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EDITORIAL

In search of a gold standard for objective clinical outcome: using dynamic biplane radiography to measure knee kinematics

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Abbreviations

ACL	Anterior cruciate ligament
DBR	Dynamic biplane radiography
IMUs	Inertial measurement units
LET	Lateral extraarticular tenodesis
PROs	Patient-reported outcomes

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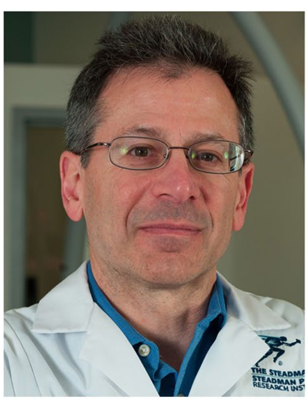

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Much of what we know, or think we know, about knee kinematics and how injury and surgical intervention affect knee kinematics is based on biomechanical studies of cadavers [11]. For example, the effects of new surgical techniques, such as anatomic ACL reconstruction, were evaluated by robotic biomechanical testing [21] prior to widespread clinical adoption.

Cadaver-based biomechanical studies use a robot to apply precise kinematics or loads [20], but typically the loads and loading rate are much less than during athletic activities. In contrast, impact simulators can apply large loads at high rates [5], however, the kinematics may not replicate in vivo activities. A limitation of all cadaver-based studies is that they cannot account for changes over time after injury or surgery, such as ligament healing and neuromuscular adaptation. Conventional motion capture, using reflective markers or inertial measurement units (IMUs), can measure changes in in vivo knee kinematics after injury or surgery, however, all measurements systems that attach sensors directly to the skin are impaired by soft tissue artifact (*i.e.* the relative motion between the skin and underlying bones) [15] which can be 35% to 65% of the true translation and rotation of the underlying bone [6] rendering those techniques inappropriate for clinical evaluation of joint kinematics after surgical procedures.

Dynamic biplane radiography (DBR) has emerged as a viable technology to accurately measure in vivo knee kinematics during activities of daily living and athletic activities. DBR can measure knee kinematics with an accuracy of about 1° in rotation and better than 1 mm in translation without soft tissue artifact [3]. Advantages of DBR over cadaver-based biomechanics studies are that kinematics can be measured under loading conditions that replicate activities of daily living or athletic activities, and that the effects of healing and neuromuscular adaptations can be assessed. The high accuracy of DBR measurements improves musculoskeletal models that predict tissue loading [7] and make it possible to measure the effects of injury, surgical intervention and rehabilitation on articular cartilage contact mechanics (combined DBR plus MRI) [2, 9] that may be related to the development of osteoarthritis [4]. The high accuracy also makes it possible to identify kinematics changes due to injury, intervention and healing using fewer subjects than are needed when using conventional motion capture.

In a recent consensus statement by the Panther ACL consensus group [18] outcomes after ACL treatment were divided into four general categories—early adverse events, patient-reported outcomes (PROs), ACL failure/recurrent ligament disruption, and clinical measures of knee function and structure. With regards to measuring knee function, the group achieved 100% agreement for the recommendation that clinical assessment of ACL injury treatment should include measures of anteroposterior and rotatory knee laxity. In this regard, the current gold standard of knee laxity measurement is dynamic biplane radiography to measure in vivo knee kinematics.

DBR exposes research participants to additional radiation exposure, so care must be taken to limit the sample size to minimize overall risk of the research study. Biplane radiography studies are also expensive and time consuming. These costs are one reason previous biplane radiography studies of knee kinematics typically include a small number of participants (10 to 20) who are often imaged at only one-time point [10, 12, 16]. To date, the largest published studies on knee kinematics using biplane radiography included 74 patients who received knee arthroplasty [13] and 49 patients who received ACL-reconstruction [1]. Given the high accuracy, increased availability, and continuous improvements in capabilities, novel data will continue to emerge from DBR research to improve our understanding of the in vivo effects of injury and surgical intervention on knee kinematics and pathology.

Two recent studies employed DBR in randomized clinical trials to measure knee kinematics and cartilage contact patterns. Tashman et al. investigated single bundle vs. double-bundle ACL-reconstruction (ACL-R) for their effects on knee kinematics following healing at 2 years [14, 19]. The authors were able to show that both techniques led to the restoration of translational and rotational kinematics, which the authors attributed to the anatomic technique that was utilized in both techniques. Chiba et al. compared ACL-R to ACL-R plus lateral extraarticular tenodesis (LET) [8, 17]. Results from that trial suggest that the addition of LET may affect sagittal knee kinematics and cartilage contact patterns during running in the early post-operative phase (6 months), but those effects are lost in the longer term (12 months). These results suggest that healing and neuromuscular adaptation may occur and diminish the effect of LET over time.

Advancements in Knee Surgery, Sports Traumatology and Arthroscopy will most certainly have to include large-scale clinical trials that are randomized with an appropriate control group. Additionally, these clinical trials will have to be supplemented with smaller scale kinematic studies that are both in vivo (i.e. testing on consented patients rather than cadaver specimens) and provide information on the function of the joint and the applied surgical technique. The combination of the two, clinical and in vivo biomechanical studies, will prove to be most powerful and will ultimately aid in improving the outcome for patients being treated for injuries related to Orthopaedic Sports Medicine.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants included in the study.

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