ANALYSIS OF OPEN AND CLOSED KINETIC CHAIN EXERCISES USING MULTIBODY COMPUTER MODELS FROM CADAVE KNEES


INTRODUCTION Empirically, strengthening of the quadriceps muscles decreases pain in the patellofemoral joint (PFJ). Rehabilitation programs for patients with anterior knee pain have generally focused on redeveloping functional strength of the knee musculature through a combination of closed kinetic chain (CKC) and open kinetic chain (OKC) exercises, although CKC exercises have been more popular [1]. This prevalence is supported by studies that compared the two cases and showed that OKC exercises create significantly higher contact stresses in the PFJ near full extension [2]. To further explore the kinematic basis of the possible advantage of CKC exercises, this study compares three types of exercises using computer simulations to determine their respective effects on the knee joint. Examination of these effects, primarily contact stress in the PFJ, can help in selecting optimal rehabilitation regimens for patients with patellofemoral pain.

METHODS

Effect of different loading conditions on the kinematics of the PFJ were simulated on three-dimensional (3D) multibody models of 3 male and 2 female knee joints. Experimental validation of these models has been previously performed on the corresponding cadaver knees [3]. For all simulations, the active quadriceps was represented by three components: rectus femoris + vastus intermedius, vastus lateralis, and vastus medialis obliquus in the ratio of 3:2:1. The three exercises, squating (CKC), leg extensions (OKC), and constant-moment leg raises (OKC), were simulated by adjusting forces across the knee at each flexion angle to create the appropriate moment about the knee for the given exercise. To simulate squatting, the flexion moments that balance the body weight were based on experimental peak moments of 82.2 Nm for males and 59.4 Nm for females, at 90° of flexion [4]. The required flexion moments for the leg extension simulations were derived from anthropometric studies for tibia and ankle [5]. Finally, to simulate a loaded leg raise exercise, a constant external moment of 10.2 Nm was added to the leg extension analysis. One-way ANOVA with significance level of p=0.05 was performed to compare the results from the three loading conditions.

RESULTS Results were averaged over the five knees for each 10° increment between 10° and 90° of knee flexion. CKC stresses became increasingly higher than the OKC values (which remained relatively constant) throughout the flexion range, for flexion angles above 20° (Fig. 1). The average and peak PFJ contact stresses were greater in the constant moment case than in the pure leg extension case. The variation of peak stress with flexion angle exhibited a similar trend to that of average stress, while the magnitude of the peak stress was generally 50-200% higher than the average stress. A significant difference between quadriceps force and patellar tendon force (PT) force was found above 50°, with only 50% of quadriceps force reaching the PT at 90° flexion (Fig 2). The moment arm of the PT force about the helical axes of the tibiofemoral joint increased in the 0°-40° range and decreased from 40°-90° of flexion (Fig. 3). DISCUSSION CKC and OKC exercises did not produce significantly different stress magnitudes at 10° and 20° of flexion. Though arguably unphysiologically, OKC exercises do not seem to lead to undue stresses at low flexion angles, contrary to previous analyses which used less physiologic load magnitudes [2]. Open chain exercises with moderate loading on the tibia would appear to be a safe alternative for a patient exhibiting a chondral lesion at the proximal aspect of the patella, making exercises in the 90° range contra-indicated. Comparison between quadriceps force and patellar tendon force showed that the extensor mechanism is not a perfect pulley for flexion angles above 50°, probably due to interlocking of patella and femur. This finding is in agreement with experimental results [6]. The mechanical advantage imparted by the patella to the knee flexion mechanism is greatest between 30° and 50°, as indicated by the magnitude of the PT moment arm. The findings of this study suggest that the load configurations employed in the analysis of PFJ mechanics must be carefully selected as they can significantly alter the conclusion regarding the merits of CKC and OKC exercises. One of the benefits of using computer analyses based on multibody models derived from cadaver data is that multiple load configurations can be tested at any flexion angle on the same PFJ model, allowing statistical analyses with repeated measures.

REFERENCES


ACKNOWLEDGEMENTS This study was supported in part by the Steadman-Hawkins Sports Medicine Foundation.