal interstitial fluid may be collected from the renal vein. Figure 2 shows that renal artery occlusion is followed by decreases in IRVP, TP, and capsular lymph pressure. Of these three parameters only IRVP returned quickly to control when renal blood flow was reinstated. The gradual recovery of TP and lymph pressure suggests they are dependent on the replacement of interstitial fluid volume lost during the period of arterial occlusion. Although glomerular filtration, tubular filling, and tubular reabsorption probably play a role in reestablishing renal tissue pressure, the present experiments cannot assess the contributions from these sources.

The similarity between Figs. 3 and 4 suggest that tissue pressure and lymph pressure are intimately related to IRVP. The finding that both TP and LP respond quickly to elevations in IRVP above its resting level suggests that the functional kidney is fully distended (2). Experimental elevations of IRVP are reflected directly as changes in TP and LP in this distended kidney.

Summary. Renal lymph protein concentration, intrarenal venous pressure (IRVP) capsular lymph pressure (LP) and tissue pressure (TP) were measured before, during and after short periods of renal artery occlusion. Pressure measurements were also monitored after experimentally elevating IRVP. Increases in interstitial protein concentration occur during renal artery occlusion and alter protein concentration in subesquent lymph samples without changing lymph flow. The recovery of TP and LP following renal artery obstruction appears to be secondary to the replacement of renal interstitial fluid volume until functional distention of the kidney is reached. Thereafter, TP and LP appear to be directly related to IRVP.

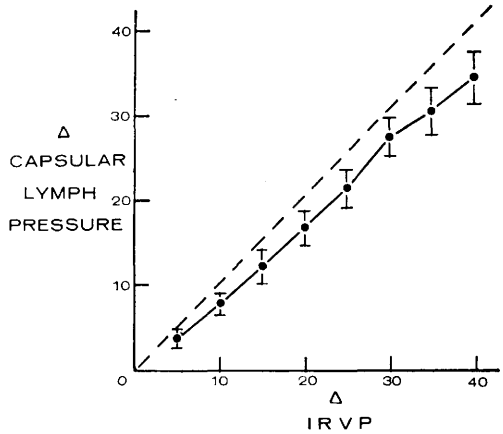

FIG. 4. Changes in capsular lymph pressure (mm Hg) which accompany increases in intrarenal venous pressure (IRVP) above resting levels: Means and standard errors are shown, as well as the line of identity (- -).

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