Reliability of Volumetry and Perimetry to Assess Knee Volume

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Context: The treatment of edema after a knee injury is usually 1 of the main objectives during rehabilitation. To assess the success of treatment, 2 methods are commonly used in clinical practice: volumetry and perimetry.

Objective: To investigate the intra- and interassessor reliability of volumetry and perimetry to assess knee volume.

Design: Cross-sectional.

Setting: Laboratory.

Participants: 45 healthy participants (26 women) with mean age of 22.4 ± 2.8 y.

Main Outcome Measures: Knee volume was assessed by 3 assessors (A, B, and C) with 3 methods (lower-limb volumetry [LLV], knee volumetry [KV], and knee perimetry [KP]). Assessor A was the most-experienced assessor, and assessor C, the least experienced. LLV and KV were performed with participants in the orthostatic position, while KP was performed with participants in supine.

Results: For the interassessor analysis, the ICC2,1 was high (.82) for KV and very high for LLV (.99) and KP (.99). For the intra-assessor analysis, ICC 2,1 ranged from moderate to high for KV (.69–.83) and was very high for LLV (.99) and KP (.97–.99).

Conclusion: KV, LLV, and KP are reliable methods, both intra- and interassessor, to measure knee volume.

Keywords: edema, knee injuries, validity

Knee edema is a common problem after a knee injury, and it is also common after surgical procedures. The presence of knee edema leads to an increase in intrajoint pressure, which can cause pain and can also be associated with arthrogenic muscle inhibition of quadriceps, which reduces functional capacity at that joint.1 Because of this, when edema is present in the knee, its reduction becomes 1 of the main objectives during rehabilitation.2 Therefore, it is important to use reliable and cost-effective methods to assess edema, methods that can give the therapist quantitative data that can be used to assess the success of the rehabilitation program.2

Due to their low costs, there are 2 common methods used in clinical practice to assess knee edema: perimetry and volumetry.3–5 Knee volumetry can be performed in different ways, and 1 of them is by isolating the knee region.4 Another alternative is the leg-volumetry method of measuring the volume of the whole limb, including the ankle joint.5 Similarly, perimetry can be analyzed in different ways, and 1 of them is to analyze only the perimeter of knee at the point where the measure takes place,3,6 while another possibility is to use those measures to calculate geometric figures, considering the knee as a cylinder or 2 conical frustums.7

Thus, there is still important information that needs to be explored regarding volume analysis of the knee, such as its level of reliability and the amount of error involved in these assessments. Therefore, the objective of the current study was to investigate the intra-assessor and interassessor reliability of volumetry and perimetry assessment of the knee.

Methods

Participants

Forty-five healthy participants (19 men and 26 women), with mean age of 22.4 ± 2.8 years, participated in the study. Participants were excluded if they presented any lower-limb injury or had a history of surgery in the last year or presence of lower-limb edema with systemic origin related to cardiac, circulatory, or kidney problems. The study was approved by the human research ethics committee of Santa Catarina State University, and written consent was obtained from all participants.

Procedures

The participants were evaluated in 2 sessions with a 30-minute interval between them (test and retest). Each session consisted of 3 assessments: lower-limb volumetry (LLV), knee volumetry (KV), and knee perimetry (KP). Each assessment was performed by 3 assessors...
in each session. The assessors were blinded to their own result and to each other’s result recorded in each assessment and each session. For that purpose, a fourth researcher was responsible for recording the measures. The sequence of assessments and assessors was randomized for each participant for the first session, and that sequence was repeated in the second session. We also randomly decided whether the left or right limb would be assessed.

**Assessors**

Assessor A was a physical therapist with more than 5 years of clinical and research experience in knee and ankle volumetry. Assessor B was a physical therapist with 3 years of experience in knee volumetry and perimetry. Assessor C was a third-year physical therapy student specially trained for this study.

**Assessments**

**Lower-Limb Volumetry.** We used an acrylic box (Figure 1[A]) completely filled with water to the level of the escape hole at a temperature of 30°C ± 2°C. Participants were instructed to introduce the assessed limb slowly into the box. They were also instructed to distribute their body weight equally on both lower limbs and to remain as still as possible until all of the exceeding water was collected in another container (Figure 1[A]). The exceeding water was measured on a 1-g-accuracy scale (Prodigital, NE7304 model, Brazil).

**Knee Volumetry.** Participants were instructed to place the assessed limb into the emptied acrylic box and to remain as still as possible. First, the assessor poured water into the box to a line marked at 5 cm below the fold from the popliteal fossa of the participant (Figure 1[B]). A second water container, with the exact amount of water needed to fill the empty box up to the second fold (5 cm above the fold of the popliteal fossa) was then used to pour water into the acrylic box. The water that remained in the container was the equivalent volume of the knee (Figure 1[B]).

**Knee Perimetry.** The participant was positioned in supine on a stretcher, with the hip in neutral position and knees in full extension. From that position the assessor marked the knee at 3 points: the fold at the popliteal fossa (P0), 5 cm above P0 (PA), and 5 cm below P0 (PB). A measuring tape was used to measure the perimeter of the limb at these 3 levels. Each assessor erased the marks after finalizing the measurement. Data on perimetry were analyzed with 3 different methods:

- **Circumference length in each point (cm).**
- **Cylinder (L):** We calculated the mean perimeter from the 3 measured perimeters, and that averaged value was used to calculate the volume of a perfect cylinder. The radius was obtained according to the formula $C = 2\pi r$ (Figure 1[C]).
- **Conical frustums (L):** The knee was considered the sum of 2 conical frustums with parallel bases. The perimeters for P0 and PA were the bases of the superior conical frustum, and the perimeters of P0 and PB formed the bases of the inferior conical frustum. The height of both cones was 5 cm, and the radius was obtained the same way as for the cylinder (Figure 1[D]). (For spreadsheet with calculations, contact the first author: nuneguilherme@live.com.)

**Statistical Analysis**

We calculated that a minimum sample size of 39 participants was necessary for the study. In the calculation we considered $\alpha = .05$ and $\beta = 0.20; \rho = 0.20$; and $\beta = 0.20$; we also considered an intraclass correlation coefficient (ICC$_{2,1}$) of .6 to be minimally acceptable ($\rho_0$) and an ICC$_{2,1}$ estimated of .8 ($\rho_1$).

Data converted in mass were converted to volume (L) (1 g = 1 mL). ICC$_{2,1}$ with 95% confidence interval was used to calculate the interassessor and intra-assessor reliability. ICC$_{2,1}$ values were classified as follows: 0 to .25 low or no, .26 to .49 low, .5 to .69 moderate, .7 to .89 high, and .9 to 1 very high. We also calculated the standard error of measurement (SEM) and the minimum detectable change at the 95% confidence level (MDC).

**Results**

Table 1 presents mean and SD for the first and second sessions for each assessment method/calculation. Table 2 presents the results for intra-assessor and interassessor reliability, SEM, and MDC for each assessment method/calculation. All methods presented at least high levels of reliability, with the exception of 1 analysis of KV. That intra-assessor analysis showed the smallest ICC value (.69), considered moderate reliability.

**Discussion**

The current study found that LLV and KP had very high intra-assessor and interassessor reliability. For KV, most analyses showed high interassessor and intra-assessor reliability, with the exception of the intra-assessor reliability for assessor C, which had moderate reliability.

Possibly, the very high reliability seen in the current study for LLV is related to the fact that this method has little interference from the assessor when compared with the KV. For LLV, the assessor’s task is only to wait for the exceeding water to overflow to another container, while for KV, the assessor needs to decide when to stop pouring water twice. In addition to that, the experience of the assessors did not influence the LLV reliability levels. One limitation of this method, though, is that the measure is not designed to isolate any specific body part, so any changes to foot, ankle, or shank would have an effect in the result. Nevertheless, when the aim is to measure the volume of the lower limb as a whole, this...
seems a good assessment option as the reliability levels were high. Furthermore, the MDC found also encourages the adoption of LLV for volume assessment, as it shows that even changes as small as 5 mL would be detected by this method.

It is clear that KV has the advantage of measuring knee volume in isolation, opposite to LLV. However, the reliability levels for KV were not as strong as the ones seen for LLV. It is possible that because this method requires the assessor to make a judgment on water level twice, any small misjudgments would have a larger impact on the final result of the assessment. It therefore seems that the assessor’s experience on making those judgments could influence the reliability for this

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**Figure 1** — Methods to assess knee volumetry. (A) Lower-limb volumetry. (B) Knee volumetry: acrylic box with water filled to the lower level of the knee (5 cm below the fold of the popliteal fossa). (C) Cylinder: $V = \pi r^2 h$, where $r =$ radius and $h =$ cone height (10 cm). (D) Cone frustums: $V_{superior} = \frac{\pi h}{3}(R^2 + Rr_1 + r_1^2)$, and $V_{inferior} = \frac{\pi h}{3}(R^2 + Rr_2 + r_2^2)$, where $r_1 =$ radius of perimetry 5 cm above the fold of the popliteal fossa, $R =$ radius of perimetry of the fold of the popliteal fossa, and $r_2 =$ radius of perimetry 5 cm below the fold of the popliteal fossa. Box dimensions: 67 × 21 × 30 cm. *10 cm is referent to space between 5 cm below and 5 cm above the fold of the popliteal fossa that was filled with a known amount of water.
Table 1  Perimetry (cm), Conical Frustums (L), Cylinder (L), Knee Volumetry (L), and Lower-Limb Volumetry (L), Mean ± SD

<table>
<thead>
<tr>
<th>Session 1</th>
<th>Perimetry</th>
<th>Conical frustums</th>
<th>Cylinder</th>
<th>Knee volumetry</th>
<th>Lower-limb volumetry</th>
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<tbody>
<tr>
<td></td>
<td>PA</td>
<td>P0</td>
<td>PB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>assessor A</td>
<td>38.8 ± 2.7</td>
<td>36.2 ± 2.2</td>
<td>34.5 ± 2.1</td>
<td>1.06 ± 0.13</td>
<td>1.06 ± 0.13</td>
</tr>
<tr>
<td>assessor B</td>
<td>38.5 ± 2.7</td>
<td>36.2 ± 2.3</td>
<td>34.4 ± 2.2</td>
<td>1.06 ± 0.13</td>
<td>1.06 ± 0.14</td>
</tr>
<tr>
<td>assessor C</td>
<td>38.5 ± 2.8</td>
<td>36.7 ± 2.2</td>
<td>34.1 ± 2.1</td>
<td>1.07 ± 0.13</td>
<td>1.06 ± 0.13</td>
</tr>
<tr>
<td>A + B + C</td>
<td>38.6 ± 2.7</td>
<td>36.3 ± 2.2</td>
<td>34.3 ± 2.1</td>
<td>1.06 ± 0.13</td>
<td>1.06 ± 0.13</td>
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<thead>
<tr>
<th>Session 2</th>
<th>Perimetry</th>
<th>Conical frustums</th>
<th>Cylinder</th>
<th>Knee volumetry</th>
<th>Lower-limb volumetry</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>PA</td>
<td>P0</td>
<td>PB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>assessor A</td>
<td>38.8 ± 2.7</td>
<td>36.1 ± 2.3</td>
<td>34.5 ± 2.2</td>
<td>1.06 ± 0.14</td>
<td>1.06 ± 0.14</td>
</tr>
<tr>
<td>assessor B</td>
<td>38.5 ± 2.8</td>
<td>36.1 ± 2.4</td>
<td>34.4 ± 2.3</td>
<td>1.05 ± 0.14</td>
<td>1.06 ± 0.14</td>
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<tr>
<td>assessor C</td>
<td>38.5 ± 2.8</td>
<td>36.6 ± 2.4</td>
<td>34.0 ± 2.1</td>
<td>1.06 ± 0.14</td>
<td>1.06 ± 0.14</td>
</tr>
<tr>
<td>A + B + C</td>
<td>38.6 ± 2.8</td>
<td>36.3 ± 2.4</td>
<td>34.3 ± 2.2</td>
<td>1.06 ± 0.14</td>
<td>1.06 ± 0.14</td>
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Abbreviations: PA, 5 cm above the fold of the popliteal fossa; P0, the fold of the popliteal fossa; PB, 5 cm below the fold of the popliteal fossa.

Table 2  Perimetry, Conical Frustums, Cylinder, Knee Volumetry, and Lower-Limb Volumetry Intraclass Correlation Coefficient (95% Confidence Interval) and Standard Error of the Measurement (SEM)/Minimal Detectable Change (MDC)

<table>
<thead>
<tr>
<th>Perimetry</th>
<th>Conical frustums</th>
<th>Cylinder</th>
<th>Knee volumetry</th>
<th>Lower-limb volumetry</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PA</td>
<td>P0</td>
<td>PB</td>
<td></td>
</tr>
<tr>
<td>Assessor A</td>
<td>.99 (.98–.99)</td>
<td>.99 (.97–.99)</td>
<td>.99 (.98–.99)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>.3/.9</td>
<td>.3/8</td>
<td>.2/4</td>
<td></td>
</tr>
<tr>
<td>Assessor B</td>
<td>.99 (.98–.99)</td>
<td>.98 (.97–.99)</td>
<td>.97 (.95–.98)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>.2/6</td>
<td>.3/8</td>
<td>.4/1.0</td>
<td></td>
</tr>
<tr>
<td>Assessor C</td>
<td>.99 (.98–.99)</td>
<td>.98 (.96–.99)</td>
<td>.99 (.98–.99)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>.2/6</td>
<td>.4/1.0</td>
<td>.2/6</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: PA, 5 cm above the fold of the popliteal fossa; P0, the fold of the popliteal fossa; PB, 5 cm below the fold of the popliteal fossa.

Note: SEM = SD 1−ICC2,1; MDC = z-score × SD × \sqrt{2(1−ICC2,1)}. The values of SEM and MDC for perimetry are in centimeters, and the values of SEM and MDC for conical frustum, cylinder, knee volumetry, and lower-limb volumetry are in liters.

For the current study, we observed that the least-experienced assessor had the lowest intra-assessor reliability levels for KV. Perhaps the decision on when to stop pouring the water in the container requires training when performing the KV, and perhaps this training depends on long-time exposure to volumetry, as opposed to the short training received by assessor C in the current study. Nevertheless, the reliability levels were still considered high, granting the method clinical applicability.

Our results corroborate the results from Man et al,4 who investigated the reliability of this method in a study that aimed to validate an optoelectronic device to measure knee volume and found that KV had very high intra-assessor reliability.

For KP, we found very high reliability for both intra-assessor and interassessor analyses, and as for LLV, assessor experience did not interfere in the results. These results are in agreement with previous studies that
investigated this same method after total knee arthroplasty and after knee anterior cruciate ligament reconstruction. This method has the benefit of being fast, cheap, and easy to use. However, it does not assess knee volume directly as it only gives a score in centimeters. Nevertheless, this method can be used to convert perimeter into volume of a cylinder or conical frustums, without sacrificing reliability. These conversion techniques were shown to be reliable for lower-limb volume, similar to what we found when investigating the technique applied to knee-volume assessment. Caution must be taken for this analysis though, as the knee shape is not a perfect cylinder or combination of conical frustums, so the results from this conversion technique should be interpreted only as an approximation of the real knee volume.

Overall, LLV, KP, and KV are reliable methods to assess volume of the knee. It seems that LLV is a better tool to assess the volume of the whole lower limb, while KP and KV target assessment of the knee. The 3 methods have strengths and limitations, so clinicians should consider the case to be assessed and make a judgment on the most appropriate method to be used.

References