Limb Volume Assessments Based on Circumference Measurements: Possibilities and Limitations

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Basics of the Method
Limb Volume from Girth Measures

- Automated Geometric Model or Algorithm
- Circumferences @ 4-12 cm intervals
- Manual Truncated Cone Model (Frustum)

Visit www.limbvolumes.org

- Affected Limb
- Contralateral Limb
- Edema Volume

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Measurement Issues
Requiring Careful Attention
Minimizing Method Error

Mark in Relation To FLAT Surface

NOT along limb

Source of large Follow-up error

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Minimizing Method Error

Ankle at 90°

Start Point
Mid-malleolus
L = 0 cm

• Measure with tape 90° to limb length
• Overlap tape with interval mark in middle.
• Pull to fixed tension

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Minimizing Method Error

Highest arm girth at axillary crease.
Stiff paper at axilla determines level

Similar procedure used at groin
Girths higher than these are angled and are inaccurate

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Calculation Algorithm Issues

What if limb is not fully circular?
Effect of Degree of Eccentricity

General Frustum Calculation Model

\[ V = \frac{\pi L (A^2 B - a^2 b)}{3(A-a)} \]

Circular to elliptical volume ratio \( V_C/V_E \)

\[ V_C/V_E = \frac{(1/4) (1 + \alpha)^3}{\alpha(1+\alpha)} \]

\( \alpha = \text{ratio of smaller to larger dimension} \)

<5% difference for ratios > \( \approx 0.6 \)
So OK for most Arms & Legs

BUT Not OK for Hands or Feet

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How to Deal with Hands and Feet?
Metric Measurements

Hand (60)

Foot (60)
Water Displacement Volumes

Displaced $H_2O$ in recovery container

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Analytical Comparisons: Metric vs. H$_2$O

- Standardized Metric Measurements
- Volume by Computerized Algorithm
- Hands and Feet N=60 each
- Volume by Water Displacement
- Compare by Regression and Limits of Agreement (LOA)

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Algorithm vs. Water Displacement

Volume by Algorithm (ml)

Volume by water displacement (V_w, ml)

$V_M = 1.00 V_W + 1.67 \text{ ml}$

$R^2 = 0.931; \ p < 0.001$

$N = 60$ Feet

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Algorithm vs. Water Displacement

Volume by Algorithm ($V_M$, ml)

Volume by Water Displacement ($V_W$, ml)

Hands

$V_M = 1.02V_W - 12.2$ ml

$r^2 = 0.985, p<0.001$

N=60 Hands

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### Limits of Agreement (%)

#### Mean Volume $(V_W + V_M)/2$ in ml

<table>
<thead>
<tr>
<th>$(V_W - V_M)/V_W$ (%)</th>
<th>Difference</th>
<th>LOA</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.9 ± 4.9%</td>
<td>±9.8%</td>
<td>+11.2 to -12.9</td>
<td></td>
</tr>
</tbody>
</table>

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Limits of Agreement (%)

![Limits of Agreement graph](image)

- Mean volume \((V_w + V_m)/2\) in ml
- Percent Difference \((V_m - V_w) / V_w\) %
- Difference: 0.21 ± 4.64, LOA ±9.28, 95% CI +11.6 to -11.2

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Manual or Automated?

$\$

Space

Pt. Mobility

Pt. Flexibility

Time

Measurer

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Limb Volumes in Liters

<table>
<thead>
<tr>
<th></th>
<th>Automated</th>
<th>Manual</th>
<th>%Diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legs N=142</td>
<td>7.16 ± 0.17**</td>
<td>6.90 ± 0.17</td>
<td>4.14 ± 0.54</td>
</tr>
<tr>
<td>Arms N=42</td>
<td>2.70 ± 0.09**</td>
<td>2.53 ± 0.09</td>
<td>6.97 ± 1.18</td>
</tr>
</tbody>
</table>

• Small (but significant) difference between volumes
  Automated → slightly larger absolute volumes

BUT: No significant difference in Edema volumes

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Automated</td>
<td>Tape Measure</td>
<td>Automated</td>
<td>Tape Measure</td>
</tr>
<tr>
<td>LEGS (N = 32 Pairs)</td>
<td>14.2 ± 3.5</td>
<td>15.4 ± 4.4</td>
<td>19.5 ± 4.7</td>
<td>19.8 ± 4.6</td>
</tr>
<tr>
<td>ARMS (N = 24 Pairs)</td>
<td></td>
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</table>

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What segment length? Compare 4 vs. 8 vs. 12 cm
## Leg Volumes (N = 140) and Reductions with Treatment based on Different Segment Lengths

<table>
<thead>
<tr>
<th>Segment Length</th>
<th>Volume Pre Treat (ml)</th>
<th>Volume Post Treat (ml)</th>
<th>Volume Reduction ml</th>
<th>Volume Reduction %</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 cm</td>
<td>6658 ± 2491</td>
<td>5453 ± 1954</td>
<td>1204 ± 775</td>
<td>17.6 ± 7.0</td>
</tr>
<tr>
<td>8 cm</td>
<td>6681 ± 2511</td>
<td>5477 ± 1969</td>
<td>1205 ± 803</td>
<td>17.5 ± 7.2</td>
</tr>
<tr>
<td>12 cm</td>
<td>6762 ± 2560</td>
<td>5570 ± 2013</td>
<td>1248 ± 823</td>
<td>17.9 ± 7.3</td>
</tr>
</tbody>
</table>

Insignificant difference between segment lengths

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How to take into account the “Control” limb?
If no change in contralateral “control” limb then need only measure it once

BUT

Control limb DOES CHANGE!
Need to measure both limbs to track changes and outcomes!

Edema Volume = 100* (Affected – Control)/Control
<table>
<thead>
<tr>
<th>Research Study Outcomes</th>
<th>Reduction in Edema volume (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Tx Edema Volume (liters)</td>
</tr>
<tr>
<td>Arms (40)</td>
<td>0.94 ± 0.54</td>
</tr>
<tr>
<td>Legs (75)</td>
<td>2.3 ± 0.2</td>
</tr>
</tbody>
</table>

Using only pre-treatment control limb value severely overestimated outcomes

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Conclusions

• Use of girth measurements to obtain limb volumes can be a useful and reliable method to assess changes in edema and lymphedema over time
• Its accuracy and reliability depend on careful attention to detail in the measurement process
• Its utility and versatility is enhanced via the use of a suitable calculation algorithm that appropriately takes into account hand or foot volumes
• Most studies indicate this volume method compares well with other methods including H$_2$O displacement but the various methods are not interchangeable.
My sincere thanks to Dr. Gyozo Szolnokky for his heroic efforts on my behalf!