Article

The patellostabilometer: a new device for quantification of mediolateral patella displacement

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Abstract: (1) Background: The mediolateral patella displacement is of interest for diagnostics and clinically relevant research questions. Apart from manual testing, no standardized method is currently available. Proper quantification of patella mobility is necessary to understand pathologies at the patellofemoral joint better; **(2) Methods**: Patella mobility was assessed in 25 healthy individuals using a Patellostabilometer, a new prototype instrument for quantification of the mediolateral patella displacement. The participants underwent measurements of the mediolateral displacement three times using the Patellostabilometer. A maximal force of 10N was applied for patella movement. Additionally, leg length, circumference of the knee, upper- and lower leg was measured. **(3) Results:** Lateral patella displacement of 18.27±3.76 mm (range 15.85-20.64mm, interquartile range (IQR) of 4.79) was measured. The medial patella displacement showed 24.47±6.59mm (range 19.29-29.76mm, IQR of 10.47). The test-retest measurement error was 2.32±1.76mm (IQR of 2.38mm), with five outliers. There was greater test-retest variability between the measurements of the medial displacement comparing to the lateral one. (4) **Conclusions:** The test-retest variability reached 7% of the patella displacement. Other parameters provided no significant correlations. Based on the natural patellofemoral mobility a precise and clinically relevant quantification of patella mobility is allowed.

Keywords: patella mobility; displacement; instability; patella; patellofemoral joint; instrumented measurement; anterior knee pain; knee anatomy; measurement reliability

1. Introduction

Both hyper- or hypomobility of the patella may become clinically symptomatic in different knee pathologies. The only method currently used as a standard and described in the literature is the manual displacement testing [1]. The latest does not allow a precise estimation of mediolateral patellar mobility due to lack of quantification of the force [2,3]. Proper quantification of patellar mobility may help to understand pathologies at the patellofemoral joint (PFJ) better. There are several anatomical and histological factors, which show direct impact on patella mobility. For instance, the soft tissue due to the medial and lateral retinaculum, including the medial patellofemoral ligament and the iliotibial band, the bony morphology of the patellofemoral compartment, the position of the patella in regard to the trochlea groove and the quadriceps and gluteus muscle function. The patella may show hypermobility, possibly ending in patella luxation, which can occur with or without trauma. The opposite, patella hypomobility, may cause stiffness and pain [4,5]. However, currently it is difficult to define a cut off between natural and pathological patella mobility because of lack of reference data and standardized quantification. Better quantification may help to identify prognostic values, which might be of therapeutical importance [6].

Several attempts had been made to define a normative range of medial and lateral patella displacement in a healthy population [3,6-10]. Moreover, there are some subtle forms of instability, which can cause anterior knee pain or giving way phenomenon [11]. Physical examination is rather unspecific and the manual inspection alone cannot serve as an objective measurement method for assessment [1-3,6,10]. Nevertheless, several attempts to quantify the patellar mobility in the coronal plane were described [3,6-10].

For improvement of measuring the patellofemoral mobility a more standardized method is recommended. The measurement has to be repeatable, providing a well-defined force to the patella. The force has to be well chosen, to produce movement, but not to cause pain or discomfort to patients with PFJ problems. Based on these requirements a Patellostabilometer (PSM) was developed.

The PSM was invented for quantifying the mediolateral patellar mobility in the coronal plane. Based on our clinical experience and the Kolowich´s quadrant method it was hypothesized that natural patellar mobility in both medial and lateral direction should not exceed 50% of the patella diameter at each direction [12]. The aim of this first device orientated study was to evaluate the reliability of the mediolateral displacement testing in healthy patients. Our hypothesis was that the new PSM device will allow quantifying the medio-lateral patella displacement in a standardized and reproducible manner.

2. Materials and Methods

2.1. Patellostabilometer device

The PSM is a new prototype device allowing quantification of the mediolateral patella displacement (Figure 1). It is composed of a knee pad, side stabilizers, one of them removable, grip arm on a frame, crank with handle and horizontal sliders. The movement of the frame on the sliders is possible in the mediolateral and craniocaudal directions. Moreover, there is an LCD screen, computer, small speaker to produce a sound signaling the amount of force as well as ports for the power supply, video transition and USB. The latter allow the connection of mouse, keyboard or flashdisk.

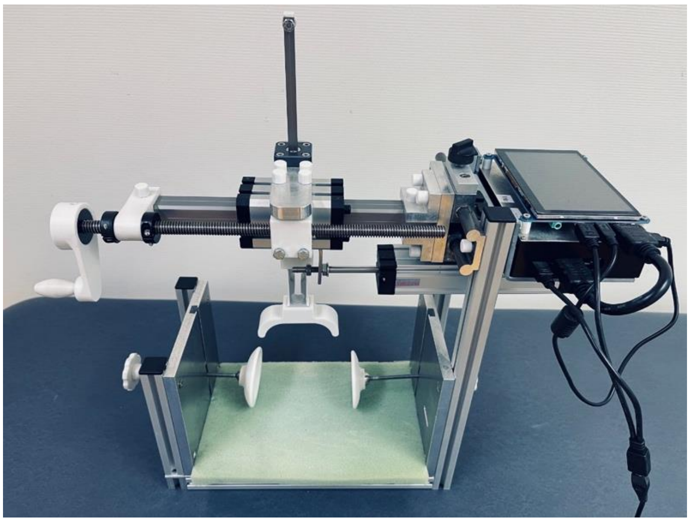

Figure 1. Patellostabilometer: knee pad in green, side stabilizers, grip arm and handle in white, metal crank, frame and sliders, LCD screen and the ports on the right as described

There are two sensors connected to the grip arm in order to measure the amount of force applied and the displacement: a load cell and a linear potentiometer. The accuracy of the potentiometer is 0.01 mm. A load cell that emits a load-dependent signal is also installed in order to be able to measure patella mobility at a defined force. Through line-

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arization it is possible to convert all measurement signals into a force or mass. These parameters are saved digitally and displayed on the screen. Thereafter those can be transferred to an USB-stick in csv file.

2.2. Study design:

Measurement of the patellofemoral mobility was performed in a test-retest-design. Inclusion criteria were healthy males and females between 18 and 45 years of age. Exclusion criteria were patellofemoral symptoms, osteoarthritis, previous surgery, generalized ligament laxity, neuromuscular diseases, chronic pain, signs of inflammation, oedema or scars. All patients were invited to the laboratory and receive a detailed explanation to ensure the most standardized test procedure possible. All patients gave written informed consent. The study was approved by the ethical committee of the university (E-02-20200405).

Twenty-five healthy individuals (7 females, 18 males, age of 32.32 ± 9.29, BMI 25.22 ± 3.44) were included in the study. Additionally, leg length, circumference of the knee, upper- and lower leg were measured. The participants underwent threefold measurements of the patellar mobility within an average interval of 11.68 ± 5.15 days.

The participants were invited one after another for the first measurement day in order to avoid longer waiting times. After information about the aim of the study, risks and data protection strategy all patients gave written informed consent. For allocating each measurement to the participant, pseudonyms were used during test procedures.

2.3. Measurement:

Patients knee was assessed in a supine position. Patella mobility and ligament function were carefully assessed prior inclusion of the participants.

For testing, patients were positioned supine, with slight elevation of the upper trunk and instructed not to contract their quadriceps muscles during testing. The PSM was positioned randomly starting with the measurement either on the right or left knee first. Special caution was paid, to place the knee central into the device centered in reference to the mechanical axis of the lower limb and the patella. The grip arm was positioned on the patella providing contact to medial and lateral edge of the patella without applying any pressure towards the trochlea. Finally the knee was stabilized due to the fixation at the medial and lateral epicondyle, preventing rotation of the leg during testing (Figure 2a). The handle for manual movement of the grip was turned clockwise to measure the lateral patella displacement, secondly counterclockwise for the medial one.

Software for data acquisition was started and the side for measurement determined. Finally, all data was saved in an electronic file, which was downloaded later for further analysis. The sensors of the device were queried at a specific frequency, the sampling rate varies by turning the crank slowly or quickly, since the output of the measured values is time-dependent. Three different acoustic signals indicated the percentage of 30%, 60% and 100% of the maximal force of 10N. The maximal force of 10N was chosen after pre-testing. A force – displacement graphic was shown on the display of the PSM during the testing in an online modus (Figure 2b). All data was saved on an USB-Flashdisk in csv file. The same procedure was repeated with the contralateral knee.

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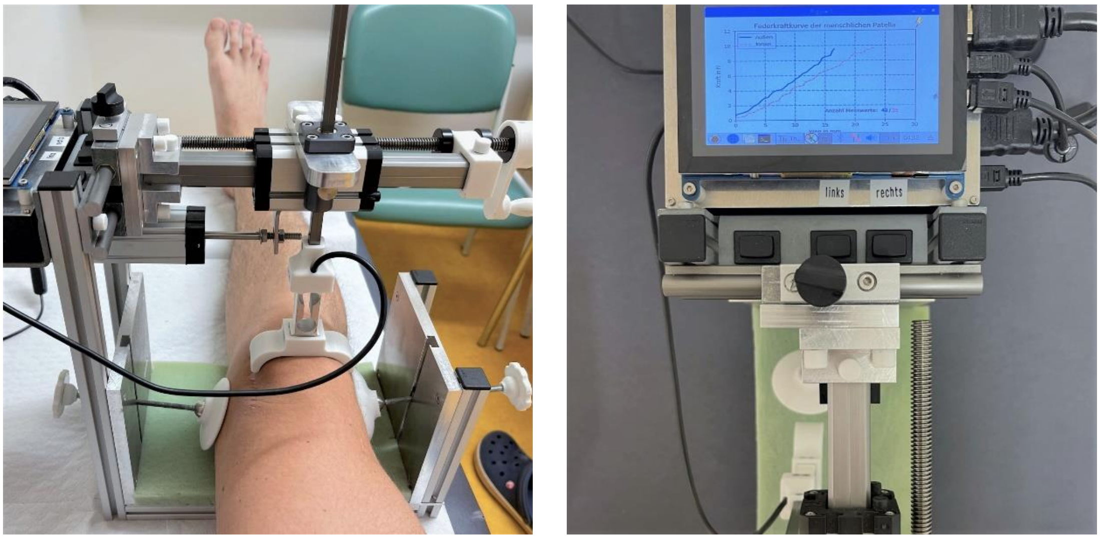

(**a**) (**b**)

Figure 2. Measurement with the Patellostabilometer: (**a**) Right leg correctly positioned in the device with the grip in the neutral position; (**b**) View from above at the LCD-screen, showing the acquired diagram of mediolateral mobility after a successful measurement. Red line represents the medial displacement, blue line the lateral one.

2.3. Statistics

Mean and interquartile range (IQR) are presented in mm for medial and lateral patella displacement. Mean differences and standard deviations (SD) will be presented for test-retest variability of measurement. Pearson and intraclass correlation (ICC) for a two-way mixed consistent model and Cronbachs Alpha were also analyzed [13].

3. Results

The lateral patella *displacement* was 18.27 ± 3.76 mm, with an Q1Q3 interquartile range (IQR) of (4.79) 15.85-20.64. The medial *displacement* was 24.47 ± 6.59mm with IQR of 10.47 (19.29-29.76) (Figure 3a). The test-retest measurement error was 2.32 ± 1.76mm with an IQR of 2.38mm, with five outliers.

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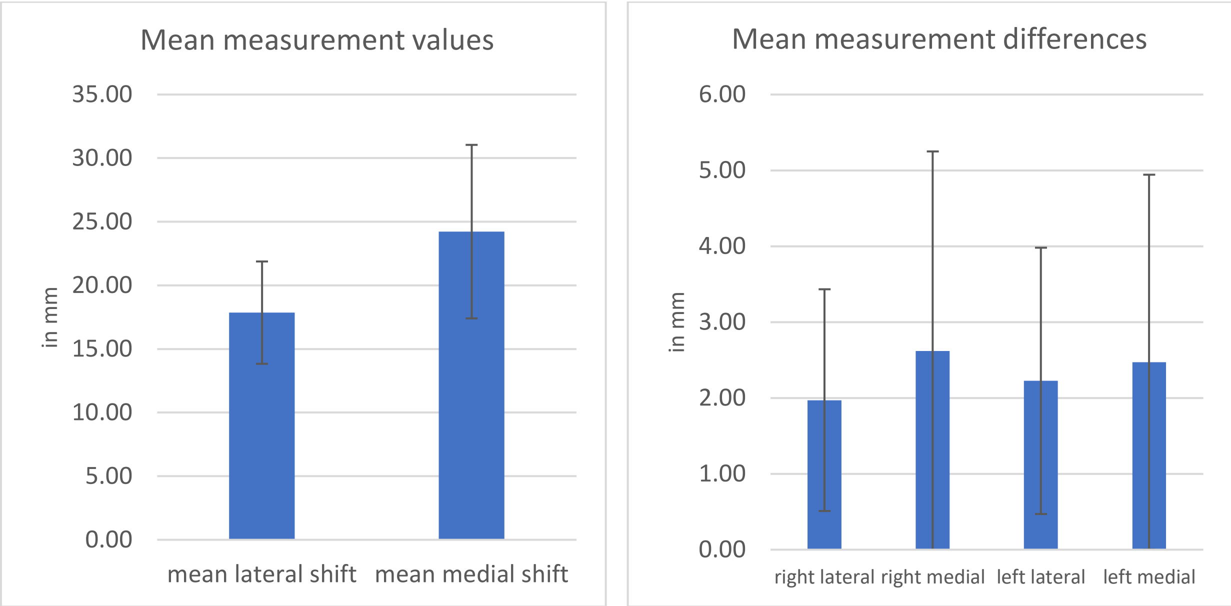

(**a**) (**b**)

Figure 3. (**a**): Mean values of all measurements with standard deviation as measurement error; (**b**) Mean values of differences between measurements with standard deviation as measurement error.

The mean differences between the patellar mobility were respectively: 1.97 ± 1.46mm for right lateral displacement, 2.62 ± 2.63mm for right medial displacement, 2.23 ± 1.76mm for left lateral displacement and 2.47 ± 2.47mm for left medial displacement (Figure 3b). The mean absolute deviation of all measurements was 1.49 ± 2.03mm. The test retest reliability correlation coefficients were r=0.81, ICC(2,1) or Cronbachs Alpha = 0.89 for lateral patella displacement and r=0.86, ICC(2,1) or Cronbachs Alpha = 0.93 for medial patella displacement.

Body height, weight, circumference of the knee, upper- and lower leg as well as the length proved no significant correlations (r=0.3).

4. Discussion

This study showed that the PSM with the described method provides reliable measurements allowing precise quantifying of mediolateral patella displacement. Therefore, our hypothesis can be accepted. The good and excellent non-parametric reliability coefficients for lateral and medial displacement testing support the usage for clinical examination. The variability within this group showed significant displacement differences between individuals. Further study should search for factors, which may show an impact on patella mobility, such as the shape of the trochlea or patella. Data about pathologies such as patellofemoral dysplasia, MPFL injury, or anterior knee problems in OA and TKA patients are also of interest. Patellofemoral mobility has been proven to have significant impact on the patellofemoral pain, instability and knee stiffness and may cause functional limitations [7,14].

Medial patella displacement was larger than the lateral displacement. This observation is coherent with the literature, reporting the greater medial patellar displacement due to existence of medial patellofemoral ligament, acting as a restraint in the lateral direction.

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The geometry of the patellofemoral joint, with a more prominent lateral trochlea is responsible for mechanical restraint of excessive mobility. The lateral facet of the femur is often larger and extends more proximally improving patellar stability [4,5]. The trochlea prominence is missing by patients suffering on trochlear dysplasia. The morphology of the articular facet of the patellofemoral joint is very variable and their impact on the mediolateral patella mobility need further investigation [15].

Conducting two tests on different days greater test-retest variability was seen between the measurements of the medial displacement comparing with the lateral one. The variability of the lateral displacement was 82% only in comparison to the medial displacement. The overall divergence of patella displacement was on average 7%. The variability is form the clinical point of view considerably low [3,16]. There have been five outliers, possibly caused by the intrinsic factors alternating data acquisition as described below.

Based on the natural patellofemoral mobility a more precise quantification of patella mobility is allowed in a more standardized manner by using the PSM. Some researchers have attempted to improve the imprecise physical measurements with instrumented techniques. Reider et al. used a device mounted to the tibial tubercle to measure the mediolateral displacement during the active flexion and extension, using the weight of 9,2 kg [17]. The results of their research group indicate that during the active motion of the uninjured knee, mean total mediolateral displacement of the patella was 22 mm, compared with 21 mm for patients with knee pain, 26 mm for patients with subluxations, and 35 mm for patients with a history of patellar dislocation. However, the measurements made during the mobility of the knee are difficult to reproduce and it is doubtful if they can be used in the standardized way.

Kolowich et al. invented a quadrant method [12]. The principle of this technique was to divide the patella into equal segments in order to quantify the medial or lateral displacement as a part of entire patellar width. The natural patella moved less than two quadrants medially or laterally when the knee flexed to 30°, which was a different position of the knee than in the current study. However this quadrant method corresponds to our clinical experience, in which the mediolateral patellar displacement in full extension should not exceed 50% of the patellar width. Beginning from the fully extended knee the patella naturally translates medially, engaging the trochlear grove at 20° of flexion. There is a natural lateral patella translation up to 90° of flexion, which is accompanied by a rapidly increasing lateral patellar tilt. Another observed motion is a minimal patella rotation in the coronal plane. [2,4-6,15,17,18]. The path, which the patella follows during knee flexion is different by each individual and according to Amis et al. this pattern does not have clinical significance [18]. The authors showed a mean difference of 6,5 mm in mediolateral patella displacement between 0° and 90° knee flexion.

In the past also stress radiographs were used to measure the patellar displacement with medially or laterally directed forces [19]. The evaluation of the instability of the patella in the coronal plane was based on side-to-side difference. Healthy subjects showed a mean difference of less than 3.5mm of medial and lateral displacement, while in patients after patella dislocations the lateral mean difference exceeded 10mm. The current study of healthy subjects showed a mean difference for the lateral displacement of 2.1mm and the medial displacement of 2.6mm.

In order to eliminate the constraint to patella displacement due to the prominent lateral trochlear facet as well as the medial trochlear facet one has to conduct the measurements in full knee extension. The natural position of the patella may play an important role, because in full extension there is no engagement of the patella in the trochlear grove. Thus, predominantly the medial and lateral periarticular soft tissue determines medial and lateral patella displacement providing a physiological Caton-Deschamps index. With the measurement starting from an extended position, the medial displacement of the patella should be greater than the lateral one [19,20]. If lateral displacement exceeds the medial one, the restraints can be considered imbalanced, with a sensitivity of 91% and specificity of 81% [20]. In contrast, in case of patella infera there is already a settlement in the trochlear grove and less displacement may be expected.

Apart from the bony anatomy, the mobility of the patella in the coronal plane is determined by the lateral and medial restrains, which are formed by the lateral and medial retinaculae [4,5]. There are two layers forming the lateral retinaculum: the superficial oblique retinaculum and the deep transverse ligament. The medial structures include the medial patellofemoral ligament, which originates from the adductor tubercle and inserts on the proximal 2/3 of the medial border of the patella, as well as the medial parapatellar retinaculum, which is formed from a condensation of two fascial planes on the medial aspect of the knee and has a broad insertion on the medial patella. Another constraint is formed through the medial patellomeniscal ligament, which originates from the anterior portion of the medial meniscus and inserts onto the inferior 1/3 of the patella and the medial patellotibial ligament, which is a thickening of the anterior capsule originating on the anteromedial aspect of the tibia and inserting on the inferior aspect of the patella [5,21].

Another important aspect is the impact of the mediolateral patellar constraints on the incidence of anterior knee pain. The pathogenesis is rather multifactorial and derives from a large number of free nerve endings and fibers, particularly in the quadriceps muscles, retinacula, patellar tendon and synovium. Anterior knee pain can result from anyone of these sources and clinicians typically have difficulty identifying its exact source [22,23]. However, patella mobility is one important factor.

There are certain factors, which can influence the data acquisition. Those measurement errors can be associated with a number of intrinsic sources such as skin and fat movement, quadriceps muscle tonus or rotation of the hip. Because of this fact, there were always multiple measures taken to avoid these errors by attention to detail.

5. Conclusions

The force-controlled measurement of medial and lateral patella displacement using the PSM showed a high reliability. More accurate quantification of patella displacement offers new insides in the understanding of clinically relevant pathologies, which are often influenced by a combination of different passive stabilizer such bony morphology and soft tissue properties.

Conflicts of Interest: The authors declare no conflict of interest.

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