Manual techniques with a goal of increasing lymphatic flow have long been a focus in the practice of osteopathic medicine. Andrew Taylor Still, MD, DO, recognized the importance of the lymphatic system and dedicated an entire chapter to this topic in *Philosophy of Osteopathy* (1899), writing, “Thus we strike at the source of life and death when we go to the lymphatics.”

Lymphatic treatments continue to be an important component of osteopathic manipulative medicine. Miller developed the lymphatic pump in 1926, stating that it is “an exaggeration of the movements of respiration.” The lymphatic pump technique is used to treat patients with edema and infections because increasing lymphatic flow improves the filtering and removal of fluid, inflammatory mediators, and waste products from interstitial space.

During the influenza pandemic of 1917, Smith reported that osteopathic manipulative treatment (OMT) decreased the mortality rate from 5% to 0.25% among 100,000 patients. Although it has been widely accepted by the osteopathic medical profession that increasing lymphatic flow is beneficial, no direct measurements of lymph flow during OMT have been reported—though there have been reports of beneficial clinical responses to lymphatic pump treatments that may have resulted from increased lymph flow.

In 1920, for example, Lane found that performing the splenic pump—another lymphatic pump technique—on two rabbits injected with washed sheep blood corpuscles increased antibody content in the serum. Sleszynski and Kelso demonstrated more recently that, in patients recovering from cholecystectomy, the lymphatic pump more rapidly returns forced vital capacity and forced expiratory volume in one second toward preoperative values as compared with incentive spirometry. Mesina et al. showed that lymphatic pump techniques, including pectoral traction and splenic pump, elicit transient basophilia of varying degree and duration in healthy men. In elderly patients hospitalized with pneumonia, Noll et al. used a standardized OMT protocol that included the application of the thoracic pump technique. Using these techniques, Noll et al. reduced the duration of patients’ use of oral antibiotics in addition to demonstrating a tendency to reduce mean duration of leukocytosis, intravenous antibiotic treatment, and the length of patients’ hospital stays. By showing an increase in antibody response to pneumococcal polysac-
charide following OMT, Measel reported that healthy patients receiving OMT with thoracic pump treatments demonstrated a statistically significant improvement in immune response over those not receiving this treatment modality. In addition, subjects receiving lymphatic and splenic pump treatments during hepatitis B vaccination demonstrated consistently higher antibody titers compared with those not receiving OMT, according to a study by Jackson et al. In a detailed review of the literature concerning the effects of OMT on the lymphatic system, Dengenhardt and Kucherer note the need for additional studies designed to test the direct effects of OMT on lymphatic circulation.

Dery et al injected albumin labeled with a fluorescent probe into the hind limbs of laboratory rats. The presence of the fluorescent probe in blood samples from the rats' tails was used as an index of lymphatic flow. When researchers applied intermittent manual pressure to the thorax of laboratory rats, however, they found that the concentration of the fluorescent probe increased in the blood samples they were taking, indicating an increase in the probe's transport through the lymphatic system.

Lymphatic flow has also been measured after cannulation of the thoracic duct, but this direct thoracic technique has not been used to investigate responses to manual medicine in animal or human studies. Cannulation and collection of lymph as a means of assessing lymph flow has been criticized by Onizuka et al, who suggest that cannulation may alter the normal pumping action of the thin-walled thoracic duct.

In the present study, an ultrasonic flow transducer was surgically implanted and used to measure lymph flow in the thoracic duct (TDF) in conscious canine subjects at rest and during manipulative intervention and physical activity. A similar approach was used by Onizuka et al to study lymph flow patterns in sheep. Increased TDF has been previously demonstrated in canine subjects during physical activity. Therefore, in our study design, we chose to have dogs undergo physical activity in the form of mild treadmill exercise to measure changes in TDF and to compare them with any changes in TDF levels produced by manipulative intervention.

The aim of the present study was to measure the effect of two types of manipulative intervention on TDF in conscious, surgically instrumented canine subjects, testing a longstanding premise of osteopathic principles and practice.

**Methods**

**Subjects**

This study was approved by the Institutional Animal Care and Use Committee at University of North Texas Health Science Center at Fort Worth—Texas College of Osteopathic Medicine and was conducted in accordance with the Guide for the Care and Use of Laboratory Animals. Five adult male mongrel dogs, free of clinically evident disease, were used as subjects for this study.

**Surgical Preparation**

The day before surgery, a weight-dependent dose of cephalixin, 35 mg per kg, was administered subcutaneously to canine subjects to help prevent postsurgical infection. On the day of surgery, acepromazine maleate (0.03 mg/kg) was provided subcutaneously as a preanesthetic. Thirty minutes later, an intravenous line was placed in subjects' antecubital vein, and thiopental sodium, 5 mg per kg, was administered. After endotracheal intubation, a surgical plane of anesthesia was maintained in canine subjects by mechanical ventilation with supplemental oxygen and isoflurane (1% to 3%). A left lateral thoracotomy was performed on canine subjects in the fifth intercostal space. A 17-gauge catheter was then implanted through a purse-string suture into the descending aorta to measure mean aortic blood pressure (BP). A 1-cm to 2-cm section of the thoracic duct was isolated at the level of the heart for placement of a 2.0-mm or 2.5-mm diameter perivascular flow transducer (model 2SB/2.5SB; Transonic Systems Inc, Ithaca, NY). Another flow transducer was placed around the ascending aorta to measure cardiac output. The catheter and the flow transducers were secured by suture to surrounding tissue.

At the conclusion of instrumentation, the catheter and the flow transducer cables were tunneled subcutaneously and exteriorized between the scapulae. A chest tube was inserted to evacuate the pneumothorax after chest closure. To minimize postoperative pain, 2.5% bupivacaine was sprayed at the point of incision immediately before closure, and buprenorphine hydrochloride (0.03 mg/kg) was administered intramuscularly. After the final layer of skin was closed with staples, triple antibiotic ointment (neomycin sulfate, polymyxin B sulfate, and bacitracin zinc) was applied to the surgical wound. Finally, the dogs' chests were wrapped with veterinary wrap bandages, and nylon jackets were used to protect the catheter and flow transducer cables.

**Measurements**

After recovery from surgery, canine subjects were placed in a standing-support sling, and TDF levels, cardiac output, and BP were recorded. Mean aortic blood pressure was measured by connecting a pressure transducer (model 1290C; Hewlett-Packard Development Company LP, Palo Alto, Calif) to the aortic catheter at the level of the heart. Output from the aortic pressure transducer and the flow transducers on the thoracic duct and the aorta were recorded on a multichannel chart recorder (model 7758; Hewlett-Packard Development Company LP, Palo Alto, Calif) and on a data acquisition system (version 1.8.5; EMKA Technologies, Falls Church, Va), which computed heart rate from the aortic pressure pulse. All baseline TDF data and cardiac variables were collected with the canine subjects in the standing-support sling.

**Experimental Protocols**

Pressure and flow variables were recorded with canine subjects at rest and then during two sessions of manipulative inter-
TDF levels were also measured in the same canine subjects during a 90-second session of treadmill exercise at 3 miles per hour with a 0% incline. This activity rate was chosen because most dogs in the present study performed well at this speed.

At the conclusion of this study, all canine subjects were euthanized humanely in accordance with established animal care and use protocols and the 1993 Report of the AVMA Panel on Euthanasia using a lethal dose of pentobarbital sodium. The chest of each dog was then opened, and the surgical placement of the flow transducer was verified.

Statistical Analysis
One-way repeated measures analysis of variance (RM ANOVA) was used to test for significant changes in TDF during manipulative interventions and physical activity. When significant differences were found, the Bonferroni post hoc test was used to compare each time point of manipulative intervention and physical activity with its respective average baseline value. To analyze the effects of manipulative intervention and physical activity on TDF levels for each canine subject, a t test was used to compare the average TDF level during manipulative intervention to the average TDF level at baseline measures. A net increase in TDF levels and an increase in peak TDF from baseline for manipulative interventions and physical activity were confirmed with a one-tailed t test. Differences between variables were considered significant if $P$ was less than .05.

Results
Manipulative Intervention

Abdominal Pump Technique

Application of the abdominal pump technique produced dramatic enhancement of TDF in canine subjects, as shown in Figure 2. Baseline levels of TDF for all five canine subjects receiving manipulative intervention using the abdominal pump technique averaged $1.57 \pm 0.20$ mL/min. Although the pattern of response varied among the subjects in this group, a significant increase in TDF from baseline levels was seen in each canine subject ($P < 0.05$).

Recovery from manipulative intervention was measured in canine subject 4 (Figure 2, middle right) and canine subject 5 (Figure 2, bottom left). In these subjects, TDF returned to baseline levels within 10 seconds after the cessation of manipulative intervention.

The mean TDF±SE for all five canine subjects is shown in the last graph in the series (Figure 2, bottom right) and demonstrates that lymphatic flow increased significantly from baseline levels during 5 seconds to 30 seconds of manipulative intervention with this technique ($P < 0.05$). Because TDF was not recorded for three canine subjects during the recovery period (ie, canine subjects 1 through 3), the recovery data provided in the last graph in the series show the mean±SE for two animals only (ie, canine subjects 4 and 5).
Thoracic Pump Technique

Similar to our findings as a result of manipulative intervention using the abdominal pump technique, the thoracic pump technique produced significant but variable increases in TDF in all canine subjects (N=5) (Figure 3). Baseline levels of TDF for all five canine subjects receiving the abdominal pump technique averaged 1.20±0.41 mL·min⁻¹, which was not significantly different from baseline levels of TDF before the abdominal pump. Once again, the pattern of response varied among canine subjects in this group, with two subjects responding to treatment early. A significant increase in TDF from baseline levels was seen in each canine subject (P<.05), and mean TDF for the group (bottom right) increased significantly from baseline levels during 5 seconds to 30 seconds of manipulative intervention (P<.05).
A significant increase in TDF from baseline levels was seen in each canine subject (P<.05). As noted elsewhere, TDFs during the recovery period after manipulative intervention were measured in canine subject 4 (middle right) and canine subject 5 (bottom left). In these two canine subjects, TDFs again returned to baseline levels within 10 seconds after the cessation of manipulative intervention.
The mean TDF±SE for all five canine subjects during the thoracic pump technique portion of the study protocol is shown in the last graph in the series (Figure 3, bottom right) and demonstrates that mean TDF for the group increased significantly from baseline levels during 7 seconds to 8 seconds of manipulative intervention using this technique (P<.05). Because recovery TDF was not recorded for three canine subjects in this study (ie, canine subjects 1 through 3), the recovery data provided in the last graph in the series show the mean±SE for two animals only (ie, canine subjects 4 and 5).

Figure 4. Lymphatic flow in the thoracic duct (TDF) in canine subjects before and during physical activity. Lymph flow was measured in four surgically instrumented mongrel dogs before, during, and after physical activity. One dog (canine subject 4) would not run on the treadmill, however, so data was not recorded for that animal. All canine subjects completing this portion of the study protocol demonstrated a similar pattern of TDF during the 90-second period of physical activity. The last graph in this series (bottom) plots the average TDF±SE. A significant increase in TDF from baseline levels was seen in each canine subject (P<.05), and mean TDF for the group (bottom) increased significantly from baseline levels during 2 seconds to 90 seconds of physical activity (P<.05).
Physical Activity

Lymphatic flow in the thoracic duct was measured in canine subjects before, during, and after physical activity (Figure 4). Because one dog (canine subject 4) would not run on the treadmill, however, data from only four subjects in the group are presented. Baseline levels of TDF for all four animals completing the physical activity portion of the study protocol averaged 1.47±0.33 mL/min⁻¹, a value that did not significantly differ from baseline TDFs as measured before manipulative intervention (ie, 1.57±0.20 mL/min⁻¹).

As during manipulative intervention, TDF increased variably but significantly in all four dogs during physical activity (P<.05).

Mean TDF among the four subjects (Figure 4, bottom) increased significantly above baseline levels from 2 seconds to 90 seconds of physical activity (P<.05).

During the manipulative intervention portion of the study protocol, the net TDF increase during each 30-second period of intervention was determined for each canine subject (Table 1). To compute net increases, TDFs for the 30-second baseline period were integrated and then subtracted from the integrated TDF during intervention. A similar approach was used to determine the net TDF increase during 90 seconds of physical activity.

The net TDF increase for 90 seconds of physical activity was divided by three so that exercise values could be compared with those for 30-second manipulative interventions. In all three of the present study’s intervention protocols, there was a net increase in TDF that was greater than zero (P<.05). The net TDF increase during physical activity was significantly greater than that produced by the thoracic pump (P<.05). Although physical activity also tended to produce a greater net TDF increase than the abdominal pump technique, the difference was not statistically significant.

Maximal increases in TDF observed during manipulative intervention or physical activity are reported in Table 2. Values were calculated by subtracting the mean baseline TDF from the peak TDF for all three intervention protocols. Although there were maximal increases in TDF for all three interventions that were significantly greater than zero (P<.05), the maximal increase in TDF was significantly greater for physical activity than for the thoracic pump technique (P<.05). When comparing results for the two manipulative interventions used in the present study, the maximal increase in TDF levels for the abdominal pump technique tended to be higher than that of the thoracic pump, but the difference was not statistically significant.

Changes in cardiac output, BP, and heart rate can alter Starling forces, thus altering lymph formation and TDF levels. Therefore, cardiac variables were recorded before and during all three intervention protocols (Table 3). Although there were no significant changes from baseline levels in any of these measures during manipulative intervention, cardiac output and heart rate increased significantly from baseline levels during physical activity (P<.05). Cardiac output was also significantly higher during physical activity than during manipulative intervention (P<.05).

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**Table 1**

Lymphatic Flow in the Thoracic Duct: Increases in Flow Level by Intervention Type (mL per 30 s)

<table>
<thead>
<tr>
<th>Canine Subject No.</th>
<th>Thoracic Pump</th>
<th>Abdominal Pump</th>
<th>Physical Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.54</td>
<td>1.91</td>
<td>1.78</td>
</tr>
<tr>
<td>2</td>
<td>0.41</td>
<td>0.20</td>
<td>1.53</td>
</tr>
<tr>
<td>3</td>
<td>0.35</td>
<td>0.86</td>
<td>0.65</td>
</tr>
<tr>
<td>4*</td>
<td>0.62</td>
<td>0.73</td>
<td>...</td>
</tr>
<tr>
<td>5</td>
<td>1.60</td>
<td>3.08</td>
<td>3.64</td>
</tr>
</tbody>
</table>

Mean±SE: 0.70±0.23 1.36±0.51 1.90±0.56

* Data were not recorded during the physical activity portion of the study protocol for canine subject 4 because the dog would not run on the treadmill.
† Data demonstrate a net increase in lymphatic flow in the thoracic duct (TDF) above baseline levels during 30-second manipulative interventions. The net increase in TDF observed during 90 seconds of physical activity was divided by three to facilitate data comparison with the results of manipulative intervention. Net increase in TDF in all three intervention groups is greater than zero (P<.05).
‡ Net TDF during physical activity was significantly greater than demonstrated during manipulative intervention with the thoracic pump technique (P<.05).
Comment

Previous animal studies have examined the effects of manipulative intervention on lymphatic flow only indirectly. In the present study, implantation of a perivascular flow transducer on the thoracic duct enabled us to gather accurate measurements of TDF levels so that the immediate effects of manipulative intervention could be studied. Both manipulative interventions used in our study protocol produced significant increases in TDF levels (P < .05).

Values for TDF have been reported for more than 100 years in experiments using cannulation of the thoracic duct. In a 1997 investigation, Onizuka et al. note TDF rates of 2 mL·kg⁻¹·hour⁻¹ in anesthetized dogs and 3 mL·kg⁻¹·hour⁻¹ in anesthetized sheep documented in two early studies, performed in 1871 and 1873, respectively. The baseline flow levels from the present study are slightly higher, at 4 mL·kg⁻¹·hour⁻¹. Onizuka et al. measured baseline lymphatic flows of 5.4 ± 3.1 mL·min⁻¹ in unanesthetized adult sheep using a Transonics flow transducer implanted on the thoracic duct, an instrumentation technique similar to the one we used for the present study. Onizuka et al. reported TDF values that were slightly higher than those observed in the present study of canines. These higher TDF values may be explained by the larger relative size of sheep or other species-related differences.

In addition to measuring TDF levels during the manipulative intervention techniques previously described, we also attempted to measure TDFs while using the pedal pump technique. This technique, however, required laying canine subjects on their backs in the standing-support sling. It was very difficult to keep the dogs relaxed in this position. In addition, we found it was necessary to modify the pedal pump technique for canine subjects because they are not able to lock their hind legs in an extension position as are human subjects. Because of this necessary modification to established OM techniques, the procedure as applied to canine subjects no longer accurately corresponded with the technique as performed on patients in the clinical setting. Although the modified pedal pump technique remained capable of producing increases in TDF levels for canine subjects, we chose not to report those data in the context of the present study because we feel that the required modifications in technique make those results not applicable to human patients.

In the two canine subjects for which recovery data was gathered (ie, canine subjects 4 and 5), TDF levels quickly returned to baseline levels following the termination of manipulative intervention. Although this observation demonstrates the ability of researchers to measure changes in TDFs accurately, it also suggests that these OM techniques, when used in the clinical setting for OMT, may not have sustained effects after treatment is completed. However, the fact that TDF levels were increased throughout manipulative intervention suggests that more frequent and/or more prolonged use of these OM techniques may have more substantial clinical benefits.

Individual approaches to patient management with the use of lymphatic pump treatments vary from patient to patient and physician to physician. In hospitalized patients, treatments may be performed daily, but they may only be done...
weekly in the outpatient setting. Because patients with edema and infection have impaired lymphatic function, applying lymphatic pump techniques more frequently may more effectively reduce lymph stasis (or lymph congestion) and restore adequate lymphatic function.

Further, by increasing the duration of intervention with the abdominal pump technique in one canine subject (canine subject 1) from 30 seconds to 240 seconds, TDF levels were maintained at increased rates during this prolonged manipulative intervention. This beneficial outcome suggests the need for additional studies to examine the optimal duration of OMT using thoracic and abdominal pump techniques to increase TDFs. In addition, further studies should be performed to gather information concerning the most effective rates of compression and the optimal combination of lymphatic pump treatments.

Although TDF levels increased significantly with manipulative intervention in this canine study, the clinical ramifications of this increase cannot be adequately evaluated from the present data. More studies must be completed to demonstrate that increases in TDFs produced by lymphatic pump techniques can significantly reduce peripheral edema or improve recovery from infection. The composition and source of the lymph that is mobilized upon application of lymphatic pump techniques would also be an important focal point for future investigations. Because lymphatic pump techniques are known to improve the immune response to pneumococcal polysaccharide and hepatitis B vaccination in humans, it is possible that the lymphatic pump techniques may have beneficial and preventive effects beyond that of increasing lymphatic transport.

Discussion
This preliminary canine study is the first to show direct, real-time increases in TDF during manipulative intervention. It is our hope that the present findings will stimulate additional osteopathic medical research in this area. Replication of these results with subsequent linking to positive clinical benefits would further support the use of lymphatic pump techniques as additional low-cost, low-technology means of treating infection in humans.

Acknowledgment
Funding for this project was provided by the Osteopathic Research Center in Fort Worth, Tex, and the National Institutes of Health’s National Center for Complementary and Alternative Medicine (Grant No. P01 AT 2023) in Bethesda, Md. The contents of this publication are solely the responsibility of the authors and do not necessarily represent the official views of the National Center for Complementary and Alternative Medicine.

References

Table 3
Lymphatic Flow in the Thoracic Duct: Cardiac Variables at Baseline Measure and During Intervention by Intervention Type, Mean±SE

<table>
<thead>
<tr>
<th>Intervention Type</th>
<th>Cardiac Output (per min)</th>
<th>Mean Aortic Pressure (mm Hg)</th>
<th>Heart Rate (beats per min)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manipulative Intervention</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Thoracic pump</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Baseline</td>
<td>5.1±0.7</td>
<td>102±3</td>
<td>116±7</td>
</tr>
<tr>
<td>- Intervention</td>
<td>5.1±0.6</td>
<td>106±4</td>
<td>126±8</td>
</tr>
<tr>
<td>□ Abdominal pump</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Baseline</td>
<td>5.1±0.7</td>
<td>104±4</td>
<td>126±8</td>
</tr>
<tr>
<td>- Intervention</td>
<td>5.3±0.7</td>
<td>107±5</td>
<td>126±12</td>
</tr>
<tr>
<td><strong>Physical Activity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Baseline</td>
<td>5.7±0.8</td>
<td>107±6</td>
<td>104±6</td>
</tr>
<tr>
<td>□ Intervention</td>
<td>8.5±0.9</td>
<td>108±3</td>
<td>160±12</td>
</tr>
</tbody>
</table>

* Cardiac output during physical activity was significantly elevated above pre-exercise baseline levels (P<.05) and was greater than that observed during manipulative intervention (P<.05). Heart rate during physical activity was also significantly increased from baseline levels (ie, resting heart rate) (P<.05).


