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Development of Lymph Hypertension During Lymphatic Occlusion

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Summary

The effects of obstruction of lymph flow on the intralymphatic pressure are studied through a mathematical model using a digital computer and intralymphatic pressure was observed to increase.

Lymph flow in the lymphatics is governed by certain intrinsic and extrinsic factors (1-10). The extrinsic factors include respiratory movements, rhythmic changes in the volumes of intestines, spleen and other organs, and also the movement of skeletal muscles, which exert an external pressure on the lymphatic walls. The intrinsic factor is the active contractility which is due to rhythmic contractions of the smooth muscle in the walls of the major lymphatics and lymph nodes. Active contractility of the lymphatics has been demonstrated through a number of in-vivo and in-vitro investigations (1-11). In addition, there are numerous valves along the lymphatics which permit unidirectional motion from the periphery toward the thoracic duct.

"Lymphangion" is a term coined by *Mislin* (1) to refer to that portion of a lymphatic vessel which is bound by two adjacent valves. *Smith* (3) observed that when the flow of lymph was halted by pressure on the vessel, the lymphangions distal to the point of occlusion continued to contract at a faster rate but eventually stopped moving in a state of marked dilation. *Hall* and his coworkers (4) have observed that when the intralymphatic pressure was increased by raising the outflow end of the cannula from the reference plain, the mean lymphatic pressure and the frequency of pressure pulses increased. They found that at a certain pressure, lymph flow ceased but pulses were maintained. It is interesting that when the cannula was clamped to prevent the outflow of lymph, the mean lymph pressure rose steadily to a maximum over a period of five to ten minutes. In the present analysis, the effects of obstruction of lymph flow on the intralymphatic pressure are investigated through a mathematical model.

Method

In references (12) and (13), the current notions of lymph propulsion are translated into a mathematical model through the use of Newton's law and the law of conservation of mass. The model consists, essentially, of equations which describe lymph flow through segments called "Lymphangions".

The law of conservation of mass as applied to lymph dynamics may be expressed as

$$\text{Rate of change of lymphangion radius} = \frac{\text{Inflow} - \text{outflow}}{\text{surface area of lymphangion}} \quad (1)$$

Newton's second law states that mass times acceleration is equal to the sum of all the forces acting on the object. For the lymph flow from one lymphangion to the next, Newton's laws may be expressed as

$$\begin{aligned}(\text{mass}) \ *(\text{acceleration of lymph}) = \ & (\text{Hydrodynamic forces}) - \\ & (\text{Viscous Resistance to Flow}) - \\ & (\text{Valve Resistance})\end{aligned} \quad (2)$$

The wals of the lymphangions are also governed by the Newton's laws.

The balance of momentum for the lymphangion wall may be expressed by

$$\text{Intra lymphatic Pressure} = \text{External pressure on the lymphangion wall} + \left(\frac{\text{Wall thickness}}{\text{lymphangion radius}}\right)\left[\text{Hoop stress in the wall due to wall elasticity} + \text{Stress developed due to active contractility}\right] \quad (3)$$

The hoop stress term is a consequent of Newton's third law which states that for every action there is an equal and opposite reaction. As the wall is deformed, the deformation of the wall causes a stress; the hoop stress is a function of the amount of stretch of the wall and wall elasticity. The stress developed due to active contractility is a function of distention of the wall and is also a function of time. In addition to the above equations, a constraint due to unidirectional flow is used.

$$(\text{outflow from a lymphangion}) \geqslant 0 \quad (4)$$

These equations govern the flow through a lymphangion chain and 4 n equations are needed if there are n lymphangions in a vessel. In order to facilitate conceptual handling of the lymphangions, each lymphangion is identified with a specific number.

For each time step the intra lymphatic pressure is computed using equation (3) and the hydrodynamic forces are then calculated. The procedure then is to compute the outflow for each lymphangion and the lymphangion radius by integrating equation (1) and (2). These values are used in the next time step to compute the pressure distribution in equation (3). The procedure is carried on by incrementing the time step. It should be pointed out that outflow from a lymphangion is same as the inflow into a lymphangion in front of it.

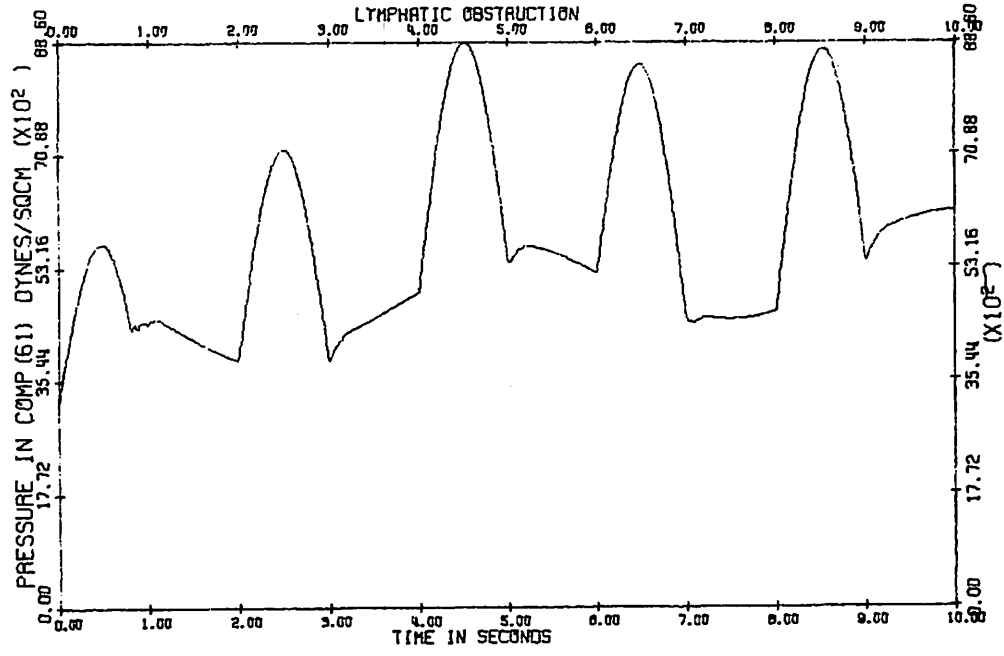

Fig. 1 Pressure pattern in intestinal trunk lymphangion 61 during the obstruction of outflow from lymphangion 61.

Results

In our numerical experiments on the digital computer, we have conceptually occluded the intestinal lymphatic trunk by setting the outflow from a lymphangion in the model to zero. This is achieved by increasing the resistance to outflow from the lymphangion to infinity in equation (2). The simulated pressure patterns in the lymphangions of the occluded lymphatic immediately distal to the occlusion are depicted in Figures 1 and 2. Figures 3 and 4 depict pressure patterns in the same lymphangions when the lymphatic was not occluded.

Discussion

Consistent with the observations of *Smith* (3) and *Hall* et al. (4), the results of this investigation predict an increase in pressure in an obstructed lymphatic vessel. It is particularly interesting that the pressure increased by 100% in ten seconds.

The obstruction of outflow causes increased distention of the lymphangion lumen due to continued pumping, of fluid into the lymphangion, by the lymphangion immediately distal to it. The increased dilation of the wall enhances the frequency and amplitude of active contractility.

Apart from causing lymphatic hypertension, the obstruction of a lymphatic vessel leads to lymph edema of the associated region provided that the obstruction is sufficiently prolonged. However. a period of a few weeks to few months is required for the development of the lymph edema (14). During the period when the outflow is obstructed, the vessel remains dilated. Several pathological changes have been noted by *Olszewski* (14) in a recent experiment involving post-surgical lymph edema. After a prolonged obstruction of the outflow, it is believed that the vessels loose the ability to contract intrinsically. This may be partially attributed to the lack of the sufficient supply of the nutrients to the vessel.

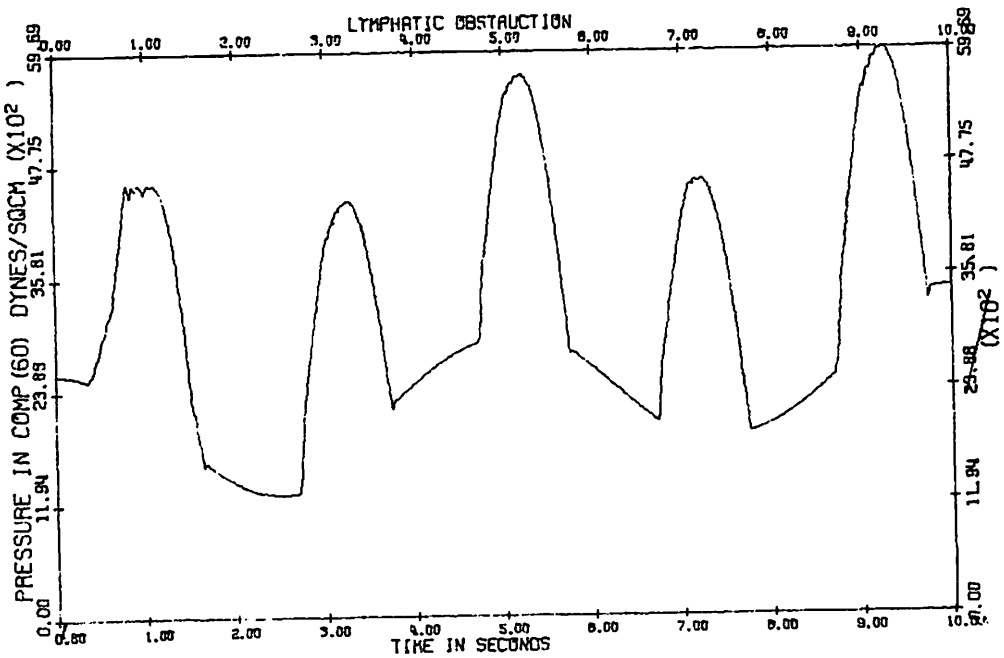

Fig. 2 Pressure pattern in lymphangion 60 (intestinal trunk) during the obstruction of outflow from lymphangion 61.

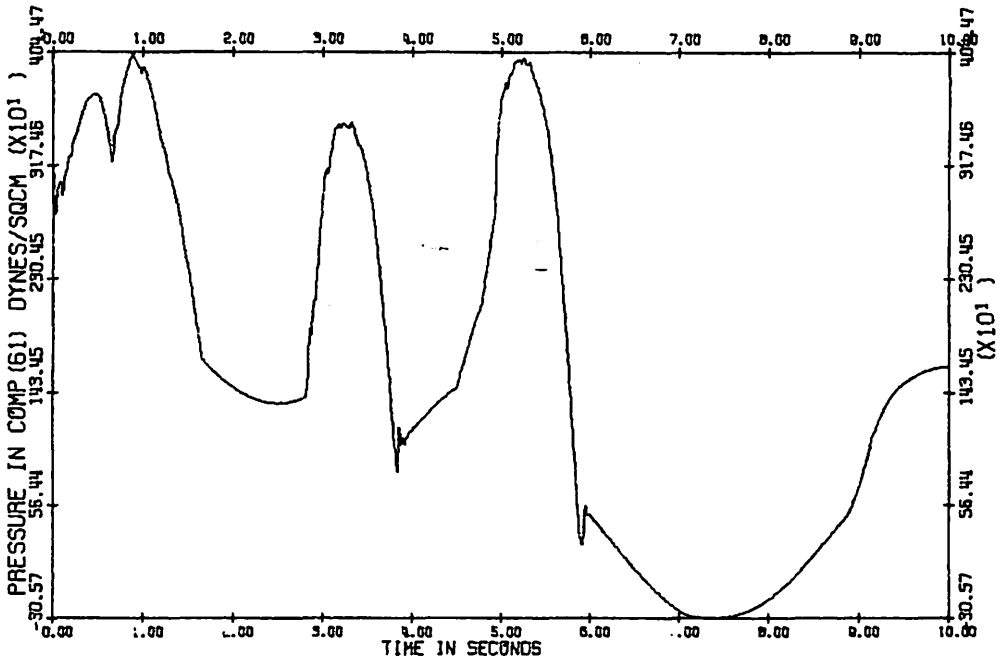

Fig. 3 Pressure pattern in unobstructed intestinal trunk lymphangion 61.

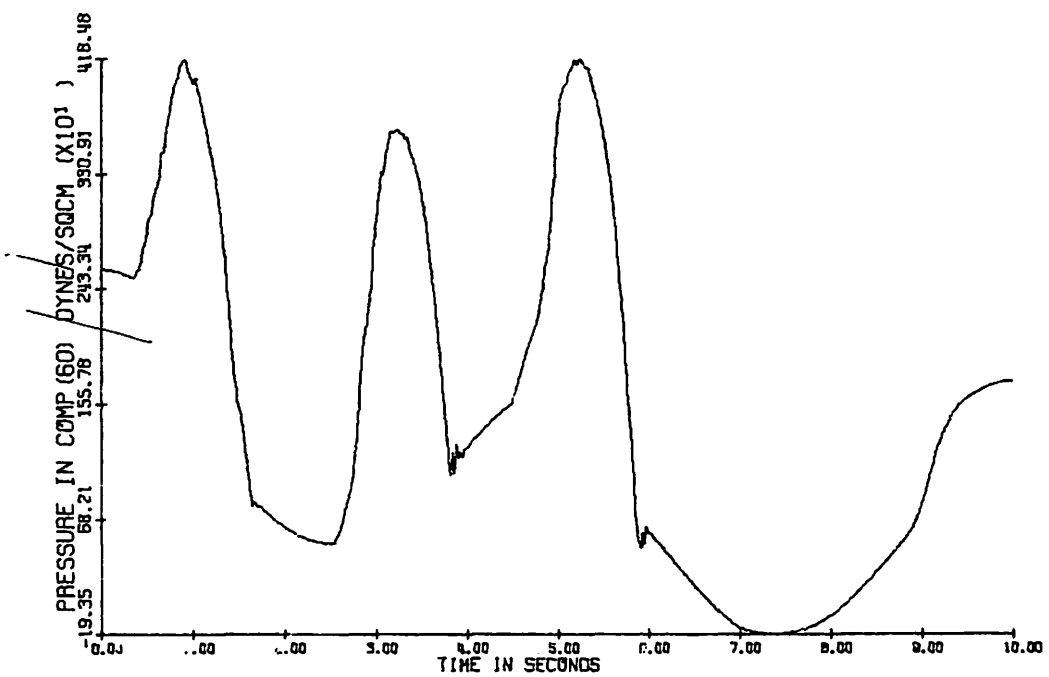

Fig. 4 Pressure pattern in unobstructed intestinal duct lymphangion 60.

References

1 *Mislin, H.:* "Structural and Functional Relations of the Mesenteric Lymph Vessels", Progress in lymphology, Ed. Ruttiman, New York, Hafner, 1967

2 *Mislin, H.:* "Die Kontraktilen Eigenschaften der Lymphgefäße", Angiologica 8:207-211 (1971) 79

3 *Smith, R.O.:* "Lymphatic Contractility, a possible Intrinsic Mechanism of Lymphatic Vessels for the Transport of Lymph" J. Exp. med., 90 (1949) 497

4 *Hall, J.G., B. Morris, G. Woolley;* "Intrinsic Rhythmic Propulsion of Lymph in the Unanaesthetized Sheep", Physiol.,Lond., 180 (1965) 336

5 *Campbell, T., T.Heath:* "Intrinsic Contractility of Lymphatics in Sheep and in Dogs", Quart. J. Exp. Physiol. 58 (1973) 207

6 *Kenmouth, J.B., G.W. Taylor:* "Spontaneous Rhythmic Contractility in Human Lymphatics", J. Physiol. (London), 133 (1956) 3

7 *Nisimura, Y:* "Lymphatics and Lymph Flow", Hiroshima J. Med. Sci., 17 No. 2 (June 1968) 53

8 *Orlov, P.C., P.G. Boriosova:* "Spontaneous and Evoked Contractile Activity of Smooth Muscles of Lymphatic Gland", (Rus.) Dokalady Acad. Sciences CCCP, 215 (1974) pp 1013

9 *Lee J.S.:* "Motility, Lymphatic Contractility and Distention Pressure in Intestinal Absorption" Am. J. Physiol., 208 (1965) 621

10 *Tirone, P., P. Schizntarelli, G. Rosati:* "Pharmacological Activity of Some Neuro-Transmitters in the Isolated Thoracic Duct of Dogs", Lymphology, 6 (1973) 65

11 *Zweifach, B.W.:* "Micropressure Measurements in Terminal-Lymphatics", Bibliotheca Anatomica, 12 (1973) 361

12 *Reddy, N.P.:* "A Discrete Model of the Lymphatic System", Ph. D. Dissertation, Texas A & M University, 1974

13 *Reddy, N.P., T.A. Krouskop and P.H. Newell, Jr:* "Biomechanics of a Lymphatic Vessel", (In Press), Blood Vessels (1975)

14 *Olszewski, W.:* "On the Pathomechanism of Development of Postsurgical Lymphedema", Lymphology, 6 (1973) 35

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