Knee Surg Sports Traumatol Arthrosc
DOI 10.1007/s00167-015-3733-2

KNEE

A matched-pair comparison of inlay and onlay trochlear designs for patellofemoral arthroplasty: no differences in clinical outcome but less progression of osteoarthritis with inlay designs

Matthias J. Feucht[1,2] · Matthias Cotic[1] · Knut Beitzel[1] · Julia F. Baldini[1] · Gebhart Meidinger[1,3] · Philip B. Schöttle[1,4] · Andreas B. Imhoff[1]

Received: 22 March 2015 / Accepted: 23 July 2015

Abstract
Purpose To compare clinical and radiographic results after isolated patellofemoral arthroplasty (PFA) using either a second-generation inlay or onlay trochlear design. The hypothesis was that an inlay design will produce better clinical results and less progression of tibiofemoral osteoarthritis (OA) compared to an onlay design.
Methods Fifteen consecutive patients undergoing isolated PFA with an onlay design trochlear component (Journey™ PFJ, Smith & Nephew) were matched with 15 patients after isolated PFA with an inlay design trochlear component (HemiCAP® Wave, Arthrosurface). Matching criteria were age, gender, body mass index, and follow-up period. An independent observer evaluated patients prospectively, whereas data were compared retrospectively. Clinical outcome was assessed using WOMAC, Lysholm score, and pain VAS. Kellgren–Lawrence grading was used to assess progression of tibiofemoral OA.
Results Conversion to total knee arthroplasty was necessary in one patient within each group, leaving 14 patients per group for final evaluation. The mean follow-up was 26 months in the inlay group and 25 months in the onlay group (n.s.). Both groups displayed significant improvements of all clinical scores ($p < 0.05$). No significant differences were found between the two groups with regard to the clinical outcome and reoperation rate. No significant progression of tibiofemoral OA was observed in the inlay group, whereas 53 % of the onlay group showed progression of medial and/or lateral tibiofemoral OA ($p = 0.009$).
Conclusion Isolated PFA using either a second-generation inlay or onlay trochlear component significantly improves functional outcome scores and pain. The theoretical advantages of an inlay design did not result in better clinical outcome scores; however, progression of tibiofemoral OA was significantly less common in patients with an inlay trochlear component. This implant design may therefore improve long-term results and survival rates after isolated PFA.
Level of evidence III.

Keywords Patellofemoral arthritis · Patellofemoral arthroplasty · Inlay · Onlay · HemiCAP Wave · Journey PFJ

Matthias J. Feucht and Matthias Cotic have contributed equally to this work and share first authorship.

✉ Andreas B. Imhoff
a.imhoff@lrz.tum.de; A.Imhoff@lrz.tu-muenchen.de

1 Department of Orthopaedic Sports Medicine, Technical University Munich, Ismaninger Str. 22, 81675 Munich, Germany

2 Department of Orthopedic Surgery and Traumatology, Freiburg University Hospital, Freiburg, Germany

3 Department of Trauma and Orthopaedic Surgery, Trauma Center Murnau, Murnau, Germany

4 Department of Orthopaedics and Trauma Surgery, Isar Medical Center, Munich, Germany

Introduction

Patellofemoral arthroplasty (PFA) has been used for more than 30 years [6, 37], but is still discussed controversial [27, 31, 35]. Poor clinical outcomes and high failure rates have led to a decline in popularity of PFA in the past [3, 6, 7, 12, 17, 26, 45, 46]. Drawbacks associated with the design of the trochlear component are believed to be the major reason for failures with early implants [31, 32, 35]. Since the introduction of new implant designs, PFA has

Published online: 01 August 2015

produced more consistent results and has regained importance in clinical practice [22, 28, 31, 32, 35, 47].

Currently available trochlear components can be divided into two groups: inlay and onlay designs [33–35]. Inlay design trochlear components are implanted flush with the surrounding cartilage after creation of a bone bed within the native trochlea. Onlay design trochlear components completely replace the anterior compartment by using the same anterior cut as known from total knee arthroplasty. Early inlay designs, also considered as first-generation implants, are associated with higher failure rates compared to second-generation onlay designs [3, 7, 26, 35, 43–45]. Therefore, onlay design trochlear components were considered the gold standard for several years [33–35]. However, with the introduction of a second-generation inlay design, which allows for individualized and anatomic trochlear resurfacing, a promising alternative implant became available [10, 14, 22, 42]. Theoretical advantages of more sophisticated inlay designs include less mechanical patellofemoral complications, increased implant stability, unaltered soft tissue tension and extensor mechanism, and less risk for overstuffing of the patellofemoral joint [10, 14, 22, 42]. However, no study so far has compared the outcomes of inlay and onlay design PFA. The purpose of this study was therefore to compare clinical and radiographic results after isolated PFA using either an inlay or onlay trochlear design of second-generation PFA. Based on the theoretical advantages of an inlay design, it was hypothesized that an inlay design will produce better clinical results and less progression of tibiofemoral osteoarthritis (OA) compared to an onlay design.

Materials and methods

Between February 2006 and September 2014, 118 patients were treated with PFA at one single institution (Department of Orthopaedic Sports Medicine, Technical University Munich, Germany). Indications for surgery were disabling noninflammatory patellofemoral OA (grade III–IV according to the Kellgren–Lawrence grading [23]) or chondrosis (grade III–IV according to Outerbridge [41]) refractory to conservative treatment and/or prior surgery [29, 30, 47]. Contraindications were symptomatic tibiofemoral OA with pain during activities of daily living, systematic inflammatory arthropathy, chondrocalcinosis, chronic regional pain syndrome, active infection, and fixed loss of knee motion [30, 47]. Relative contraindications for PFA were uncorrected patellofemoral instability, patellofemoral malalignment, and tibiofemoral malalignment. In those patients, PFA was combined with patellar stabilizing and/or realignment procedures [4, 27, 30, 47], according to an algorithm described in detail elsewhere [22]. For the purpose of this study, only patients who underwent isolated PFA were included ($n = 64$).

An onlay trochlear design (Journey™ PFJ, Smith & Nephew, Andover, MA, USA) was the standard implant for several years at our institution. However, with the introduction of a second-generation inlay trochlear design (HemiCAP® Wave, Arthrosurface, Franklin, MA, USA), the onlay design was subsequently replaced. In total, 15 patients received isolated implantation of the onlay design component between February 2006 and August 2008, and 49 patients received isolated implantation of the inlay design component between September 2008 and September 2014. Since the patients were not randomized preoperatively, a matched-pair analysis was conducted in order to minimize selection bias. Matching criteria were age (±5 years), gender, body mass index (±5 kg/m^2), and follow-up period (±3 months). The patient selection and matching process is shown in Fig. 1.

Implants and surgical technique

The inlay trochlear component used in this series was the HemiCAP® Wave Patellofemoral Resurfacing Prosthesis (Fig. 2). This system intends to replicate joint biomechanics by intraoperative joint surface mapping, three-dimensional socket reaming, and implantation of a matching, contoured trochlear inlay component. Eight different implants with varying offsets and radii of curvature are available [22].

Onlay PFA was performed with the Journey™ PFJ (Fig. 3). This implant intends to restore normal patellar tracking by an asymmetric design with a deepened and lateralized trochlear groove. Four different implant sizes are available for each site [4].

The surgical techniques for both implants have been described in detail elsewhere [4, 22]. We did not routinely resurface the patella. In our clinical practice, the patella is only resurfaced in patients with patellofemoral incongruence because of severe patellar dysplasia, focal osteonecrosis or osteolysis, and subchondral bone defects [24]. In this series, patellofemoral resurfacing was performed in five patients within each group (33 %). Post-operative rehabilitation was identical for both groups. Patients performed partial weight-bearing with 20 kg for 2 weeks, followed by progression of weight-bearing with 20 kg per week. Full range of motion was allowed immediately.

Clinical and radiographic evaluation

An independent observer who was not a participating surgeon followed all patients prospectively. The clinical outcome was evaluated using the WOMAC score [5], Lysholm score [36], and visual analogue scale for pain (pain VAS) [19]. The WOMAC score was assessed according to the

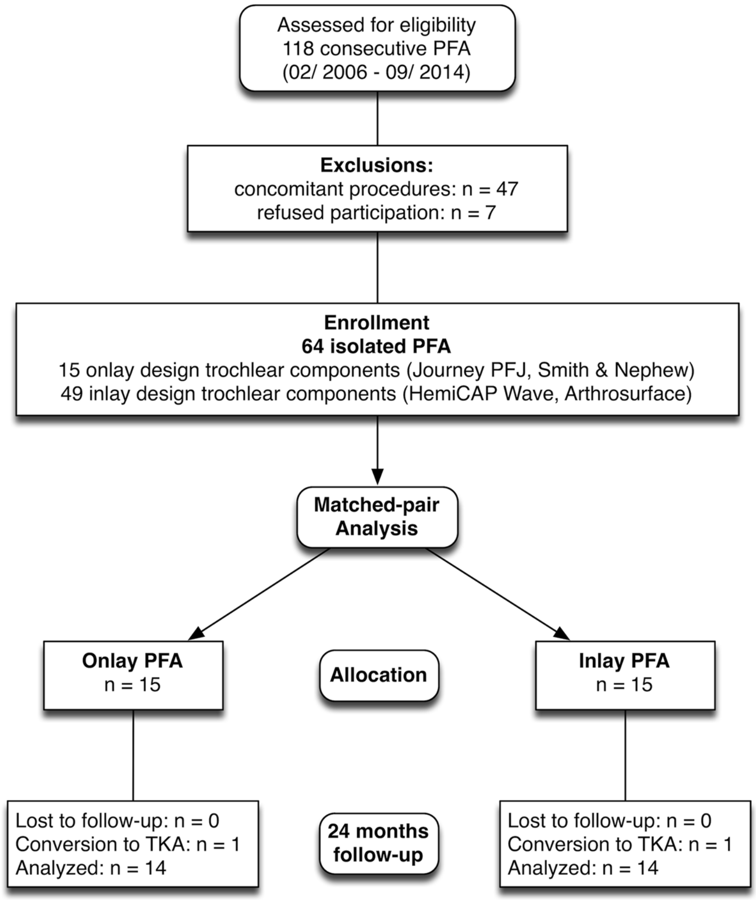

Fig. 1 Flow chart of the patient selection and matching process

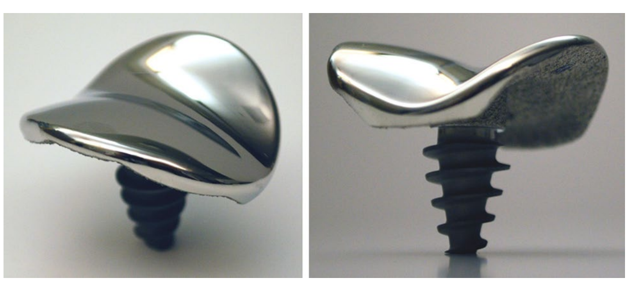

Fig. 2 Second-generation inlay trochlear design (HemiCAP® Wave, Arthrosurface, Franklin, MA, USA). Reprinted with kind permission from Arthrosurface

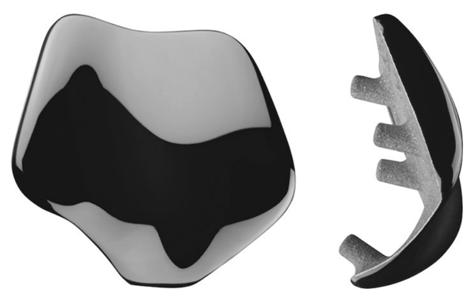

Fig. 3 Onlay trochlear design (Journey™ PFJ, Smith & Nephew, Andover, MA, USA). Reprinted with kind permission from Smith & Nephew

KOOS User's Guide (available at http://www.koos.nu/KOOSGuide2003.pdf). Standardized answer options were given as five Likert boxes, and each question got a score from 0 to 4. A normalized percentage score (100 indicating no problems and 0 indicating extreme problems) was calculated for each subscale. Radiographic evaluation was performed using the Picture Archiving and Communication System (PACS, Philips Medical Systems, Sectra Imtec AB, Sweden). Radiographs included weight-bearing anteroposterior view, true lateral view, and patellar skyline view. The Kellgren–Lawrence grading [23] was used to assess progression of tibiofemoral OA, and the Caton–Deschamps Index [11] was used to assess patellar height. In order to analyse and to compare the preoperative anatomy of the patellofemoral joint, the sulcus angle [9] and congruence angle [38] were measured on axial radiographs, the shape of the patella was graded according to Wiberg [48], and trochlear dysplasia was graded according to Dejour [16].

The study was approved by the institutional review board of the Technical University of Munich (registration number

Table 1 Patient characteristics and matching criteria

	Inlay	Onlay	Significance
Number of patients	15	15	n.s.
Gender distribution[#]			n.s.
Male	73 %	73 %	
Female	27 %	27 %	
Age (years)[#]	48 ± 8	49 ± 8	n.s.
Body mass index (kg/m^2)[#]	27 ± 3	27 ± 3	n.s.
Follow-up (months)[#]	26 ± 11	25 ± 10	n.s.
Surgical history of the ipsilateral knee joint			
Patellofemoral[a]	60 %	73 %	n.s.
Others[b]	20 %	7 %	n.s.
Trochlear dysplasia (Dejour classification)			n.s.
None	33 %	13 %	
Type A	33 %	80 %	
Type B	7 %	0 %	
Type C	13 %	7 %	
Type D	13 %	0 %	
Patellar shape (Wiberg classification)			n.s.
Type I	18 %	50 %	
Type II	73 %	50 %	
Type III	9 %	0 %	
Sulcus angle (°)	137 ± 10	140 ± 6	n.s.
Congruence angle (°)	2 ± 27	9 ± 18	n.s.
Patellar resurfacing	33 %	33 %	n.s.
Reoperations others than TKA[c]	13 %	13 %	n.s.
Conversion to TKA	7 %	7 %	n.s.

Values are given as percentage of the corresponding study group, or as mean ± SD

n.s. not significant, *kg/m²* kilograms per square metre, *TKA* total knee arthroplasty

[#] Matching criteria

[a] *Inlay group*: Cartilage debridement ($n = 6$), microfracturing ($n = 1$), osteochondral autologous transfer ($n = 1$), open reduction and internal fixation of a patellar fracture ($n = 1$); *Onlay group*: Cartilage debridement ($n = 7$), microfracturing ($n = 1$), osteochondral autologous transfer ($n = 1$), open reduction and internal fixation of a patellar fracture ($n = 2$)

[b] *Inlay group*: Partial resection of the medial meniscus ($n = 1$), partial resection of the lateral meniscus ($n = 1$), anterior cruciate ligament reconstruction ($n = 1$); *Onlay group*: Partial resection of the medial meniscus ($n = 1$)

[c] *Inlay group*: Implantation of a new trochlear component because of component disassembly ($n = 1$), lateral facetectomy of the patella because of lateral hyperpression syndrome ($n = 1$); *Onlay group*: Valgus high tibial osteotomy because of medial compartment pain ($n = 1$), debridement and irrigation because of superficial wound infection ($n = 1$)

419/13), and all patients gave their written informed consent to participate in this investigation.

Statistical analysis

Data were analysed using SPSS version 22.0 (IBM-SPSS, New York, USA). The nonparametric Wilcoxon test for two related samples was used to compare the pre- and postoperative values within each group. The nonparametric Mann–Whitney *U* test for independent samples was used to compare patient characteristics, follow-up, clinical scores, and radiographic data between the two groups. All statistical tests were performed two-sided. Statistical significance was considered at $p < 0.05$. An a priori power analysis was calculated with a difference of 30 points and a SD of 20 points in the Lysholm score. It established a sample size of eight patients per group with $\alpha = 0.05$ and a power of 80 %.

Results

The detailed patient characteristics of both groups are provided in Table 1. Based on the matched-pair design of the study, no significant differences were found between the two groups for gender, age, body mass index, and follow-up period. In addition, no significant group differences were found for the preoperative anatomy of the patellofemoral joint (sulcus angle, congruence angle, trochlear dysplasia according to Dejour, and patellar shape according to Wiberg), previous knee surgery, number of patients with patellar resurfacing, and reoperations during the study period. One patient within each group was revised to a total knee arthroplasty during the follow-up period and subsequently excluded from the clinical and radiographic evaluation. Therefore, 14 patients in each group were available for final follow-up (Fig. 1).

Clinical results

The detailed results of the clinical scores are shown in Tables 2 and 3. In both groups, statistically significant improvements ($p < 0.05$) of all analysed scores were observed. In addition, both groups displayed significant improvements of all WOMAC subscales. At final follow-up, no statistically significant difference was found between the two groups for any score. In addition, no significant difference was found when the delta between preoperative and follow-up values was compared between the two groups.

Table 2 Results of the Lysholm score and pain VAS

	Inlay	Onlay	Significance
Pain VAS			
Preoperative	6 ± 2	8 ± 2	$p = 0.016$
Follow-up	4 ± 3#	4 ± 3#	n.s.
Delta	3 ± 3	4 ± 3	n.s.
Lysholm score			
Preoperative	34 ± 11	32 ± 20	n.s.
Follow-up	66 ± 23#	57 ± 22#	n.s.
Delta	33 ± 25	25 ± 27	n.s.

Values are given as mean ± SD

Delta describes the difference between preoperative and follow-up values

n.s. not significant, *VAS* visual analogue scale

Statistically significant improvement compared to preoperative ($p < 0.05$)

Table 3 Results of the WOMAC score

	Inlay	Onlay	Significance
WOMAC pain			
Preoperative	57 ± 18	48 ± 24	n.s.
Follow-up	75 ± 19#	79 ± 22#	n.s.
Delta	18 ± 26	31 ± 25	n.s.
WOMAC stiffness			
Preoperative	49 ± 21	56 ± 22	n.s.
Follow-up	70 ± 24#	70 ± 17#	n.s.
Delta	21 ± 24	14 ± 22	n.s.
WOMAC function			
Preoperative	66 ± 14	52 ± 25	n.s.
Follow-up	80 ± 19#	79 ± 19#	n.s.
Delta	14 ± 21	26 ± 22	n.s.
WOMAC overall			
Preoperative	63 ± 14	51 ± 24	n.s.
Follow-up	78 ± 18#	78 ± 19#	n.s.
Delta	15 ± 21	26 ± 22	n.s.

Values are given as mean ± SD

Delta describes the difference between preoperative and follow-up values

n.s. not significant

Statistically significant improvement compared to preoperative ($p < 0.05$)

Radiographic results

The detailed radiographic results are shown in Table 4. None of the patients in the inlay group showed progression of tibiofemoral OA. In contrast, the onlay group showed significant progression of tibiofemoral OA in the medial ($p = 0.008$) and lateral ($p = 0.046$) compartment, with 53 % of the patients showing progression of medial and/or lateral tibiofemoral OA ($p = 0.009$). Comparing the delta between preoperative and follow-up values of both groups, the onlay group showed a significantly higher delta in the medial compartment compared to the inlay group ($p = 0.024$). With regard to patellar height, no significant difference between pre- and post-operative was found in the inlay group, whereas a small but statistically significant decrease in patellar height was found in the onlay group ($p = 0.022$).

Discussion

The main finding of the present study was that isolated PFA using either a second-generation inlay or onlay trochlear design significantly improves functional outcome scores and pain, without significant differences between both implants. However, progression of tibiofemoral OA was significantly more common in patients with an onlay trochlear design.

Outcomes of PFA are mainly influenced by patient selection, surgical technique, and design features of the trochlear component. Early failures of PFA are usually related to patellar maltracking or instability, whereas long-term failures are mainly the result of progressive tibiofemoral OA [8, 13, 33]. Based on the current knowledge, early failures are mainly related to problems associated with the design of the trochlear component [6, 26, 29, 31, 32, 45]. First-generation trochlear components were characterized by an inlay design, which replaced the worn cartilage without addressing the subchondral bone. These implants were associated with poor clinical results and high failure rates [3, 7, 26, 35, 43–45]. Attempts to improve the success rates of PFA have led to the development of second-generation trochlear components, which are grossly characterized by an onlay design [35, 44, 47]. These implants are based on the trochlear cuts of total knee arthroplasty, replacing the entire anterior trochlear surface [35]. In general, good short- and medium-term results with low failure rates can be expected with currently available onlay design trochlear components [1, 2, 4, 28, 40]. In a recent review article, Lonner and Bloomfield [33] summarized the results of PFA and concluded that onlay-style trochlear prostheses are associated with lower revision rates and higher functional success rates compared to first-generation inlay-style prostheses. According to Lonner and Bloomfield [33], high success rates and good functional outcomes are more easily achievable with contemporary onlay designs. However, implantation of onlay design components is also associated with specific problems: Since an intramedullary rod guides the anterior femoral cut, malpositioning of the intramedullary guiding in a flexed or extended position increases the risk of patella catching (Fig. 4a, b). Depending on the thickness of the implant and amount of bone resection, an onlay design may overstuff the patellofemoral joint, leading to increased patellofemoral loads and soft tissue irritation (Fig. 4c) [18, 21, 39]. Furthermore, a too broad component with medial or lateral overhang may cause soft tissue impingement and limited range of motion [32].

Design improvements of PFA not only led to the introduction of onlay design components, but also to the development of improved inlay designs. In the authors' opinion,

Table 4 Radiographic results. Kellgren–Lawrence grading is given as median (interquartile range); progression of tibiofemoral OA is given as number of patients (percentage of the corresponding study group); Caton–Deschamps Index is given as mean ± SD

	Inlay	Onlay	Significance
KL medial			
Preoperative	2 (1–2)	2 (1–2)	n.s.
Follow-up	2 (1–2)	2 (2–3)#	n.s.
Delta	0 (0–0)	1 (0–1)	$p = 0.024$
KL lateral			
Preoperative	2 (1–2)	1 (1–2)	n.s.
Follow-up	2 (1–2)	2 (1–2)#	n.s.
Delta	0 (0–0)	0 (0–1)	n.s.
Progression of tibiofemoral OA			
Medial	0 (0 %)	7 (47 %)	$p = 0.024$
Lateral	0 (0 %)	4 (27 %)	n.s.
Medial and/or lateral	0 (0 %)	8 (53 %)	$p = 0.009$
CDI			
Preoperative	0.9 ± 0.2	1.0 ± 0.1	n.s.
Follow-up	0.9 ± 0.2	0.9 ± 0.2#	n.s.
Delta	0.0 ± 0.1	−0.1 ± 0.1	n.s.

Delta describes the difference between preoperative and follow-up values

KL Kellgren–Lawrence, *CDI* Caton–Deschamps Index, *n.s.* not significant

Statistically significant difference compared to preoperative ($p < 0.05$)

these prostheses must also be considered as second-generation implants. One example of second-generation inlay PFA is the HemiCAP® Wave prosthesis. This system uses intraoperative joint surface mapping, three-dimensional socket reaming, and implantation of contoured inlay components in order to more closely reproduce the geometry of the distal femur. Different trochlear components with varying offsets allow for individualized and anatomic trochlear resurfacing. Potential advantages of an inlay design prosthesis include less removal of bone (Fig. 4d), increased intrinsic implant stability, unaltered soft tissue tension and extensor mechanism, and less risk for overstuffing of the patellofemoral joint [10, 14, 42].

The present study is the first that directly compared second-generation inlay and onlay trochlear designs for PFA. Both implants significantly improved functional outcome scores and pain, without significant differences between both groups. In addition, no significant difference between both implants was found with regard to the reoperation rate, which was low in both groups. None of the patients with an inlay component required reoperation because of patellofemoral maltracking or mechanical patellofemoral complications such as catching, snapping, or clunking. We therefore conclude that the development of the second-generation inlay component used in the present study has resolved design-specific complications of first-generation inlay designs and can be considered a valuable alternative to currently used onlay designs, with the theoretical advantages of an inlay design component.

Progression of tibiofemoral OA is the most common reason for the failure of PFA using modern prosthetic designs [13, 25, 44]. An interesting finding of the present study was that none of the patients with an inlay component showed progression of tibiofemoral OA, whereas more than half of the patients in the onlay group demonstrated progression of medial and/or lateral tibiofemoral OA. The true reason for this observation remains unknown; however, one hypoth-esis is that the more anatomic approach of the inlay design better reproduces the complex kinematics of the patel-lofemoral joint. Soft tissue irritation due to overstuffing

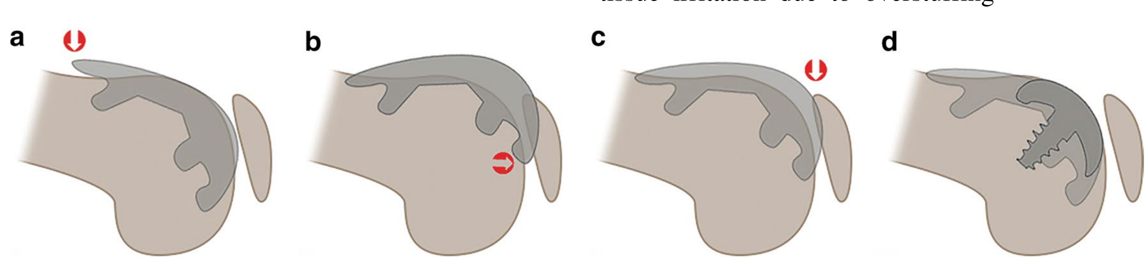

Fig. 4 Problems associated with onlay design trochlear components for patellofemoral arthroplasty. **a** A flexed intramedullary guidance increases the risk of patella catching from extension to flexion; **b** An extended intramedullary guidance increases the risk of patella catching from flexion to extension, and the risk of anterior notching; **c** Risk of anterior overstuffing; **d** Increased bone loss after onlay in comparison with inlay design components

of the patellofemoral joint with an onlay component may cause persistent synovitis, which is a well-known risk factor for the development and progression of OA due to secretion of pro-inflammatory cytokines [15]. Whether an inlay design component also prevents progression of tibiofemoral OA over a longer follow-up period remains unknown.

A specific pitfall of inlay design components is that rotation of the prosthesis is determined by the rotation of the distal femur. In patients with significant internal rotation, isolated inlay PFA may result in patellar maltracking and instability because of an internally rotated trochlear component. In our clinical practice, we therefore combine inlay PFA with a supracondylar femoral derotation osteotomy if femoral antetorsion exceeds 20° [20, 22]. On the other hand, when using an onlay design prosthesis, rotation of the trochlear component is determined by the surgeon, and internal rotation of the distal femur can be corrected to some degree by placing the femoral component in external rotation. An onlay design component might therefore be beneficial in patients with minor rotational malalignment to avoid femoral osteotomy. In addition, an onlay design component might be considered in patients with high-grade trochlear dysplasia, since positioning of an inlay prosthesis can be difficult in such cases, especially for inexperienced surgeons. However, we also use inlay PFA in patients with type C and D dysplasia, and did not observe specific complications so far.

This study has several limitations. First, only a small number of patients were investigated. Despite a relatively large number of PFA performed at our institution, only a small group of patients fulfilled the inclusion criteria. In our clinical practice, PFA is performed with concomitant realignment or stabilizing procedures in about half of the cases. Since the purpose of this study was to compare different trochlear components, only patients with isolated PFA were included. Second, the follow-up is relatively short, and therefore, the long-term outcomes of both prostheses remain unknown. However, since implant-related failures are commonly observed in the early post-operative phase, we believe that the follow-up period was adequate to compare different implants. Third, patients were not randomized preoperatively, and therefore, this study does not provide the highest level of evidence. Nevertheless, a matched-pair design was chosen to achieve adequate comparability by minimizing confounding factors.

With regard to the clinical relevance of the present study, our results suggest that good functional outcome can be achieved with both implant designs. However, given the lower progression of tibiofemoral OA seen in patients with an inlay trochlear component, this implant design may improve long-term results and survival rates after isolated PFA.

Conclusion

Isolated PFA using either a second-generation inlay or onlay trochlear design significantly improves functional outcome scores and pain. The theoretical advantages of an inlay design did not result in better clinical outcome scores compared to an onlay design. However, progression of tibiofemoral OA was significantly less common in patients with an inlay trochlear component.

Compliance with ethical standards

Conflict of interest A. B. Imhoff and P. B. Schöttle are consultants for Arthrosurface. The company had no influence on study design, data collection, and interpretation of the results or the final manuscript.

References

1. Ackroyd CE, Chir B (2005) Development and early results of a new patellofemoral arthroplasty. Clin Orthop Relat Res 436:7–13
2. Ackroyd CE, Newman JH, Evans R, Eldridge JD, Joslin CC (2007) The Avon patellofemoral arthroplasty: five-year survivorship and functional results. J Bone Joint Surg Br 89(3):310–315
3. Arciero RA, Toomey HE (1988) Patellofemoral arthroplasty. A three- to nine-year follow-up study. Clin Orthop Relat Res 236:60–71
4. Beitzel K, Schottle PB, Cotic M, Dharmesh V, Imhoff AB (2013) Prospective clinical and radiological two-year results after patellofemoral arthroplasty using an implant with an asymmetric trochlea design. Knee Surg Sports Traumatol Arthrosc 21(2):332–339
5. Bellamy N, Buchanan WW, Goldsmith CH, Campbell J, Stitt LW (1988) Validation study of WOMAC: a health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of the hip or knee. J Rheumatol 15(12):1833–1840
6. Blazina ME, Fox JM, Del Pizzo W, Broukhim B, Ivey FM (1979) Patellofemoral replacement. Clin Orthop Relat Res 144:98–102
7. Board TN, Mahmood A, Ryan WG, Banks AJ (2004) The Lubinus patellofemoral arthroplasty: a series of 17 cases. Arch Orthop Trauma Surg 124(5):285–287
8. Borus T, Brilhault J, Confalonieri N, Johnson D, Thienpont E (2014) Patellofemoral joint replacement, an evolving concept. Knee 21(Suppl 1):S47–S50
9. Brattstroem H (1964) Shape of the intercondylar groove normally and in recurrent dislocation of patella. A clinical and X-ray-anatomical investigation. Acta Orthop Scand Suppl 68(SUPPL 68):61–148
10. Cannon A, Stolley M, Wolf B, Amendola A (2008) Patellofemoral resurfacing arthroplasty: literature review and description of a novel technique. Iowa Orthop J 28:42–48
11. Caton J, Deschamps G, Chambat P, Lerat JL, Dejour H (1982) Patella infera. Apropos of 128 cases. Rev Chir Orthop Reparatrice Appar Mot 68(5):317–325
12. Charalambous CP, Abiddin Z, Mills SP, Rogers S, Sutton P, Parkinson R (2011) The low contact stress patellofemoral replacement: high early failure rate. J Bone Joint Surg Br 93(4):484–489
13. Dahm DL, Kalisvaart MM, Stuart MJ, Slettedahl SW (2014) Patellofemoral arthroplasty: outcomes and factors associated

with early progression of tibiofemoral arthritis. Knee Surg Sports Traumatol Arthrosc 22(10):2554–2559
14. Davidson PA, Rivenburgh D (2008) Focal anatomic patellofemoral inlay resurfacing: theoretic basis, surgical technique, and case reports. Orthop Clin North Am 39(3):337–346
15. de Lange-Brokaar BJ, Ioan-Facsinay A, van Osch GJ, Zuurmond AM, Schoones J, Toes RE, Huizinga TW, Kloppenburg M (2012) Synovial inflammation, immune cells and their cytokines in osteoarthritis: a review. Osteoarthr Cartil 20(12):1484–1499
16. Dejour H, Walch G, Nove-Josserand L, Guier C (1994) Factors of patellar instability: an anatomic radiographic study. Knee Surg Sports Traumatol Arthrosc 2(1):19–26
17. Dy CJ, Franco N, Ma Y, Mazumdar M, McCarthy MM, Della Valle AG (2012) Complications after patello-femoral versus total knee replacement in the treatment of isolated patello-femoral osteoarthritis A meta-analysis. Knee Surg Sports Traumatol Arthrosc 20(11):2174–2190
18. Ghosh KM, Merican AM, Iranpour F, Deehan DJ, Amis AA (2009) The effect of overstuffing the patellofemoral joint on the extensor retinaculum of the knee. Knee Surg Sports Traumatol Arthrosc 17(10):1211–1216
19. Gould D, Kelly D, Goldstone L, Gammon J (2001) Examining the validity of pressure ulcer risk assessment scales: developing and using illustrated patient simulations to collect the data. J Clin Nurs 10(5):697–706
20. Hinterwimmer S, Minzlaff P, Saier T, Niemeyer P, Imhoff AB, Feucht MJ (2014) Biplanar supracondylar femoral derotation osteotomy for patellofemoral malalignment: the anterior closed-wedge technique. Knee Surg Sports Traumatol Arthrosc 22(10):2518–2521
21. Hollinghurst D, Stoney J, Ward T, Pandit H, Beard D, Murray DW (2007) In vivo sagittal plane kinematics of the Avon patellofemoral arthroplasty. J Arthroplasty 22(1):117–123
22. Imhoff AB, Feucht MJ, Meidinger G, Schottle PB, Cotic M (2015) Prospective evaluation of anatomic patellofemoral inlay resurfacing: clinical, radiographic, and sports-related results after 24 months. Knee Surg Sports Traumatol Arthrosc 23(5):1299–1307
23. Kellgren JH, Lawrence JS (1957) Radiological assessment of osteo-arthrosis. Ann Rheum Dis 16(4):494–502
24. Kim BS, Reitman RD, Schai PA, Scott RD (1999) Selective patellar nonresurfacing in total knee arthroplasty. 10 year results. Clin Orthop Relat Res 367:81–88
25. Kooijman HJ, Driessen AP, van Horn JR (2003) Long-term results of patellofemoral arthroplasty. A report of 56 arthroplasties with 17 years of follow-up. J Bone Joint Surg Br 85(6):836–840
26. Krajca-Radcliffe JB, Coker TP (1996) Patellofemoral arthroplasty. A 2- to 18-year followup study. Clin Orthop Relat Res 330:143–151
27. Leadbetter WB (2008) Patellofemoral arthroplasty in the treatment of patellofemoral arthritis: rationale and outcomes in younger patients. Orthop Clin North Am 39(3):363–380
28. Leadbetter WB, Kolisek FR, Levitt RL, Brooker AF, Zietz P, Marker DR, Bonutti PM, Mont MA (2009) Patellofemoral arthroplasty: a multi-centre study with minimum 2-year follow-up. Int Orthop 33(6):1597–1601
29. Leadbetter WB, Ragland PS, Mont MA (2005) The appropriate use of patellofemoral arthroplasty: an analysis of reported indications, contraindications, and failures. Clin Orthop Relat Res 436:91–99
30. Leadbetter WB, Seyler TM, Ragland PS, Mont MA (2006) Indications, contraindications, and pitfalls of patellofemoral arthroplasty. J Bone Joint Surg Am 88(Suppl 4):122–137
31. Lonner JH (2004) Patellofemoral arthroplasty: pros, cons, and design considerations. Clin Orthop Relat Res 428:158–165
32. Lonner JH (2008) Patellofemoral arthroplasty: the impact of design on outcomes. Orthop Clin North Am 39(3):347–354
33. Lonner JH, Bloomfield MR (2013) The clinical outcome of patellofemoral arthroplasty. Orthop Clin North Am 44(3):271–280
34. Lustig S (2014) Patellofemoral arthroplasty. Orthop Traumatol Surg Res 100(1 Suppl):S35–S43
35. Lustig S, Magnussen RA, Dahm DL, Parker D (2012) Patellofemoral arthroplasty, where are we today? Knee Surg Sports Traumatol Arthrosc 20(7):1216–1226
36. Lysholm J, Gillquist J (1982) Evaluation of knee ligament surgery results with special emphasis on use of a scoring scale. Am J Sports Med 10(3):150–154
37. McKeever DC (1955) Patellar prosthesis. J Bone Joint Surg Am 37-A(5):1074–1084
38. Merchant AC, Mercer RL, Jacobsen RH, Cool CR (1974) Roentgenographic analysis of patellofemoral congruence. J Bone Joint Surg Am 56(7):1391–1396
39. Monk AP, van Duren BH, Pandit H, Shakespeare D, Murray DW, Gill HS (2012) In vivo sagittal plane kinematics of the FPV patellofemoral replacement. Knee Surg Sports Traumatol Arthrosc 20(6):1104–1109
40. Odumenya M, Costa ML, Parsons N, Achten J, Dhillon M, Krikler SJ (2010) The Avon patellofemoral joint replacement: five-year results from an independent centre. J Bone Joint Surg Br 92(1):56–60
41. Outerbridge RE (1961) The etiology of chondromalacia patellae. J Bone Joint Surg Br 43-B:752–757
42. Provencher M, Ghodadra NS, Verma NN, Cole BJ, Zaire S, Shewman E, Bach BR Jr (2009) Patellofemoral kinematics after limited resurfacing of the trochlea. J Knee Surg 22(4):310–316
43. Smith AM, Peckett WR, Butler-Manuel PA, Venu KM, d'Arcy JC (2002) Treatment of patello-femoral arthritis using the Lubinus patello-femoral arthroplasty: a retrospective review. Knee 9(1):27–30
44. Tarassoli P, Punwar S, Khan W, Johnstone D (2012) Patellofemoral arthroplasty: a systematic review of the literature. Open Orthop J 6:340–347
45. Tauro B, Ackroyd CE, Newman JH, Shah NA (2001) The Lubinus patellofemoral arthroplasty. A five- to ten-year prospective study. J Bone Joint Surg Br 83(5):696–701
46. van Wagenberg JM, Speigner B, Gosens T, de Waal Malefijt J (2009) Midterm clinical results of the Autocentric II patellofemoral prosthesis. Int Orthop 33(6):1603–1608
47. Walker T, Perkinson B, Mihalko WM (2012) Patellofemoral arthroplasty: the other unicompartmental knee replacement. J Bone Joint Surg Am 94(18):1712–1720
48. Wiberg G (1941) Roentgenographic and anatomic studies on the patellofemoral joint with special reference to chondromalacia patellae. Acta Orthop Scand 12:319–410