Lymphology 20 (1987) 219-223

COMPARISON OF VISCOELASTIC PROPERTIES OF WALLS AND FUNCTIONAL CHARACTERISTICS OF VALVES IN LYMPHATIC AND VENOUS VESSELS

T. Ohhashi

Department of Physiology, Shinshu University School of Medicine,
Matsumoto, Japan

ABSTRACT

The principal function of the lymphatic and venous system is to maintain a favorable environment for cells of the body. As a consequence mainly of hydrostatic forces, shifts of fluid usually occur between the vascular system and the extracellular space. To compensate for these shifts the veins are capable of active and passive changes in capacity that serve to modulate the filling pressure of the heart by adjusting the central blood volume. In addition to the venous function, the lymphatic function also contributes to compensate for the fluid shifts by drainage from the interstitial space. Namely, the general function of the lymphatic system is to return fluid and protein which escapes from the blood capillaries to the lymph circulation. To elucidate the mode of venous and lymph transport, therefore, it is of essential importance to obtain basic knowledge of the mechanical characteristics of the walls of the vessels and the functional characteristics of the lymphatic and venous valves dividing two adjacent compartments. In this communication, in order to answer the question, "Are Lymphatics Different From Blood Vessels?", I would like to review a comparison of viscoelastic properties of walls and functional characteristics of valves in lymph and venous vessels by use of our original data obtained with isolated canine veins and thoracic ducts and with isolated bovine mesenteric lymphatics (1-9).

Mechanical characteristics of lymph vessels

Fig. 1 shows typical recordings of pressure-radius relationships in one lymphangion preparation of isolated canine thoracic duct. It is one of the typical fibrous-typed lymph vessels which have a few smooth muscle cells within a large number of elastic and collagen fibers in the wall. The curves recorded at the valvular and intervalvular portion of a lymphangion are similar in pattern to what has been observed in isolated canine jugular vein. The calculated circumferential elastic moduli of the walls was about 2.0x10^5 dynes/cm^2. The curves have small hysteresis loops but no phasic fluctuations of the pressure produced by spontaneous contractions.

Fig. 2 shows pressure-radius relationships in the one-lymphangion preparations isolated from bovine mesenteric lymphatics. The vessel is well known as one of the muscle-typed collecting lymph vessels. Thus, smooth muscle cells in the wall are well developed and arranged

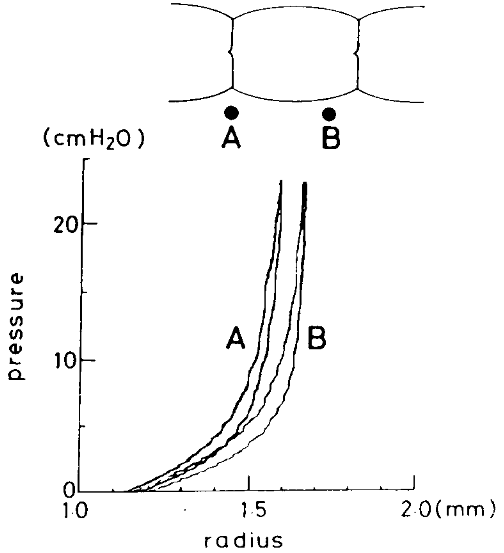

Fig. 1. Passive pressure-radius relationships in single lymphangion specimen isolated from canine thoracic duct. A: valvular portion. B: intervalvular portion.

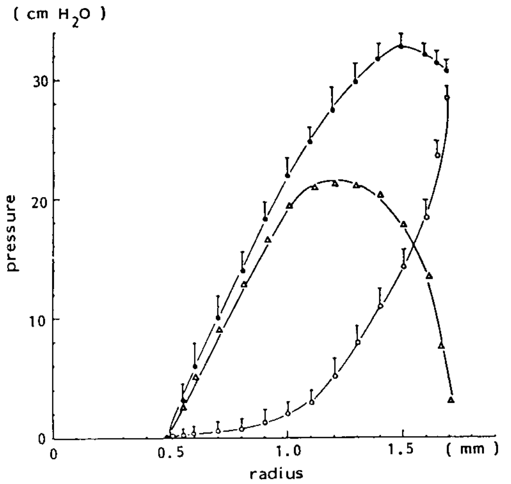

Fig. 2. Passive pressure-radius (o), total pressure radius (o), and actively generated pressure-radium (Δ) relationships in single lymphangion specimen isolated from bovine mesenteric lymphatics. Vertical bars stand for standard errors. Data from Ohhashi et. al. (3) by permission.

in three layers; the internal longitudinal, intermediate circumferential and external longitudinal.

A curve depicted by open circles is similar in pattern to what has been observed in isolated canine portal vein. Circumferential elastic moduli of the walls are calculated to be about 0.4×10^5 dynes/cm^2 in the physiological pressure range, the value being smaller than those in the fibrous lymph vessels. An increase in the radius causes an appearance of spontaneous contractions. A curve depicted by dots represents the total pressure-radius relationship, the total pressure being the sum of hydrostatically imposed and actively generated pressure. Hence, the active pressure increases with increasing radius up to a certain maximum value. Further augmentation in radius produces a fall in pressure.

The spontaneous contractions of lymphatic smooth muscles in isolated bovine mesenteric lymphatics are regulated not only by the magnitude of stretch but also by the rate and acceleration of deformation. The rhythm and amplitude of spontaneous contractions have also been modified by humoral and neural factors. The morphological characteristics corresponding to spontaneous contraction in bovine mesenteric lymphatics are summarized as follows: (1) A large number of mitochondria are observed on both sides of the nucleus. (2) Numerous glycogen granules are also found among and around the mitochondria. (3) Blood capillaries are found within the smooth muscle layers of the walls. The former two structural features may be a morphological manifestation of the high metabolic activity required for the spontaneous contraction of lymphatic smooth muscle cells. The presence of vasa vasorum within the media may reflect the relatively high oxygen requirement of the smooth muscle cells and relatively low oxygen supply from the lymph flow. An ample supply of oxygen may be required to maintain the spontaneous contraction.

Such mechanical and morphological characteristics of lymph vessels are summarized in *Table 1*. As shown in the table, there are marked regional differences in viscoelastic properties of the walls of lymph vessels. Namely, the muscle-typed collecting lymph vessel is more compliant than the fibrous typed

Table 1
Mechanical and morphological characteristics of isolated bovine mesenteric lymphatics and canine thoracic duct

	Mesenteric Lymphatic	**Thoracic Duct**
outer diameter (mm)	2.8 (8 cmH_2O)	3.0 (5 cmH_2O)
wall thickness (μm)	100	50
Young's moduli (10^5 dynes/cm^2)	0.4	2.0
spontaneous activity (/min)	2-4	0
structure	smooth muscle >> collagen fiber	collagen fiber >> smooth muscle

vessel. It is able to elicit a marked spontaneous contraction.

Mechanical characteristics of venous vessels

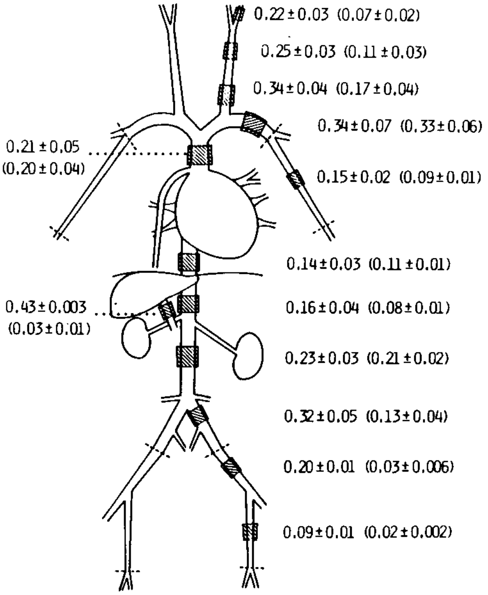

Fig. 3. The distensibilities with (intra-parenthesis) and without (extra-parenthesis) activation of venous smooth muscles calculated from pressure-volume curves in the isolated canine trunk and peripheral veins.

There are also marked regional differences in venous distensibility. *Fig. 3* demonstrates the average value of distensibilities with and without activation of venous smooth muscles calculated from the pressure-volume curves in the isolated canine trunk and peripheral veins. The numbers intra- and extra-parenthesis show the distensibilities with and without the activation of venous smooth muscles ranging from 0 to 5cm H_2O in the pressure, respectively. The largest distensibility in all isolated canine veins is observed in the hilar portal vein. Activation of venous smooth muscles in the hilar portal vein also causes the most reduction of the distensibility. In the case of trunk veins, the distensibilities of inferior caval veins passed through the diaphragm are significantly lower than those obtained with the superior and infrarenal inferior caval veins. The mechanical characteristic may be related to a preventive function of the venous wall itself against collapse. If not, contractions of striated muscles in the diaphragm may cause collapse of veins, inhibition of venous return, and then syncope. The non-uniform distensibility of venous walls is also understood in terms of local differences in the architecture of venous walls. Thus, in correspondence with the mechanical characteristics of trunk veins, the wall thickness of suprarenal inferior caval vein is about 2.5 times as great as those in other trunk veins. Smooth muscle cells in the wall are well developed, and arranged in two layers: the internal circumferential and external longitudinal. Embryological differences in the genesis of the vein may account for the existence of longitudinal smooth muscle layers. The longitudinal smooth muscle layers in the venous walls, therefore, are observed only in the hilar portal vein and suprarenal inferior caval vein.

The longitudinal smooth muscle cells are capable of inducing spontaneous contractions in the venous preparations. *Fig. 4* shows typical recordings of spontaneous contractions in longitudinal preparations isolated from canine suprarenal inferior caval veins. The preparations contract isometrically at a rate of 1-2 beats per minute. The contractions, not affected by tetrodotoxin, disappeared in a calcium-free environment and reappeared soon after an addition of lmM barium chloride. These results suggest that venous spontaneous contraction may be generated myogenically.

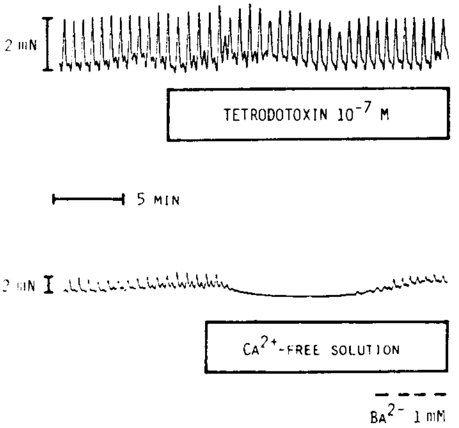

Fig. 4. Effects of tetrodotoxin ($10^{-7}M$), calcium-free environment, and barium chloride (1mM) on the spontaneous contractions observed in longitudinal strips isolated from canine suprarenal inferior caval veins.

Functional characteristics of lymphatic valves

The value of endurance limits of lymphatic valves was measured as one of the parameters representing the functional characteristics of valves. The endurance limit of a valve has been studied by use of the isolated cylindrical preparations with two compartments, the lumen of which is divided into two by a valve located between the inlet and outlet cannulas. Pressure in the downstream half is elevated stepwise by injection of Krebs solution through the microsyringe. The reflux is determined by a rise of pressure in the upstream half. The endurance limit is defined as the lowest pressure in the downstream half at which the reflux began. The values of endurance limits of lymphatic valves in the isolated canine thoracic ducts and bovine mesenteric lymphatics are 48.4 and 68.1cm H_2O, respectively. The values are four to eight times as high as the expected intraluminal pressures under physiological conditions.

Functional characteristics of venous valves

Fig. 5 demonstrates typical recordings of pressure changes in the upstream and downstream half of a venous valve in isolated monkey lateral saphenous vein. A slight reflux, along with a rise of pressure in the upstream half is noticed at a downstream pressure of 60cm H_2O. The average value for endurance limits of the valves in monkey saphenous

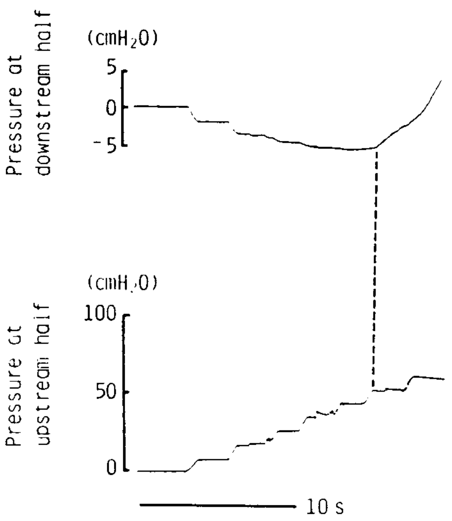

Fig. 5. Typical recordings of pressure changes in the upstream and downstream half of a venous valve in isolated monkey lateral saphenous vein.

veins is 68.2cm H_2O. The safety factor against reflux in the peripheral venous valve is high as in the lymphatic valves. However, there is a marked species difference in the endurance limits of venous valves.

CONCLUSION

In this communication, the mechanical and morphological characteristics of lymph vessels and veins, and the endurance limits of lymphatic and venous valves are briefly reviewed using our original data. There are marked regional differences in the viscoelastic properties of the lymphatic and venous walls and in the value of endurance limits of lymphatic and venous valves. Therefore, my answer to the question whether lymphatics are different from blood vessels is yes and no from the viscoelastic property points of view. The answer may be dependent on the materials selected to compare functional and morphological characteristics. Thus, it is unwise to attempt to generalize about all lymph vessels and veins of the body from the characteristics of those of one tissue type.

REFERENCES

1. Ohhashi, T, S Fukashima, T Azuma: Vasa vasorum within the bovine mesenteric lymphatics. Proc. Soc. Exp. Biol. Med. 151 (1977), 582.
2. Ohhashi, T, T Azuma, M Sakaguchi: Transmembrane potential in bovine lymphatic smooth muscles. Proc. Soc. Exp. Biol. Med. 159 (1978), 350.
3. Ohhashi, T, T Azuma, M Sakaguchi: Active and passive mechanical characteristics of bovine mesenteric lymphatics. Am. J. Physiol. 239 (1980), H88.
4. Ohhashi, T, S Kobayashi, S Tsukahara, T Azuma: Innervation of bovine mesenteric lymphatics: From the histochemical points of view. Microvasc. Res. 24 (1982), 377.
5. Azuma, T, T Ohhashi, IC Roddie: Bradykinin-induced contractions of bovine mesenteric lymphatics. J. Physiol. (Lond.) 342 (1983a), 217.
6. Ohhashi, T, JA Olschowka, DM Jacobowitz: Vasoactive intestinal peptide inhibitory innervation in bovine mesenteric lymphatics: A histochemical and pharmacological study. Circ. Res. 53 (1983b), 535.
7. Ohhashi, T, T Azuma: Variegated effects of prostaglandins on spontaneous activity in bovine mesenteric lymphatics. Microvasc. Res. 27 (1984), 71.
8. Ohhashi, T, K Morimoto: Functional and morphological characteristics of canine veins and venous valves. In *Advances in Phlebology*. Sakaguchi, S (Ed.), John Libbey & Co. Ltd., London, (1987), 34.
9. Ohhashi, T: Regulation of motility of small collecting lymphatics. In *Advances in Microcirculation*. Staub, NC, AR Hargens, (Eds.), S. Karger AG, Basel, (1987), *(in press)*.

Toshio Ohhashi, M.D.
Department of Physiology
Shinshu University
School of Medicine
3-1-1 Asahi
Matsumoto 390, JAPAN