Regulation of the Patellofemoral Contact Area: an Essential Mechanism for Maintaining Physiological Patellofemoral Joint Kinetics?

1Goudakos, I; 1König, C; 1,2Schöttle, PB; 1 Taylor, WR; 1Pöpplau, B; 1Singh, N; 1Duda, GN; +1Heller, MO
+1Julius Wolff Institut and Center for Musculoskeletal Surgery, Charité – Universitätsmedizin Berlin, Germany,
1Department of Sports Medicine, Klinikum rechts der Isar, Technische Universität München, Germany
Senior author markus.heller@charite.de

INTRODUCTION:
Reduced patellofemoral (PF) contact area, elevated pressure and increased patellar tilt are often associated with anterior knee pain. Therefore, quantification of biomechanical parameters that characterize both the kinematics and the kinetics of the joint in an experimental, as well as clinical setting, is of increasing importance. Whilst a number of approaches have been suggested to determine contact area and tilt in human subjects in vivo, the measurement of the PF pressure during weight bearing conditions remains a challenge. Animal studies, however, have highlighted the importance of the interaction between contact area and pressure for the physiological function of the joint under weight bearing conditions [1]. In vitro analyses allow PF pressure measurements, thus offering an alternative approach for developing a better understanding of the interaction between kinematic and kinetic parameters of the joint. However, in most in vitro experiments reported so far, the loading conditions were either oversimplified or considerably lower than those occurring during challenging activities of daily living. The aim of this study was to determine the effect of load magnitude on the interaction of kinematic and kinetic parameters of the PF joint over the complete range of loading from unloaded up to physiological levels during both walking and stair climbing.

METHODS:
In order to apply muscle loads that were calculated based on a validated musculoskeletal model [2], 4 muscle groups: the Mm. rectus fem. together with the vastus intermedius, the vastus med., the vastus lat. and the sartorius together with the semitendinosus of six intact cadaveric knees, were instrumented with extension hulls [3]. In a specially designed set-up, nine load cases (5 for walking and 4 for stair climbing) that simulated critical instances of the gait cycles - in terms of extreme muscle forces and knee flexion angles - were applied to the knees, with knee flexion ranging from 12° to 57°. The set up allowed for individual muscle load control of three quadriceps components from a passive joint state up to physiological load levels (max. total of 3509 N). Optical markers were attached to the femur, patella and tibia for patellar tilt measurements (Vicon, Oxford Metrics, UK), and a pressure sensitive film was inserted into the joint for pressure and contact area measurements (K-Scan #4000, TekScan Inc., South Boston, MA) (Fig. 1). For data analysis, a curve fit was performed on the mean curves of the knees (n=6) (Matlab, Mathworks Inc., Natick, MA).

RESULTS:
Physiological-like muscle loading was successfully applied to the knee in a multi-planar loading manner, simulating both walking and stair climbing; both the force magnitudes and the direction of the loads were considered, together with the flexion angle of the knee. The PF contact area increased inversely with the total muscle load (R² between 0.872 and 0.996) and reached a maximum average of 5.7 ± 0.8 MPa for stair climbing at 39° of knee flexion. The maximum slope for the pressure regression lines was reported for the load cases at 12° of knee flexion and was approximately twice as high as at 39°. The patellar lateral tilt demonstrated a dependency on the total muscle force only in the load cases at 12° of knee flexion. In these load cases, the tilt increased non-linearly (R² ≥ 0.942) and reached a maximum average of 2.4 ± 1.7° for stair climbing.

DISCUSSION:
In this study, it was demonstrated that the magnitude of the muscle loads significantly influenced essential parameters of PF biomechanics, including PF contact area and pressure, as well as patellar tilt. A key finding was that the dependency of contact area and tilt on muscle load is clearly non-linear, a dependency previously described only for the feline PF joint [3]. Hence, the extrapolation of data acquired under non-physiological loading to the in vivo situation should be critically considered. Whilst the PF contact area rose with increasing muscle loads and thus attenuated the pressure increase, our data also suggests that the regulating capacity of this mechanism is exhausted in humans under high loads, i.e. loads greater than approx. 1 BW - conditions often associated with PF pain [4]. Furthermore, the steeper PF pressure increase at lower flexion angles suggests that excessive muscle loads could lead to considerable pressure levels, even when the knee is near full extension. Such high muscle loads potentially occur during demanding activities or uncoordinated movements. In summary, we have demonstrated that the regulation of the contact area is an essential mechanism that modulates the kinetics of the human PF joint. Surgical procedures (realignment/stabilizing procedures), as well as conservative treatment (bracing/taping) of PF pathologies, should therefore aim to restore this key regulating mechanism, especially at knee flexion angles close to full extension.


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Figure 1: CAD visualization of the experimental set-up near extension (left) and in flexion (middle). Cadaveric knee with attached optical markers and pressure sensor (right).

Figure 2: PF contact area and pressure as a function of total muscle load - Mean curves (normal lines), standard deviations (dashed lines) and the curve fits (bold lines) are presented for three different load cases of stair climbing at 12°, 30° and 39° knee flexion.