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The patellar shift index: a reliable and valid measure for patellofemoral congruence following total knee arthroplasty with unresurfaced patella

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Objective: The aim of this study was to develop a new radiographic measure, the patellar shift index (PSI), for the precise estimation of patellar position relative to the trochlea after a total knee replacement with an unresurfaced patella.

Methods: This study included radiographs of 51 patients suffering from anterior knee pain following total knee arthroplasty. Patellofemoral axial radiographs were analyzed to compare the reliability of the PSI to the classical measures of patellofemoral congruence, the lateral patellar tilt (LPT) and patellar displacement (PD). Intra-rater reliability of the PSI, LPT and PD was estimated using the intraclass correlation coefficient (ICC) and the inter-rater reliability using Krippendorff's alpha (Kα). Agreement proportion of was calculated for the PD. Face validity of the PSI was also tested.

Results: The PSI had excellent intra (mean ICC=0.91) and inter-rater (Kα=0.92) reliability, as did LPT (mean ICC=0.96; Kα=0.89). The calculation of PD caused a low level of agreement (47.1%) between evaluators in terms of which images could be measured. The exclusion of these radiographs resulted in a high PD intra (ICC=0.96) and inter-rater (Kα=0.97) reliability.

Conclusion: The PSI appears to be a reliable and valid measure for patellofemoral congruence in a replaced knee joint with an unresurfaced patella. The superiority of the PSI is the result of its consideration of the geometry and size of the replaced knee joint and independence from radiographic magnification.

Key words: Patellar shift index; patellofemoral congruence; total knee arthroplasty.

Patellofemoral complications following total knee arthroplasty occur in 1 to 50% of cases, the majority of which are associated with abnormal patellar tracking.[1,2] Numerous techniques for the measurement of patellofemoral congruence have been described in the literature although there is no consensus regarding the ideal method.[3]

Currently, radiographic measures of patellofemoral congruence may be divided into groups. Angular techniques, which impart the position of the patella relative to the trochlea in the form of angles, include the congruence angle, the lateral patellofemoral angle and the lateral patellar tilt (LPT).[4-6] Linear displacement measures, expressing patellar translation in millimeters, are the lat-

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eral patellar displacement, the patellar displacement (PD) and the linear displacement measurement.[3,5,7] The bisect offset and the patellofemoral congruence measure are displacement ratios, serving as quantitative relations between two similar magnitudes.[8,9] The LPT and the PD techniques have been outlined in previous studies as more reproducible than the others.[3,10]

During knee replacement, the original landmarks necessary for computing the classic measures of patellofemoral congruence are distorted due to the resection of joint surfaces and implantation of the prosthesis. Furthermore, the interpretation of linear displacement measurements is also influenced by radiographic magnification and knee dimensions.

The differences in patellar morphology (Wiberg classification), discrepancy of bony and cartilaginous contours, resection of the facets during surgery and stress-induced remodeling reduce the credibility of inter-articular ridge together with the facets as a landmark for patellofemoral alignment measures.

The need for a valid and reliable radiographic measurement tool for patellofemoral congruence which takes into account the replaced knee joint has emerged due to the unreliable landmarks for the current measures and the necessity to compare results among researchers.

The objective of this study was to develop a new radiographic method, the patellar shift index (PSI), for the measurement of patellar mediolateral alignment relative to the femoral groove, to estimate its intra- and inter-rater reliability and to compare its reliability to that of the LPT and the PD among patients following total knee arthroplasty with an unresurfaced patella.

Materials and methods

The study included 51 patellofemoral axial X-rays (Merchant view) of patients with patellofemoral pain syndrome following total knee arthroplasty. Radiographs were obtained from our digital database and analyzed. Only patients with unresurfaced patellae were included in the study. The mediolateral position of the patella relative to the trochlea was investigated. A new measure, the PSI, was developed.

Approval from the Medical Research Ethics Committee of East Tallinn Central Hospital was obtained.

The calculation of the PSI is described in Fig. 1. Lines 1 and 2 are drawn parallel to the medial and lateral trochlear shoulders. Line 3 joins the apices of the anterior femoral condyles. The intersection of first three lines creates two distinct reference points at the level of the anterior femoral condyles, determining the trochlear width. Line 4 is drawn from the most medial edge of the patella to its most lateral border to determine the patellar width. The center of the trochlea is calculated on Line 3 by bisecting the distance between the two anterior reference points. Line 5 is drawn from the center of the trochlea at a right angle to Line 3. The center of the patella is identified by bisecting Line 4. Line 6 is drawn from the center of the patella at a right angle to Line 3. The distance between Lines 5 and 6 is called the patellar shift. Trochlear width and patellar shift are measured. The PSI is calculated by dividing the patellar shift with the trochlear width (PSI=patellar shift/trochlear width). The index is rounded up to two decimal points. Patellar shift can be either medial or lateral with medial patellar shift marked with a "-" sign.

The intra-rater and inter-rater reliability of the PSI were estimated by one orthopedic surgeon, one radiologist and two medical students.

The value of the PSI was calculated twice at a two-week interval with each researcher working independently of the others.

Radiographs were printed on an A4-size sheet of paper. Measurements were carried out by hand using the technique described above with a pencil and a transparent ruler.

The reliability of the PSI was compared to the reliability of the LPT and the PD.

The LPT (Fig. 2) is the angle between the transverse axis of the patella and the anterior intercondylar line. The patellar transverse axis is defined as the line between the medial and lateral patellar corners.[6]

The PD (Fig. 3) is the distance between the deepest point of the trochlear groove and the lowest point of the articular ridge of the patella.[3]

LPT and PD values were also calculated twice at a two-week interval by the same researchers engaged in the measurement of the PSI.

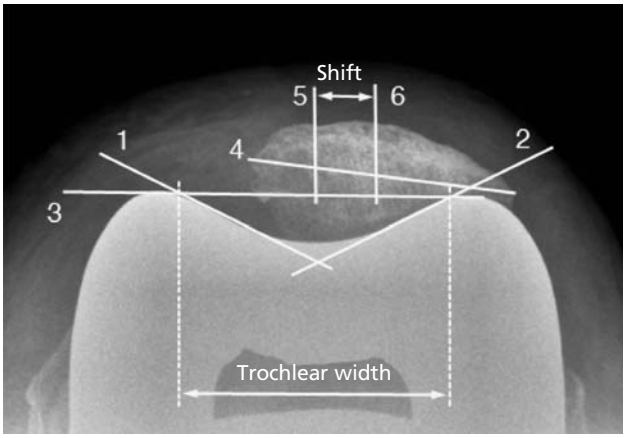

Fig. 1. Measurement technique for the patellar shift index (PSI).

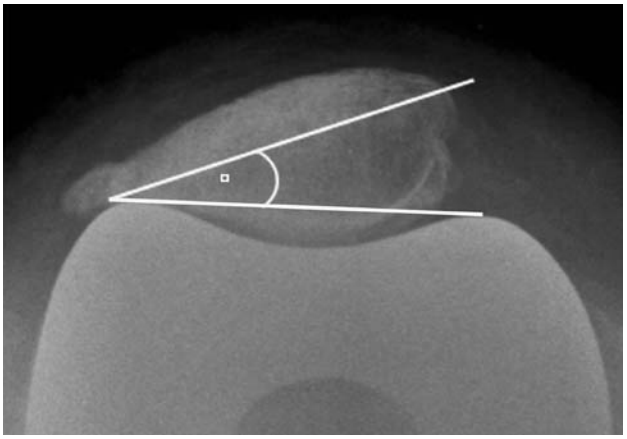

Fig. 2. The lateral patellar tilt (LPT).

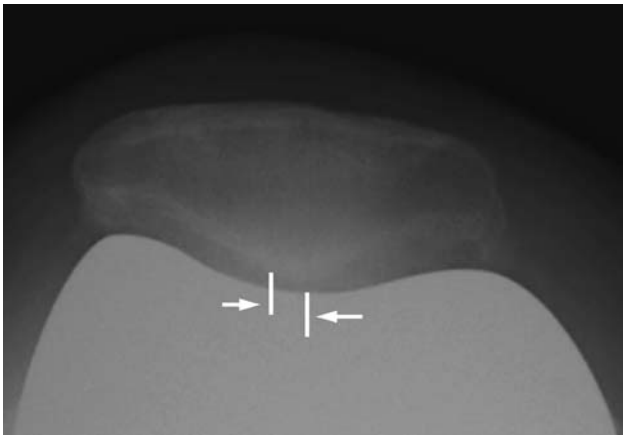

Fig. 3. The patellar displacement (PD).

The face validity of PSI was tested by 4 orthopedic surgeons not involved in the calculation of radiographic patellofemoral congruence measures. Each surgeon was asked to visually evaluate 5 images of the 51 radiographs of their own choice and rank them in a descending order in terms of the magnitude of patellar displacement. Each surgeon created a unique set of 5 images out of 51. The mean PSI (2 measurements by all 4 investigators) of each selected image was compared to the visual ranking of the respective radiograph. The image with greater displacement on visual inspection was assumed to have a higher PSI value.

The intraclass correlation coefficient (ICC), a two-way mixed model on absolute agreement, with 95% confidence intervals was used to analyze the intra-rater reliability.[11] Its values can range from 0 to 1, with a higher value indicating greater reliability.

Krippendorff`s alpha (Kα) is a reliability coefficient developed to estimate reliability regardless of the number of observers, levels of measurement, sample sizes and the presence or absence of missing data.[12] Inter-rater reliability is usually regarded as being sufficient if alpha is greater than 0.70. Confidence intervals of 95% were calculated.

The consistency of PD measurements was verified by calculating the proportion of agreement indicating the number of measurements of the PD for which observers agreed over the total amount of observations. An agreement above 70% was considered acceptable.[13]

Results

The intra-rater reliability of the LPT, the PD and the PSI are presented in Table 1. Results were excellent for all three methods.

The inter-rater reliability, characterized by Krippendorff's alpha, was high for all three measurements (Table 2).

Indefinable landmarks did not allow for the measurement of PD in 16 radiographs. These images were excluded from the reliability analysis of the displacement technique.

In the calculation of PD, 16 of 51 radiographs were noted to having missing landmarks and all necessary landmarks were found in only 8 images by all investigators. The proportion of agreement for measurements of PD remained as low as ((16+8)/51)×100=47.1%.

Table 3 summarizes the results of the face validity test.

In general, images displaying larger patellofemoral incongruity on visual inspection had higher PSI values. Although there was a difference between the surgeon`s estimation and the PSI value in one case, the results were

Table 1. Intraclass correlation coefficients (ICCs).

	Rater 1		Rater 2		Rater 3		Rater 4		Mean
	ICC	95% CI	ICC	95% CI	ICC	95% CI	ICC	95% CI	
Lateral patellar tilt	0.99	0.98- 0.99	0.94	0.89-0.96	0.97	0.95-0.98	0.95	0.91-0.97	0.96
Patellar displacement*	0.99	0.98-0.99	0.97	0.92-0.98	0.98	0.93-0.99	0.98	0.90-0.99	0.98
Patellar shift index	0.85	0.75-0.91	0.85	0.76-0.92	0.97	0.94-0.98	0.99	0.97-0.99	0.91

*Images with missing landmarks were excluded from analysis.

quite similar and did not diverge from the general pattern.

Discussion

Total knee arthroplasty does not reproduce normal patellofemoral kinematics despite well-aligned components.[14] Patellar maltracking, seen in most knees with patellofemoral complaints, may be the expression of the imbalance of the peripatellar soft tissues, incorrect implant positioning, overstuffing of the patellofemoral joint or errors in the resection of the patella.[15-17]

Correlation cannot be found between patellar pain and standard axial X-rays, as this method is not a good measurement of patellar tracking (malalignment). Standard axial radiographs do not relate patellar position to clinical symptoms.[18] Weight-bearing Merchant radiograph on the other hand is a better measurement method for maltracking, resulting in better correlation between the radiographs and patellofemoral pain.[19]

Some causes of patellofemoral complaints, including mid-flexion instability and patella baja secondary to joint line elevation, do not affect the appearance of the patellofemoral joint in the axial plane.[20-22] Therefore, the analysis of patellofemoral axial views should be complemented with anteroposterior and lateral views of the knee when trying to treat anterior knee symptoms.

All three measures for patellofemoral congruence tested in the present study, the PSI, LPT and PD, showed high intra- and inter-rater reliability. However, the results of the last two should be interpreted with some reservation.

Despite their high reliability, the measurement of patellar tilt angle does not allow for the quantification of patellar displacement because the inclination of the patella does not correlate with maltracking.[10] Figs. 4a and 4b present luxated patella with a smaller tilt angle than the subluxed knee cap.

Table 2. Krippendorff's alpha (Kα) coefficients.

	Kα	95% CI
Lateral patellar tilt	0.89	0.84-0.92
Patellar displacement	0.97*	0.96-0.99
Patellar shift index	0.92	0.88-0.94

*Images with missing landmarks were excluded from analysis.

Table 3. Visual ranking of the radiographs and corresponding mean values of the patellar shift index (PSI).

Surgeon 1		Surgeon 2		Surgeon 3		Surgeon 4	
Visual	PSI	Visual	PSI	Visual	PSI	Visual	PSI
X-ray 29	1.20	X-ray 29	1.20	X-ray 29	1.20	X-ray 29	1.20
X-ray 53	0.33	X-ray 3	0.60	X-ray 3	0.60	X-ray 3	0.60
X-ray 83	0.32	X-ray 45	0.27	X-ray 67	0.23	X-ray 10	0.30
X-ray 50	0.30	X-ray 66	0.17	X-ray 82	0.24	X-ray 67	0.23
X-ray 49	0.09	X-ray 88	0.09	X-ray 8	0.04	X-ray 8	0.04

The high intra- and inter-rater reliability of the PD technique was only achieved by excluding images which did not qualify due to indefinable landmarks. The low proportion of agreement (47.1%) among investigators reflects the difficulty in interpreting radiographic landmarks and should be considered a limitation for the PD measurement technique.

As radiographic magnification causes variability in linear displacement measurements expressing patellar shift in millimeters, the distance measured on radiographs cannot be considered as true displacement.[7,23,24] The images may be analyzed with a computer using digital software, on plain films or in a printed form. The difficulty in ensuring the same mag-

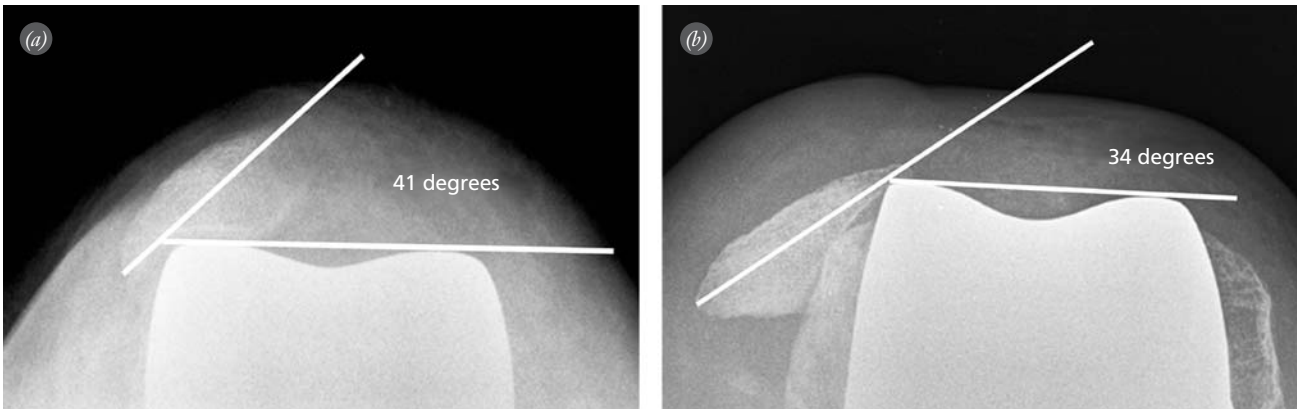

Fig. 4. **(a, b)** Patellar tilt does not correlate with the extent of displacement.

nification on each media reduces the reproducibility of linear displacement measurements.

As a ratio, the PSI is independent of radiographic magnification, allowing for the analysis of X-ray images using different media (digital, plain X-ray films, printed paper) and comparison of results among researchers.

Additionally, linear displacement measurements do not take into account the size effect: the same amount of displacement in millimeters more greatly affects the biomechanics of a smaller knee than a large joint. The PSI circumvents the size effect, enabling comparison of results among patients with different knee dimensions. As a ratio, the PSI relies on proportions rather than expressing the results in absolute numbers.

Due to the dependence on radiographic magnification and the varying size of anatomic structures, the numerical results of linear displacement measurements cannot be used as standardized decision-making tools. Angular techniques and displacement ratios are independent of radiographic magnification and size effect.

Although the geometry of the femoral components of the knee prosthesis has been designed to replicate the normal anatomy as closely as possible, components with both anatomic and symmetric trochlear designs have flatter contours of the anterior limits of femoral condyles and bottom of the trochlear groove compared to the natural human knee joint. This makes it difficult to pinpoint the highest points of both femoral condyles and the lowest point of the trochlear groove; the three basic references on the femoral side for the calculation of the currently available measures for patellofemoral congruence.

The position relative to the trochlear groove is considered the most immediate way to describe patellar tracking.[25] The sulcus angle, outlining the shape of the femoral intercondylar groove, has been shown to be relatively insensitive to the angulation between the X-ray beam and the femur.[4,26] This means that trochlear width can also be considered a trustworthy measure significantly uninfluenced by X-ray projection.

According to PSI methodology, the femoral landmarks are created by intersection of lines, thereby avoiding imprecision due to rounded and flat anterior limits of the condyles and the bottom of the trochlear groove.

Measures based on the conformity of the lowest point on the articular ridge of the patella and the lowest point of the trochlea do not take into account the specific relationships between the geometry of the surface of the articular cartilage and the subchondral osseous anatomy of the patella.[27] It is misleading to judge upon the conformity of the lowest points of the patella and the trochlea relying on bony landmarks only because the cartilaginous and osseous geometry of the patella do not resemble each other.[28] Conventional radiographs depict only osseous anatomy and are incapable of revealing the discrepancy of bony and cartilaginous contours as compared to the patellofemoral axial MRI shown in Fig. 5.

Additionally, as patellar shape changes on different cross-sections, the articular ridge and facets of patella are not the best available references for evaluating the patellofemoral congruence.[26]

The articular surface (lateral facet) of the unresurfaced patella adapts to the geometry of the femoral component through a stress-induced biological response called remodeling following as many as 40 to 85% of cases of total knee arthroplasty.[29,30] Compared to anatomically designed femoral components, non-anatomical units cause more extensive changes in patellar shape.[9] Fig. 6 demonstrates a case of a subluxed and remodeled patella.

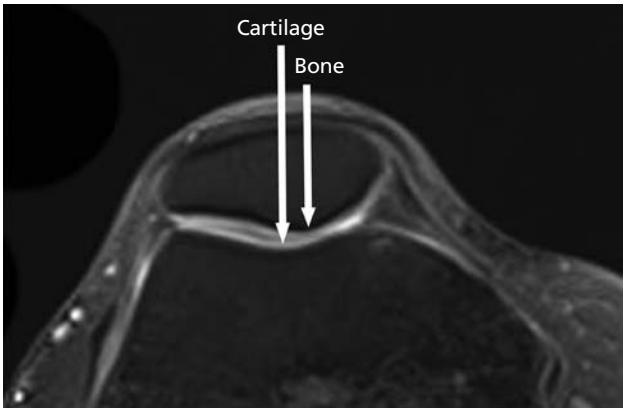

Fig. 5. Non-matching cartilaginous and osseous geometry of the patella on axial MRI.

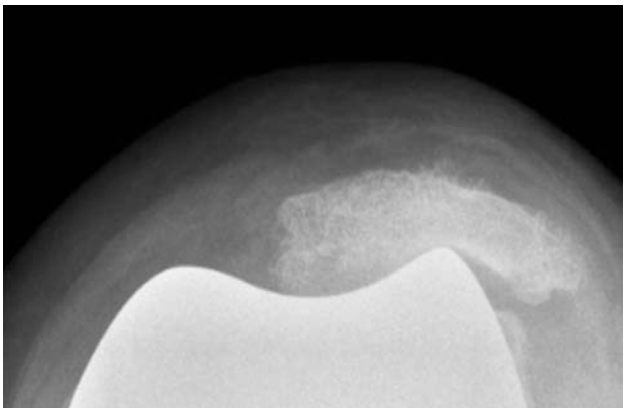

Fig. 6. Remodeling of a laterally subluxed patella.

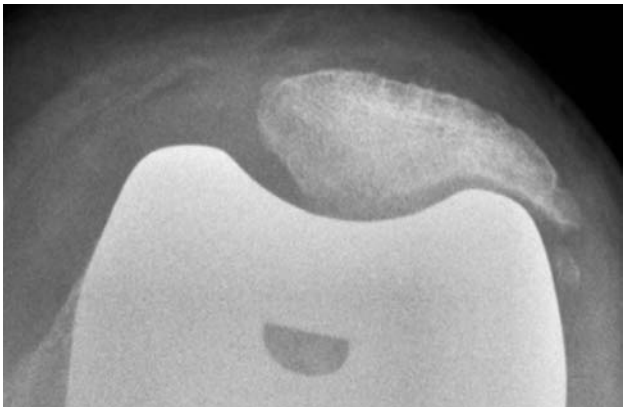

Fig. 7. A laterally subluxed patella with a centered inter-articular ridge.

Remodeling will shift patellar landmarks from their original location. As illustrated in Fig. 7, disfigured patella may lead to a situation in which the inter-articular ridge is congruent with the deepest point of the trochlea, with the patella shifted off the center.

Patellar remodeling together with the discrepancy of bony and cartilaginous geometry does not cause misinterpretation of landmarks in the calculation of the PSI. The center of the knee cap is found independently of patellar morphology exactly midway on a line between its medial and lateral edges, which are seldom altered by stress-induced changes and osteophyte removal at surgery.

Strengths of this study include the inclusion of four reviewers with different levels of medical training and the measurement of the same set of radiographs independently from each other on two occasions. On the other hand, the relatively small number of measurements is a weakness of the study, although a sample of 50 is usually considered feasible for reliability studies.[13]

In conclusion, we introduced the patellar shift index, a new reliable and valid measure for patellofemoral congruence for evaluation of patellar alignment following total knee arthroplasty with an unresurfaced patella. Necessary landmarks for the calculation of the PSI are always present and well-discernible. Independence from radiographic magnification and knee dimensions makes the PSI applicable on different media (computer, printed radiograph) and, most importantly, allows comparison of results among patients and researchers.

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Conflicts of Interest: No conflicts declared.

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