Is Goniometer Accurate Enough for Routine Clinical Practice?

Jeffry Hartanto[1], Wee Kheng Leow[1], Andy Khye Soon Yew[2], Joyce Suang Bee Koh[2], Tet-Sen Howe[2]
[1]National University of Singapore, Singapore, SG, [2]Singapore General Hospital, Singapore, SG
Email: jhartanto@comp.nus.edu.sg

INTRODUCTION: Accurate measurement of knee flexion angle, which is the angle between tibial and femoral shafts, is important for assessing post-operative outcomes and performing some surgical procedures. For example, in medial patellofemoral ligament (MPFL) reconstruction, the knee is advised to be fixed at 30° flexion angle when performing the reconstruction [1]. Imprecise identification of the flexion angle may produce abnormal joint motion. To measure knee flexion angle, goniometer is commonly used in routine clinical practice due to its non-invasiveness, radiation-free, low-cost and accessibility. Goniometer is placed on the skin at the lateral side of the knee, which estimates the position and orientation of tibial and femoral shaft. The "gold standard" for verifying the accuracy of goniometer is to compare its flexion angle measurement with that measured from X-ray image of the knee [2]. However, X-ray only capture 2D shape of femoral and tibial shafts, which renders such verification method to be less reliable. With the advanced of imaging and computation techniques, a 3D knee model can be efficiently and accurately constructed from CT scans. The 3D knee model fully captures the shape of femoral and tibial shafts. Thus, measuring flexion angle from the 3D knee model should be more accurate than the current gold standard. This study verifies the accuracy of goniometer for measuring flexion angles by comparing its measurements with those computed from the 3D knee models. Ultimately, this study may provide insights on the applicability of goniometer in routine clinical practice, especially for aiding knee surgeries.

METHODS: CT scans of five cadaver knees (age: 53–78 years; 4 males and 1 female; 3 left and 2 right knees) were captured between 0° and 120° flexion angles at intervals of 30°. Specifically, the knee was strapped on a custom jig with hinges. The knee is flexed along with the jig to a certain flexion angle that is measured using goniometer. The flexion angle measurement was performed by placing the center of goniometer at lateral femoral epicondyle (LFE). The proximal and distal arms of the goniometer were then aligned to greater trochanter and lateral malleolus, respectively. Note that these bony landmarks are determined through palpation. Then, the angle between the two arms estimates the flexion angle of the cadaver's knee, or the *experimentally* measured knee flexion angle. For assessing the accuracy of goniometer measurement, 3D knee models need to be constructed from the acquired CT scans. First, bone region in the CT scans were segmented using standard thresholding method. Then, 3D knee models were constructed from the segmented CT scans using marching cubes method. Next, two lines that estimate the center line of femoral and tibial shaft were computed based on their respective shape (Fig. 1a). Finally, the angle between the two lines was computed within a plane that has normal intersects sulcus of femoral condyle and LFE (Fig. 1b-c). This angle estimates the flexion angle of the 3D knee model, or the *computationally* measured knee flexion angle.

RESULTS: To verify the accuracy of goniometer, differences in degree from experimentally measured to computationally measured flexion angles are computed for the five joint poses of all subjects (Fig. 2). The differences are larger in early and late knee flexion compared to the mid knee flexion. Specifically, the computed flexion angles are larger than the experimentally measure flexion angles in early knee flexion and are smaller in late knee flexion. The difference at the third joint pose, or 60° of experimentally measured flexion angle, is the smallest compared to other joint poses. These results are consistent across the five subjects.

DISCUSSION: The results show that goniometer overestimates the flexion angle in early knee flexion and underestimates it in late knee flexion. The underestimated flexion angle measurement of goniometer in late knee flexion is consistent with the findings reported in [2]. However, at full knee flexion, the magnitudes of the differences found in this study is significantly higher, about 20°, as compared to that those reported in [2], about 3°. These results provide an evidence that verification of goniometer using X-ray image is not reliable. Most importantly, the results indicate that flexion angle measurement using goniometer is not accurate, especially in early and late knee flexion. Thus, its applicability in routine clinical practice should be limited to those procedures that can deal with flexion angle deviation of about 20°. This study has a few limitations. Firstly, the CT scans did not capture the entire femoral and tibial shafts. This might affect the estimation of femoral and tibial shafts, and subsequently the accuracy of computed flexion angles. Another limitation of this study is the small dataset size. Lastly, comprehensive comparison with flexion angles measured from X-ray image is not feasible in this study because X-ray image of the cadavers' knees were not acquired. Future works include increasing the size of dataset to capture larger variations of knees. Also, the CT scans should capture entire femoral and tibial shafts for more accurate estimation of computed flexion angles. Lastly, flexion angle measurement from X-ray image of the cadavers' knees should be acquired for more comprehensive and fair comparisons.

SIGNIFICANCE: This paper provides an evidence that using goniometer for assessing outcome of pre-operative planning and aiding knee surgeries is not advisable, especially when accurate identification of flexion angle is critical in early and late knee flexion. Moreover, a more reliable verification of flexion angle measurement tools can be achieved by comparing their measured flexion angles with those computed from 3D knee model, instead of comparing them with the flexion angles measured from X-ray image of the knee.

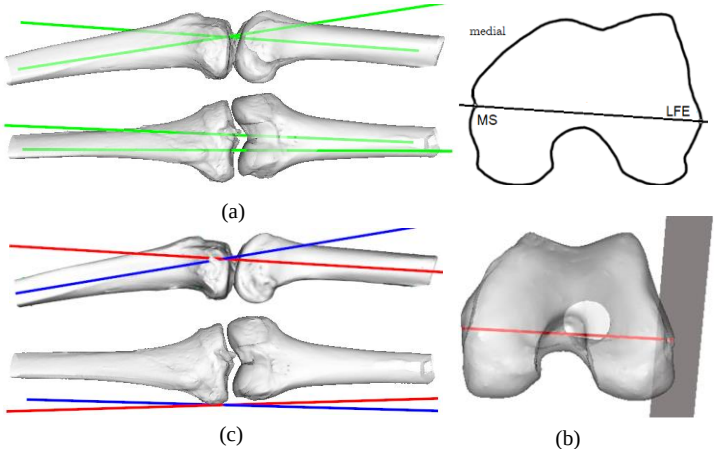

Fig. 1. Procedure for measuring flexion angle of 3D knee models. (a) Two lines (yellow) that estimate the shapes of femoral and tibial shafts, respectively. (b) The plane (green) with its normal (red line) intersects the lateral femoral epicondyle (LFE) and medial sulcus (MS). (c) Projection of the two lines into the plane are used to measure flexion angle of 3D knee model.

REFERENCES
[1] Smith, M. K. et al. Curr. Rev. Musculoskelet., 11(2):241–252, 2018.
[2] Edwards, J. Z. et al. J. Arthroplasty 19(3):369–372, 2004.

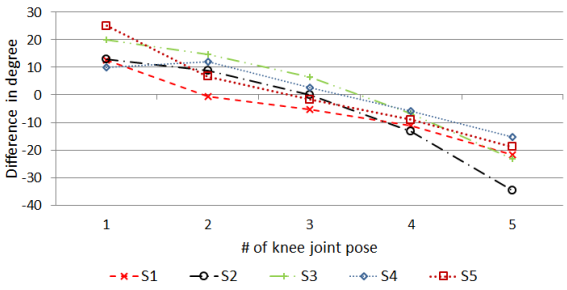

Fig. 2. Differences between experimentally and computationally measured knee flexion angles at different knee joint poses of the five subjects.