A 3D Dynamic Diagnostic Tool for Detection of Patellar Maltracking

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***Abstract*—Patellar maltracking may be an underlying cause of patellofemoral pain and knee instability. Currently there is no dynamic diagnostic device to detect maltracking before surgery is required. The PatFinder device entails a knee brace combined with multiple gyroscopes to accurately track the patella kinematics during gait. Three tests are performed to verify the accuracy of each gyroscope and the device as a whole. The anticipated results will show that the gyroscope and mounting device provide clinically relevant data in regards to the tracking and movement of the patella.**

Keywords—patella; maltracking; gyroscope; calibration; displacement;

I. Introduction

Approximately 400,000 people in the U.S. suffer from patellofemoral pain every year [1]. Most of these patients suffer from patellar maltracking. Maltracking occurs following cruciate ligament surgeries, specifically following repair of the anterior cruciate ligament (ACL), and it is not easily observed or examined until permanent damage has occurred. There are many knee braces on the market which provide support as the patient seeks physiotherapy to strengthen surrounding muscles and ligaments of the patella. However, there are few devices used for diagnostic intervention of patellar maltracking, and many require complex optical sensor systems or stationary imaging devices. As such, these are not practical for intraoffice use; thus, there is a need for a diagnostic device to detect cases of patellar maltracking before surgery is required to repair a torn ligament from subluxation or articular cartilage damage.

The PatFinder utilizes gyroscope technology and a novel brace-like device to measure patella angular displacement during weight-bearing dynamic motion [Figure 1].

Fig. 1. PatFinder device with gyroscopes enclosed.

II. Materials and Methods

A. Gyroscopic Technology and Testing

To construct a brace-like device that can be easily used within clinics and physical therapy practices, gyroscopes are used to produce accurate and real-time data of the patella during weight-bearing motion. Digital gyroscopes are micro-electromechanical motion sensors that measure angular velocity in up to three axes. By integrating the angular velocity through MATLAB software [MathWorks Inc, Natick, MA] the angular displacement can be calculated. Calibration testing of the gyroscopes use fixed speed motors to verify the angular velocity measurements in a one and two-gyroscope system. The two-gyroscope system will be utilized with the brace-like device to obtain patellar angle values during continued motion. One reference gyroscope will be placed on the tibial tuberosity since it is a recognizable and repeatable landmark to clinicians and physical therapists. The second will be placed on patella to track movement of the patella in three axes [Figure 2].

Fig. 2. Reference gyroscope and patella gyroscope position on the knee.

Two tests will be conducted to ensure precise angular velocity measurements. The first test involves calibrating each gyroscope to ensure gyroscope output correlates to known voltage values. The gyroscope will be mounted onto an orthogonal cube and placed on a platform at the end of a High Torque Turbo Geared Motor DC 12V motor (10 and 20 RPM) as shown in Figure 3. The second test repeats the initial test to verify accurate output from two gyroscopes without crosstalk.

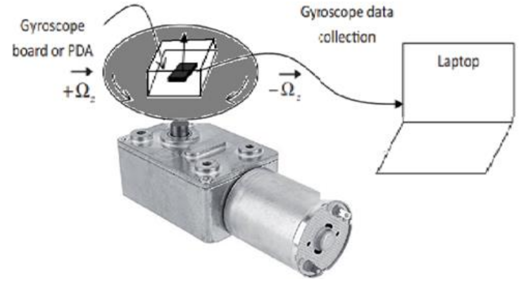

Fig3. Gyroscope measurement testing setup.

The gyroscope calibration parameters modify the raw data to allow the gyroscopes to accurately output the angular velocity. 100 samples of angular data will be collected and averaged for each gyroscope. This will act as the zero-rate level which is subtracted from all gyroscope calculations. A motor will be used to rotate a mounting platform at +/-60 degrees/second (dps) [per manufacturer specifications] with a full rotation performed upon achieving a stable angular velocity. Once the angular velocity is stable the data will be collected for one full rotation. This process will be repeated at +/- 120 dps for each axis. The least squares method will be used on a matrix with the known angular data and a matrix with the raw gyroscope data to determine six gyroscope calibration parameters for each device.

To compare the calculated angular displacement values to known rotation angles, a manual goniometer test will be completed. The gyroscope will be mounted on an orthogonal cube and placed on a platform at the end of a motor shaft as shown in Figure 3. The platform will be turned counterclockwise and after 90 degrees of rotation, the motor will be turned off. A handheld goniometer will measure the actual angular displacement and will be compared to the software output. The platform will then be rotated to 180, 270, and 360 degrees using an identical procedure to determine rotational displacement for full range of rotation.

B. Spring Plunger on Patella Gyroscope Casing Slip Test

The stabilization fixture will be assembled and positioned 90 degrees from its vertical orientation under an axial loading machine. This position will allow a shear force to be placed on the plunger rod. Loads varying from 1-10 N will be applied for 6 sample runs at each load value (increments of 1N). For each applied load the displacement x of the plunger rod, as shown in Figure 4, will be measured using a digital caliper. The stabilization fixture is determined to pass if all measured displacements are ≤ 2.5 mm. The testing will be replicated for three gyroscope casing surfaces: PLA (no coating), rubber 1 coating, and rubber 2 coating. Results will determine if a rubber coating is necessary on the gyroscope casing to limit or eliminate slip.

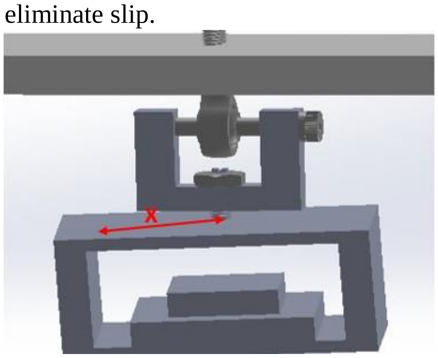

Fig. 4. Patella gyroscope casing slip test setup.

III. Results (Anticipated)

A. Gyroscope Measurement Testing

Calibration data for the gyroscope will be a linear curve of angular velocity over time. Expected data for testing of the single and double gyroscope setup will be a comparison of actual angular displacement using a goniometer and calculated angular displacement from the MATLAB software.

B. Spring Plunger on Patella Gyroscope Casing Slip Test

The PLA surface without a rubber coating will likely cause a larger displacement of the spring plunger than the surface with a rubber coating. The plunger displacement can exceed 25 mm but the maximum anticipated displacement is 12 mm. The maximum anticipated displacement of 12 mm occurs at an applied force of 10 N on the PLA surface without coating. The results will show that it is beneficial to use a rubber coating. Expected results are shown in Figure 5.

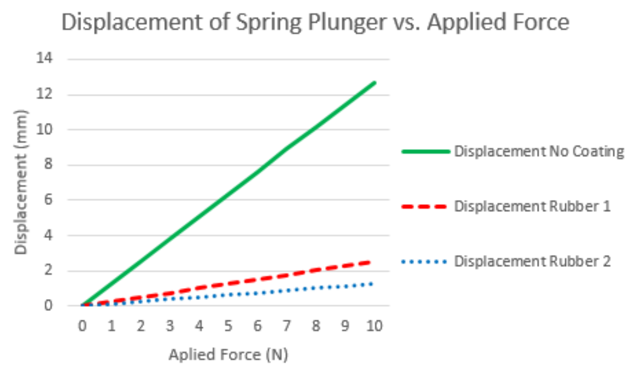

Fig. 5. Anticipated displacement of testing surfaces vs. applied force.

IV. Discussion

The angular velocity data integrated to obtain displacement using MATLAB software is critical to the accuracy of the output data. Statistical comparison of the calculated values with actual displacement values measured with a goniometer will ensure that the MATLAB software is providing accurate data when compared to known angular displacements. Maintaining an approximate coefficient of variation equal to 5% variation for known and calculated values is critical to ensure the MATLAB program can provide clinically relevant data used in diagnoses.

Displacement of the spring plunger on the patella gyroscope casing surface must be minimized to ensure that the gyroscope is taking measurements of the patella. During weight-bearing dynamic motion, the patella can move freely and the gyroscope casing must allow the knee to not only move freely but isolate patellar angular displacement from the total knee angulation. Any slip between the gyroscope casing and spring plunger nose will result in measurement of angular velocity due to noise or the knee instead of the patella. Thus, data will be optimized for the patella if the contact surface of the plunger minimizes slip with a selected rubber coating surface.

V. Conclusion

With the production of the PatFinder and the expected outcomes of the tests, the technology can be adapted to any joint in the body.

References

[1] Golant, Physical Medicine and Rehabilitation, 2013.