ABSTRACT

Purpose. To assess normal patellar tracking during walking using the 9-camera infrared system.

Methods. Four men and 6 women aged 25 to 33 (mean, 29) years each performed 16 walking trials on one occasion. They had prominent patellae with minimal soft tissues (minimising skin artefacts), and their knees and lower limbs were normal and symmetrical. 12 retro-reflective markers (2.5 cm in diameter) were taped to anatomic landmarks of the lower body. Two additional markers (1.4 cm in diameter) were first placed on the medial and lateral points and then proximal and distal points of the patella. Patellar motion relative to the centre of the knee joint was defined as angles between the centre of the knee joint and the 2 sets of patellar markers (medial-lateral and proximal-distal). The mean, maximum, and minimum values of these angles in a standing position were recorded, as was patellar tracking during walking. The X, Y, and Z coordinates for each marker were smoothed out throughout the capturing time. A single gait cycle per trial was chosen for analysis.

Results. During walking, the centre of the knee joint and the patella did not move in unison, and the extent of separation was subject dependent. In 70% of the participants, the maximum angle between the centre of the knee joint and each set of markers occurred in the swing phase (0–43%) of the gait cycle. When analysing both sets of markers together, the percentage of participants became 60%. The extent of knee flexion was subject dependent. There was more medial-lateral motion (shift) of the patella than proximal-distal (tilt) motion during the gait cycle. These indicated that the maximum amount of patellar shift and tilt occurred in the swing and early stance phases of the gait cycle and that abnormal patellar motion can be detected if excessive shift or tilt occurs outside of these phases.

Conclusion. Patella mal-tracking could be attributed to the position of the lower body segments rather than the absorption or generation of forces.

Key words: biomechanics; gait; patella; walking

Patellar tracking during the gait cycle

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INTRODUCTION

Patellar motion relative to the trochlear groove of the femur during knee flexion and extension is known as patellar tracking. Abnormal patellar tracking is associated with most patellofemoral disorders and is the most common reason for revision surgery following total knee replacement. The exact cause of and optimal treatment for patellofemoral pain syndrome (PFPS) is debatable. There is no universal agreement on normal patellar tracking; comparison between studies is difficult because of different methodologies used. PFPS can be diagnosed and treated more effectively if normal patellar tracking is known. We therefore assessed the normal patellar tracking during barefoot walking.

MATERIALS AND METHODS

Between September 2005 and December 2005, a pilot study was undertaken to assess the reliability of the 9-camera infrared system for measuring lower body and patella kinematics during barefoot walking. One man aged 31 years (86 kg in weight and 1.8 m in height) performed 10 walking trials on each of 8 separate occasions. The coefficient of variation for the patellar motion relative to the centre of the knee joint within and between each session was <1%.

Between January 2006 and August 2006, 4 men and 6 women aged 25 to 33 (mean, 29) years each performed 16 barefoot walking trials on one occasion. Their mean weight and height were 64 (standard deviation [SD], 14) kg and 1.73 (SD, 0.11) m, respectively. They had prominent patellae with minimal soft tissues (minimising skin artefacts), and their knees and lower limbs were normal and symmetrical.

RESULTS

During walking, the centre of the knee joint and the patella did not move in unison, and the extent of separation was subject dependent. The time of occurrence of the maximum and minimum angles relative to the percentage of the gait cycle and the knee flexion angle at those times are shown in the Table. In 70% of the participants, the maximum angle between the centre of the knee joint and each set of markers occurred in the swing phase (0–43%) of the gait cycle. When analysing both sets of markers together, the percentage of participants became 60%. The extent of knee flexion was subject dependent. During the gait cycle, there was more medial-lateral motion (shift) of the patella than proximal-distal (tilt) motion. These

![Figure](image_url)

The angles (θ) between the centre of the knee joint and (a) the medial-lateral or (b) the proximal-distal patellar markers.
indicated that the maximum amount of patellar shift and tilt occurred in the swing and early stance phases of the gait cycle, and that abnormal patellar motion can be detected if excessive shift or tilt occurs outside of these phases.

**DISCUSSION**

Patellar tracking during active or passive knee flexion has been studied. The problems with cadaveric studies are associated with the difficulty in simulating normal biomechanical forces. In vivo studies were limited to small sample sizes owing to the invasive procedure involved.

Pain secondary to mal-tracking of the patella affects knee flexion and extension at different times during the gait cycle. During normal walking, the beginning of the swing phase is marked by flexion of the knee and the other joints of the lower body to draw the toe up and away from the ground as the body moves forward. The most common abnormality of patella tracking consists of excessive lateral displacement of the patella in terminal knee extension. Medial-lateral patellar motion (shift) is important in clinical practice.

Several anatomic abnormalities of the lower limb are related to disorders of the patellofemoral joint. Distal patellar mal-alignment resulting from an increased Q angle may be found in straight, knocked, and bowed knees. Similarly, patella alta (high-riding patella) or patella baja (low-lying patella) can cause patellofemoral pain due to excessive compressive forces across the articular surface. These biomechanical problems highlight the importance of proximal-distal translation (tilt) of patella during knee flexion. In our study, 3-dimensional patellar tracking during walking was identified in vivo non-invasively. Further research is required to separate patellar tracking into 2 planes for assessing tilt and shift.

In a normal gait, the knee joint undergoes 2 phases of flexion. The first flexion wave begins from a position of nearly full extension at initial contact and reaches a maximum of 15º during the shock absorption associated with loading. The second flexion wave peaks during the initial swing phase to provide foot clearance. Peak flexion of the knee occurs during the swing phase of the gait cycle, and patellar motion follows the centre of the knee joint. In our study, patellar mal-tracking was more likely to be associated with the position of the lower limbs during the swing phase rather than the shock absorption phase. This could be due to poor motor control of the limbs, as their acceleration becomes greater during the swing phase compared to the stance phase of walking.

Individuals with PFPS due to mal-tracking of the patella often reported difficulty in ambulation. Gait analysis of patients with PFPS has shown a significant reduction in knee flexion angle; such patients may develop a compensatory gait to avoid pain. In our study, at the times of maximum and minimum angles of the patella markers relative to the centre of the knee joint, the knee flexion was >20º in 60 to 70% of participants and <15º in 80% of participant (<24º in all), respectively. This suggests that when the knee is more extended, the patella

| Participant | Angle between the centre of the knee joint and the medial-lateral patellar markers | Angle between the centre of the knee joint and the proximal-distal patellar markers |
|------------|-------------------------------------------------|-------------------------------------------------|
|            | Mean (range) | During minimum angle | Mean (range) | During maximum angle |
| Gait cycle (%) | Knee flexion angle | Gait cycle (%) | Knee flexion angle | Gait cycle (%) | Knee flexion angle |
| 1 | 117º (140º–112º) | 46 | 11º | 19 | 48º | 149º (152º–146º) | 49 | 18º | 25 | 33º |
| 2 | 138º (151º–123º) | 36 | 6º | 6 | 36º | 160º (161º–148º) | 41 | 12º | 11 | 36º |
| 3 | 133º (151º–111º) | 40 | 4º | 15 | 34º | 152º (158º–140º) | 39 | 4º | 8 | 34º |
| 4 | 108º (141º–95º) | 84 | 10º | 20 | 44º | 144º (155º–132º) | 86 | 14º | 25 | 36º |
| 5 | 142º (144º–123º) | 36 | -3º | 15 | 56º | 163º (164º–155º) | 46 | 15º | 67 | 6º |
| 6 | 117º (136º–111º) | 88 | 7º | 13 | 39º | 151º (154º–146º) | 53 | 8º | 27 | 21º |
| 7 | 149º (156º–137º) | 50 | 24º | 43 | 8º | 152º (160º–147º) | 47 | 21º | 42 | 8º |
| 8 | 129º (143º–123º) | 38 | 10º | 43 | 13º | 144º (146º–138º) | 38 | 17º | 43 | 12º |
| 9 | 128º (151º–117º) | 42 | 0º | 51 | 7º | 151º (159º–143º) | 41 | 9º | 44 | 9º |
| 10 | 133º (147º–129º) | 41 | 0º | 44 | 30º | 149º (156º–150º) | 75 | 1º | 31 | 21º |

* Swing and stance phases indicate 0 to 43% and 44 to 100% of gait cycle, respectively.
and centre of the knee joint are in a similar position to that prevailing in the standing position. This variability may be attributed to the difference in gait speed. A peak knee flexion during walking depends on speed. Similarly, increasing walking speed is associated with increased step length and range of movement. As the patellar motion is related to the knee flexion, it is likely to be affected by the walking speed. In addition, there are gender differences in human gait; females walk with lesser step width and more pelvic movement. We should have considered both speed and gender when analysing patella mal-tracking during walking.

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REFERENCES

1. Laprade J, Lee R. Real-time measurement of patellofemoral kinematics in asymptomatic subjects. Knee 2005;12:63–72.
2. Harwin SF. Patellofemoral complications in symmetrical total knee arthroplasty. J Arthroplasty 1998;13:753–62.
3. Grelsamer RP, Weinstein CH. Applied biomechanics of the patella. Clin Orthop Relat Res 2001;389:9–14.
4. Katchburian MV, Bull AM, Shih YF, Heatley FW, Amis AA. Measurement of patellar tracking: assessment and analysis of literature. Clin Orthop Relat Res 2003;412:241–59.
5. Heegaard J, Leyvraz PF, Curnier A, Rakotomanana L, Huiskes R. The biomechanics of the human patella during passive knee flexion. J Biomech 1995;28:1265–79.
6. Davis RB, Ounpuu S, Tyburski D, Gage JR. A gait analysis data collection and reduction technique. Hum Mov Sci 1991;10:575–87.
7. van Kampen A, Huiskes R. The three-dimensional tracking pattern of the human patella. J Orthop Res 1990;8:372–82.
8. Koh TJ, Grabiner MD, De Swart RJ. In vivo tracking of the human patella. J Biomech 1992;25:637–43.
9. Piazza SJ, Delp SL. The influence of muscles on knee flexion during the swing phase of gait. J Biomech 1996;29:723–33.
10. Garth WP. Clinical biomechanics of the patellofemoral joint. Oper Tech Sports Med 2001;9:122–8.
11. Ounpuu S, Gage JR, Davis RB. Three-dimensional lower extremity joint kinetics in normal pediatric gait. J Pediatr Orthop 1991;11:341–9.
12. Nadeau S, Gravel D, Hebert L, Arsenault AB, Lepage Y. Gait study of patients with patellofemoral pain syndrome. Gait Posture 1997;5:21–7.
13. Winter DA. The biomechanics and motor control of human gait: normal elderly and pathological. Waterloo, Ontario, Canada: University of Waterloo Press; 1991.
14. Oberg T, Karsznia A, Oberg K. Basic gait parameters: reference data for normal subjects, 10-79 years of age. J Rehabil Res Dev 1993;30:210–23.
15. Oberg T, Karsznia A, Oberg K. Joint angle parameters in gait: reference data for normal subjects, 10-79 years of age. J Rehabil Res Dev 1994;31:199–213.