

# Chapter 9

## Physiology – Lymph Flow

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It is in only a few centers that tissue fluid and lymph hydraulics have thus far been studied under normal conditions in the soft tissues of the human limb and in lymphedema.<sup>1-9</sup> Although knowledge of extravascular fluid hydraulics is indispensable for understanding the manual and pneumatic massage events in tissues and after surgical lymphatico-venous anastomoses, few data are available in the pertinent literature.

### Tissue Fluid Pressure and Flow

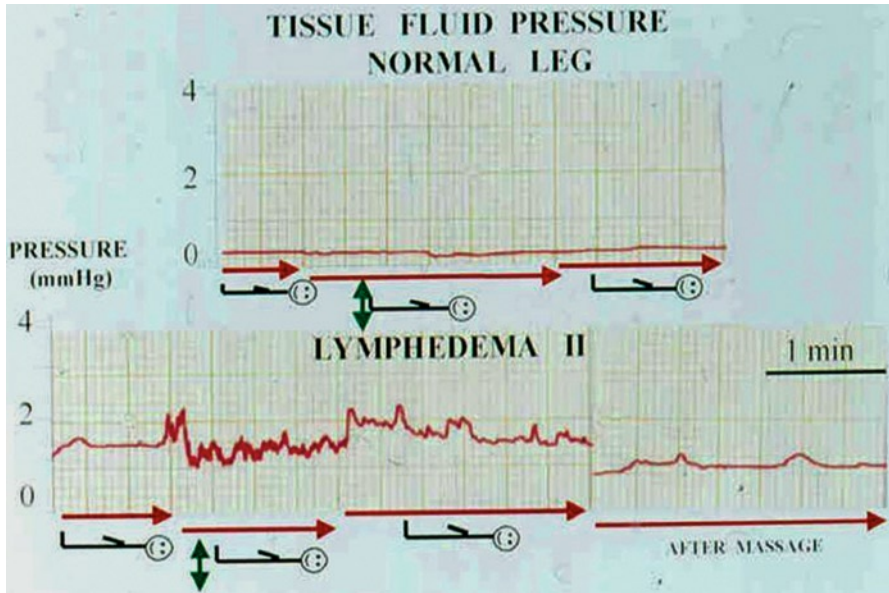
Lymph flow from normal and lymphedematous tissues cannot be analyzed without some knowledge of mobile tissue fluid pressure and movement. Lymph is a product of plasma capillary filtrate. This filtrate forms tissue fluid. A number of tissue humoral and cellular components derived from skin, subcutaneous tissue, fascia, and muscle mix in the interstitial space with the capillary filtrate and flow into the lymphatics. In the lymphatics, the tissue fluid becomes lymph. Forces driving tissue fluid to the lymphatics are responsible for filling vessels and initiating flow.

### *Pressures in the Normal Limb*

Under normal conditions, tissue (interstitial) fluid pressure in the lower limb subcutaneous tissue at rest, when measured, ranges between  $-3$  and  $+1$  mmHg (Fig. 9.1). It is slightly negative, which also has been observed in animals. Active movements of the calf (contractions of muscles) may slightly decrease the pressure due to

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**Fig. 9.1** Tissue fluid pressures in the subcutaneous tissues of a normal and a lymphedematous calf in the horizontal position. *Upper panel:* pressure approximating zero, not affected by muscular contractions. *Lower panel:* pressure approximating 2 mmHg, with minor fluctuations, during calf muscle contractions. Tissue fluid pressure is low even in the advanced stages of lymphedema, due to expansion of the interstitial space of the subcutis

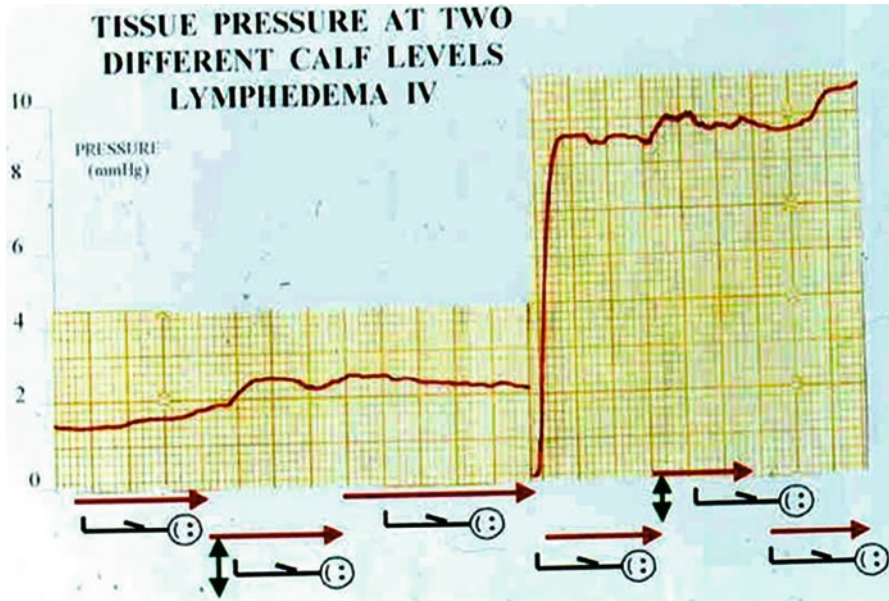
emptying of the interstitial space; however, these differences are of no clinical importance (Fig. 9.1).

### ***Pressures in the Lymphedema***

In obstructive lymphedema, the resting tissue fluid pressure increases above zero, but remains within a low range, between 1 and 10 mmHg<sup>9</sup> (Fig. 9.2). Higher pressures are observed in advanced stages (III and IV). There are no significant changes in pressure elicited by the change from a horizontal to an upright position. Moreover, active contractions of calf muscles do not generate higher pressures (Fig. 9.1). Manual massaging of lymphedematous calf soft tissues may even increase the pressure above 100 mmHg. However, removal of the massaging hand brings about an immediate drop in pressure to zero.

### ***Normal Tissue Fluid Flow***

In a normal subcutaneous tissue there is no detectable flow at rest or during walking or massage.<sup>6</sup>



**Fig. 9.2** Tissue fluid pressures recorded at the mid-calf (left panel) and ankle level in lymphedema, stage IV. Minor differences depending on the level of measurement. Note lack of effect of muscular contractions and low levels of pressure

### ***Tissue Fluid Flow in Lymphedema***

Excess accumulated tissue fluid moves radially from the site of applied force during muscular contractions and massaging, but not unidirectionally toward the root of the extremity. This makes massage of soft tissues without immediate distal compression (bandaging) non-effective. Tissue fluid flow can be seen on lymphoscintigraphy, depicting artificial channels created by deformation of the subcutaneous tissue by the compressed fluid.

## **Lymph Pressure and Flow**

### ***Extrinsic Factors that Propel Lymph***

#### **Normal Conditions**

Muscular activity, respiratory movements, passive movements and arterial pulsation have no effect on lymph flow.<sup>1-3,5,6</sup> Generally, the lymphatics of the limb are empty, with only a few microliters of lymph in some lymphangions. There is no hydrostatic pressure in normal leg lymphatics in the upright position.<sup>3,6</sup>



**Fig. 9.3** Pressure (lateral) and flow recorded in a normal calf lymphatic vessel. Three pulse waves are seen (*red curve*). They are of different amplitude. Also, the time intervals between contractions are of different duration. The contraction of each lymphangion generated pressures propelling flow (*blue curve*). The ascending component of the curve shows the stroke volume. Flow occurred only during lymphangion contractions

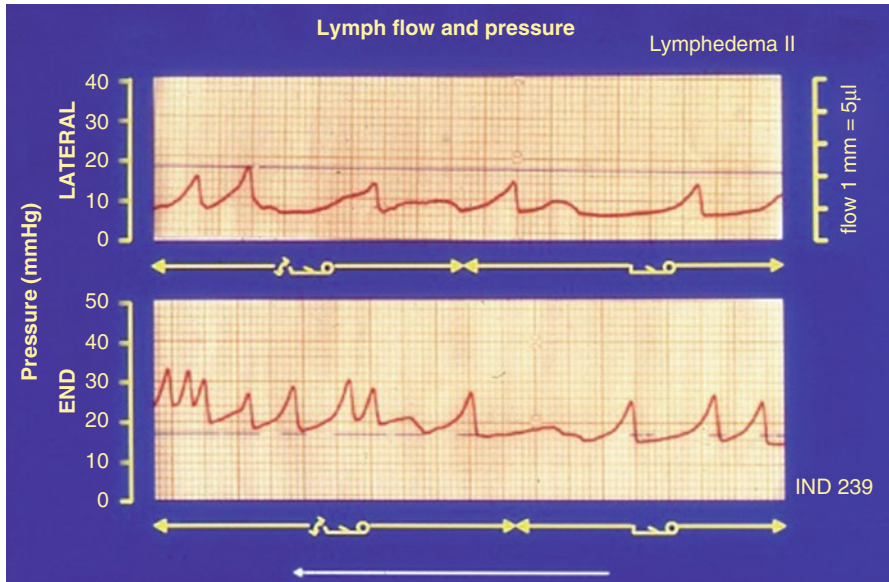
### Lymphedema Conditions

Muscular contraction of the foot and calf may increase lymph pressure to values above 100 mmHg. In lymphedema, patent lymphatics are filled with lymph and pressing of the muscles against the skin creates a pressure gradient between the distal and proximal lymphatics.<sup>3,6</sup>

### *Intrinsic Factors that Propel Lymph*

Lymph is propelled by autonomous rhythmic contractions of lymphangions.<sup>1-6</sup> Tissue fluid enters the initial lymphatics to flow into the lymphangions. Stretching of the lymphatic wall by inflowing tissue fluid evokes contractions of the lymphatic wall muscles (according to Starling's law) and generates flow.

Lymph pressures in normal limbs. Lymphatics contract rhythmically with a frequency that depends on the volume of the tissue fluid entering.<sup>3,6</sup> In regions with high capillary filtration rates and tissue fluid formation, the frequency is high. The recorded pressures at rest, without regard to whether they are obtained in the supine or upright position, with free proximal flow (lateral pressure), range between 7 and 30 mmHg and during foot flexion, between 10 and 30 mmHg (Fig. 9.3). The pulse amplitudes are 3–20 mmHg and 5–17 mmHg and the pulse frequencies are 0.6–6/min and 2–8/min respectively.<sup>3,6</sup> The resting end pressures with obstructed flow (e.g. corresponding to lymphatic obstruction in postsurgical lymphedema) range between 15 and 55 mmHg, and during foot flexion 15– 50 mmHg. The pulse amplitudes are 3–35 mmHg and 3–14 mmHg and the pulse frequencies are 2.5–10/min and 3–12/min respectively. Massaging of the foot or tapping of lymph-laden tissues has no effect



**Fig. 9.4** Lymph pressure recorded in a patient with lymphedema, stage III. Spontaneous pressure waves generated by a damaged lymphangion are low and unable to create flow (*flat blue line*)

on lymph pressure. Heating of the foot significantly increases the pressure, amplitude, and frequency of lymphatic contractions.

**Pressures in Lymphedematous Limbs**

In obstructive lymphedema only a few lymphatic collectors remain patent. The recorded pressures during rest range from 5 to 45 mmHg depending on the surviving contractility force of the damaged lymphatic musculature.<sup>7,9</sup> During calf muscular contractions, pressures are generally low, ranging from 10 to 25 mmHg, although tiptoeing may, in some cases, generate pressures exceeding 200 Hg.

**Lymph Flow in Normal Limbs**

Flow occurs only during spontaneous contractions of lymphangions.<sup>3</sup>

**Lymph Flow in Lymphedematous Limbs**

As most collectors are partially or totally obliterated, there might be only some spontaneous flow in patent vessel segments at different levels of the limb.<sup>7,8</sup> Correlation of pressures and flow, in most cases, demonstrates the ineffectiveness of the lymphangions’ contractions (Fig. 9.4). This is the consequence of the destruction of vessel musculature and valves.

## General Remarks

In post-inflammatory, post-surgical, and post-traumatic lymphedema, as well as in the so-called idiopathic lymphedema (i.e., lymphedema of unknown etiology), the intra-lymphatic pressures and flow are abnormal due to: a) destruction of lymph vessel muscle cells, b) destruction of valves, or c) partial or total lumen obstruction. Tissue fluid finds its way to the non-swollen parts of the limb along hydraulically created tissue channels.

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