Elevation of Inferior Vena Cava Pressure and Thoracic Lymph and Urine Flow

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With the technical assistance of Raymond S. Moore, B.S.

With an increase in renal vein pressure by partial obstruction of the inferior vena cava in dogs, there follows an increase in thoracic lymph flow and a simultaneous decrease in urine flow and urine sodium excretion per minute. The increase in lymph flow appears to be caused by an increased production of renal lymph, since control animals with absent or nonfunctioning kidneys fail to show this lymph flow increase. Renal deviation of fluid and sodium to the lymphatics may similarly occur in heart failure and account for the retention of sodium and water.

In a previous communication from this laboratory studies were reported showing that renal lymphatic pressure and flow are increased after an elevation in renal vein pressure. The suggestion was made that under physiological conditions of elevated renal vein pressure such as occurs in right heart failure, similar events may occur. Renal deviation of fluid and sodium to the lymphatics might therefore be in part the mechanism for the retention of sodium in heart failure.

The kidney has 3 routes by which fluid leaves it—the ureteral, the venous, and the lymphatic. Studies extending over the past 95 years, in addition to the above-mentioned one indicate that these systems bear relationships to one another and operate reciprocally.

In 1863 Ludwig and Zawarykin observed that the renal hilar lymphatic vessel becomes distended when the ureter is occluded. Kaiserling and Sootsmayer observed that ligation of the renal lymphatics in rabbits is followed by an increase in urine flow. Earlier in 1929, Schmidt and Hayman found in the dog following evisceration including hepatectomy and unilateral nephrectomy, that the thoracic lymph flow was increased following ligation of the renal vein of the remaining kidney.

Goodwin and Kaufman have observed that thoracic lymph flow is increased following ureteral obstruction, a procedure which appears to increase renal lymph flow.

It has not been possible to date to devise a method for the quantitative collection of the entire renal lymph output. However, the observations of Schmidt and Hayman and those of Goodwin and Kaufman suggest that measurements of thoracic lymph flow permit some conclusions regarding changes in renal lymph production. The purpose of this communication is to describe acute experiments showing that the thoracic lymph flow is increased following the elevation of the inferior vena cava pressure above the renal vein at a time when the renal excretion of sodium and water is decreased.

Methods

Eighteen large mongrel dogs were studied under pentobarbital anesthesia. The thoracic duct was exposed and cannulated with a short length of polyethylene tubing of the largest diameter, usually size 190, that could be inserted into the duct. The pressure in the renal vein was elevated by one of two methods. In one method a double lumen cardiac catheter with a terminal inflatable balloon and an opening behind the balloon for pressure measurement was inserted into the inferior vena cava via the femoral vein and extended above the renal veins. Inflation of the balloons resulted in readily controllable pressure elevation in the inferior vena cava and renal veins. The lumen of the catheter for pressure measurement was filled with saline containing 20 mg. sodium heparin per

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100 ml. solution and lead to a Sanborn Electro-
manometer model no. 131 C and an Offner Oscillo-
graph recorder. One to 1.5 mg./Kg. sodium
heparin* was given intravenously immediately
prior to the insertion of the balloon catheter.

In the other method, a 10 inch length of umbili-
cal tape was placed around the inferior vena cava
and threaded through a 3/4 inch length of Tygon
tubing, 1/4 inch inside diameter. Tape and tubing
were brought out of the abdomen. Pressure in
the inferior vena cava was elevated by gently
pulling on the umbilical tape and fixing it into
place against the Tygon tubing with a hemostat.
The pressure in the vena cava below the point
of constriction was measured by means of a poly-
ethylene size 90 catheter filled with heparin and
saline and connected to the electromanometer-re-
order system.

Urine was collected by one of two methods. The
ureters were catheterized by passing a polyethylene
catheter size 200 through an incision in each ureter
up to the uretero-pelvic junction. The ureters
were not transected. In two experiments, urine
was collected during 20 minute periods by bladder
washing with several 30 ml. portions of 5 per cent
glucose in sodium-free water. Thoracic lymph was
collected in 15 ml. graduated centrifuge tubes con-
taining approximately 0.06 mg. ammonium heparin
as an anticoagulant. Approximately 1.5 ml./min.
of a physiological solution of glucose and elec-
trolytes containing 70 mEq. of sodium/liter was in-
jected intravenously.† Sodium was analyzed in
the urine and thoracic lymph by an internal stand-
ard flame photometer. As a rule study periods
were 10 min., and several in succession were run
at base line and elevated inferior vena cava pres-
sures. Occasionally several of the study periods
were 5 or 7 min. For comparative purposes lymph
and urine volumes were extrapolated to 10 min.
values.

RESULTS

The following four experiments illustrate
the events seen quite generally in the experi-
ments on 15 dogs. In two dogs it was not pos-
sible to catheterize the thoracic duct. One
dog went into shock immediately after the
ligatures were placed around the inferior vena
cava. The results are then based on studies
on 15 animals.

*Lipo-hepin, 10 mg. per cc., Darwin Laboratories,
Los Angeles, California.
†Cutter Laboratories balanced electrolyte solution,
D5-V-E-S. This solution was diluted with an equal
part of distilled water, giving a final concentration
of 70 mEq/liter sodium.

Table 1.—Thoracic Lymph and Urine Flow with
Inferior Vena Cava Pressure Elevation

<table>
<thead>
<tr>
<th>IVC pressure</th>
<th>Urine</th>
<th>Thoracic lymph</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm. Hg</td>
<td>ml./10 min. mEq./min.</td>
<td>ml./10 min. mEq./min.</td>
</tr>
<tr>
<td>4</td>
<td>3.3</td>
<td>0.15</td>
</tr>
<tr>
<td>5</td>
<td>3.9</td>
<td>0.22</td>
</tr>
<tr>
<td>24</td>
<td>0.7</td>
<td>0.02</td>
</tr>
<tr>
<td>24</td>
<td>0.3</td>
<td>—</td>
</tr>
<tr>
<td>24</td>
<td>0.3</td>
<td>0.01</td>
</tr>
<tr>
<td>13</td>
<td>0.6</td>
<td>0.04</td>
</tr>
<tr>
<td>8</td>
<td>3.3</td>
<td>0.06</td>
</tr>
<tr>
<td>6</td>
<td>2.7</td>
<td>0.09</td>
</tr>
</tbody>
</table>

*Inferior vena cava pressure elevated by balloon
catheter. Urine collected by ureteral catheters and
combined.

Thoracic Lymph and Urine Flow with In-
ferior Vena Cava Pressure Elevation. The
double lumen type balloon catheter was used
for inferior vena cava pressure elevation. The
results of such an experiment are summarized
in table 1. It will be noted that when the in-
ferior vena cava pressure varied between 5
and 8 mm. Hg the urine output averaged 3.3
ml. from both kidneys each 10 min. period,
while the thoracic lymph flow averaged 3.4 ml.
each 10 min. period. When the inferior vena
cava pressure was elevated to 24 mm. of Hg
the urine output averaged 0.4 ml./period,
while the lymph flow averaged 6.1 ml./period.
The decrease in urine output appears to be
matched by an equal increase in lymph out-
put. The changes in the sodium output of the
urine and lymph are self evident.

Thoracic Lymph Flow with Inferior Vena
Cava Pressure Elevation after Renal Artery
Occlusion. The balloon catheter was used for
elevating and measuring pressure in the in-
ferior vena cava. In table 2, which shows
typical results, both renal arteries were com-
pletely occluded by means of rubber-shod
′bulldog′-type clamps. It will be noted that
after complete renal artery occlusion, ele-
vation of the inferior vena cava pressure did
not produce an increase in thoracic lymph
flow. At the conclusion of this study, a sim-
ple experiment was performed indicating that
changes in intrarenal pressure affected tho-
racic lymph flow. The left kidney was gently compressed by finger pressure; soon thereafter the thoracic lymph flow was seen to increase.

**Thoracic Lymph Flow with Inferior Vena Cava Pressure Elevation in Nephrectomized Dog.** Both kidneys were removed. The balloon catheter was inserted into the inferior vena cava via the femoral vein to just above the level of the transected renal veins. In table 3, it will be noted that there is no increase in thoracic lymph flow following elevation in inferior vena cava pressure. Except for the first, all periods were 7 instead of 10 minutes. Volumes are expressed per ten minutes, for comparative purposes.

**Thoracic Lymph and Urine Flow with Inferior Vena Cava Pressure Elevation.** The balloon catheter was used for elevating the inferior vena cava pressure. Mannitol in a concentration of 3.0 Gr./100 ml., was added to the intravenous solution, which was given at the rate of 1.5 ml./min. From the results of a typical experiment shown in table 4, it can be seen that, in addition to the decrease in urine flow after elevation of inferior vena cava pressure, there is an even greater decrease in sodium excretion, which persisted into periods of lower vena cava pressure.

Figure 1 is a summary of these studies comparing the thoracic lymph and urine flow before and after the elevation of inferior vena cava pressure. Controls were of three types. In two dogs, the balloon catheter was inflated below the renal veins. In one dog the kidneys were removed and in one dog the renal arteries were completely occluded. It will be noted that the thoracic lymph flow in this group of animals was not increased as it was in the noncontrol group of animals. There was, in fact, some slight decrease in thoracic lymph flow with elevation in the inferior vena cava pressure in the control group.

**DISCUSSION**

These findings add to the evidence already available that with an increase in renal vein pressure caused by an elevation of the inferior vena cava pressure, the thoracic duct lymph flow is increased while the urine flow is decreased. Also, the urine sodium excretion is decreased while the total lymph sodium is increased. Since the increase in lymph flow occurs only in animals with intact kidneys when the pressure in the renal veins is elevated, it would appear that an increase in formation of renal lymph is responsible for the increased thoracic lymph flow.

These studies give some additional support to the idea previously expressed that the three outflow tracts of the kidney (i.e., the ureteral, the venous and the lymphatic) are interdependent and operate in a reciprocal fashion. The idea is based upon the following observations.
**THORACIC LYMPH AND URINE FLOW**

**Table 3.—Thoracic Lymph Flow with Inferior Vena Cava Pressure Elevation in Nephrectomized Dog***

<table>
<thead>
<tr>
<th>IVC pressure (mm Hg)</th>
<th>Thoracic lymph flow (ml/10 min.)</th>
<th>Sodium (mEq./min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>6.0</td>
<td>0.077</td>
</tr>
<tr>
<td>8</td>
<td>4.9</td>
<td>0.060</td>
</tr>
<tr>
<td>27</td>
<td>3.0</td>
<td>0.035</td>
</tr>
<tr>
<td>8</td>
<td>3.4</td>
<td>0.043</td>
</tr>
<tr>
<td>8</td>
<td>3.6</td>
<td>0.045</td>
</tr>
<tr>
<td>16</td>
<td>3.0</td>
<td>0.037</td>
</tr>
<tr>
<td>19</td>
<td>4.4</td>
<td>0.055</td>
</tr>
<tr>
<td>14</td>
<td>5.1</td>
<td>0.064</td>
</tr>
<tr>
<td>14</td>
<td>3.4</td>
<td>0.048</td>
</tr>
</tbody>
</table>

*Inferior vena cava pressure elevated by balloon catheter at level of transected renal veins.

**Table 4.—Thoracic Lymph and Urine Flow with Inferior Vena Cava Pressure Elevation***

<table>
<thead>
<tr>
<th>IVC pressure (mm Hg)</th>
<th>Thoracic lymph</th>
<th>Sodium (mEq./min.)</th>
<th>Urine</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>3.6</td>
<td>0.012</td>
<td>3.5</td>
</tr>
<tr>
<td>20</td>
<td>2.8</td>
<td>0.003</td>
<td>9.5</td>
</tr>
<tr>
<td>7</td>
<td>4.6†</td>
<td>0.003</td>
<td>4.0†</td>
</tr>
<tr>
<td>7</td>
<td>3.8†</td>
<td>0.003</td>
<td>2.9†</td>
</tr>
<tr>
<td>23</td>
<td>3.1†</td>
<td>0.003</td>
<td>10.0†</td>
</tr>
<tr>
<td>22</td>
<td>2.3†</td>
<td>0.003</td>
<td>8.8†</td>
</tr>
<tr>
<td>7</td>
<td>4.55</td>
<td>0.003</td>
<td>3.4</td>
</tr>
<tr>
<td>9</td>
<td>5.2</td>
<td>0.002</td>
<td>3.3</td>
</tr>
</tbody>
</table>

†10 minute values calculated from 5 minute periods.

Previously referred to: Obstruction of the renal lymphatics cause an increase in urine flow; obstruction of the ureter causes an increase in renal lymphatic pressure and flow; obstruction of the renal vein causes an increase in renal lymphatic pressure and an increase in renal lymphatic flow.

Direct quantitative measurements of renal lymph production have not been made, but Schmidt and Hayman have estimated by indirect methods that the renal lymph flow in dogs is of the same order of magnitude as urine flow. Significant decreases in urine flow accompanied by proportional increases in lymph flow would be expected to lead to a net retention of fluid and sodium of significant amounts.

If the events seen in the present experiments prevail under conditions of chronic elevation of renal vein pressure an additional mechanism for the retention of sodium in heart failure would be at hand.

How an increase in renal vein pressure causes an increase in renal lymphatic flow is a matter of conjecture. Sugarman et al. and Kaplan et al. have suggested that renal lymph originates in part from the reabsorbate in the distal and collecting tubules. One of us observed that the rise in renal lymphatic pressure that followed partial occlusion of the renal veins is preceded by elevation in renal interstitial pressure. It is possible then that rises in interstitial pressure lead to an increase in drainage of the interstitial spaces by the lymphatics, promoting replenishment of the interstitial fluid by an increase in tubular reabsorption. Alterations in tubular blood flow by elevations in the renal vein pressure may also be a factor in promoting the increased tubular reabsorption of sodium and water. Further, a rise in renal interstitial pressure caused by renal vein pressure elevation would be expected to cause an increase in tubular intraluminal resistance to flow and an increase in tubular reabsorption of water. Any or all of these mechanisms may be involved in the pathway by which fluid and sodium, originally destined for excretion, finds its way to the lymphatic system following elevations in renal vein pressure.

In progress and similar to these are studies in animals with chronic elevation in inferior vena cava pressure. These will be reported subsequently.

**Summary**

It has previously been observed that elevation of renal vein pressure increases renal lymphatic pressure. The present study demonstrated that elevation of the inferior vena cava pressure above the renal veins to levels of between 13 to 40 mm Hg is followed by a significant increase in thoracic lymph flow and a decrease in urine flow and sodium excretion. The thoracic lymph flow was not ob-
served to be increased in a group of control animals after elevation in the inferior vena cava pressure.

The conclusion is drawn that the increase in thoracic lymph flow is due to an increase in production of renal lymph. The possible mechanisms for this event and its connection with retention of sodium and water in physiological states of elevated renal vein pressure such as right heart failure are discussed.

**SUMMARIO IN INTERLINGUA**

Ha essite observate previemente que un elevation del pression de vena renal resulta in un augmentation del pression lymphatic. Le presente studio demonstra que un elevation del pression in le vena cave inferior supra le venas usque a nivellos de inter 13 e 40 mm de Hg es sequite per un augmento significative del fluxo de lympha thoracic e per un reductio del fluxo de urina e del excretion de natrium. Nulle augmento del fluxo de lympha thoracic esseva observate post augmento del pression in le vena cave inferior de un gruppo de animales de controlo.

Es formulate le conclusion que le augmento del fluxo de lympha thoracic es causate per un augmento del production de lympha renal.

Le mechanismos possibile pro iste occurrenceia e su connexion con retention de natrium e de aqua in statos physiologic de elevate pression de vena renal—per exemplo in disfallimento de corde dextere—es discutite.

**REFERENCES**

Elevation of Inferior Vena Cava Pressure and Thoracic Lymph and Urine Flow
YALE J. KATZ, A. T. K. COCKETT and RAYMOND S. MOOR

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