Measuring Dynamic Knee Motion with an Instrumented Spatial Linkage Device

Brian S Baum, MS; Fabian E Pollo, PhD; Robert W Jackson, MD;
Prashant Komdeur, MD; Ericka Calton, MS
Department of Orthopaedics, Baylor University Medical Center, Dallas, TX

Introduction: The knee is a complex joint that moves with six degrees-of-freedom (DOF). Clinicians and researchers have been studying the knee for many years using a variety of devices including x-rays, arthrometers, fluoroscopy, and MRI [4, 6, 7] to understand this joint's motion and use that information to help design better knee braces, improve rehabilitation, and enhance prosthetics. However, these devices only allow for static or very limited dynamic measurements of knee motion. Dynamic measurements provide much more detailed and accurate descriptions of knee motion during every day and sports-related activities. Recently, techniques designed to measure dynamic knee motion have been developed, including using intracortical pins [5] and a point cluster technique [1] from a camera-based analysis system. Unfortunately, these procedures are either invasive and/or require an expensive system and confinement to a laboratory. Therefore, there is a need for a clinically useful non-invasive device that measures dynamic knee joint kinematics allowing for more freedom of movement. This paper discusses the development of an instrumented spatial linkage device (ISLD) that measures knee motion in six DOF during dynamic activities [2] and its application to an ACL deficient patient.

Figure 2

Statement of Clinical Significance: The ISLD allows for a more complete understanding of 3-dimensional knee motion during dynamic activities and may lead to better evaluation and diagnosis of knee injuries.

Methodology: The knee joint moves in six DOF, which may be simulated with a universal (ball) joint. The linkage system for the ISLD may be represented as two special universal joints separated by a sliding link. The ISLD has five rotary potentiometers and one linear potentiometer mounted in a 7075 T6 aluminum frame that weighs approximately 0.15 kg (Figure 1). The ISLD frame ranges in length from 17.15 to 22.42 cm and extends laterally from the leg 4.45 cm. The ends of the device are flat with rectangular 6061 T6 aluminum plates or "arms" that slide into rails mounted onto leg cuffs made of a flexible aluminum material. The ISLD arms secure to the rails with small set-screws that inhibits movement of the arms inside the rails. The leg cuffs were designed by a brace manufacturer (Bledsoe Brace Systems, Grand Prairie, Texas) to provide a comfortable and stable attachment to the leg (Figure 2). They mold around the bony protuberances of the leg and are anchored by muscle bulges such as the gastrocnemius to prevent slippage. The cuff attachments do not restrict knee motion and thus allow full range of motion. The ISLD connects to a 12-bit DATAQ A/D converter via an

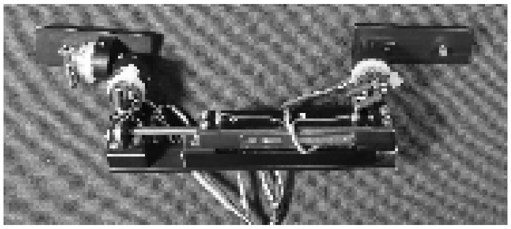

Figure 1

umbilical cord. Knee joint coordinate system transformations were determined using the Grood and Suntay method [3].

The accuracy of the ISLD was tested with a Model 14943-Rxyz Positioner (Oriel Corporation, Stratford, CT, USA). To test the usefulness of the ISLD, the device was applied to a 32-year old subject with an acute ACL injury. Testing was performed pre-operatively and repeated three months after ACL reconstructive surgery for comparison.

Results: The ISLD accurately measures joint motion to within ±0.8 mm in translation and ±1.4 degrees in rotation without taking into account the effects of extraneous skin motion due to soft tissues [2]. For the ACL example, we focused on anterior/posterior (A/P) tibial translation with respect to the femur, which is the most affected pattern in ACL injuries. Figure 3 shows pre-operative tibial translation of both the injured ("affected") and uninjured ("unaffected") knee during the gait cycle. The injured knee exhibits a continuous posterior tibial slide throughout the entire gait cycle and is shifted anteriorly compared to the uninjured knee. Figure 4 compares the injured knee pre-operatively and 3 months after ACL reconstructive surgery. These results show the post-operative tibial translation pattern is relatively neutral throughout stance phase, similar to the pattern of the uninjured knee data taken pre-operatively, but a tightening affect is observed during the swing phase.

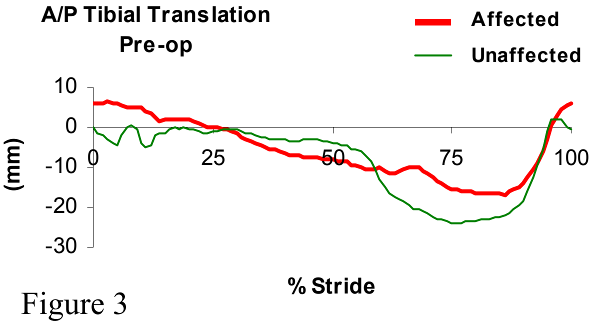

Figure 3

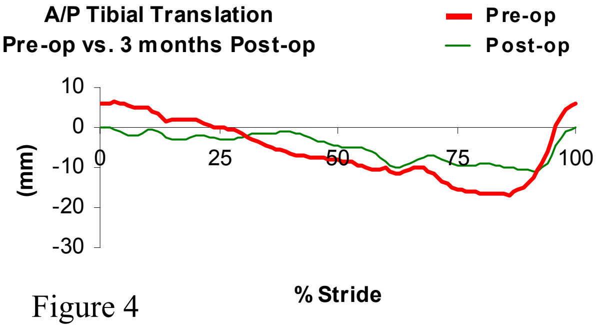

Figure 4

Discussion: The ISLD provides kinematic data that takes into account the effects of joint forces, as well as the dynamic stabilizers (muscles and ligaments) that are employed during activities of daily living and sports-related activities. Therefore, such a device can become a clinically useful tool for evaluating knee joint stability, to plan treatment options and follow progress. In the example above, the ISLD allowed us to evaluate and compare the kinematics of a knee with a ruptured and subsequently repaired ACL.

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