A machine-learning based knee acceleration parameter correlates with external knee adduction moment during gait

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INTRODUCTION:

The external knee adduction moment (KAM), which corresponds mechanical loads in the medial compartment of the knee joint during gait. It is known as important mechanical and clinical digital marker for knee osteoarthritis (KOA).[1] Wang et al developed a wearable sensor system using a single inertial measurement unit (IMU) at ankle, artificial neural network and XGBoost to simply estimate KAM and reported excellent results to estimate KAM [2]. However, the data were obtained from limited numbers of advanced KOA (only 3%) and there is a concern to estimate KAM of advanced KOA by their system. In this study, we developed machine learning algorithm to obtain an acceleration parameter to correlate the KAM using a single IMU, using gait data of KOA with various grade.

METHODS:

Gait data of 46 KOA patients and 14 asymptomatic subjects (50 females and 10 males) were obtained to generate the artificial intelligence (AI) algorithm. Mean age was 62.9 ± 12.8 years old and mean Body Mass Index (BMI) was 22.3 ± 3.3 kg/m. A total of 32,27,25,28 and 8 knees were allocated to the Kellgren-Lawrence (KL) grade 0,1,2,3, and 4 respectively. Simultaneous measurements of 3D motion capture system (200 frames/second; Oqus, Qualisys, Sweden) and IMUs (200Hz, TSND151, ATR-Promotions, Kyoto, Japan) attached to the bilateral tibial tubercle were performed during a 5m walk. Visual 3D (C-motion, Rockville, MD, USA) was used for knee joint kinematics and kinematics calculations. The first peak value of KAM in the stance phase was defined as peak KAM, and KAM impulse, the timed integral of all the KAMs was calculated for stance duration. Total of 3 accelerations and 3 angular velocities about 3 orthogonal axis from IMU sensers were used to estimate peak KAM and KAM impulse. Gait data of 121 randomly extracted trials were used as training data, and a machine learning model based on 5-fold cross validation to estimate KAM using those accelerations and angular velocities was created. Finally, we developed and tested the machine learning algorithm to calculate an acceleration parameter (iKAM) to correlate peak KAM and KAM impulse using the data from rest of 31 gait trials. Mean absolute percent error (MAPE), mean absolute error (MAE) of the acceleration parameters and correlation coefficient between iKAM and KAM were calculated.

RESULTS:

MAPE and MAE of iKAM_peak of training data set were 13.0% and 0.0428 Nm.s/(BWxHt), and those of test data set were 17.3% and 0.0505 Nm.s/(BWxHt), respectively. MAPE and MAE of iKAM_impulse of training data set were 20.4% and 0.0214 Nm.s/(BWxHt), and those of test data set were 21.4% and 0.0212 Nm.s/(BWxHt), respectively. Peason's correlation coefficients between iKAM (peak, impulse) and KAM (peak, impulse) were 0.870 and 0.975 in train data set (Figure 1), and those in the test data set were 0.591 and 0.690, respectively.

DISCUSSION:

We have introduced a novel knee acceleration parameter (iKAM) from a single IMU on the knee which shows good agreement with the conventional KAM. Wang et al. reported successful results to estimate KAM from 6 axis IMU data, as the correlation coefficient between predicted and true KAM were up to R^2 of 0.956. While the excellent estimation of KAM, there was a lack in the advanced OA knee data to train the algorithm. In particular, there was a limitation in the data range in their KAM value. The true and predicted KAM of their data ranged from 0 to 4 % Nm/(BW*Ht), while the reported KAM value of KOA patients ranged from 3.66 ± 1.20 %Nm/(BW*Ht) with KL grade 1 to 4.23 ± 1.12 %Nm/(BW*Ht) with KL grade 3 [1]. Thus, the system by Wang et al. likely to have limitation to estimate the knee with KAM beyond 4%Nm/(BW*Ht), that should be majority of the KAM of OA knees.

SIGNIFICANCE/CLINICAL RELEVANCE:

A machine-learning based knee acceleration parameter (iKAM) well correlates with KAM of KOA during gait. The AI system simply requires a single IMU attached to the patients knee, and it is expected to become an useful clinical tool to evaluate gait abnormality of KOA.

REFERENCE

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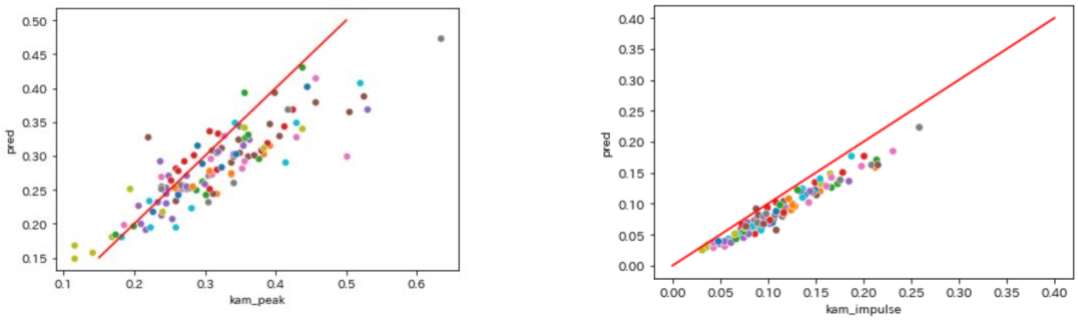

Figure 1 Scatter plots of iKAM_peak and KAM peak in train data set (left) and those of iKAM_impulse and KAM impulse (right)