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Comparison of a simplified skin pointer device compared with a skeletal marker for knee rotation laxity: A cadaveric study using a rotation-meter

Ken Lee Puah, Andy Khye Soon Yew, Siaw Meng Chou, Denny Tijauw Tjoen Lie

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Author contributions: Puah KL performed the experiment, analysis and wrote the manuscript; Yew AKS designed and performed the experiment and edited the manuscript; Chou SM designed the experiment, obtained funding and edited the manuscript; Lie DTT designed the experiment, obtained funding and edited the manuscript.

Conflict-of-interest statement: No potential conflicts of interest relevant to this article were reported.

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Abstract
AIM
To compare the measurements of knee rotation laxity by non-invasive skin pointer with a knee rotation jig in cadaveric knees against a skeletally mounted marker.

METHODS
Six pairs of cadaveric legs were mounted on a knee rotation jig. One Kirschner wire was driven into the tibial tubercle as a bone marker and a skin pointer was attached. Rotational forces of 3, 6 and 9 nm applied at 0°, 30°, 45°, 60° and 90° of knee flexion were analysed using the Pearson correlation coefficient and paired t-test.

RESULTS
Total rotation recorded with the skin pointer significantly correlated with the bone marker at 3 nm at 0° (skin pointer 23.9 ± 26.0° vs bone marker 16.3 ± 17.3°, r = 0.92; P = 0.0), 30° (41.7 ± 15.5° vs 33.1 ± 14.7°, r = 0.63; P = 0.037), 45° (49.0 ± 17.0° vs 40.3 ± 11.2°, r = 0.81; P = 0.002), 60° (45.7 ± 17.5° vs 34.7 ± 9.5°, r = 0.86; P = 0.001) and 90° (29.2 ± 10.9° vs 21.2 ± 6.8°, r = 0.69; P = 0.019) of knee flexion and 6 nm at 0° (51.1 ± 37.7° vs 38.6 ± 30.1°, r = 0.90; P = 0.0), 30° (64.6 ± 21.6° vs 54.3 ± 15.1°, r = 0.73; P = 0.011), 45° (67.7 ± 20.6° vs 55.5 ± 9.5°, r = 0.65; P = 0.029), 60° (62.9 ± 22.4° vs 45.8 ± 13.1°, 62.9 ± 22.4° vs 45.8 ± 13.1°, r = 0.65; P = 0.029).
Due to pain. Knee rotation was at 22°-58°, 36° ± 6.3°, r = 0.62; P = 0.043) of knee flexion and at 90° at 0° (69.7 ± 40.0° vs 55.6 ± 30.6°, r = 0.86; P = 0.001) and 60° (74.5 ± 27.6° vs 57.1 ± 11.5°, r = 0.77; P = 0.006). No statistically significant correlation with 9 nm at 30° (79.2 ± 25.1° vs 66.9 ± 15.4°, r = 0.59; P = 0.055), 45° (80.7 ± 24.7° vs 65.5 ± 11.2°, r = 0.51; P = 0.11) and 90° (54.7 ± 21.1° vs 39.4 ± 8.2°, r = 0.55; P = 0.079). We recognize that 9 nm of torque may be not tolerated in vivo due to pain. Knee rotation was at its maximum at 45° of knee flexion and increased with increasing torque.

CONCLUSION
The skin pointer and knee rotation jig can be a reliable and simple means of quantifying knee rotational laxity with future clinical application.

Key words: Rotatometer; Rottometer; Knee; Laxity; Cruciate; Biomechanics; Measurement

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Core tip: We describe a cadaveric study utilising a knee rotation jig paired with a skin pointer for the measurement of knee rotation laxity which has the potential for clinical application.


INTRODUCTION
With increased interest in rotational stability with anterior cruciate ligament reconstruction as seen with the anatomical anterior cruciate ligament (ACL) reconstruction and the double-bundle ACL reconstruction, the need for an objective measurement of knee rotation arises in order to compare subjective clinical scores with rotational stability[1]. Registry data currently do not show any significant difference in knee outcome scores between single-bundle and double-bundle ACL reconstructions though proponents of the double-bundle technique recommend it as it is considered to be able to restore both rotational stability and anterior-posterior stability[2-3]. Stress radiography with the use of Roentgen Stereophotogrammetric Analysis (RSA) has been described previously with accuracy as high as 10-250 µm and 0.03-0.6° for translations and rotations, respectively, though it is an invasive procedure[3,4]. With variability of the pivot shift test amongst even trained orthopaedic surgeons, it becomes imperative that a non-invasive objective instrument be available to assess a patient’s knee rotational stability[5]. There is a need for a portable, non-invasive yet simple to use device to measure knee rotation laxity in the clinic.

Almquist et al[6-8] has described a Rotometer which is a modified chair with the foot strapped to a rotating plate with measurements taken off a goniometer at the foot plate. However there was difference in the Rotometer readings compared to RSA at 90° flexion with 6 nm of torque and this has been attributed to be due to the measurements being taken at the foot which would thus include ankle rotation. To negate the effect of ankle rotation, we propose taking measurements off a fixed point more proximal and closer to the knee joint at the tibial tubercle with a non-invasive skin pointer while immobilizing the ankle in a foam boot. We designed a cadaveric study to assess the reliability of taking measurements off a non-invasive skin pointer placed over the tibial tubercle against that of a skeletally-mounted nail using a novel knee rotation jig modified from the Rotometer with a view to extending this to in-vivo testing.

To compare a non-invasive method of measuring knee rotation using a skin pointer against a nail fixed to the tibial tuberosity of a cadaveric knee specimen mounted on a knee rotation jig.

MATERIALS AND METHODS
Six pairs of cadaveric legs were mounted individually on a prototype knee rotation jig modified from the Rotometer described by Almquist et al[1] with a locking mechanism to set knee flexion at several predetermined flexion angles (Figure 1). These cadaveric legs were stored frozen and were thawed prior to use in this study. The jig, which is collapsible, foldable and portable, was securely clamped to a table using vice clamps. Each specimen was anchored to the jig at the femur with bolts for stability and at the foot and ankle with an Aircast Foam Walker (Aircast, Summit, NJ, United States) attached to a rotating baseplate (Figure 2). The Aircast Foam Walker was mounted to the baseplate to negate the effect of ankle rotation by immobilizing the ankle and foot. The jig features two adjustable metal side plates with Velcro straps which will be used for in-vivo testing subsequently. One Kirschner wire was driven into the apex of the tibial tubercle as a bone marker for reference and a skin pointer was attached above the tibial tubercle using a Velcro strap.

A torque wrench was attached to the baseplate and each knee was pre-conditioned prior to taking the first measurement against a mounted protractor. Using the torque wrench, a rotational force of 3, 6 and 9 nm was then applied at 0°, 30°, 45°, 60° and 90° of knee flexion. This was repeated 3 times at each torque and knee flexion for both internal and external rotation for each specimen. The respective readings of the bone marker and skin pointer were recorded and analysed using SPSS for Windows using the Pearson correlation coefficient and the paired t-test.
RESULTS

The readings for total rotation obtained with the skin pointer significantly correlated with that of the bone marker at 3 nm at 0°, 30°, 45°, 60°, and 90° of knee flexion (Table 1 and Figure 3). Similarly the readings for total rotation obtained with the skin pointer significantly correlated with that of the bone marker at 6 nm at 0°, 30°, 45°, 60° and 90° of knee flexion. However, although the readings between the skin pointer and bone marker correlated significantly at 3 nm of torque, there was a significant difference on paired t-test between the two readings through all degrees of flexion. With 6 nm of torque, there was a significant difference between the readings at 45°, 60° and 90° of flexion.

With 9 nm of torque, there was a statistically significant correlation at 0° and 60° but no statistically significant correlation at 30° and 90° of knee flexion though there was a similar trend to 3 and 6 nm of torque (Table 3 and Figure 5). With 9 nm of torque, there was a significant difference between the readings at 45°, 60° and 90° of flexion. We found that at 9 nm torque, the cadaveric specimen would not return to the neutral starting position, suggestive of deformation of the specimen.

The skin pointer exaggerated the amount of rotation compared to the bone marker at all torques and angles of knee flexion with the maximum difference of 15.6° at 45° knee flexion with 9 nm of torque. For both the skin pointer and the bone marker, knee rotation increased with increasing knee flexion with maximum rotation at 45° flexion with subsequent decrease in rotation till 90° of knee flexion was reached (Figures 3-5). With increasing torque at a fixed flexion, knee rotation increased (Figure 6).

DISCUSSION

Apart from stress radiography with the use of RSA which is an invasive procedure, other instruments have been described to measure knee rotation including Almquist’s Rottometer from which our prototype jig is based on, Lars Rotational Laximeter, Vermont Knee Laxity Device, Tsai et al’s rotational knee laxity measurement device and Ahrens’ torsiometer. Almquist’s Rottometer includes a chair where measurements were taken from the foot which may have contributed to its reported inaccuracy as ankle and foot rotation could still contribute to movement and readings. The use of an Aircast® Foam Walker boot to immobilize the foot and ankle and the use of a skin pointer close to the knee joint as in our study would help to minimize systematic error from foot and ankle movement. Mouton et al used a prototype rotrometer with a similar ski boot and delivered the torque through a rotational handle bar and measured rotation through an inclinometer attached to the bar. Tsai’s device utilized a magnetic tracking system with an Aircast® Foam Walker boot with reliable results. Ahrens’ utilized a torsiometer with Schanz pins to mount the cadaveric limbs skeletally with a potentiometer to measure rotation and demonstrated that cadaveric knees with arthroscopically resected ACLs had greater rotation than cadaveric knees.

<table>
<thead>
<tr>
<th>Knee flexion (°)</th>
<th>Total rotation (°)</th>
<th>Skin pointer</th>
<th>Nail</th>
<th>Pearson’s r</th>
<th>r P-value</th>
<th>t-test P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>23.88 ± 25.99</td>
<td>16.33 ± 17.32</td>
<td>0.92</td>
<td>0.000</td>
<td>0.032</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>41.70 ± 15.49</td>
<td>33.06 ± 14.66</td>
<td>0.63</td>
<td>0.037</td>
<td>0.042</td>
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</tr>
<tr>
<td>45</td>
<td>48.97 ± 16.97</td>
<td>40.30 ± 11.20</td>
<td>0.81</td>
<td>0.002</td>
<td>0.030</td>
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<tr>
<td>60</td>
<td>45.73 ± 17.45</td>
<td>34.70 ± 9.45</td>
<td>0.86</td>
<td>0.001</td>
<td>0.008</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>29.21 ± 10.89</td>
<td>21.15 ± 6.75</td>
<td>0.69</td>
<td>0.019</td>
<td>0.016</td>
<td></td>
</tr>
</tbody>
</table>
with the ACL intact\textsuperscript{[12]}. Robotic arm technology has also been described to deliver the rotational force to mimic the dial test\textsuperscript{[15,16]}. The Rotab\textsuperscript{®} device measures medial knee rotation when delivering an anterior translation force to measure anteromedial knee instability\textsuperscript{[17]}, A similar device which measures passive medial knee rotation with anterior translation of the tibia was described by Kurimura et al\textsuperscript{[18]}. 

### Table 2  Total knee rotation measured at 0°, 30°, 45°, 60° and 90° of knee flexion with 6 nm of torque

<table>
<thead>
<tr>
<th>Knee flexion (°)</th>
<th>Total rotation (°)</th>
<th>Pearson's $r$</th>
<th>$r$ P-value</th>
<th>$t$-test $P$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Skin pointer</td>
<td>51.12 ± 37.73</td>
<td>0.90</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Nail</td>
<td>38.61 ± 30.07</td>
<td>0</td>
<td>0.011</td>
</tr>
<tr>
<td>30</td>
<td>Skin pointer</td>
<td>64.64 ± 21.61</td>
<td>0.73</td>
<td>0.029</td>
</tr>
<tr>
<td></td>
<td>Nail</td>
<td>54.27 ± 15.11</td>
<td>0.65</td>
<td>0.031</td>
</tr>
<tr>
<td>45</td>
<td>Skin pointer</td>
<td>67.73 ± 20.60</td>
<td>0.65</td>
<td>0.043</td>
</tr>
<tr>
<td></td>
<td>Nail</td>
<td>55.48 ± 9.45</td>
<td>0.62</td>
<td>0.051</td>
</tr>
<tr>
<td>60</td>
<td>Skin pointer</td>
<td>62.85 ± 22.43</td>
<td>0.65</td>
<td>0.031</td>
</tr>
<tr>
<td></td>
<td>Nail</td>
<td>45.79 ± 13.05</td>
<td>0.65</td>
<td>0.031</td>
</tr>
<tr>
<td>90</td>
<td>Skin pointer</td>
<td>43.61 ± 17.56</td>
<td>0.62</td>
<td>0.043</td>
</tr>
<tr>
<td></td>
<td>Nail</td>
<td>30.97 ± 6.25</td>
<td>0.65</td>
<td>0.031</td>
</tr>
</tbody>
</table>

*Significant difference between skin pointer and nail $P < 0.05$

*Significant correlation between skin pointer and nail $P < 0.05$

![Figure 3](image3.png)

**Figure 3** Knee rotation measured at 0°, 30°, 45°, 60° and 90° of knee flexion with 3 nm of torque.

![Figure 4](image4.png)

**Figure 4** Knee rotation measured at 0°, 30°, 45°, 60° and 90° of knee flexion with 6 nm of torque.
Hoshino et al. described a motion capture method using skin markers to measure the anterior translation of the distal femur in anaesthetised patients undergoing the pivot shift test.

Computer assisted surgery (CAS) devices which use motion-tracking technology and bony reference points can be used too but are invasive and are best used in the operating theatre during surgery. The benefit

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**Table 3** Total knee rotation measured at 0°, 30°, 45°, 60° and 90° of knee flexion with 9 nm of torque

<table>
<thead>
<tr>
<th>Knee flexion (°)</th>
<th>Skin pointer (°)</th>
<th>Nail (°)</th>
<th>Pearson’s r</th>
<th>r P-value</th>
<th>t-test P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>69.67 ± 39.91</td>
<td>55.61 ± 30.61</td>
<td>0.86</td>
<td>0.001</td>
<td>0.046</td>
</tr>
<tr>
<td>30</td>
<td>79.18 ± 25.14</td>
<td>66.91 ± 15.42</td>
<td>0.59</td>
<td>0.055</td>
<td>0.072</td>
</tr>
<tr>
<td>45</td>
<td>80.67 ± 24.65</td>
<td>65.48 ± 11.23</td>
<td>0.51</td>
<td>0.112</td>
<td>0.040</td>
</tr>
<tr>
<td>60</td>
<td>74.52 ± 27.57</td>
<td>57.09 ± 11.50</td>
<td>0.77</td>
<td>0.006</td>
<td>0.017</td>
</tr>
<tr>
<td>90</td>
<td>54.70 ± 21.05</td>
<td>39.39 ± 8.22</td>
<td>0.55</td>
<td>0.079</td>
<td>0.018</td>
</tr>
</tbody>
</table>

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**Figure 5** Knee rotation measured at 0°, 30°, 45°, 60° and 90° of knee flexion with 9 nm of torque.

**Figure 6** Knee rotation at 45° of flexion with 3, 6, and 9 nm of torque.
Our aim is to eventually develop a portable and user-friendly device which can be used for objective measurement of knee rotation in a non-invasive manner. The investigation of the utility of our rotation jig mated with a robotic arm for kinematic measurements is currently ongoing which may negate the effect of translation of the knee in vivo. Our next phase is to collect data on volunteers with uninjured knees followed by patients with knee injuries and patients after surgery to document changes in knee rotational laxity with pathology and treatment.

In conclusion, the skin pointer combined with a knee rotation jig can be a reliable and simple means of quantifying knee rotation in the cadaveric knee with potential application in vivo as a non-invasive means of measuring knee rotation in the clinic.

**ARTICLE HIGHLIGHTS**

**Research background**

With double-bundle and anatomical single-bundle anterior cruciate ligament reconstruction for restoration of rotational knee kinematics, the need for objective clinical measurement of knee rotational laxity arises. Evaluation of knee rotation remains a challenge with intra-observer variability in the pivot shift test.

**Research motivation**

We aim to compare a non-invasive skin pointer with a knee rotation jig in cadaveric knees against a skeletally mounted marker.

**Research methods**

Six pairs of cadaveric legs were mounted on a knee rotation jig. One Kirschner wire was driven into the tibial tubercle as a bone marker and a skin pointer was attached. Rotational forces of 3, 6 and 9 nm applied at 0°, 30°, 45°, 60° and 90° of knee flexion. Results were analysed using the Pearson correlation coefficient and paired t-test.

**Research results**

Total rotation recorded with the skin pointer significantly correlated with the bone marker at 3 nm at 0° (skin pointer correlation 23.9 ± 26.0° vs bone marker 16.3 ± 17.3°, r = 0.92; P = 0.0), 30° (41.7 ± 15.5° vs 33.1 ± 14.7°, r = 0.63; P = 0.037), 45° (49.0 ± 17.0° vs 40.3 ± 11.2°, r = 0.81; P = 0.002), 60° (45.7 ± 17.5° vs 34.7 ± 9.5°, r = 0.86; P = 0.001) and 90° (20.2 ± 10.9° vs 21.2 ± 6.8°, r = 0.69; P = 0.018) of knee flexion and 6 nm at 0° (51.1 ± 37.7° vs 38.6 ± 30.1°, r = 0.90; P = 0.0), 30° (64.6 ± 21.6° vs 54.3 ± 15.1°, r = 0.73; P = 0.011), 45° (67.7 ± 20.6° vs 55.5 ± 9.5°, r = 0.65; P = 0.029), 60° (62.9 ± 22.4° vs 45.8 ± 13.1°, r = 0.65; P = 0.031) and 90° (43.6 ± 17.6° vs 31.0 ± 6.3°, r = 0.62; P = 0.043) of knee flexion and at 9 nm at 0° (69.7 ± 40.0° vs 55.6 ± 30.6°, r = 0.86; P = 0.001) and 60° (74.5 ± 27.6° vs 57.1 ± 11.5°, r = 0.77; P = 0.006). No statistically significant correlation with 9 nm at 30° (79.2 ± 25.1° vs 66.9 ± 15.4°, r = 0.59; P = 0.055), 45° (80.7 ± 24.7° vs 65.5 ± 11.2°, r = 0.51; P = 0.11) and 90° (54.7 ± 21.1° vs 39.4 ± 8.2°, r = 0.55; P = 0.079). We recognize that 9 nm of torque may not be tolerated in vivo due to pain.

**Research conclusions**

We have measured knee rotation on a cadaveric knee utilising a knee rotation jig paired with a skin pointer against that of a skeletally mounted bone marker and have found a significant correlation between the two methods for the same magnitude of torque and knee flexion. We recognise that the use of the skin pointer introduces error due to movement of the soft tissue which increases with increasing torque.

**Research perspectives**

Our aim is to eventually develop a portable and user-friendly device which can be used for objective measurement of knee rotation laxity in a non-invasive manner. This may entail the use of accelerometers or robotic arms to measure the magnitude of torque and knee flexion. We recognise that the use of the skin pointer combined with a skin rotation jig can be a reliable and simple means of quantifying knee rotation in the cadaveric knee with potential application in vivo as a non-invasive means of measuring knee rotation in the clinic.
REFERENCES


