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Patellar instability and quadriceps avoidance affect walking knee moments

Damian A. Clark [a], Danielle L. Simpson [a], Jonathan Eldridge [b], G. Robert Colborne [a,c,*]

[a] Centre for Comparative and Clinical Anatomy, University of Bristol, Southwell Street, Bristol BS2 8EJ, United Kingdom
[b] Bristol Royal Infirmary, Upper Maudlin Street, Bristol BS2 8HW, United Kingdom
[c] Institute of Veterinary, Animal and Biomedical Sciences, Massey University, Private Bag 11 222, Palmerston North 4442, New Zealand

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ABSTRACT

Purpose: To classify patients with patellofemoral (PF) instability on the basis of their mechanical gait characteristics, and to relate gait deficits to patellofemoral congruence.
Methods: Thirteen patients awaiting patellar stabilisation surgery were recruited for gait analysis and magnetic resonance imaging, MRI assessment of PF congruence. Patients were grouped into two subgroups (P1, P2) based on knee joint moment during stance, and their total support moments (TSMs) during stance were compared against eight healthy Control subjects. PF congruence was compared between groups from MRI data captured at 0, 20 and 40° of passive knee flexion and during dynamic extension.
Results: Five patients were classified into group P1 because they demonstrated a knee extensor moment during early stance, and eight patients into group P2 because they did not. The TSM of the more affected limb in group P1 was not significantly different from Control values in early stance but the difference was significant ($P < .05$) in late stance. In group P2, both the less and more affected limbs were significantly different from Control TSM values in early stance, but only the more affected limb in late stance. Patellofemoral contact areas as measured by MRI were greatest for the Control patients, and least for patient group P2 especially during the active extension trials.
Conclusions: Patients with patellofemoral pain and instability walked with a slightly flexed knee, avoiding extension. The MRI measurements of joint contact agreed with the patient groupings according to gait mechanics. Cartilage contact across the PF joint can be an objective measure of instability.

1. Introduction

Patellofemoral instability is a painful and disabling problem for young adults, and it is more common among women. It varies in severity from slight patellar maltracking in the trochlear groove to complete dislocation. Disorders of the patellofemoral joint, PFJ represent 20 to 40% of knee problems and are common complaints following sporting injuries [1]. This joint is particularly susceptible to instability due to the incongruence of its articular surfaces during full extension. The knee relies on both dynamic and static factors for stability of the patellofemoral articulation, and the articulating surface of the patella changes depending on the degree of knee flexion and the patella's position on the distal femur [2,3]. The most common anatomical anomalies to contribute to instability include patella alta, trochlear dysplasia and generalised hypermobility. Malalignment of the knee joint can also predispose the PFJ to instability; anatomical valgus results in a lateral distracting force on the patella caused by the malalignment of the quadriceps tensile force on the patellar ligament [3]. Damage to the medial restraining structures caused by a traumatic dislocation in a previously normal joint can also lead to instability.

Inverse dynamics analysis of gait combines kinematic, morphometric and force data in a linked-segment model and is used to evaluate limb joint angular excursions, net joint moments and net joint powers. It has been used to examine the effect of patellofemoral pain syndrome, [4–6], knee osteoarthritis [7], total knee arthroplasty [8] and surgical changes to the knee joint's lateral retinaculum [9,10] but to date the significance of PFI on gait is unknown.

Gait studies on patients with PFPS have identified deficits in gait patterns [4,5]. Modifications in temporospatial parameters of gait have been observed, such as decreased knee joint angular displacement, swing phase angular velocity and cadence [4,6] leading to the conclusion that the patients avoided pain at the PFJ during walking by reducing knee flexion, which then reduced the articular forces at the PFJ. Joint moments in particular can be affected by weakness [11], pain [12,13] and instability [14]. Winter [11] found that there was a knee net flexor moment in late stance in patients after total knee replacement

Abbreviations: ACL, anterior cruciate ligament; ANOVA, analysis of variance; GRF, ground reaction force; MRI, magnetic resonance imaging; MTP, metatarsophalangeal; PFI, patellofemoral instability; PFJ, patellofemoral joint; PFPS, patellofemoral pain syndrome; TSM, total support moment.

* Corresponding author at: Institute of Veterinary, Animal and Biomedical Sciences, Massey University, Private Bag 11 222, Palmerston North 4442, New Zealand. Tel.: +64 6 356 9099x85185.
E-mail address: G.R.Colborne@massey.ac.nz (G.R. Colborne).

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due to the underuse of their knee extensors. On the other hand, Chesworth et al. [15] found that there were no modifications to the gait pattern in PFPS patients following reported improvement in their other symptoms. The PFJ reaction forces cannot be easily measured non-invasively, but the overall sagittal knee moment can indicate the pattern of flexor and extensor forces transmitted across the joint.

Over 50 patellofemoral indices have been described using both plane x-ray and other axial imaging techniques [16,17]. The majority of these are focused on identification of the causes of PFI, particularly in relation to patella alta and trochlear dysplasia. Patellofemoral indices can be clinically useful, but do not measure contact area, pressure, or any other mechanical property of the joint. Heino Brechter et al. have described a technique [18] for direct measurement of the contact area between the patella and the trochlea from MRI which permits assessment of congruence between the articulating femoral and patellar surfaces. Objective measurement of instability requires the knee to be put in a variety of conditions where it may become unstable. As the knee flexes, the patella is initially congruent against the femoral trochlea in its inferior portion and then in fuller flexion is congruent only in its superior portion [2].

There are significant gaps in the understanding of gait deficits in patients with PFI. The purpose of this study was to compare pre-operative patients with patellofemoral instability against control subjects using inverse dynamics analysis of gait. The aim was to describe gait deficits that are present in patients with PFI, and to relate those gait deficits to patellofemoral contact area as measured by MRI. It was hypothesized that patients were likely to modify their gait pattern to reduce loading through the patellofemoral joint. A quadriceps avoidance strategy, to reduce the articular forces at the patellofemoral joint during walking, would be identified by a reduction in knee extensor moment in early stance during weight acceptance, and again in late stance when the quadriceps would normally control the collapse of the knee into the swing phase. Reduction of total limb support moment would indicate a reduction in weight-bearing forces and smaller individual joint moments as the subject avoided loading that limb.

2. Patients and methods

2.1. Patients

Thirteen patients with PFI (six male, seven female, mean (standard deviation, SD) age 25.9 (8.6) years) were recruited from the clinical caseload awaiting patella stabilisation surgery at Southmead Hospital, North Bristol NHS Trust. Clinical diagnosis of PFI included a range of symptoms depending on severity. Primary PFI occurs due to anatomic malalignment, trauma and ligamentous laxity. Of the 13 patients, eight reported their right limb to be more affected, or had right unilateral symptoms, and five reported their left limb to be more affected, or unilaterally affected. Pre-operative function was assessed with the Tegner Lysholm questionnaire. Eight additional Control subjects (five male, three female, mean (SD) age 24.8 (4.5) years) showing no PFI or other gait deficits were recruited for comparison. All subjects gave their informed consent prior to participation in the study and ethical approval was received from the local quote REC number ethical review board.

2.2. Gait analysis

Subjects wore tight leggings or shorts for gait analysis, and walked in their socks without shoes. Spherical retroreflective markers (18 mm diameter) were affixed to the skin or leggings overlying centres of rotation of the fifth metatarsophalangeal (MTP), ankle, knee and hip joints on both left and right lower limbs, to identify limb segmental endpoints. The MTP joint marker was placed on the distal extremity of the fifth metatarsal bone, the ankle marker on the lateral malleolus, the knee marker on the lateral epicondyle of the femur at the proximal attachment of the lateral collateral ligament, and the hip marker on the greater trochanter. An additional marker was placed on the iliac crest to identify the pelvis as a segment for calculation of the hip joint angle. Marker placement was based on palpation of the underlying bony landmarks and visual confirmation of placement symmetry between sides.

Prior to data collection, subjects were instructed to undertake a series of practice walks at their own, self-selected natural pace along a 10 m walkway equipped with a Kistler force platform[1] embedded flush in the floor and a 4-camera Qualisys kinematic system[2] set-up in a semicircle and focused on the area around the force platform. The force platform location was calibrated in the three-dimensional kinematic volume of space, and recorded ground reaction forces, GRFs in the vertical (Fz), antero-posterior (Fy) and medio-lateral (Fx) directions in synchrony with the 3D kinematic data. The kinematic X, Y and Z calibration axes were aligned with the force platform X, Y and Z axes. Kinematic and force data were collected at 200 Hz for three seconds per trial. The subjects walked in both directions along the walkway, and six trials of kinematic and force platform data from each limb were collected for each subject. Trials were only accepted when the limb closest to the cameras struck the force platform near the centre during a normal stride. After data collection and before removal of the markers, the subjects were weighed and distances between markers on the limb were recorded as a measure of segment lengths. Segmental centre of mass location was identified as a percentage distance from the proximal joint marker and limb segment masses were calculated as a percentage of total body mass [19].

2.3. Gait data analysis

Qualisys Track Manager[2] was used to identify and track marker motions from the raw kinematic data and these data were combined with each subject's limb morphometric data and the force data in a custom program[3] to calculate ankle, knee and hip net joint moments in the sagittal (YZ) plane using inverse dynamics [20]. The resultant sagittal plane GRF vector was calculated from the Fy and Fz forces and the appearance and disappearance of this force vector during data processing identified the beginning and end of the stance phase.

Net joint moments were calculated to be negative on the posterior or plantar side of the limb and were normalised to each subject's body mass. The six normalised trials per limb per subject were averaged within-subject, and then further ensemble-averaged across subjects. Two subgroups were evident in the overall group of clinical patients according to the profiles and amplitudes of the normalised knee moment curves: one with similar left–right knee moment profiles and at least a small knee extensor moment during the weight acceptance period in early stance (group P1), and one with no extensor moment during weight acceptance in early stance (group P2). The hip, knee and ankle moments from both the more affected and less affected sides were then averaged per patient group. Stance phase duration was normalised by converting the raw number of frames of data per stance phase to 101 data points. TSM was calculated as the sum of all the individual net joint moments after reversing the sign of the moment at the knee so it was negative on the anterior side of the knee joint before including it in the sum with the other joints. In this way, all the moments contributing to anatomical extension of the joints were summed as the TSM. For each patient, right and left TSMs were plotted and used to identify which limb was more and less affected. TSM curves were then compiled for the more affected and less affected limb in each of these two patient subgroups, for comparison against the control curves and against each other.

[1] Kistler Instrumente AG, Eulachstrasse 22, PO Box 8408, Winterthur, Switzerland.
[2] Qualisys AB, Packhusgatan 6, 411 13 Gothenburg, Sweden.
[3] Inverse Dynamics Analysis. Centre for Comparative and Clinical Anatomy, University of Bristol, Bristol, UK.