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Quantitative analysis of dynamic patellar tracking in patients with lateral patellar instability using a simple video system

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ABSTRACT

Background: As patellar dislocation occurs during activity, it is more important to assess the behavior of the patellofemoral joint under dynamic conditions. The aim of this study was to compare patellar tracking between knees with and without patellar dislocation in patients with an unstable patella and healthy controls using a simple video technique.
Methods: Twenty-three knees with patellar dislocation (dislocated group), 23 contralateral knees without dislocation (non-dislocated group), and 23 healthy knees (control group) were examined. Those with skin markers on anatomical landmarks were made to extend their knees actively, and skin markers were attached to the examiner's fingertips and the patella was followed by pinching. The knee during active knee extension was recorded with digital video cameras. The patella was tracked on imaging software, and the mediolateral patellar position (% patellar position: %PP) was calculated in reference to the knee width consecutively.
Results: %PP was significantly different between the dislocated and control groups, from 30° (mean $\pm$ SD: 58.9 $\pm$ 6.2%, 54.6 $\pm$ 4.7%) to 5° (64.2 $\pm$ 5.2%, 55.2 $\pm$ 5.2%). It was also significantly different between the non-dislocated and control groups, from 25° (58.9 $\pm$ 7.1%, 54.5 $\pm$ 4.6%) to 5° (63.8 $\pm$ 6.5%, 55.2 $\pm$ 5.2%). No significant difference in %PP was found between the dislocated and non-dislocated groups.
Conclusion: With the new video system, patellar tracking during active knee extension was successfully quantified. The tracking patterns were the same in knees with and without patellar dislocation, and the tracking in patients significantly differed from that in the controls at lower knee flexion angles.
Clinical relevance: The development of a quantitative examination technique for dynamic patellar tracking, which is easy to use and repeatedly applicable in a clinical situation, could help to follow-up the time-dependent changes and analyze the treatment effect on an unstable patella.

1. Introduction

Current evidence suggests that nonoperative treatment fails in more than 40% of cases of primary patellar dislocation resulting in redislocation [1,2], and 55% of patients with primary dislocation cannot return to sports without surgery [3]. However, no standard treatment for acute and recurrent patellar dislocation has been developed, because of the complex injury mechanism and individual variations in the associated predisposing factors such as general joint laxity, patella alta, abnormal Q angle, femoral trochlear dysplasia, laterally displaced tibial tuberosity, insufficient medial patellofemoral ligament (MPFL), and imbalance in the medial and lateral extensor muscles [4–7]. In addition, combined patellofemoral cartilage lesions [6,8,9] and soft tissue injury caused by repetitive dislocations alter the patellofemoral joint congruency, further complicating the treatment strategy.

Most knees with an unstable patella typically show lateral subluxation or displacement of the patella during early knee flexion. The detection of this change in physical tests and imaging examinations is crucial to diagnosing an unstable patella. The active patellar subluxation test (APS test) [10] has been used in the clinical setting to evaluate dynamic patellar tracking, and the lateral shift and tilt of the patella during active knee extension are considered positive findings for an unstable patella. Although this tool is simple and noninvasive, with no need for special instruments or facilities, the interpretation of the findings is highly dependent on the examiner and the results are not shown quantitatively. By contrast, the patellar shift and tilt are clinically measured on radiographs and computed tomography (CT) with high accuracy. However, the radiation exposure is harmful, and the measurements are acquired only under static conditions at limited knee flexion angles. However, various methods to evaluate dynamic patellar tracking quantitatively have been proposed in previous studies, such as the use of custom-made devices for cadaveric specimens [11–13], dynamic CT [14], open magnetic resonance imaging (MRI) [15–19], ultrasound transducers [20], and optoelectronic motion capture [21]. However, these systems require special facilities and equipment, and are expensive and time consuming. A quantitative examination technique for dynamic patellar tracking that can be easily and repeatedly used in

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the clinical setting must be developed to monitor time-dependent changes and analyze the effect of treatment on the unstable patella.

To quantitatively analyze dynamic patellar tracking, we recently developed a new method using a digital video camera system that measures the mediolateral patellar position in reference to the knee width during active knee extension. The aims of this study were to investigate the patellar tracking pattern of both knees with patellar dislocation and contralateral knees without patellar dislocation in patients with an unstable patella, and to compare these patterns with those in healthy control subjects. We hypothesized that (1) the patellar tracking pattern would differ between patients and controls, and (2) the pattern would differ between the knee with and without patellar dislocation in patients due to a combination of soft tissue/cartilage injuries and patellar dislocation.

2. Materials and methods

2.1. Patients and control subjects

Twenty-three patients (six males and 17 females, 21.1 ± 9.4 years old) with an unstable patella, who were treated in our institute from July 2011 to January 2015, were recruited to this study. All patients presented with unilateral recurrent patellar dislocation, which was diagnosed by a combination of history of dislocation and physical examination, radiographic, CT, and MRI findings.

MRI was performed from the 1st to 20th day after the patellar dislocation. The symptomatic knees in all patients showed a bone bruise in the lateral femoral condyle and the medial patellar facet indicating recent patellar dislocation. This appeared as a bone marrow lesion with high signal intensity in a fat-suppression sequence. The contralateral knee had no history of patellar dislocation and was asymptomatic without any complaints of pain, discomfort, or apprehension. The mean time period between the latest patellar dislocation and the data acquisition was 3.5 ± 2.8 months (range of 1 week to 9 months), and the mean number of dislocations was 3.0 ± 1.9 (range of 2 to 10). The patients who were unable to perform active full extension of the knee before surgery because of pain or swelling or those with a history of any knee surgery were excluded from this study. Both the knee with patellar dislocation (dislocated group) and the contralateral knee without patellar dislocation (non-dislocated group) were investigated. None of the patients in this series were found to have a hypermobile patella, defined as an abnormal medial and lateral laxity in the patellar glide test [22].

For the comparative study between patients with an unstable patella and healthy controls, 23 healthy age- and sex-matched volunteers (six males and 17 females, 20.9 ± 6.8 years old; control group) with no current complaints or symptoms of the knee joint and no history of patellofemoral joint problems or knee injuries were included. A unilateral knee in each control subject was randomly selected for the investigation. The study was approved by the institutional review boards of our university hospital, and written informed consent was obtained from all patients and control subjects or their guardians before their participation.

2.2. Evaluation of anatomical parameters related to an unstable patella in patients

The predisposing anatomical factors for an unstable patella were determined using plain radiographs and CT images of bilateral knees of all patients. The patellar height was assessed on lateral radiographs by measuring the Insall–Salvati ratio [23] and Caton–Deschamps index [24]. In Merchant's view, the sulcus angle and congruence angle were measured to detect trochlear dysplasia and abnormal congruence [25]. To assess the lateral displacement of the tibial tuberosity and lateral patellar inclination, the tibial tuberosity–trochlear groove distance (TT–TG) [2,4] and patellar tilt [26] were measured on axial CT images.

2.3. Quantitative analysis of patellar tracking in patients with unstable patella and controls

A measurement technique using digital video cameras was developed to evaluate the mediolateral position of the patella in reference to knee width. Two large reflective-surface markers (of diameter 25 mm) were placed on the most proximal prominence of the medial and lateral femoral epicondyles of the tested knee using an elastic band to measure the knee width (knee markers). The femoral epicondyles are generally easy to palpate and determine the knee width more accurately. To record the changing position of the subject's patella during knee extension, the examiner pinched the medial and lateral edges of the patella with the tips of the thumb and index fingers, on which small markers (diameter 14 mm) were attached (patellar markers) (Figure 1). Additional large markers were placed on the greater trochanter of the femur (GT), the anteroposterior center of the lateral knee joint space (LJS), and the lateral malleolus (LM) (angle markers) to measure the knee flexion angle (Figure 2). For the APS test, the subject was seated on a table and made to extend the knee actively from the hanging-free position to full extension, and the examiner followed the patella by pinching with the thumb and index fingers. To keep the patellar marker in place in reference to the patella, the tips of the thumb and index fingers were fixed on the medial and lateral edges of the patella throughout each trial of the APS test. The frontal and lateral views of the knee joint were simultaneously recorded with two digital video cameras (HDR-HC3, Sony, Japan) at 30 Hz during the APS test.

The data scanned from the digital video cameras were transferred to a personal computer. Using imaging software (Dartfish software TeamPro 5.5, DARTFISH), both frontal and lateral images were synchronized, and the patellar position was measured on the frontal image and knee flexion angle on the lateral image. First, a horizontal axis was established on the frontal image (Figure 1). The lateral edge of the medial knee marker, the medial edge of the lateral knee marker, and the center of the medial and lateral patellar markers were projected on the horizontal axis and defined as 'Mv' point, 'Lv' point, 'mv' point, and 'lv' point, respectively. The center of the patella was defined by the midpoint between mv and lv (Pv point = mv + lv / 2). The mediolateral patellar position in reference to knee width (%PP) was determined by dividing the distance from Mv to Pv by the distance from Mv to Lv (%PP = Mv–Pv / Mv–Lv × 100). A decrease in %PP indicates medial translation and an increase in %PP indicates lateral translation of the patella. In the lateral view, the angle 'α' composed of two lines

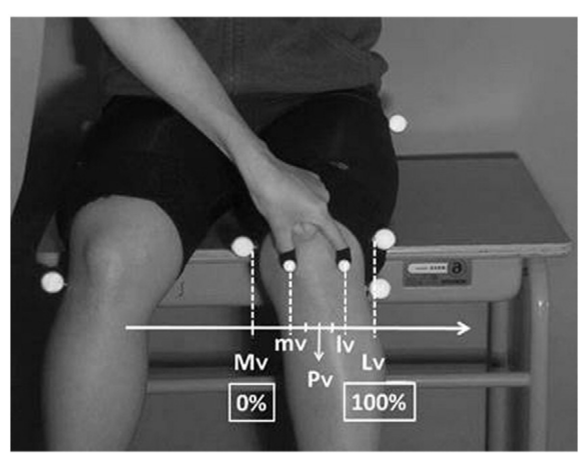

Figure 1. Measurement of mediolateral position of the patella on the video image (frontal view). The mediolateral patellar position in reference to knee width (%PP) was defined by dividing the Mv–Pv distance by the Mv–Lv distance (%PP = Mv–Pv / Mv–Lv × 100). lv, lateral patellar edge; Lv, lateral epicondyle; mv, medial patellar edge; Mv, medial epicondyle; Pv, midpoint of the patella.