Pressure on the Tibial Plateau when Standing from a Seated Position

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Abstract. The object of this study was to estimate changes in pressure on the tibial plateau as a person stands up from being seated in a chair. Eight young men and eight young women performed this task while being photographed by a video camera from the left side in such a way that movements of individual segments of the body in the sagittal plane could easily be determined. All subjects used the same chair, which had a seat height of 40 cm. Myoelectric activity was recorded from the left rectus femoris during the task as well. Pressure on the tibial plateau was calculated on the basis of a rigid-body link model and of published data on area of contact between the femur and the tibia at different angles of knee flexion. Pressure estimated in this manner was highest at the onset of the task and decreased in a fairly uniform fashion over angular displacement of the knee into full extension. Because the peak pressure was at the very beginning of the task, adjusting height of the chair to height of the subject became a more critical variable than we had originally anticipated. Also, because we used the same values for area of joint contact for all subjects, we found that adjusting the magnitude of the area of contact to the size the subject was another consideration worthy of further investigation.

Key words: Sit-to-stand, Knee, Joint pressure.

INTRODUCTION

Many patients with osteoarthritis or rheumatic disease of the knee are unable, because of pain, to easily assume a standing position from a seated position. This important activity of daily living has been the subject of much study (for a review, see Usuda, et al.¹). In some studies, forces in the knee joint have been calculated²-⁴. Because the area of bony contact in the knee varies according to the angle of the knee in the sagittal plane⁵, however, the actual load on the knee should be considered in terms of pressure rather than simply joint force. Directly measuring pressure within a knee joint is invasive and difficult, so we examined the actual movement of standing from a seated position in young healthy subjects and estimated pressure on the tibial plateau during such movement based on mechanical modeling and previously available data.

METHODS

Eight men and eight women, acquaintances of the investigators, freely volunteered to be subjects in this study. Their characteristics are summarized briefly in Table 1. For the observations the men wore only shorts, the women shorts and an aerobics bra. A reflective light green sphere was affixed to the top of the head, and reflective light green tape was placed over the left tragus of the ear, over the left shoulder at the level of the top of the sternum, over the left hip 2 cm above and 2 cm...
in front of the greater trochanter, over the left knee at the joint line one third of the way from the back, and over the left outer malleolus at the ankle.

The subject sat on an ordinary folding chair with the seat 40 cm above the floor, with the buttocks placed deeply back in the seat, in a natural and comfortable sitting position. He or she folded the arms to prevent them from covering a lateral view of the marker over the left hip during the standing movement.

A video camera (Sony DCR-VX1000) was used to record the standing movement. The camera, oriented to view the left side of the subject, was placed six meters away from the subject. Prior to recording the standing activity, a calibration frame was placed where the subject was to be seated and the frame recorded. The subject then sat in the chair and stood up from it three times, the activity being recorded by the camera each time.

A surface electromyogram was recorded from the left rectus femoris, with the electrodes placed 5 cm proximal to the patella. The amplified signal was digitized at 2,000 samples per second and stored in a computer. This myoelectric activity was synchronized to the video recording by means of a visual-analog signal generator, whose pulses could be counted in the video recording as images and sampled simultaneously with the electromyogram as voltages.

To estimate the force exerted by the knee extensors ($F_2$) and the reaction force at the knee ($F_3$), we characterized the body in two dimensions as a series of four rigid links: the head, the trunk and arms, the femora, and the lower legs and feet (Fig. 1). For simplicity, we calculated the estimates on the basis of static equilibrium. Location of center of gravity and mass of each modeled segment were chosen on the basis of data provided by Yokoi.

The moment arm ($L_2$) by which the knee extensors act on the knee is known to change slightly in the course of knee extension, but estimating exact values is difficult and we chose to use 50 mm as a constant moment arm for all subjects.

To calculate pressure on the tibial plateau, data available from Maquet et al. were used to estimate the area of contact between the femur and the tibia for a given angle of knee extension. Pressure was calculated as the component of reaction force at the knee joint directed along the axis of the tibia divided by the area of contact between the femur and the tibia. We assumed bilateral symmetry in the subject and in the manner by which the subject stood from a seated position, and analyzed selected frames of video data from the time at which the subject’s buttocks left the surface of the chair until the knees achieved full extension.

Although this study was primarily descriptive in nature, statistically significant differences were tested between men and women with use of the t-test.

### RESULTS

Pressure on the tibial plateau was higher just as the subject began to stand from a seated position than at any subsequent moment (Fig. 2). As the knee extended, the pressure on the tibial plateau decreased in a quasi-linear fashion. This pattern
was found in all 16 subjects. Peak pressure on the tibial plateau was $7.29 \pm 1.91$ mPa (mean ± standard deviation), about five times larger than the pressure calculated for full standing.

Absolute pressure on the tibial plateau was greater in men than in women ($p<0.001$, Fig. 3). When normalized to body weight, pressure on the tibial plateau still differed between men and women ($p<0.05$, Fig. 4). This difference no longer reached statistical significance when pressure on the tibial plateau was normalized to the product of weight and height (Fig. 5). The effect of height on pressure normalized to body weight can be seen in Figure 6, showing that tall people were subjected to greater pressure on the tibial plateau per amount of body weight than were short people, at least under the conditions of this study.

The magnitude of muscle force calculated from the model showed a linear decrease over the course of knee extension. Myoelectric activity in the rectus femoris, on the other hand, remained constant as knee extension progressed from 60 to 40 degrees, otherwise grossly corresponding to the calculated force (Fig. 7).
DISCUSSION

In the act of standing from a seated position, pressure on the tibial plateau was found to be greatest at the very beginning of the task, with the pressure progressively decreasing as the activity continued. As the knee progresses through extension, the area of contact between the femoral and tibial condyles increases from 11.60 cm$^2$ to 20.13 cm$^2$, with the greatest increase seen as the knee extends from 50 degrees to 20 degrees$^5$). We thus anticipated that pressure on the tibial plateau might likewise undergo a non-uniform change during the activity, but the actual pressures of our subjects decreased rather uniformly. This can be explained by the fact that whereas the contact area increased 1.6 times in the course of standing up, the initial force at the knee was 3.2 times the final force in full standing.

Pressure on the tibial plateau was five times greater at the very beginning of standing from a seated position than in full standing. This large pressure may be attributable primarily to the relatively large horizontal distance between the center of gravity of the upper body and the knee, giving rise to a large flexing moment of force about the knee due to gravity. In our model, the moment due to gravity had to be counteracted by an equally strong extending moment of force produced by the knee extensors (Fig. 1). From the equilibrium condition $F_1 \times L_1 = F_2 \times L_2$ and the fact that the force $F_1$ due to an unchanging mass and moment arm $L_2$ at the knee were fixed quantities, the force $F_2$ exerted by the knee extensors was set to depend entirely on the moment arm $L_1$ of the upper body, which was of course greatest at the beginning of the activity. The strong force $F_2$ of the knee extensors in turn gave rise to a strong reaction $F_3$ in the knee joint, directed mainly in the direction of the long axis of the tibia. This strong reaction force, along with the fact that the area of contact between femoral and tibial plateaus was relatively small in the flexed knee at the beginning of the activity, gave rise to high pressure on the tibial plateau.

A corollary of this idea is that the very high pressure on the tibial plateau at the beginning of standing from a seated position can be decreased insofar as the subject initially leans far forward before lifting the buttocks from the chair, thereby decreasing the length $L_1$ of the moment arm of the upper body about the knee.

Because women outnumber men in having osteoarthritis in the knee$^8$), we anticipated finding that pressure on the tibial plateau would be greater in women than in men. We instead obtained opposite results. Normalizing pressure to body weight did not change the nature of the results, but additionally taking height into consideration appeared to satisfactorily account for the greater plateau pressure in the men. Two features of our study are
probably responsible for this relationship, overriding any clear suggestion of intrinsic differences between men and women.

First, all subjects were assigned the same values for area of contact between the femoral and tibial condyles\(^5\), regardless of sex or body dimensions. A subject with a long femur and great body weight would thus have larger values for moment arm and force against a given area of contact pressure than would a smaller subject. Secondly, all subjects began the standing activity from the same chair, which was 40 cm high. A subject with a relatively short tibia might not be starting the standing activity with a full right angle at the knee and so would begin the activity with a “head start” and thus a slightly smaller moment arm than if sitting in a lower chair. These factors would favor larger values of pressure to be found in tall heavy subjects (generally the men) than in short light subjects (generally the women).

Findings by Hashimoto corroborate the nature of our results\(^9\). He looked at floor reaction forces during standing from a seated position with the seat height set to 30 cm, the height of the lower leg, and 1.2 times the height of the lower leg. Of the three chair heights, standing was easiest from the chair whose height was 1.2 times the height of the lower leg.

Clearly one way to decrease the load involved in standing from a seated position is to elevate the height of the chair. If the chair is too high, however, the feet might not comfortably reach the floor and sitting would then become less stable. Although determination of an optimal chair height requires further study, the role of chair height on the amount of pressure borne on the tibial plateau is obvious enough to have clinical implications.

**SUMMARY**

Pressure on the tibial plateau during standing from a seated position was estimated from video recordings with the aid of a rigid-body link model. In spite of a known increase in weight-bearing area in the knee as it extends during the activity, such a change had little effect on the manner in which pressure on the tibial plateau decreased. Pressure was highest when the subject was just beginning to stand, mainly because the moment arm of the upper body acting about the knee was longest then.

Height of the chair appears to play a great role in determining the maximum load on the knee. Further study is required to ascertain the nature of all body dimensions to accurately estimate pressure in the knee.

**REFERENCES**