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INCREASED ABDOMINAL LYMPH FLOW INCREASES LUNG LYMPHATIC OUTFLOW PRESSURE IN SHEEP

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ABSTRACT

We tested the hypothesis that increased lymph flow from the abdominal organs would increase the pressure within the thoracic duct at the thoracic duct-lung lymphatic junction. Cannulas were placed into the thoracic duct via the caudal mediastinal (lung) node efferent lymphatics in 4 sheep. After the sheep recovered from the surgery, we monitored the thoracic duct pressure with pressure transducers. To increase lymph flow from the lower body, we infused Ringers solution (59 ± 19 [mean ± SD] ml/kg body weight in 30 min.) intravenously into the sheep and we inflated a balloon in the inferior vena cava. This technique causes substantial increases in lymph flow from the lower body (mainly from the liver and intestines) through the thoracic duct. During the infusions, the thoracic duct pressure increased significantly from 4.1 ± 2.9 cm H_2O *(baseline) to 6.8 ± 1.7 cm* H_2O*. The neck vein pressure (pressure at the outflow of the thoracic duct) did not increase from baseline (3.0 ± 2.6 cm* H_2O*). Thus our results support the hypotheses that increased flow through the thoracic duct causes increased thoracic duct pressure.*

We have previously used circuit analysis techniques to model the lymphatic drainage system in animals (1). One of the most important predictions from our analysis was that lymphatic flow from one or more organs may interfere with the lymphatic drainage from other organs. A key element of this prediction is that high lymph flows cause increased pressure within the large collecting lymphatic ducts. The thoracic duct in sheep is a good place to test this hypothesis because most of the lymph from the abdominal organs drains through the thoracic duct (2). Also, in most sheep, lung lymph drains to the thoracic duct (3). Thus an increase in lymph flow from the abdominal organs might increase the thoracic duct pressure and slow lymph flow from the lungs.

In the present study, we tested the hypothesis that increased lymphatic flow would increase the thoracic duct pressure at the outflow to the lung lymphatics. We directly measured the thoracic duct pressure in awake sheep. When we caused an increase in lymph flow from the abdominal organs, the thoracic duct pressure increased significantly.

MATERIALS AND METHODS

We have previously described our technique to place cannulas into the thoracic duct (6). For this study, 4 sheep (40-50 kg) were anesthetized with halothane and ventilated with O_2. We opened the right chest to expose the thoracic duct and the caudal mediastinal lymph node (CMN). To identify the CMN efferent vessels, we injected Evans blue dye into the node. Then we cannulated the CMN efferent vessels in the direction of flow, and we advanced the cannulas into the thoracic duct. Because the cannulas did not obstruct flow in the thoracic duct, lymph flowed freely through the duct past the cannula tip and into the neck veins (4).

Once we had placed the lymphatic cannulas, we tunneled the free end of the cannulas through the chest wall and closed the chest. We placed cannulas into the right jugular vein and into the inferior vena cava via the right femoral vein. We also placed a 43 ml Fogarty balloon cannula into the inferior vena cava. We positioned the balloon between the hepatic veins and the right atrium of the heart. Thus, when inflated, the balloon would increase the venous pressure to the liver and intestines (major lymph producers) and all other tissues in the lower body.

We allowed the sheep to recover for 1-3 days before we performed the experiments. During the recovery period, lymph dripped from the open lymphatic cannulas.

The Experiments

We used pressure transducers to monitor the pressures in the neck veins, inferior vena cava and thoracic duct. The olecranon was used as the zero pressure reference level (4-7). We monitored the pressures for 10-30 minutes, then we increased the thoracic duct flow rate. To increase the thoracic duct flow, we used the same technique we have previously used to cause large increases in lymph flow from the abdominal organs (7,8). We rapidly infused 2.6 ± 0.9 liters (59 ± 19 ml/kg) of warmed Ringers solution intravenously into the sheep. Ordinarily intravenous infusions cause increased venous pressure throughout the body. However, during the infusions we inflated the inferior vena caval balloon. That caused the excess vascular volume to pool in the veins of the lower body and it prevented an increase in neck vein pressure. We frequently adjusted the balloon inflation to maintain the neck vein pressure constant. It was important to maintain the neck vein pressure constant because the thoracic duct drains into veins in the neck. Thus increases in neck vein pressure cause increases in thoracic duct pressure (4). After 30 minutes, we stopped the infusions and deflated the balloon.

Statistics

Data are presented as mean ± SD in the text and mean ± SE in the figures. We used two-way analysis of variance (between times and between sheep) to test for changes in the data during the infusions. We accepted $P<0.05$ to indicate significance.

RESULTS

Fig. 1 shows the neck vein and thoracic duct pressures for 5 experiments in our 4 sheep. At baseline the neck vein pressure was 3.0 ± 2.6 cm H_2O and thoracic duct pressure was 4.1 ± 2.9 cm H_2O. During the infusions, the thoracic duct pressure increased significantly and for the last 10 minutes of the infusions, thoracic duct pressure was 6.8 ± 1.7 cm H_2O. Because we inflated the inferior vena caval balloon, the neck vein pressure did not increase during the infusions. However, the inferior vena caval pressure increased from 12.9 ± 5.0 cm H_2O to 44.1 ± 7.8 cm H_2O.

DISCUSSION

Our results support our hypothesis that increased flow through the thoracic duct increases the pressure within the duct. According to Ohm's Law, the pressure driving flow through a resistance is equal to the product of flow rate times resistance. We believe that the increase in thoracic duct pressure in our sheep was due to the increased lymph flow through the resistance of the thoracic duct. The resistance of the short length of duct between the lung lymphatics and the neck veins is probably very low (4) and that may explain why the thoracic duct

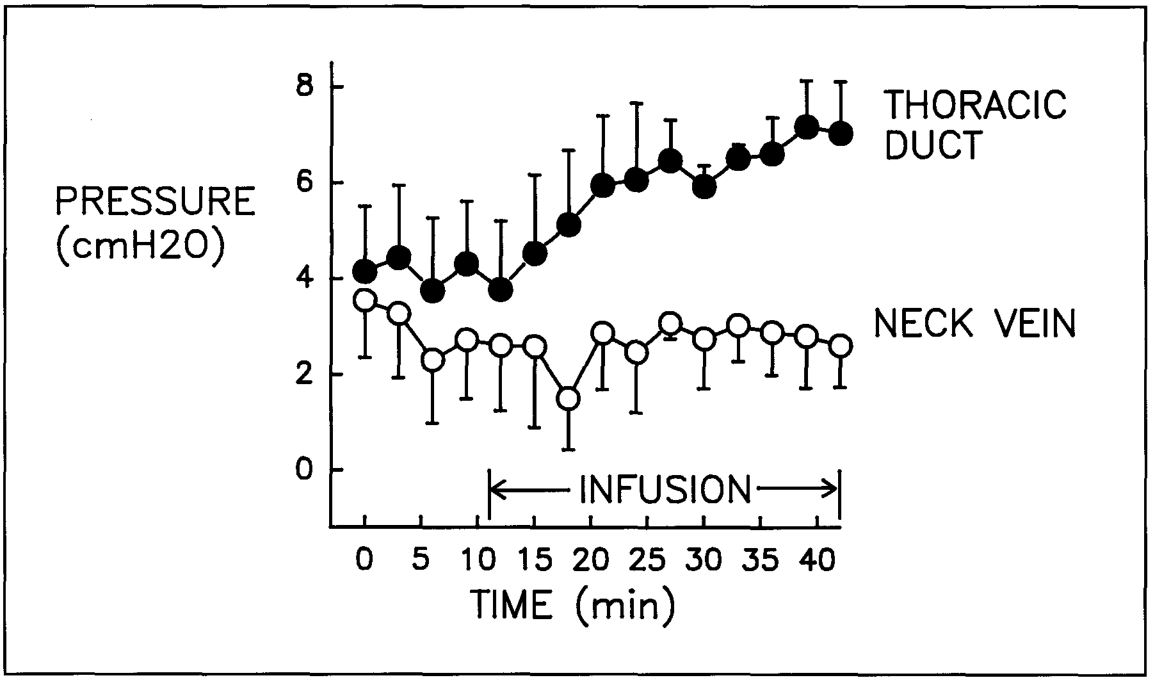

Fig. 1. Thoracic duct and neck vein pressures for 4 experiments. Ringers solution was infused intravenously during the infusion period.

pressure increase in our sheep was so small (2-4 cm H_2O). Accordingly, we expect that the thoracic duct pressure would increase much more than we found if the thoracic duct resistance was increased. Thoracic duct resistance might be increased by agents which constrict lymphatic smooth muscle or by partial obstruction of the duct.

Many investigators believe that lymphatic vessels actively pump lymph towards the neck veins (9-11). This pumping activity, which depends on contraction of the lymphatic vessel smooth muscle, increases with increased fluid load to the lymphatics. Thus active pumping may modify the pressure vs. flow characteristics of lymphatic vessels. Although we are convinced that active pumping affects the pressure vs. flow relationships of many lymphatic vessels, we found no evidence of active thoracic duct pumping in this study or in previous studies (4). Thus we doubt that pumping influenced our thoracic duct pressure data in this study.

Intravenous infusions with Ringers solution increase lymph formation because they increase venous pressure and reduce plasma protein osmotic pressure. Both of those changes should cause increased fluid filtration from the blood capillaries. Lymphatic vessels, in turn, remove the filtrate from the tissues and transport it to the thoracic duct. We chose to use the intravenous infusion-vena caval balloon technique in this study because it produces very large increases in thoracic duct flow (8). In fact, we know of no technique to cause greater increases in thoracic duct flow. However, thoracic duct flow is increased substantially in many human diseases (2,12) and thoracic duct flow rates higher than we produced probably increase thoracic duct pressure more than we found.

Increased thoracic duct pressure is important because it may hinder the ability of the lymphatics to remove edema fluid from the lungs. In previous studies, we have shown that lung lymphatic outflow pressures of 25-30

cmH_2O virtually stop lung lymph flow (6) and accelerate pulmonary edema formation in sheep (5,13). In the present study, the thoracic duct pressure increased from 4.1 ± 2.9 cm H_2O to only 6.8 ± 1.7 cm H_2O. From previously reported lung lymph flow vs. outflow pressure data (6), we estimate that an increase in thoracic duct pressure from 4.1 to 6.8 cm H_2O at the outflow to the lung lymphatics would slow lung lymphatic flow by 10-15%.

We conclude that increased lymph flow through the thoracic duct does increase the thoracic duct pressure. However, in our experiments the pressure increase was small.

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