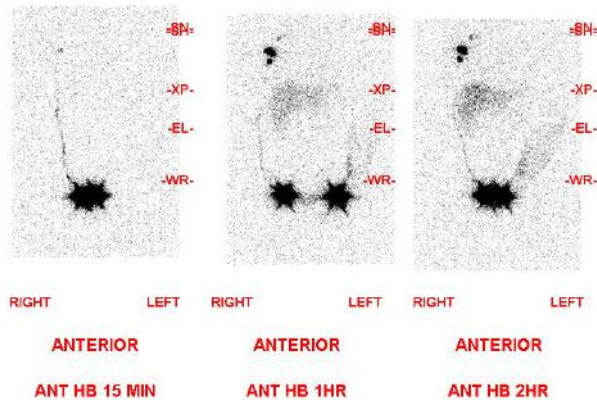
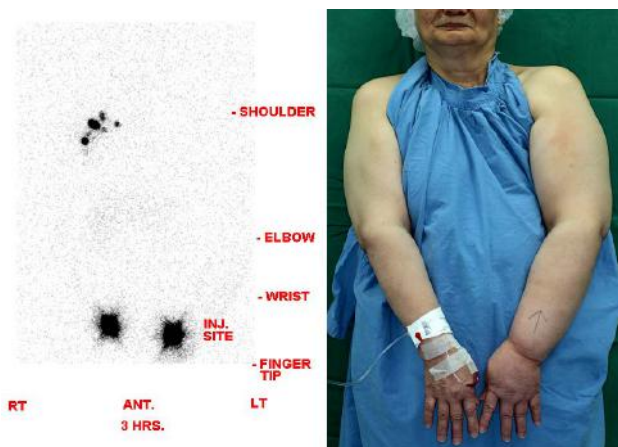




stage, as there is no functional lymphatic vessel remaining in the limb, there may be a complete stagnation of the radioactive dye at the injection site [Figure 2].



**Figure 1:** Lymphoscintigraphy of a patient with left upper limb lymphedema after breast cancer treatment. (Left) The lymph nodes at the right axilla were shown up by radioactive contrast as early as 15 minutes. A lymphatic vessel was also visualized. (Middle) The uptake of the right axillary lymph nodes was denser at 1 hour after contrast injection. (Right) In the left upper limb, dermal backflow pattern was shown up to the level of elbow.



**Figure 2:** (Right) A patient with left upper limb lymphedema for 10 years after axillary dissection and radiotherapy for breast cancer. The clinical stage of her edema was ISL (International Society of Lymphology) stage II. (Left) Her upper limb lymphoscintigraphy showed a complete stagnation of contrast at 3 hours after contrast injection.

The main advantages of lymphoscintigraphy include the ease of availability and the relatively straightforward interpretation of the study images. The lymphatic function of the limb can also be assessed semi-quantitatively with transport index [5,6]. The obvious disadvantages include use of radiation and inherited suboptimal resolution

## Limb Volume

### Background

Limb volume is one of the most common methods used by health care providers to follow up the disease progress of lymphedema. On one hand, the total volume of a limb is contributed by the volumes of different components i.e. skin, subcutaneous fat, muscles and bones. On the other hand, the disease process of lymphedema mainly takes place in the skin and subcutaneous layer, while the muscle and bones are spared [7-9].

Therefore, in theory, the disease progression should be more accurately assessed by the change in volume of the skin and subcutaneous fat rather than the total limb volume. The total limb volume can be considered as a measurement of the overall clinical outcome of lymphedema i.e. including musculoskeletal compartment hypertrophy due to heavy limb.

However, since the volume of skin and subcutaneous fat is difficult to be calculated separately, health care providers in general use total limb volume for disease follow-up.

Another precaution of using the limb volume for disease assessment is that the change in patient's body weight has to be taken into consideration for any changes in the limb volume.

### The gold standard - water displacement study

Water displacement study has long been considered as the gold standard of limb volume measurement. Therefore, to validate a new investigation modality on limb volume, researchers often compare the findings derived from the new investigation with those derived from water displacement study [10-12].

Water displacement study is easy to be carried out. However, this can be cumbersome to be implemented in the setting of an ordinary clinic e.g. the need of water tank, sizable water collection and measurement container, drainage system and hygienic issues.

### Truncated cone formula

A human limb can be imagined as a stack of truncated cones of different shapes. The volume of a truncated cone can be calculated from the height and circumference of the cone i.e. frustum formula. Therefore, the total volume of a limb can be calculated by summing up the volumes of the imaginary truncated cones of each limb segment.

There are two papers in the literatures which studied the calculation of limb volume from circumference measurements [10, 11].

An early study by Karges et al. compared the calculated limb volume with water displacement volume in 14 patients with post-mastectomy upper limb lymphedema. The truncated cone volume was calculated using the frustum formula. The height of each truncated cone, i.e. the interval of circumference measurements, was around 3-4 cm. In this study, the mean calculated limb volume was 2022.90 ml and the mean volume of the limb derived from water displacement was 2118.52 ml. The mean difference between the water displacement volume and the calculated volume was 95.62 ml. It was found that there is a high correlation between the calculated volume and the water displacement volume [10].

Brorson et al. also calculated the limb volume with the truncated cone method. The hand volume was excluded in the calculation. His group has developed Excel-based computer programs to calculate limb volume from circumference measurements. The height of each segment of cone was set at 4 cm. The mean volume of lymphedema limb (including hand volume) from water displacement was 3138 ml. And the calculated mean limb volume was 2972 ml (excluding hand volume). It was found that the findings derived from calculation method correlated with the measurements from water displacement method [11].

The limb volume calculation method appears to be simple and correlates well with the water displacement study.







