KNEE JOINT LAXITY IN 3D

Pedersen, Dennis; Vanheule, Valentine; Wirix-Speetjens, Roel; Taylan , Orçun; Delport, Hendrik Pieter; Scheys, Lennart; Andersen, Michael Skipper

Publication date:
2017

Document Version
Accepted author manuscript, peer reviewed version

KNEE JOINT LAXITY IN 3D

Dennis Pedersen MSc[1]*, Valentine Vanheule PhD[2], Roel Wirix-Speetjens PhD[2], Orçun Taylan MSc[3], Hendrik Pieter Delport PhD[3], Lennart Scheys PhD[3], Michael Skipper Andersen PhD[4]
[1,4,]*Aalborg University, Aalborg East, 9220, Denmark, dp@m-tech.aau.dk
[2] Materialise N.V., Leuven, 3001, Belgium
[3] Katholieke Universiteit Leuven, Leuven, 3000, Belgium

INTRODUCTION

The knee joint is one of the most complex joints in the human body. Joint laxity assessments have been a valuable resource in order to understand the biomechanics and pathologies of the knee. Knee ligaments works together to provide stability in multiple directions, therefore injuries or modifications should also be assessed in multiple directions to understand their impact on knee laxity (Yagi et al. 2007). Clinical laxity tests like the Lachman test, Pivot-shift test and Drawer test are, however, subjective of nature and will often only provide basic information of the joint (Cooperman et al. 1990). Arthrometers on the other hand are objective but still limited in terms of quantifiability, soft-tissue artefacts, repeatability and one-dimensionality (Musahl and Kuroda 2017). Stress radiography is another option for assessing knee laxity; however, this method is also limited in terms of quantifiability and one-dimensionality (Garavaglia et al. 2007). Furthermore, extended use of stress radiography may expose both operator and patient to excessive radiation (Balonov and Shrimpton 2012). To our knowledge, the only methods not affected by previously mentioned limitations are invasive measures primarily performed intraoperatively. We propose a non-invasive low-dose radiation method to accurately measure knee joint laxity in 3D.

MATERIALS AND METHODS

An arthrometer was developed by combining a parallel manipulator (H-820, Physik Instrumente, Germany) and multi-axis force/moment sensor (Omega85, ATI Industrial Automation, USA). The arthrometer is designed to impose multidirectional force controlled loads to the knee joint through a fixation device. Thereby, clinically relevant loads can be applied to the joint while controlling forces in any direction, allowing unconstrained knee joint motion. The device is designed to be used in conjunction with a low-dose biplanar x-ray system and 3D image data in order to track tibiofemoral kinematics under applied loads (figure 1).

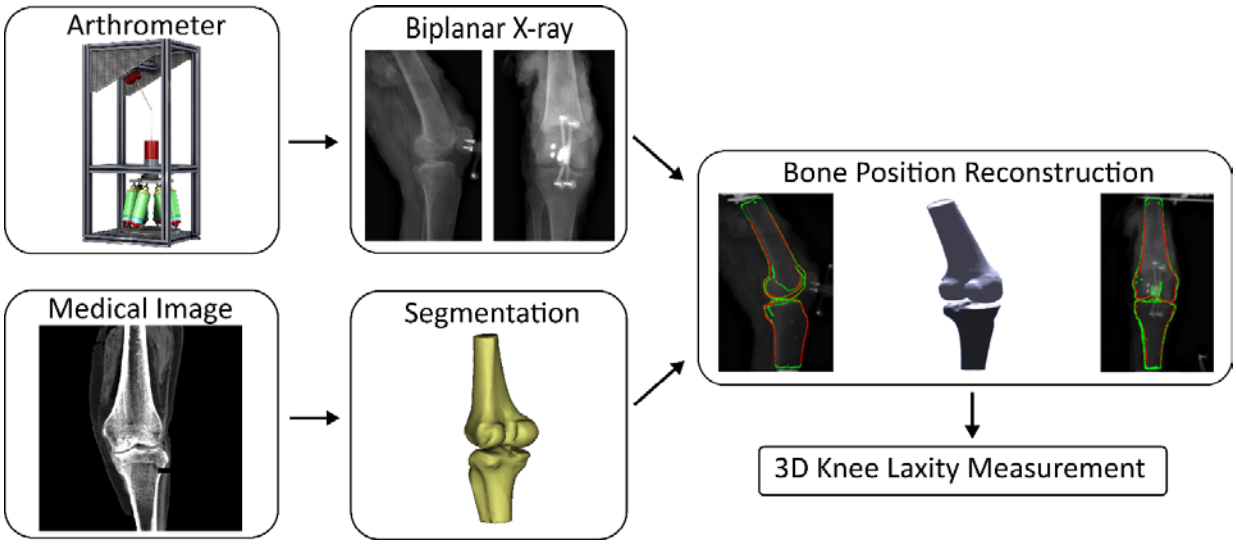

Figure 1 - Flowchart representing the different processes in the proposed method from acquiring image data to processed 3D knee joint laxity measurement.

As proof-of-concept, a cadaveric knee (female, age 73) was CT scanned (SOMATOM Definition Flash, Siemens) and subsequently mounted at 30 degrees of flexion in the device and placed inside a biplanar x-ray scanner (EOS, EOS imaging, France). Biplanar x-rays were obtained for eleven static load cases: anteroposterior loading (67 N, 134 N, -67 N and -134 N), mediolateral loading (12 N, 24 N, -12 N and -24 N) and internal/external moment (3 Nm, 6 Nm and -3 Nm). Subsequently, the 3D bone geometries of femur and tibia were segmented from the CT image using Mimics (Materialise, Belgium). Bone position and orientation for each load case were reconstruction by registering the 3D bone geometries onto the biplanar x-ray images using an iterative closest point match between contours of the x-ray images and projected contours of the bone onto the image planes using Matlab (Mathworks, USA). The relative translations and rotations between the reconstructed tibia and femur were computed in AnyBody Modeling System (AnyBody technology, Denmark) following ISB recommendations.

RESULTS

The primary tibiofemoral translation and rotation from the eleven different load cases is presented in Figure 2A. Anteroposterior loading of 67 N, 134 N, -67 N and -134 N resulted in an anteroposterior translation of 3.49 mm, 4.22 mm, -6.55 mm and -7.87 mm respectively. Mediolateral loading of 12 N, 24 N, -12 N and -24 N resulted in a mediolateral translation of 3.11 mm, 4.17 mm, -2.46 mm and -5.48 mm respectively. Internal/external moment of 3 Nm, 6 Nm and -3 Nm resulted in an internal/external rotation of 10.15°, 12.72° and -20.23° respectively.

Primary and selected secondary translations and rotations from anteroposterior load cases are presented in Figure 2B. Anteroposterior loading of 67 N, 134 N, -67 N and -134 N resulted in internal/external rotation of 1.04°, 3.44°, -10.46° and -13.97° and mediolateral translation of -6.83 mm, -5.73 mm, -1.10 mm and 1.27 mm respectively.

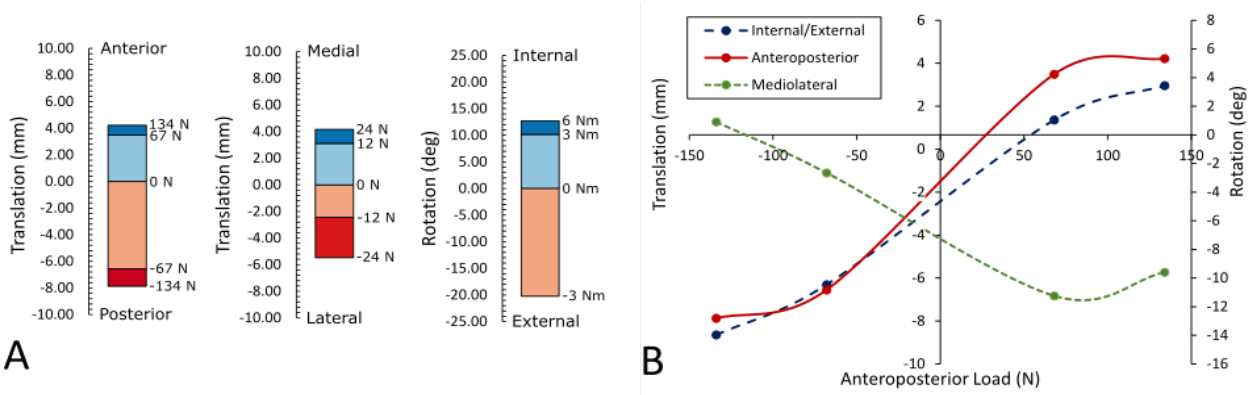

Figure 2 – Primary translations (mm) and rotations (deg) for the load cases investigated in this study can be seen in figure 2A. Anteroposterior translations (solid line), mediolateral translations (dotted line) and internal/external rotations (dashed line) for the anteroposterior load cases can be seen in figure 2B.

DISCUSSION

The preliminary results from this study displays that the device is capable of measuring primary knee laxity kinematics similar to what have been reported in previous studies (Daniel et al. 1984). Additionally, the results also displays that the method is capable of capturing coupled motions like the internal/external rotation when anteroposterior loads are applied (Zantop et al. 2007).

This method is combining concepts from robotic arthrometry and stress radiography into one unified solution that potentially enables unprecedented 3D joint laxity measurements non-

invasively. The method potentially eliminates limitations present in previous methods and significantly reduces the radiation exposure of the patient compared to conventional stress radiography (Luo et al. 2015). However, several aspects of the method can still be optimized e.g. efficiency, processing time and cost. Furthermore, aspects like the bone position reconstruction needs to be validated as well as the overall system. Lastly, this study used a cadaveric knee to investigate the method; the next step would be to investigate it in vivo.

We have displayed that the presented method is capable of obtaining knee joint laxity in 3D. The method enables advanced assessment of knee joint laxity and the interplay between ligaments. Potentially, this method could be used to improve subject-specificity of musculoskeletal models or provide preoperative reference laxity for arthroplasty and follow-up assessments.

REFERENCES

Balonov MI, and Shrimpton PC. Effective Dose and Risks from Medical X-Ray Procedures. *Annals of the ICRP* 41(3–4), pp: 129–41, 2002.

Cooperman JM, Riddle DL, and Rothstein JM. Reliability and Validity of Judgments of the Integrity of the Anterior Cruciate Ligament of the Knee Using the Lachman's Test. *Physical therapy* 70(4), pp: 225–33, 1990.

Daniel DM, Stone ML, Sachs R, and Malcom L. Instrumented Measurement of Anterior Knee Laxity in Patients with Acute Anterior Cruciate Ligament Disruption. *The American journal of sports medicine* 13(6), pp: 401–7, 1984.

Garavaglia G et al. 2007. Accuracy of Stress Radiography Techniques in Grading Isolated and Combined Posterior Knee Injuries: A Cadaveric Study. *The American Journal of Sports Medicine* 35(12), pp: 2051–56, 2007.

Luo TD, Stans AA, Schueler BA, Larson AN. Cumulative Radiation Exposure With EOS Imaging Compared With Standard Spine Radiographs. *Spine Deformity* 3(2), pp: 144–50, 2015.

Musahl V and Kuroda R. *Rotatory Knee Instability*. Springer Internaltional Publishing, 2017

Yagi M et al. Double-Bundle ACL Reconstruction Can Improve Rotational Stability. *Clinical orthopaedics and related research* 454(454), pp: 100–107, 2007.

Zantop T et al. The Role of the Anteromedial and Posterolateral Bundles of the Anterior Cruciate Ligament in Anterior Tibial. *The American journal of sports medicine* 35(2), pp: 223–27, 2007.

DISCLOSURES

Valentine Vanheule and Roel Wirix-Speetjens is employed by Materialise N.V. Hendrik Pieter Delport is consulting Materialise N.V., Ortho-Expert B.V. BVBA and Mobelife N.V.