DEVELOPMENT OF REFERENCE METHOD FOR THE QUANTIFICATION OF CLINICAL ACL EXAMS

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INTRODUCTION

Tears of the anterior cruciate ligament (ACL) are a common injury, affecting over 100,000 patients per year in the US alone [1], and reconstructions of the ligament are performed over 200,000 times a year worldwide [2]. The ACL is an important structure for knee stability, playing a vital role during normal walking patterns and pivoting motions during sports [3]. While imaging methodologies can be used to visualize the injured ligament, manual clinical examinations are necessary to determine the extent of the injury and the functional capabilities of the knee [3].

While there are numerous orthopedic clinical examinations to assess knee stability, the pivot shift test is a multiplanar maneuver shown to be the most specific diagnostic test to detect ACL tears [4]. It’s lack of false positives and its high correlation to clinical and patient-reported outcomes make it the most informative clinical exam in the orthopedic surgeon’s arsenal [4]. Unfortunately, the results of these orthopedic exams are subjective, limiting their use as diagnostic exams that can be compared over time and between patients and physicians.

It has been found after studying the kinematics of the knee during the pivot shift maneuver that the anterior tibial translation correlates well with the clinical grade given by the physician after a positive test [5]. While devices such as electromagnetic tracking systems and visual navigation systems can be used to track anterior tibial translation during the pivot shift [6,7], these methods are extremely invasive and complex, making them inappropriate for use in a clinical setting.

In order to obtain quantitative data in a non-invasive way, a 2D image analysis method has been developed at the Orthopedic Robotics Laboratory at the University of Pittsburgh to measure the anterior tibial translation during the pivot shift. The application has been tested on small quantities of patients [8], but a comprehensive assessment of how the 2D image analysis correlates to the actual 3D kinematics of the knee has not been published.

OBJECTIVE

The objective of the study was to develop software for an electromagnetic tracking system (Nest of Birds, Ascension Technology, Shelburne VT) that can track the 6 degrees of freedom kinematics of the knee during a pivot shift maneuver. This electromagnetic tracking system will then be used as a reference method in order to validate the results of the 2D simple image analysis method.

HYPOTHESIS/SUCCESS CRITERIA

Because the electromagnetic tracking system will be used as a reference, it needs to be accurate. Based on the manufacturer’s specifications, the device should have a translational accuracy of at least 0.5 mm and a rotational accuracy of at least 0.5 degrees. This means that when moved or rotated a known amount, the reading will be within 0.5 mm or 0.5 degrees of that amount. The device also needs to be repeatable, showing a less than 0.5 mm or 0.5 degree standard deviation after multiple trials. The system should also be able to display results immediately after recording data, allowing for quick analysis of the test.

METHOD

To communicate with the electromagnetic device, software in Matlab (Mathworks, Natick, MA) was created in order to send commands such as reading the position and orientation of each sensor relative to the transmitter’s 3-axis coordinate system. Then code was written to read the data and store it into an array for future calculations.

In order to know the position and orientation of the bone as it relates to the sensors position and orientation, Grood-Suntay joint coordinate systems were generated for each the femur and tibia [9] after affixing the sensors to the leg with titanium pins. To do so, with the leg in a static position, a stylus is pressed against bony landmarks on either the femur or tibia and the position of those points is recorded. From those points in space, an orthogonal coordinate system is generated. Matrix manipulations can then be performed in order to relate how theibia is positioned and oriented relative to the femur. Decomposition of this matrix yields a relationship between the two bones in all six degrees of freedom. These relationships can be recorded over time by Matlab and graphed immediately after data acquisition, allowing quick visual inspection of the data for any discrepancies. A graphical user interface was finally generated to allow for ease of use.

In order to verify the accuracy of the system, the sensors were fixed to goniometers in arrangements allowing the measurement in the distal/proximal and medial/lateral directions and the ab/adduction and flexion/extension directions. In order to test these four degrees of freedom, one sensor was moved 20mm distally 5 times, laterally 20mm 5 times, abducted 20 degrees 5 times, and flexed 5 times. Averages and standard deviations were calculated and examined. All tests were performed manually.
RESULTS
All results provided are the average and standard deviation of 5 trials. When moved distally 20 mm along the goniometer, the electromagnetic system reported a mean of 19.9±0.3 mm. Testing in the lateral direction showed 19.6±0.4 mm. Abducting one sensor relative to the other 20 degrees, the system reported 19.9±0.3 degrees and rotating the sensor as flexion produced results of 20.2±0.3 degrees. As can be seen in Figure 1, all values were very close to 20mm or degrees.

DISCUSSION
The creation of the software to run the electromagnetic tracking system was a success. After learning to communicate with the device and perform calculations on the received data, 6 degrees of freedom kinematics could be gathered and reported immediately after recording. By creating a graphical user interface for easy interaction, a lay person will be able to use the system with a minimum of training.

The results of the verification study were positive. Each of the translations and rotations were within either 0.5 mm or 0.5 degrees of the actual intended movement, showing the software did not affect the electromagnetic system's stated accuracy of 0.5 mm and 0.5 deg. The standard deviation of each of the tests was also less than 0.5 mm or degrees, showing a high degree of repeatability. Because of this, the electromagnetic system was deemed to be an appropriate reference method for the validation of the 2D simple image analysis method.

This study was limited by a few factors. Because of the time taken to communicate with the device and store the data, the maximum record rate of the electromagnetic system was only 30Hz. Electromagnetic interference was a large factor in the location of testing. Being close to any large quantities of metal or devices emitting electromagnetic radiation caused a large amount of noise. Thus a location had to be found in order to minimize this interference. A limitation of the verification testing was that they were performed manually, and so human error was a factor in the final position of the sensor. Further verification could use a more accurate mechanical method to move the sensors and test in all 6 degrees of freedom.

It was found that because it met accuracy and repeatability requirements, the electromagnetic system is viable reference method to validate the 2D simple image analysis method to quantify anterior tibial translation during a pivot shift maneuver. This means that the 2D simple image analysis method is one step closer to being a viable method for clinicians to objectively judge knee stability in a non-invasive way.

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REFERENCES