Predicting Achilles tendon force using outdoor measurable features – A pilot study

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HOW PRECISELY CAN EASILY MEASURABLE VARIABLES PREDICT PATELLAR TENDON FORCES DURING RUNNING?

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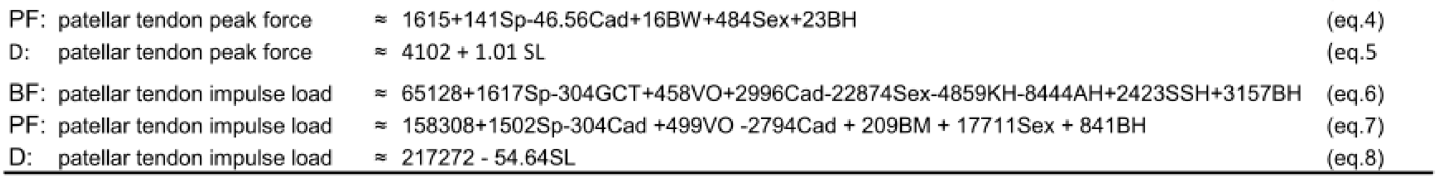
INTRODUCTION

The patellar tendon condition, jumper's knee, is commonly affecting runners. To successfully prevent jumper's knee injuries, in-depth knowledge is needed about the loads in the involved anatomical structures [1]. Hence, developing algorithms to predict cumulative force in the patellar tendon may be an important step to improve our insights into injury etiology [1]. Importantly, such algorithms should be fueled with self-reported data from runners and with data that are easily accessible while completing a running session outside a biomechanical laboratory. Therefore, the main objective of the present study was to investigate whether algorithms can be developed for predicting patellar tendon force and impulse per stride during running, using measures that can be collected by runners using commercially available devices. A secondary objective was to evaluate the predictive performance of the algorithms.

METHODS

Running trials from 24 recreational runners were collected with the MVN Link system (Xsens Technologies B.V, Enschede, The Netherlands) and a Garmin Forerunner 735XT (Garmin Ltd., Olathe, Kansas, USA) at three different running speeds (10, 12 and 14 km/h). Prior to data collection, the runners were informed about the purpose of the study, study design, equipment, and signed a declaration of informed written consent. During data collection, 3-D kinematic data of the full body were recorded at 240 Hz with the Xsens MVN link motion capture suit. Running dynamic data were recorded each second (60Hz) with the Garmin watch paired with a heart rate strap (HRM-Run; Garmin Ltd). The kinematic data from Xsens were processed in a computer model (AnyBody Managed Model Repository version 2.2) of the musculoskeletal system using the AnyBody Modeling System (version 7.2) to estimate the patellar tendon forces. We predicted ground reaction forces from the kinematics [2]. Each runner provided 24 running strides, giving 576 running strides in total (= 24 runners * 4 strides * 2 legs * 3 speeds) with an estimate of patellar tendon force. Each of the four strides was paired with the observation from the Garmin watch closest in time to this measure.
Data were analyzed statistically using a mixed-effects multiple regression model, which described the association between the estimated forces in the anatomical structures and the training load variables during the fixed running speeds. In the mixed model, runner-specific random effects were used to consider possible correlation between repeated observations for each runner at different running speeds. The

Table 1: The predictive algortihms of patellar tendon peak and impulse load during running based on outdoor measurable features



BF:	patellar tendon peak force	≈	1228+147Sp-53Cad+10BW+650Sex-140KH-256AH+175SSH+90BH	(eq.3)
PF:	patellar tendon peak force	≈	1615+141Sp-46.56Cad+16BW+484Sex+23BH	(eq.4)
D:	patellar tendon peak force	≈	4102 + 1.01 SL	(eq.5
BF:	patellar tendon impulse load	≈	65128+1617Sp-304GCT+458VO+2996Cad-22874Sex-4859KH-8444AH+2423SSH+3157BH	(eq.6)
PF:	patellar tendon impulse load	≈	158308+1502Sp-304Cad +499VO -2794Cad + 209BM + 17711Sex + 841BH	(eq.7)
D:	patellar tendon impulse load	≈	217272 - 54.64SL	(eq.8)

Sp:Speed; GCT:Ground contact time length; VO:Vertical Oscilation; Cad:Cadence; SL:Step length; KH:Knee height; AH:Ankle height; SSH:Shoe sole height; BH:Body height; BF: Best fitted; PF: Practically feasible; D:Distance response variable is either the estimated peak force or estimated impulse per stride in the patellar tendon. The predictor variables are the different training load variables from the Garmin watch (speed, ground contact time, vertical oscillation and cadence) and anthropometric variables of the runners, including body mass (kg), sex, knee height (cm), ankle height (cm), shoe sole height (cm) and body height (cm). This resulted in an algorithm to predict the estimated tendon force in the patellar tendon. A “best fitted” (BF) and a “practically feasible” (PF) model were fitted for both peak force and impulse per stride. For BF, all 10 variables were used, while PF did not use knee, ankle and shoe sole height. Both the BF and the PF models were identified by fitting all potential combinations of predictors (BF:2^{10}=1024 and PF:2^7=128). BF and PF were compared to an algorithm where only distance per stride (approximate for running distance) was used to predict peak patellar tendon force and impulse per stride. The prediction error (PE; eq. 1) was assessed for each of the algorithms using a cross-validation estimating the difference between the tendon force estimated using AnyBody and the tendon force predicted by the algorithms.

$$PE = \sqrt{[observed - predicted]^2}. \qquad (\text{eq. } 1)$$

The algorithm with the lowest prediction error was regarded as the best. A relative proportion of prediction error (PPE) was developed to get an impression of the size of error with respect to the structure specific force:

$$PPE = \frac{absolute\ acccuracy\ (N)}{mean\ structure\ specific\ (N)} 100 \qquad (\text{eq. } 2)$$

The statistical analyses were performed in R-studio (1.4).

RESULTS AND DISCUSSION

For each of the four force variables, the best BF and PF models were selected according to the PE defined in equation 1 (Table 1; eq. 3-8). The prediction error was below 743 N for peak force and 24176 Ns for impulse, while the proportion of prediction error was 16% or below for all patellar tendon algorithms. The algorithms fitted using distance per stride revealed a prediction error of 934 N for peak force and 35139 Ns for impulse, while the proportion of prediction error was 23% or below. A graphical comparison of the different algorithms is provided in figure 1. From a visual inspection of figure 1, it seems that both the blue prediction line and scatters are closer to the diagonal black line in both algorithms compared to the predicted forces from distance.

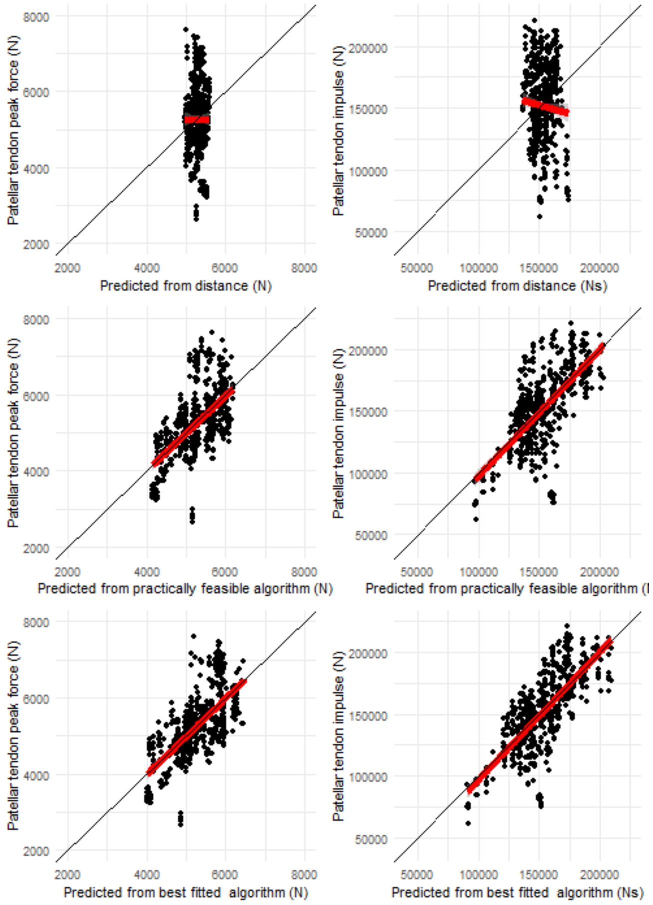


Fig 1: The prediction of peak and impulse forces using the different algorithms. The blue line is the predicted, while the black diagonal line is the perfect fitted line. The black dots are the observed force on the y-axis and predicted forces on the x-axis.

CONCLUSIONS

The results from the present study may be used by researchers examining the etiology underpinning jumper’s knee since they allow them to approximate cumulative load in the patellar tendon. Ultimately, such anatomical structure-specific approximations of load may be used in combination with changes in other types of exposures (running shoes, surface etc.) to estimate the influence the occurrence of Jumper’s knee [1].

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