An accurate method for measuring knee joint space width despite variations in beam projection angles

Sung Eun Kim, Keehyun Kim, Byung Sun Choi, Hyuk-Soo Han, Myung Chul Lee, Du Hyun Ro

Department of Orthopedic Surgery
Seoul National University
College of Medicine
Background

- **Joint space width (JSW)** is important for assessing knee osteoarthritis (OA) severity
- Accurate measurement of JSW is **challenging** due to:
  - Anatomical variation
  - Patient posture
  - X-ray beam projection angle
Background

- Often, **two separate lines** are observed on the medial tibia plateau
- **No consensus** exists on which of the two lines should be used for measurement of JSW
Purpose

- To develop an **accurate method** for measuring knee JSW despite beam projection inaccuracies
- By:
  1. Simulation study
  2. Proof of concept study (real patient data)
1. Simulation study

- From May 2020 to Aug 2020
- 30 knees from 15 patients scheduled for TKA
- Digital reconstruction radiographs (DRR) were generated from CT images

Excluded:
- Patients with knee contracture > 15°
- Hip-knee-ankle angle deviation > 15° from neutral
- Knees with joint obliteration
• DRR (Knee AP images) generated by various beam projection angles (BPA)
  ▪ caudal tilting to cephalic tilting
  ▪ 0 °, 5 °, 10 °, 20 ° from the posterior tibial slope angle (PTSA)
• The actual JSW (red box) was measured from CT (sagittal view) at BPA parallel to PTSA
Three Methods for measuring JSW

1. $D_{AB}$: Distance from tibial anterior border
   ~ medial femoral condyle
2. $D_{PB}$: Distance from tibial posterior border
   ~ medial femoral condyle
3. AVD: Average of $D_{AB}$ and $D_{PB}$

$\rightarrow$ Compared $D_{AB}$ vs $D_{PB}$ vs AVD
(With actual JSW measured from CT)
Materials & Methods

2. Proof of concept study

- From Dec 2022 to Feb 2023
- 100 knees from 50 patients
- Knee AP images with three BPA (Neutral, Cephalic tilt 5°, Caudal tilt 5°)

Compared $D_{AB}$ vs $D_{PB}$ vs AVD
(in terms of discrepancy of three BPA values)
## Results

- **Patient characteristics**

<table>
<thead>
<tr>
<th></th>
<th>Simulation study (n=30)</th>
<th>Proof of concept study (n=100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (range)</td>
<td>70.0±5.9 (60 to 79)</td>
<td>58.8±14.3 (18 to 84)</td>
</tr>
<tr>
<td>Body mass index</td>
<td>27.1±2.8 (23.6 to 37.6)</td>
<td>25.8±3.91 (20.0 to 32.8)</td>
</tr>
<tr>
<td>Sex (Female, %)</td>
<td>73%</td>
<td>74%</td>
</tr>
<tr>
<td>Kellgren-Lawrence grade</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade 0</td>
<td>-</td>
<td>20%</td>
</tr>
<tr>
<td>Grade 1</td>
<td>-</td>
<td>8%</td>
</tr>
<tr>
<td>Grade 2</td>
<td>-</td>
<td>41%</td>
</tr>
<tr>
<td>Grade 3</td>
<td>63.3%</td>
<td>31%</td>
</tr>
<tr>
<td>Grade 4</td>
<td>26.7%</td>
<td>-</td>
</tr>
</tbody>
</table>
**Results (Simulation study)**

- $D_{AB}$, $D_{PB}$, and AVD values of 30 knees according to various BPA

<table>
<thead>
<tr>
<th>BPA</th>
<th>$D_{AB}$</th>
<th>$D_{PB}$</th>
<th>AVD</th>
<th>p-value $^a$</th>
<th>p-value $^b$</th>
<th>p-value $^c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>20° caudal</td>
<td>-4.50±2.04</td>
<td>7.13±3.50</td>
<td>1.44±2.30</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.003</td>
</tr>
<tr>
<td>10° caudal</td>
<td>0.00±1.07</td>
<td>6.00±1.37</td>
<td>3.00±1.16</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.120</td>
</tr>
<tr>
<td>5° caudal</td>
<td>1.37±0.89</td>
<td>4.37±0.76</td>
<td>2.87±0.72</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.066</td>
</tr>
<tr>
<td>0° (CT value)</td>
<td>2.71±0.59</td>
<td>2.71±0.59</td>
<td>2.71±0.59</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5° cephalic</td>
<td>3.50±0.72</td>
<td>0.71±0.89</td>
<td>2.11±0.70</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>10° cephalic</td>
<td>3.72±1.15</td>
<td>-2.02±1.53</td>
<td>0.85±1.16</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>20° cephalic</td>
<td>4.14±1.19</td>
<td>-8.67±2.47</td>
<td>-2.76±1.47</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

$^a$ Paired-samples t-test between $D_{AB}$ Values at selected BPA and $D_{AB}$ Values at BPA 0°

$^b$ Paired-samples t-test between $D_{PB}$ Values at selected BPA and $D_{PB}$ Values at BPA 0°

$^c$ Paired-samples t-test between AVD Values at selected BPA and AVD Values at BPA 0°

AVD method was less different from CT value compared to $D_{AB}$ & $D_{PB}$
Results (Proof of concept study)

- $D_{AB}$, $D_{PB}$, and AVD values of 100 knees according to various BPA

<table>
<thead>
<tr>
<th></th>
<th>Neutral tilt</th>
<th>5° Caudal tilt</th>
<th>5° Cephalic tilt</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_{AB}$</td>
<td>6.87±1.8</td>
<td>5.52±1.29</td>
<td>7.74±1.83</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>$D_{PB}$</td>
<td>1.40±1.79</td>
<td>2.49±1.34</td>
<td>-0.39±2.27</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>AVD</td>
<td>4.13±1.06</td>
<td>4.01±1.00</td>
<td>3.68±1.22</td>
<td>0.011</td>
</tr>
</tbody>
</table>

→ AVD method was more consistent compared to $D_{AB}$ and $D_{PB}$
Limitations

- Exclusion of severe knee deformity cases may limit applicability.
- Only knee extended AP views evaluated.
- Different demographics between simulation and proof of concept study.
Conclusion

- A simple method (AVD) for measuring JSW was developed in this study, even when X-rays are taken at unintended angles.
- This method can potentially help reduce measurement errors and improve the accuracy of JSW assessment in clinical practice.