International Orthopaedics (2019) 43:611–617
https://doi.org/10.1007/s00264-018-4075-8

ORIGINAL PAPER

Predictors for secondary patellar resurfacing after primary total knee arthroplasty using a "patella-friendly" total knee arthroplasty system

Philip P. Roessler[1] · Randa Moussa[1] · Cornelius Jacobs[1] · Karl F. Schüttler[2] · Thomas Stein[3] · Frank A. Schildberg[1] · Dieter C. Wirtz[1]

Received: 29 March 2018 / Accepted: 24 July 2018 / Published online: 1 August 2018

Abstract

Purpose Patellar resurfacing (PR) in total knee arthroplasty (TKA) is still one of the major controversies in orthopaedic surgery today. The aim of the present retrospective case-control study was to identify predictors for secondary patellar resurfacing (SPR) after initial TKA to create a rationale for surgeons to decide which patients to resurface primarily. It was hypothesized that proper TKA implantation and component positioning as well as a maintained physiological patellar geometry will lead to a reduced risk of SPR. Overmore, it was hypothesized that intrinsic factors like overweight might also have an influence on the need for SPR.
Methods After identification of suitable patients and age/sex matching in a 1:2 fashion, 29 cases (TKA/SPR) and 58 controls (TKA) were included and screened for available clinical and epidemiological data as well as for radiographic data after primary TKA. Pearson's correlation analysis as well as logistic regression modeling was performed to identify possible predictors for SPR following TKA.
Results Binary logistic regression was able to correctly classify 88.5% of patients into case or control groups. It indicated that patella tilt, patella height, and thickness as well as the delta angle were significant predictors of a need for SPR following primary TKA. An increase in patellar width by 1 mm will increase the risk of SPR, while an increase in patellar thickness by 1 mm will reduce it. An increase in patellar tilt by 1° will also increase the risk of SPR. Finally, an increase in delta angle by 1° will again reduce the risk of SPR.
Conclusions Easy and accessible radiographic measurements have been identified as possible predictors of SPR following primary TKA. Although indication for primary PR may still remain a controversial topic, a rationale has been proposed in this study to support surgeons in objectively estimating an individual patient's risk for SPR prior to primary TKA measuring the patella tilt, width, and thickness. Overmore, regarding surgical aspects of TKA, tibial component positioning has also been shown to be of importance to reduce the risk of SPR.

Keywords Total knee arthroplasty · Patellar resurfacing · Patellofemoral pain · Predictors

Introduction

Patellar resurfacing (PR) in total knee arthroplasty (TKA) is still one of the major controversies in orthopaedic surgery today [1]. While most surgeons in the USA routinely perform PR during TKA for medicolegal reasons, most European surgeons only tend to do so after subjective evaluation of individual patient's risk for development of anterior knee pain after TKA. Part of this controversy are complications commonly seen with PR such as patella fractures, osteonecrosis, overstuffing, patellofemoral instability, and even rapid implant wear as well as loosening [1, 2]. Revision rates after primary PR-related complications reported in the literature range up to 10% [3]. This relatively high rate has not been

✉ Philip P. Roessler
philip.roessler@ukbonn.de

1 Department of Orthopaedics and Trauma Surgery, University Hospital Bonn, Sigmund-Freud-Str. 25, 53127 Bonn, Germany

2 Center for Orthopedics and Traumatology, University Hospital Giessen & Marburg, Marburg, Germany

3 Department of Sporttraumatology - Knee- and Shoulder-Surgery, Berufsgenossenschaftliche Unfallklinik Frankfurt am Main, Frankfurt, Germany

lowered yet, despite the evolution of modern TKA implant designs and surgical techniques like patellar decompression or patelloplasty in primary TKA [4–7].

On the other hand, anterior knee pain after primary TKA without PR is seen in 4 to 49% of patients and possible causes for this phenomenon are numerous [8, 9]. Although secondary patellar resurfacing (SPR) has not been shown to consistently relieve pain, it is the most commonly performed procedure in these cases [10]. The need for SPR is reported to be around 13% [1, 11]. This may be masked by a selection bias though, as treatment with SPR is often regarded as the only option in patients with persistent anterior knee pain following TKA, which cannot be explained by other causes like component malrotation, torsional deformities, or patella shift [12]. TKA implant designs may also add to the development of post-operative anterior knee pain [13], although today it is widely accepted to be a more complex and multifactorial problem involving not only static but also dynamic variables [5, 10].

Previous studies either focused on the risk of revision following TKA with PR, instead of trying to identify surgery-related predictors leading to SPR following TKA [12, 14–17], or tried to compare groups with and without PR in primary TKA, but often with limited study designs or insufficient outcome parameters [18]. A recent study by Franck et al. investigated predictive factors to identify patients that may benefit from primary PR with a specialized implantation method [2]. However, this can only be one half of the medal, as the overall quality of TKA implantation as a potential hazard for SPR has not been addressed yet. As a consequence, the aim of the present retrospective case-control study was to identify predictors for SPR after initial TKA to create a rationale for surgeons to decide which patients to resurface primarily. It was hypothesized that proper TKA implantation and component positioning as well as a maintained physiological patellar geometry will lead to a reduced risk of SPR. Overmore, it was hypothesized that intrinsic factors like overweight might also have an influence on the need for SPR.

Methods

Patients

The present study is a retrospective clinical case series of patients that underwent SPR for persistent anterior knee pain after primary TKA with the Genesis II knee system (Smith & Nephew plc, London, UK). The records of 516 patients that were treated with primary TKA between December 2005 and December 2015 at our department were reviewed. Fifty-seven patients with persistent anterior knee pain treated by SPR were identified while 459 patients retained primary TKA only. After exclusion due to previously defined criteria (Table 1), the remaining patients were age/sex matched in a 1:2 fashion, subsequently generating 29 cases (TKA/SPR) and 58 controls (TKA) as shown in Fig. 1. Epidemiological and clinical data were collected from the database. Post-operative plain radiographs included knee standing anterior-posterior, horizontal beam lateral, and patella skyline views at 30° of knee flexion as well as long leg standing anterior-posterior.

Table 1 Exclusion criteria

Incomplete clinical records
Incomplete radiographic records
Knee surgery other TKA
Aseptic loosening of TKA
Septic loosening of TKA or periprosthetic joint infection
Pathological gait or posture
Acute or chronic knee instability
Leg axis deviations > 5° in frontal plane

Surgery

During the index procedure (primary TKA), patellar finishing and denervation were performed routinely. The Genesis II knee system (Smith & Nephew plc, London, UK) was used in all patients. Variants included cruciate retaining (CR) (cases $n = 24$; controls $n = 46$), posterior stabilized (PS) (cases $n = 1$; controls $n = 3$), or condylar constrained (CC) (cases $n = 4$; controls $n = 9$). Approaches chosen were either medial parapatellar (cases $n = 26$; controls $n = 49$), subvastus (cases $n = 2$; controls $n = 7$), or median (cases $n = 1$; controls $n = 2$).

SPR was carried out via the same approach previously chosen for primary TKA. After inspection of the TKA and patella tracking during passive motion, the patella was everted, and the articular portion resected to prepare it for PR. Additional intra-operative procedures were subtle soft tissue release of the patella ($n = 10$), lateral facetectomy ($n = 7$), medial facetectomy ($n = 2$), medial/lateral combined facetectomy ($n = 2$), or resection of proximal/distal osteophytes ($n = 19$) to prepare the patella for PR. Prior to implantation, a jet lavage was performed. All PR used were original ultra-high molecular weight polyethylene (UHMW PE) (Smith & Nephew plc, London, UK) either as onlay ($n = 10$) or biconvex/onlay ($n = 19$) variants cemented with Palacos low-viscosity bone cement (Heraeus Medical GmbH, Wertheim, Germany). Mean implant size was 29 (range 23–32; increment 3).

Predictor evaluation and radiological assessment

Due to age/sex matching, body mass index (BMI) was the only screened epidemiological predictor in this study. Assumed radiographic predictors included the patella index according to Caton/Dechamps (Fig. 2) [19], patella tilt in

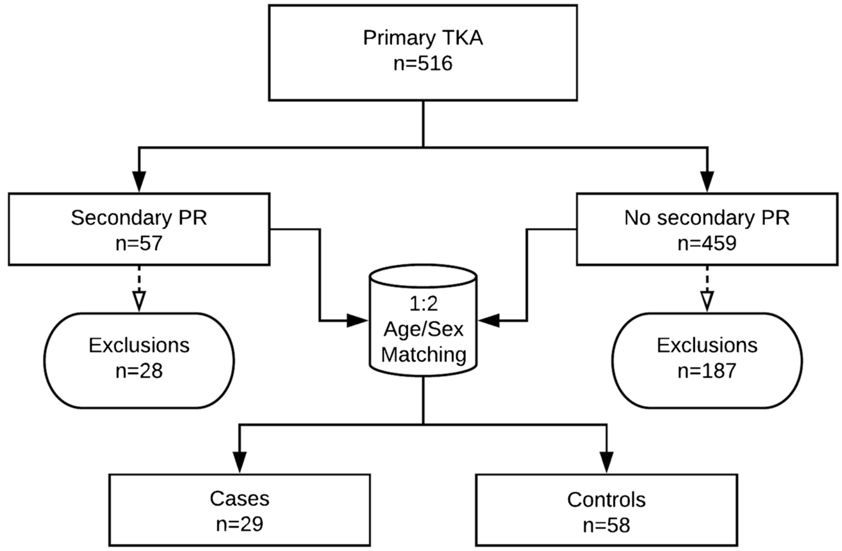

Fig. 1 Patient selection

30° flexion (Fig. 3) [20], and patella width and thickness (Fig. 4) as well as all reported measurement angles of the "Knee Society total knee arthroplasty roentgenographic evaluation and scoring system" (TKA-RESS) [21]. All radiographic measurements were carried out in post-operative standardized (reference body) control radiographs acquired after the index procedure (primary TKA) and rated independently by two blinded experienced orthopaedic surgeons.

Statistical analysis

Kaplan-Meyer analysis was used to visualize implant survival after primary TKA. Descriptive statistics have been calculated for all epidemiological and radiographic data. An unpaired *t* test with Welch's correction was used to directly compare case and control groups. Descriptive and nonparametric analyses

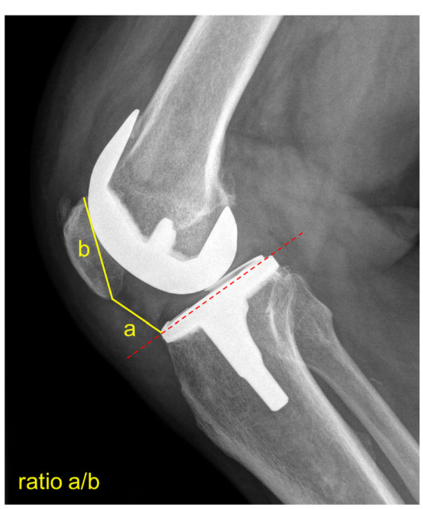

Fig. 2 Caton/Deschamps index: ratio (a/b) of anterior aspect of TKA tibial component to inferior point of patella back (a) and patella back inferior to superior (b)

were performed using Graph Pad Prism 6 (Graph Pad Inc., La Jolla, CA, USA). Pearson's bivariate correlation analysis was used to determine those independent variables ($r > 0.20$) that would possibly be suitable as predictors for the dependent study variable. Hence, binary logistic regression was performed to determine the significance of the assumed predictors. Correlative and regression analyses were performed using IBM SPSS Statistics 24.0 (IBM Corp., Armonk, NY, USA). Data are given as means ± standard deviation (SD) and ranges if not indicated otherwise. The level of significance was set at $p < 0.05$.

Results

No intra-operative complications could be recorded after index procedure. Early post-operative (< 4 weeks after surgery) complications included haematoma (cases $n = 1$; controls $n = 3$), with two of them requiring surgical evacuation (cases $n = 0$; controls $n = 2$). All patients were allowed immediate full

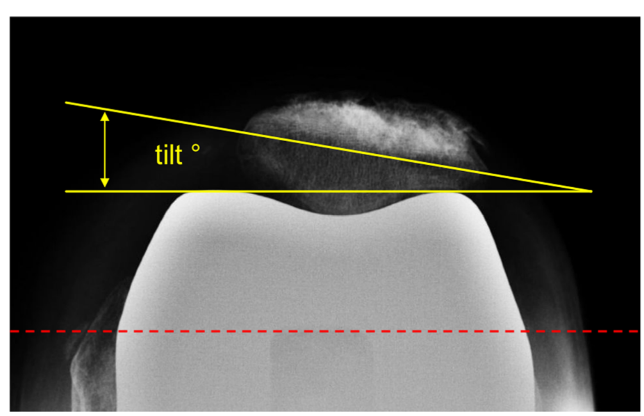

Fig. 3 Patella tilt in 30° flexion (tangential view of patella)

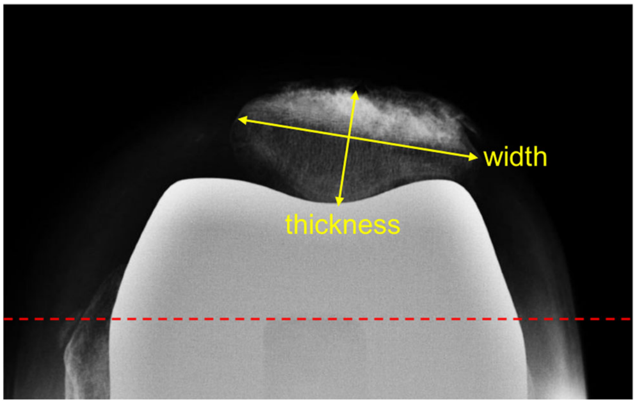

Fig. 4 Patella width and thickness in 30° flexion (tangential view of patella)

weight-bearing post-operatively. Mean hospitalization after index procedure was nine ± three days (range 5–17 days) in the case and ten ± four days (range 5–20 days) in the control group. Survival analysis comparing those patients that needed SPR (cases) with those that did not need revision surgery after primary TKA (controls) is shown in Fig. 5. Epidemiological characteristics and radiographic data of the patients are depicted in Table 2.

Correlation analysis yielded five promising predictors that were included in the regression model in a second step (Table 3). The binary logistic regression model used was significant (χ^2 = 70.15, p < 0.0001) and was able to correctly classify 88.5% of patients into case or control groups. It indicated that patella tilt, patella height, and thickness as well as the delta angle were significant predictors of a need for SPR following primary TKA, while beta angle did not yield significant results (Table 4). An increase in patellar width by 1 mm will increase the risk of SPR, while an increase in patellar thickness by 1 mm will reduce it. An increase in patellar tilt by 1° will also increase the risk of SPR. Finally, an increase in delta angle by 1° will again reduce the risk of SPR.

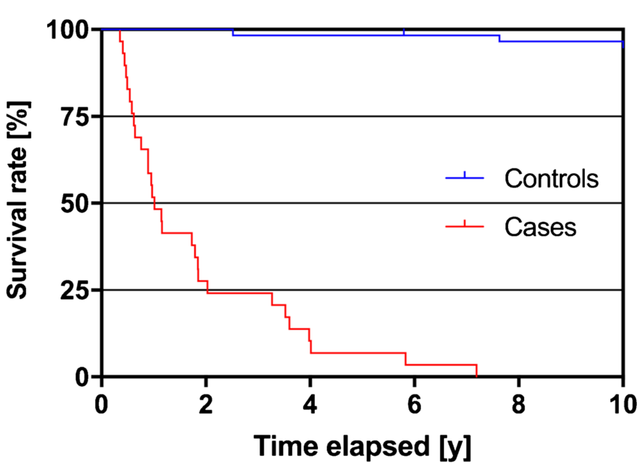

Fig. 5 Kaplan-Meier survivorship curve for case (TKA/SPR; red) and control (TKA; blue) groups. Implantation of SPR was chosen as the endpoint for the cases group, whereas revision surgery for other causes was chosen for the control group. Remarkably, around 75% of cases receive their revision and implantation of SPR within less than two years after the index procedure (primary TKA). The survivorship of the control group can be regarded in line with values reported in the literature [22]

Discussion

The most important finding of the present study is that patella tilt as well as its width and thickness as determined in skyline view knee plain radiographs is a possible predictor of SPR following primary TKA. Furthermore, the delta angle, which is, in some way, comparable to the posterior tibial slope in horizontal beam lateral knee plain radiographs, has also been recognized as a possible predictor regarding prior TKA component positioning. Thus, the primary hypothesis was accepted, while the secondary hypothesis had to be dismissed as intrinsic factors like BMI did not prove significant to predict the need for SPR in this model.

The search for possible predictors to identify those patients at risk of developing anterior knee pain following primary TKA, eventually needing SPR, has been going on since the development of the first TKA models. Surprisingly until today, there is little to no data on this topic and most surgeons tend to base their pre-operative decisions for or against primary PR on intuitive patient- or implant-related characteristics, although attempts have been made to standardize patellar referencing and cutting [23]. Well-preserved retropatellar cartilage or proper patellofemoral alignment and mechanics only being some of these highly subjective parameters have never been quantified in specially designed studies until today [1].

Table 2 Patient characteristics for cases (TKA/SPR) and matched 1:2 controls (TKA)

Independent variable	TKA/SPR N = 29	TKA N = 58	p
Age [year]	60.76 ± 11.85	60.76 ± 11.74	n.s.
Sex f/m [n]	20/9	40/18	n.s.
Weight [kg]	90.07 ± 13.76	91.72 ± 13.59	n.s.
Height [m]	1.70 ± 0.10	1.71 ± 0.12	n.s.
BMI [kg/m^2]	31.51 ± 5.96	31.88 ± 6.63	n.s.
Caton/Deschamps Index	0.87 ± 0.24	0.97 ± 0.24	n.s.
Patella width [mm]	50.49 ± 6.62	44.61 ± 5.90	0.0002
Patella thickness [mm]	19.20 ± 3.98	21.92 ± 2.12	0.0015
Patella tilt [°]	7.89 ± 5.48	3.50 ± 2.01	0.0002
Alpha angle [°]	99.84 ± 3.33	99.75 ± 2.96	n.s.
Beta angle [°]	91.17 ± 2.40	90.19 ± 1.02	0.0424
Gamma angle [°]	4.62 ± 4.58	3.27 ± 1.95	n.s.
Delta angle [°]	87.82 ± 6.62	93.39 ± 4.84	0.0002

Table 3 Correlation analysis to dependent variable (TKA/SPR)

Independent variable	*R*	*p*
BMI	− 0.028	n.s.
Caton/Deschamps Index	− 0.188	n.s.
Patella width [mm]	0.415	< 0.0001
Patella thickness [mm]	−0.412	< 0.0001
Patella tilt [°]	0.509	< 0.0001
Alpha angle [°]	0.013	n.s.
Beta angle [°]	0.279	0.009
Gamma angle [°]	0.206	n.s.
Delta angle [°]	−0.436	< 0.0001

Available studies exclusively focus on anterior knee pain or, in an even higher percentage of cases, on the underlying causes of PR failure only [24].

Different designs of trochlear grove in Genesis II implant did not have influence on the patella alignment, but on the patella tilt and mediolateral translation. Tilting angles would be reduced with an increase in height of the lateral trochlear grove margin. Consequently, kinematics were improved, leading to the assumption that a containment of patellar tracking is essential to reduce early cartilage wear after TKA [5]. The Genesis II TKA has been shown to generate highest patellofemoral contact area as compared to different trochlear design modifications, thus allowing an improved patella tracking. No significant differences could be shown with regard to peak pressures [5]. Restoration of the native femoral patellar groove with its high norm variance does not seem to be achievable with one implant type coming in different sizes only, as the geometry and multifactorial anatomical composition of the patellofemoral complex cannot be addressed. This could again empower the arguments for an individualized approach in primary TKA, as has been proposed earlier. As for the different types of coupling that have been included in the present study, it has to be stated that a recent meta-analysis did not find any significant differences between CR and much higher constrained PS designs regarding post-operative pain [25]. Due to the relatively small amount of CC and PS designs in both groups, we opted against sub-group analyses in this study.

Table 4 Binary logistic regression model

Assumed predictor	OR	CI 95%	*p*
Patella width [mm]	1.489	1.153–1.922	0.002
Patella thickness [mm]	0.527	0.361–0.769	0.001
Patella tilt [°]	1.429	1.092–1.870	0.009
Beta angle [°]	1.020	0.597–1.745	n.s.
Delta angle [°]	0.830	0.721–0.957	0.010

In the present study, the female/male ratio was around 2:1, being in concordance with recent literature although relatively high variations may apply even up to a ratio of 5:1 [26, 27].

BMI, due to its unfavorable impact on force distributions and peak loads and thus cartilage wear, did not have a significant influence on the need for SPR after primary TKA. This finding is supported by previous other clinical studies on the same topic [28, 29].

Patellar height in the sagittal plane, as determined by the Caton/Deschamps Index, did not prove to be a predictor for SPR in this set of patients, although it has to be agreed that alterations to this parameter might also influence other important surrogates and therefore have to be considered prior to surgery. Literature provides several hypotheses to this approach but fails to deliver a clear solution, due to an abundance of several scenarios and assessment methods for sagittal patellar height [30]. Width and thickness of the patella, however, have been shown to be predictors for SPR in the present study. Various other studies indirectly support these findings, however being conducted in regard of different research questions [31, 32]. Increasing width corresponds with maltracking and thus also indirectly with tilting, which leads to pathologic biomechanics and early, often unilateral, cartilage wear—despite SPR commonly treated with patellar facetectomy [33]. Reduced thickness—also predicting secondary SPR—will lead to reduced patellofemoral contact pressures and a loss of containment that subsequently will also end up in patellofemoral instability and associated anterior knee pain. Atraumatic patellar instability after TKA, especially without pain, may have several other secondary causes like an increased gamma angle or a trend towards external rotations of the tibial component [34]. Surgeons performing primary TKA often struggle with the question how much of the damaged patellar surface to resect or how to perform finishing [33]. Therefore, the width/thickness ratio as determined by CT has been proposed as a measurement to estimate the optimal resection height resected—according to these findings, freehand resection should be avoided as it produces largely variable results [31].

Patellar tilt appears to be a good predictor of SPR. This finding is, in part, supported by investigations by Scheurer et al. showing a correlation between the tilting on plain radiographs following SPR and overall patient satisfaction, demonstrating also a subjective experience of patella maltracking [29]. Either way, with or without PR, an imbalance of the different actors in the patellofemoral complex seems to be responsible for this problem, possibly influenced or aggravated by other variables found in the present study.

The delta or sagittal tibial angle as proposed in the TKA-RESS by the Knee Society in 1989 [21] describes the angle between the sagittal tibial axis and the tibial TKA component. Thus, it has a direct proportional connection to the posterior tibial slope measured in native knee joints. As the Genesis II system generally has 4° of slope within its articular insert and 3° of slope built into the tibial cutting block, the resulting 7° of slope are usually within acceptable ranges for TKA [35]. Increasing slopes may result in decreased posterior cruciate ligament (PCL) forces, while decreasing slopes may increase the PCL force and thus allow more tibial ap-translation, eventually also increasing the patellofemoral forces. Given the results of the present study, delta angles of ~88° (TKA/SPR) equal an actual slope of 5° whereas ~93° (TKA) equal an actual slope of 0°. Biomechanical and kinematic results by Marra et al. [36] indicate a gradual significant reduction in patellofemoral contact forces with a slope increase from −3° to 9°. This leads to the assumption that insufficient patellar tracking (and thus tilting) may contribute more to the development of anterior knee pain and subsequent SPR than does sheer peak contact force.

The present study also has some limitations. Its design as a retrospective case-control study does not generate the most consistent results; however, the research question hardly allows a prospective study due to the limited number of available cases. For this reason, we also performed a 1:2 age/sex matching to at least minimally improve overall power. Moreover, the present study compared primary TKA with or without SPR to trace back possible predictors that might even be helpful before the initial TKA. To prove these predictors, a secondary study comparing pre-operative states between both groups would be desirable, but again will be hard to conduct. Secondly, a correlation of clinical parameters regarding anterior knee pain and post-operative outcomes would be desirable. Unfortunately, those parameters were not reported consistently within clinical records and thus had to be excluded. Three-dimensional imaging (i.e. CT) was only available for around 20% of all patients, which led to an exclusion of a correlation to plain radiographic parameters, even though this would have been desirable. But with plain radiographs still being the most important diagnostic tool in the indication of primary TKA besides history taking and clinical assessment, the present study is able to highlight the most important features to examine to estimate surgical outcomes.

Retrospective long-term studies (> 10 years) have shown no significant differences between TKA with or without primary PR regarding clinical outcome as well as radiographic features [37]. However, this collective may be underpowering or even missing those patients exhibiting the above-named predictors that lead to secondary SPR in the first place. This example demonstrates the importance of a clear definition of the research question to be able to extrapolate results in the end.

In the end, it is to state that literature does not provide hard evidence to opt for primary PR in TKA [15]. Despite this, the present study at least helped to develop possible predictors for preoperative patient selection to avoid high revision rates due to the need for SPR in a certain patient population.

Conclusions

Easy and accessible radiographic measurements have been identified as possible predictors of SPR following primary TKA. Although indication for primary PR may still remain a controversial topic, a rationale has been proposed in this study to support surgeons in objectively estimating an individual patient's risk for SPR prior to primary TKA measuring the patella tilt, width, and thickness. Overmore, regarding surgical aspects of TKA, tibial component positioning has also been shown to be of importance to reduce the risk of SPR.

Acknowledgements The authors wish to thank Johannes Wagenhaeuser, MD, for his kind support in obtaining the radiographic datasets.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. For this type of study, formal consent is not required. Additional approval for this study was obtained from the institutional review board of our hospital (study no. 224/17).

References

1. Schindler OS (2012) The controversy of patellar resurfacing in total knee arthroplasty: Ibisne in medio tutissimus? Knee Surg Sports Traumatol Arthrosc 20:1227–1244. https://doi.org/10.1007/s00167-012-1985-7
2. Franck F, Ouanezar H, Jacquel A et al (2018) The predictive factors of secondary patellar resurfacing in computer-assisted total knee arthroplasty. A prospective cohort study. Int Orthop 42:1051–1060. https://doi.org/10.1007/s00264-017-3630-z
3. Wood DJ, Smith AJ, Collopy D et al (2002) Patellar resurfacing in total knee arthroplasty: a prospective, randomized trial. J Bone Joint Surg Am 84-A:187–193
4. Helmy N, Anglin C, Greidanus NV, Masri BA (2008) To resurface or not to resurface the patella in total knee arthroplasty. Clin Orthop Relat Res 466:2775–2783. https://doi.org/10.1007/s11999-008-0420-3
5. Leichtle UG, Lange B, Herzog Y et al (2017) Influence of different patellofemoral design variations based on Genesis II total knee endoprosthesis on patellofemoral pressure and kinematics. Appl Bionics Biomech 2017:5492383–5492310. https://doi.org/10.1155/2017/5492383
6. Lee GW, Lee S-M, Jang S-J, Son J-H (2013) The efficacy of patellar decompression for improving anterior knee pain following total knee arthroplasty without patellar resurfacing. Arch Orthop Trauma Surg 133:561–567. https://doi.org/10.1007/s00402-013-1702-0
7. Cerciello S, Robin J, Lustig S et al (2016) The role of patelloplasty in total knee arthroplasty. Arch Orthop Trauma Surg 136:1607–1613. https://doi.org/10.1007/s00402-016-2577-7
8. Waters TS, Bentley G (2003) Patellar resurfacing in total knee arthroplasty. A prospective, randomized study. J Bone Joint Surg Am 85-A:212–217

9. Popovic N, Lemaire R (2003) Anterior knee pain with a posterior-stabilized mobile-bearing knee prosthesis: the effect of femoral component design. J Arthroplast 18:396–400
10. Petersen W, Rembitzki IV, Brüggemann G-P et al (2014) Anterior knee pain after total knee arthroplasty: a narrative review. Int Orthop 38:319–328. https://doi.org/10.1007/s00264-013-2081-4
11. Enis JE, Gardner R, Robledo MA et al (1990) Comparison of patellar resurfacing versus nonresurfacing in bilateral total knee arthroplasty. Clin Orthop Relat Res 260:38–42
12. Pavlou G, Meyer C, Leonidou A et al (2011) Patellar resurfacing in total knee arthroplasty: does design matter? A meta-analysis of 7075 cases. J Bone Joint Surg Am 93:1301–1309. https://doi.org/10.2106/JBJS.J.00594
13. Werth L, Saffarini M, Amsler F et al (2017) The need for secondary resurfacing is affected by trochlear height in total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 25:3818–3823. https://doi.org/10.1007/s00167-016-4319-3
14. Nizard RS, Biau D, Porcher R et al (2005) A meta-analysis of patellar replacement in total knee arthroplasty. Clin Orthop Relat Res 436:196–203
15. Pilling RWD, Moulder E, Allgar V et al (2012) Patellar resurfacing in primary total knee replacement: a meta-analysis. J Bone Joint Surg Am 94:2270–2278. https://doi.org/10.2106/JBJS.K.01257
16. Pakos EE, Ntzani EE, Trikalinos TA (2005) Patellar resurfacing in total knee arthroplasty. A meta-analysis. J Bone Joint Surg Am 87:1438–1445. https://doi.org/10.2106/JBJS.D.02422
17. Li S, Chen Y, Su W et al (2011) Systematic review of patellar resurfacing in total knee arthroplasty. Int Orthop 35:305–316. https://doi.org/10.1007/s00264-010-1109-2
18. van Hemert WLW, Senden R, Grimm B et al (2009) Patella retention versus replacement in total knee arthroplasty; functional and clinimetric aspects. Arch Orthop Trauma Surg 129:259–265. https://doi.org/10.1007/s00402-008-0640-8
19. Caton J (1989) Method of measuring the height of the patella. Acta Orthop Belg 55:385–386
20. Grelsamer RP, Bazos AN, Proctor CS (1993) Radiographic analysis of patellar tilt. J Bone Joint Surg (Br) 75:822–824
21. Ewald FC (1989) The knee society total knee arthroplasty roentgenographic evaluation and scoring system. Clin Orthop Relat Res 248:9–12
22. McCalden RW, Hart GP, MacDonald SJ et al (2017) Clinical results and survivorship of the GENESIS II total knee arthroplasty at a minimum of 15 years. J Arthroplast 32:2161–2166. https://doi.org/10.1016/j.arth.2017.02.006
23. Assi C, Kheir N, Samaha C et al (2017) Optimizing patellar positioning during total knee arthroplasty: an anatomical and clinical study. Int Orthop 41:2509–2515. https://doi.org/10.1007/s00264-017-3557-4
24. Calvisi V, Camillieri G, Lupparelli S (2009) Resurfacing versus nonresurfacing the patella in total knee arthroplasty: a critical appraisal of the available evidence. Arch Orthop Trauma Surg 129:1261–1270. https://doi.org/10.1007/s00402-008-0801-9
25. Li N, Tan Y, Deng Y, Chen L (2014) Posterior cruciate-retaining versus posterior stabilized total knee arthroplasty: a meta-analysis of randomized controlled trials. Knee Surg Sports Traumatol Arthrosc 22:556–564. https://doi.org/10.1007/s00167-012-2275-0
26. Muñoz-Mahamud E, Popescu D, Nuñez E et al (2011) Secondary patellar resurfacing in the treatment of patellofemoral pain after total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 19:1467–1472. https://doi.org/10.1007/s00167-011-1402-7
27. Daniilidis K, Vogt B, Gosheger G et al (2012) Patellar resurfacing as a second stage procedure for persistent anterior knee pain after primary total knee arthroplasty. Int Orthop 36:1181–1183. https://doi.org/10.1007/s00264-011-1463-8
28. Parvizi J, Mortazavi SMJ, Devulapalli C et al (2012) Secondary resurfacing of the patella after primary total knee arthroplasty does the anterior knee pain resolve? J Arthroplast 27:21–26. https://doi.org/10.1016/j.arth.2011.04.027
29. Scheurer P, Reininga IHF, van Jonbergen H-PW, van Raay JJAM (2015) Secondary patellar resurfacing following total knee arthroplasty: a cohort study in fifty-eight knees with a mean follow-up of thirty one months. Int Orthop 39:1301–1306. https://doi.org/10.1007/s00264-015-2684-z
30. Prudhon JL, Caton JH, Aslanian T, Verdier R (2018) How is patella height modified after total knee arthroplasty? Int Orthop 42:311–316. https://doi.org/10.1007/s00264-017-3539-6
31. Huang A-B, Luo X, Song C-H et al (2015) Comprehensive assessment of patellar morphology using computed tomography-based three-dimensional computer models. Knee 22:475–480. https://doi.org/10.1016/j.knee.2015.05.010
32. Huang A-B, Qi Y-S, Song C-H et al (2016) Novel customized template designing for patellar resurfacing in total knee arthroplasty. J Orthop Res 34:1798–1803. https://doi.org/10.1002/jor.23200
33. Pagenstert G, Seelhoff J, Henninger HB et al (2014) Lateral patellar facetectomy and medial reefing in patients with lateral facet syndrome after patellar-retaining total knee arthroplasty. J Arthroplast 29:2156–2162. https://doi.org/10.1016/j.arth.2014.06.014
34. Nedopil AJ, Howell SM, Hull ML (2017) What clinical characteristics and radiographic parameters are associated with patellofemoral instability after kinematically aligned total knee arthroplasty? Int Orthop 41:283–291. https://doi.org/10.1007/s00264-016-3287-z
35. Hernigou P, Deschamps G (2004) Posterior slope of the tibial implant and the outcome of unicompartmental knee arthroplasty. J Bone Joint Surg Am 86-A:506–511
36. Marra MA, Strzelczak M, Heesterbeek PJC et al (2018) Anterior referencing of tibial slope in total knee arthroplasty considerably influences knee kinematics: a musculoskeletal simulation study. Knee Surg Sports Traumatol Arthrosc 26:1540–1548. https://doi.org/10.1007/s00167-017-4561-3
37. Ogon M, Hartig F, Bach C et al (2002) Patella resurfacing: no benefit for the long-term outcome of total knee arthroplasty. A 10- to 16.3-year follow-up. Arch Orthop Trauma Surg 122:229–234. https://doi.org/10.1007/s00402-001-0364-5