Development of a Novel UHMWPE Contact Sensor for Measuring Dynamic Patellofemoral Contact Pressure

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Statement of Purpose: Instances of anterior knee pain and patellar fracture are more and more widely considered as significant complications following total knee replacement (TKR). Specifically, the patellofemoral (PF) joint contact pressure and contact area, associated with the geometrical conformity between the articular interfaces, directly correlate with the polyethylene wear and deformation of the patellar component [1]. Hence, real-time measurement of PF joint contact condition is significant in assessing clinical outcomes and implant long-term success. In addition to existing film-based sensors, which could alter the contacting surface topology [2], the current study aimed to provide a novel solution for measuring the dynamic PF contact distribution, with minimum alternations to the mechanical and tribological properties of the articular PF joint interface.

Methods: A UHMWPE contact sensor was initially machined from a compression molded GUR4150 UHMWPE resin block. A 5x5 grid of 1.59 mm holes were machined into the block and filled with UHMWPE powder blended (8% in weight [3]) with electrically conductive carbon-black (CB) nano-particles. The assembled block was further molded at 130 °C using a carver press [3] and machined into a patellar component (Stryker Triathlon®, Stryker Corp., Kalamazoo, MI) (Fig. 1a). Wires were attached to the backside of the patellar component to connect each sensing point to the corresponding channel within a customized data acquisition system. A data stream of voltage variation could be exported, to measure the instantaneous contact pressure applied on sensing points. In addition, an extra wire was attached to the femoral component to apply an excitation voltage. A graphic software interface built in Labview (v7.1, National Instruments Corp., Austin, TX) was written to store incoming data, and visualize and analyze the dynamic contact pressure distribution.

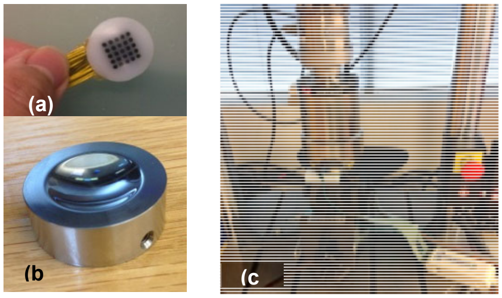

Fig.1 (a) The UHMWPE patellar pressure sensor; (b) The stainless-steel calibration indenter; and (c) The experimental setting for sensor performance evaluation.

The pressure sensor was then calibrated in uniaxial compression using Instron MTS machine (Model 8874, Instron Inc., Norwood, MA). A stainless steel indenter (Fig.1b) with conformal geometry and known contacting area was designed to ensure evenly distributed pressure. Compressive loading was linearly increased from 0 to 5000 N, corresponding to calculated contact pressure of 0-15 MPa. Load cell readings were numerically matched to fit the calibration curve for each sensing point, correlating its voltage response to physical loading.

The UHMWPE sensor capability was further validated by comparing the pressure reading with a Tekscan K-scan™ sensor (Tekscan Inc., South Boston, MA), which was placed on the top of the domed patellar button surface. A dynamic compression loading ramp from 0 to 900N was applied on both sensors via customized indenter that tightly covers the sensor matrix area with deformable foam (Fig. 1c). The comparative tests were repeated four times and the statistical equivalence between real-time readings obtained with both sensors was evaluated.

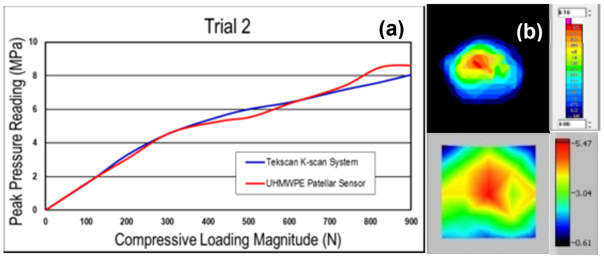

Fig.2 (a) Peak pressure magnitude variation under compression loading ranging from 0 to 900N; (b)Contact pressure distribution at 500N compression presented by Tekscan (up) and UHMWPE patellar sensor (down).

Results: As depicted in Fig.2 (a), the Tekscan and UHMWPE patellar sensor demonstrated close peak pressure responses. Generalized linear regression analysis with maximum likelihood estimation was performed using SAS statistical package (v9.4, SAS Institute Inc., Cary, NC) based on all 4 trials, and the difference between the peak pressure variation curves obtained by both sensors was proven to be insignificant, with p-value of 0.8955. As shown in Fig.2 (b), the pressure distribution contours at all loading levels obtained by both sensors demonstrated the same pattern as well. For the patellar sensor, linear interpolation was imposed among sensing points for continuous presentation of pressure distribution.

Conclusions: In the current study, the novel patellar was shown to be accurate and robust in capturing the real-time pressure magnitude and distribution during a ramp-based dynamic loading process. Since the sensing area of the UHMWPE patellar sensor is slightly smaller than the indenter's cross sectional area, full contact area could not be displayed, causing inconsistency between the two pressure distribution plots.

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