CLINICAL ARTICLE

Patterns of Compartment Involvement in End-stage Knee Osteoarthritis in a Chinese Orthopedic Center: Implications for Implant Choice

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Objectives: Knee osteoarthritis (OA) is a prevalent disease in the elderly, causing pain and contributing to poor quality of life. Surgical intervention, such as knee arthroplasty, can be used in those with end-stage knee OA. Total knee arthroplasty (TKA) is one of the most common surgical procedures for end-stage knee OA, with promising clinical outcomes. However, a large proportion of patients with isolated compartment OA can be treated with unicompartmental knee arthroplasty (UKA) instead. UKA has shown better patient-reported functional outcomes, and lower mortality and major complication rates than TKA. The percentage of UKA in knee arthroplasty varied in different orthopedic centers, and we believed that the requirement for UKA was underestimated in many centers. A retrospective study was carried out on our Chinese patient population presenting for knee arthroplasty; it aimed to identify the proportion of patients that might be suitable for UKA.

Methods: A retrospective cross-sectional study of 155 consecutive patients (168 knees) awaiting TKA for end-stage primary OA was performed. The pattern and grade of OA was recorded from preoperative weight-bearing anteroposterior and non-weight-bearing lateral radiographs. The medial, lateral, patellofemoral compartment was given an individual Kellgren–Lawrence grade on the radiographs, and those grade ≥3 were defined as end-stage OA. The compartments involvement was established then. The integrity of the anterior cruciate ligament (ACL) was determined by the modified Keyes classification on lateral radiographs. The applicability for total or partial knee arthroplasty was determined according to the compartments involvement.

Results: Medial compartment involvement was found in 154 (91.7%) knees, while the involvement of the lateral compartment and patellofemoral joint was found in 54 (32.1%) and 57 (33.9%) knees, respectively. Eighty-one (48.2%) of the knees showed medial compartment OA with or without patellofemoral joint involvement, and modified Keyes classification grade 1, indicating an intact ACL, and, hence, potential suitability for medial UKA. Isolated lateral OA indicating possible suitability for lateral UKA was identified in 11 knees (6.5%). No patients showed isolated patellofemoral joint OA. The other 76 (45.2%) knees could be treated by TKA.

Conclusions: The medial compartment was the most commonly affected in our Chinese patients indicated for knee arthroplasty. More than half of the patients in this group could be treated by either medial or lateral UKA.

Key words: Compartment involvement; Implant choice; Knee osteoarthritis; Unicompartmental knee arthroplasty

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Disclosure: The authors declare that they have no conflict of interest. This work was supported by the Nanjing Medical Science and Technique Development Foundation (QRX17009), the Six Categories of Top Talents, the Jiangsu Provincial Department of Human Resources and Social Security (WSW-002), and a Medical Research Grant supported by the Jiangsu Provincial Commission of Health and Family Planning (Q201612).
Received 17 August 2017; accepted 4 February 2018

Introduction

Total knee arthroplasty (TKA) is the most successful treatment for end-stage knee osteoarthritis (OA), offering patients' significant symptomatic relief and functional improvement, while demonstrating a low long-term failure rate[1,2]. There has been an increase in the global burden of OA as well as the requirement for TKA. More than 620 000 TKA were carried out in the USA in 2009, with >97% of these performed for OA[3,4]. It is estimated that the total volume of primary TKA procedures required will be nearly 1 million in 2015 and more than 1.3 million in 2020[5]. In the UK, the number of TKA inserted tripled between 1991 and 2006[6].

In patients with unicompartmental end-stage knee OA, partial knee replacement can be used instead of TKA. Both unicompartmental knee arthroplasty (UKA)[7] and patellofemoral joint (PFJ) replacement (PFJR)[8,9] aim to replace the diseased region of the knee while preserving the intact compartments and ligaments. UKA for medial compartment OA is the most widely-used approach for partial knee replacement. Reported advantages include a less invasive approach with less bone resection, low complication rates, easier postoperative rehabilitation, faster recovery, greater range of motion, and good long-term survivorship[10–12]. Patients who undergo UKA showed a superior functional outcome compared to TKA patients[13], and were more likely to forget their artificial joint in daily life[14]. Good outcomes have been reported for the Oxford mobile-bearing UKA in overweight, younger, and more active patients[15,16], as well as in the presence of co-existent PFJ degeneration[15,17–19]. In addition, isolated PFJ OA could be treated with PFJR instead of TKA[8,9].

In China, the number of joint replacements is increasing. An estimated 200 000 total hip and knee arthroplasty operations were carried out in 2012[20,21], and the number increased to more than 580 000 in 2017. Although UKA has been carried out for decades in Europe and North America, it has only recently become available in China and, thus, is only carried out in a few centers, with limited short-term outcomes reported[22–26]. It is not clear how many patients with end-stage knee OA in China might be suitable for UKA and PFJR. A greater understanding in this area would benefit the orthopedic community and enhance patient choice. Prior to the introduction of UKA in our institution (Drum Tower Hospital, Nanjing), we treated all symptomatic end-stage knee OA with TKA.

Despite several advantages, the usage of UKA remains relatively lower than TKA. Possible reasons might be the concern regarding the progression of OA in the other compartments, the more technical demanding nature of the procedure, and the higher revision rate for UKA than TKA. It has been shown that the progression of OA in the other compartments did not serve as the major reason for UKA revision[27,28], and the lateral progression of OA following medial UKA is mainly due to existing OA in the lateral compartment before the medial UKA[27]. A higher revision rate has been reported for UKA than TKA[29–31]; however, one of the key reasons is most surgeons do too few partial knee arthroplasties to obtain good results. It is suggested that the revision rate of UKA could be comparable to that of TKA if surgeons had at least 12 UKAs per year, and UKA was used in 20%–50% of knee arthroplasty cases[32]. Hence, it is critical to estimate the number and percentage of UKA in our clinical practice to evaluate the risk of failure.

We studied a consecutive series of 155 patients who presented to our outpatient clinic with symptomatic knee OA requiring TKA. Radiographs taken as part of their routine clinical work-up were reviewed, and the severity of OA in the medial, lateral, and patellofemoral compartments was recorded. The aim of this study was to answer the following questions. First, what pattern of OA is seen in our Chinese patient population prior to knee arthroplasty? Second, what proportion of patients is suitable for partial knee replacement in the form of UKA or PFJR?

Patients and Methods

Patients

The Hospital Clinical Research Ethics Committee approved this retrospective cohort study (No. 2015-039-01), which included a consecutive series of 155 patients. All patients had a diagnosis of end-stage osteoarthritis and underwent TKA between 2012 and 2013 in the first author's center. OA in at least one compartment had to be classified as Kellgren/Lawrence (K/L) grade ≥3 for patients to be considered for arthroplasty in our institution[33,34]. All patients had failed conservative treatment for at least 3 months. The patient records were reviewed, and the following exclusion criteria were applied: (i) arthritis caused by other pathogenesis, such as trauma, or rheumatoid or ankylosing spondylitis; (ii) history of surgical intervention on a lower extremity, including fracture, osteotomy, ligament reconstruction, or meniscectomy; (iii) skeletal deformity in a lower extremity that could affect the alignment in either coronal or sagittal planes (i.e. fibrous dysplasia); (iv) co-existent pathogenesis in the spine, hip, or ankle that could significantly affect the lower extremity alignment; and (v) muscular strength less than grade IV, such as stroke, post-poliomyelitis, or paralysis of either side.

Radiological Examination

Weight-bearing antero-posterior (AP) and non-weight-bearing lateral radiographs of the indexed knee were routinely taken before surgery. The weight-bearing AP radiograph was taken with the knee fully extended and the tibial tuberosity and patellae facing forward. Images were taken by centering the X-ray beam on the knee. For the lateral radiographs, the patients were positioned on their side with the knee flexed and the lateral side of knee on the film.

Radiological Assessment

On the AP and lateral radiographs, the severity of OA in medial, lateral, and PFJ compartments was graded separately using the K/L scale (grade 0, no osteophyte and joint space

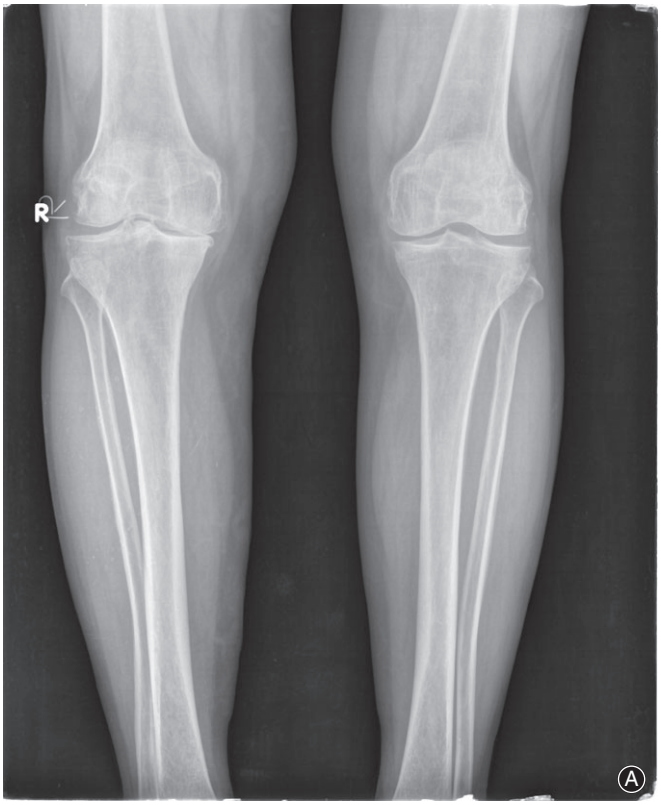

Fig. 1 Legend on next coloumn.

narrowing; grade 1, possible osteophytes only; grade 2, definite osteophytes and possible joint space narrowing; grade 3, moderate osteophytes and/or definite joint space narrowing; and grade 4, large osteophytes, severe joint space narrowing, and/or bony sclerosis)[33,34]. Severe OA was defined if the K/L grade was ≥3[34]. The presence of severe OA was used to determine the pattern of compartment involvement in each knee.

The modified Keyes classification[35] was used to evaluate the integrity of the anterior cruciate ligament (ACL). On the lateral radiographs, the bone erosion was classified as grade 1 when the tibial wear was limited to the anteromedial compartment, as grade 2 once the erosion extended to the posterior margin of the plateau, and as grade 3 when there was a subluxation of the tibia on the femur. Grade 1 indicated an intact or degenerative ACL, grade 2 suggested a degenerated or torn ACL, and grade 3 demonstrated a high possibility of ACL tear.

Because high reliability in assessing the K/L grading[34] and modified Keyes classification[35] has been reported in previous studies, the radiographic assessment was done by the first author (W-J. W) only. Thirty knees were randomly selected and re-analyzed to test the intra-observer reliability with 4-week intervals.

Applicability of Partial Knee Arthroplasty

Medial compartment knee OA in the presence of a functioning ACL and an intact lateral compartment with or without PFJ degeneration can be treated with medial UKA (Fig. 1)[15,16,18,36,37]. However, patients with a knee varus of more than 15°, fixed flexion deformity over 10°, or range of motion less than 90° would be excluded. Similarly, isolated lateral compartment knee OA can be treated by lateral UKA. In addition, isolated primary PFJ OA and secondary PFJ OA are indicated for PFJR, but only if minimal OA is evident in the tibiofemoral joint (K/L grade <2)[9].

Statistical Analysis

Intra-observer reliability was analyzed by intraclass correlation coefficients. The modified Keyes classification was compared within different subgroups (defined by compartment involvement) using the χ^2-test. The level of significance was defined as $P < 0.05$.

Fig. 1 The knee indicated for medial unicompartmental knee arthroplasty (UKA). A 73-year-old woman complained of severe pain close to the medial knee joint line during walking for 2 years. The pain could not be relieved by tramadol, and so total knee arthroplasty (TKA) was carried out. (A) The antero-posterior (AP) weight bearing X-ray film showed K/L grade 4 in medial compartment, but only grade 1 in lateral compartment. (B) On lateral X-ray film, the patellofemoral joint showed K/L grade 1 degeneration. Tibia plateau was classified as modified Keyes grade 1. This knee could be treated with medial UKA as an alternative to TKA.

Results

One hundred and fifty-five patients comprising a total of 168 TKA were recruited in the present study. There were 126 women and 29 men, with a mean age of 66.4 ±7.2 years (41.8–81.5 years). The intra-class correlations for intra-observer reliability were 0.985 (95% confidence interval, 0.969–0.994) for the classifications of K/L Grade, and 0.965 (95% confidence interval, 0.937–0.993) for the modified Keyes classification in 30 randomly selected knees.

Compartment Involvement of Osteoarthritis

The distributions of OA with K/L grade ≥3 in different compartments are summarized in Table 1 and Fig. 2. Medial compartment involvement was found in 154 (91.7%) knees, while the involvement of lateral and PFJ OA was found in 54 (32.1%) and 57 (33.9%) knees, respectively. Isolated medial, lateral, and PFJ OA was found in 86 (51.2%), 11 (6.5%), and 2 (1.2%) knees, respectively. Isolated medial OA was the most common pattern, followed by tri-compartment involvement (16.7%) and medial with co-existing PFJ OA (15.5%).

Anterior Cruciate Ligament Integrity Determined by the Modified Keyes Classification

On the lateral radiographs, 109 (64.9%) knees were considered grade 1 based on the modified Keyes classification, and 55 (32.7%) and 4 (2.4%) presented as grade 2 and 3, respectively. The incidence of grade 1 modified Keyes classification was more commonly found in knees with single compartment involvement by OA (Table 2, $\chi^2 = 21.1$, $P < 0.001$).

Applicability of Unicompartmental Knee Arthroplasty

Grade 1 of modified Keyes classification indicates structural integrity of the ACL[35]. Hence, in the 109 knees, 66 with isolated medial OA as well as 15 with medial and co-existing PFJ OA (48.2%) were eligible for Oxford medial UKA, while 11 with isolated lateral OA (6.5%) were indicated for Oxford lateral UKA. According to our criteria, both patients with isolated PFJ OA showed K/L grade 2 in medial and lateral compartments of the tibiofemoral joint, and were not indicated for PFJR[9]. As a result, 76 (45.2%) knees could not be treated with UKA and were indicated for treatment with TKA instead (Table 1, Fig. 3).

TABLE 1 The distributing of patterns of end-stage knee OA (knees)

	Modified Keyes classification			
Compartments	1	2	3	Total
Medial	66	20		86
Medial + PFJ	15	10	1	26
Lateral	11			11
Lateral + PFJ		1		1
PFJ	1	1		2
Medial + Lateral	5	8	1	14
Tri-compartments	11	15	2	28
Total	109	55	4	168

OS, osteoarthritis; PFJ, patellofemoral joint; UKA, unicompartmental knee arthroplasty

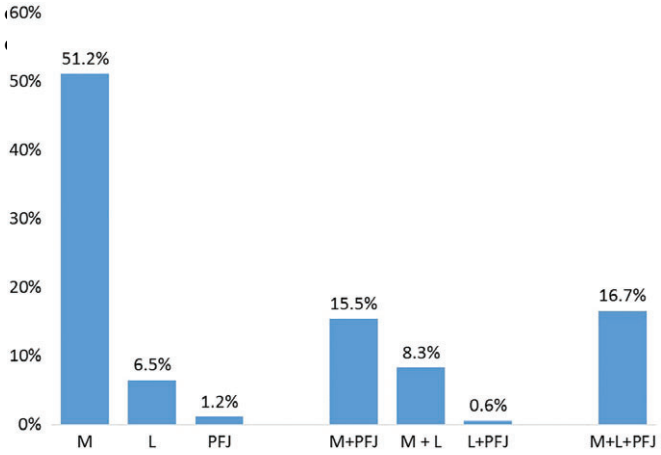

Fig. 2 The distribution of compartment involvement in knee osteoarthritis (OA). The proportion of the involvement of isolated compartment, bi-compartment, and tri-compartment OA is shown. The medial compartment is more commonly affected in both isolated compartment and bi-compartment knee OA. L, lateral; M, medial; PFJ, patellofemoral joint.

Discussion

We have shown that over 50% of the 168 knees included in this study had isolated medial compartment OA and may be considered suitable for UKA. In total, medial compartment involvement was found in 91.7% of knees, while the lateral compartment and PFJ OA were identified in 32.1% and 33.9%, respectively. On the lateral X-ray films, erosion of cartilage extending to the posterior tibial plateau was identified in 40.5% of knees, and the incidence increased if more compartments were affected by OA.

It is well known that the medial compartment is more frequently affected in OA of the knee; however, the

TABLE 2 Distribution of tibial cartilage erosion in end-stage knee osteoarthritis with different numbers of compartments involved (knees)

	Number of compartments involved		
Modified Keyes classification	Single	Double	Triple
1	78	20	11
2, 3	21	21	17

Comparison of the modified Keyes classifications with different numbers of compartments involved was carried out by χ^2-test ($\chi^2 = 21.1$, $P < 0.001$).

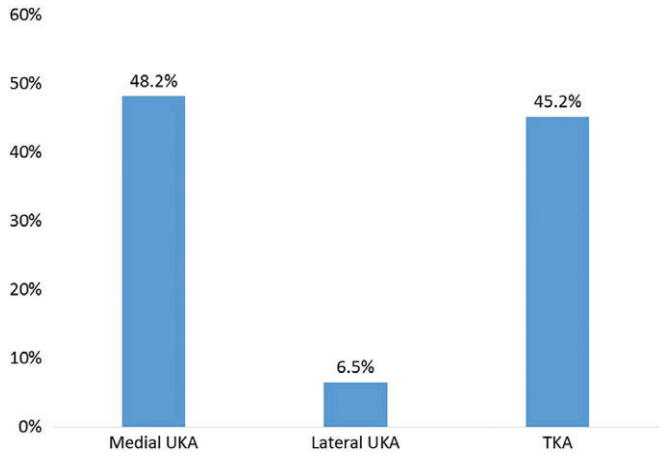

Fig. 3 The proportion of implant selection for end-stage knee osteoarthritis (OA). A total of 48.2% of knees indicated for medial unicompartmental knee arthroplasty (UKA) were composed of isolated medial OA (39.3%) and medial OA with co-existing PFJ OA (8.9%), with modified Keyes classification grade 1. A total of 6.5% of knees indicated for lateral UKA were composed of isolated UKA with modified Keyes classification grade 1 only; 2 patients with K/L grade 4 PFJ OA were suggested for total knee arthroplasty (TKA) due to grade 2 OA in tibiofemoral joint, and all other knees were suggested for TKA. PFJ, patellofemoral joint; UKA, unicompartmental knee replacement.

prevalence in Chinese subjects is not well documented. Two studies reporting the patterns of compartment involvement in tibiofemoral OA were reviewed (Table 3)[38,39]. In a population-based study, Felson *et al.* identified 288 knees with OA from 1084 US subjects[38], and 757 knees with OA from 1781 Chinese subjects. OA was described radiographically using K/L grade ≥2 and joint space narrowing ≥1. Isolated medial compartment OA was seen in 85.4% of US subjects and 59.7% of Chinese subjects. None of the knees showed both medial and lateral disease. In subjects participating in the Multicenter Osteoarthritis Study (MOST), Wise *et al.* found 305 cases of OA in 722 knees from African American subjects and 1535 cases of OA in 4480 knees from White American subjects[39]. Isolated medial compartment OA was seen more frequently in the White American population (63.9% and 79.3%), and the medial compartment predominance of knee OA was thought to be due to the constitutional varus leg alignment in the general population[40–43]. In young adults, the mechanical axis of the leg is more likely to pass through the medial plateau than the lateral plateau, and the incidence of varus alignment (HKA ≤−3°) is more than 10 times that of valgus alignment (HKA ≥3°)[40,41]. Varus alignment increases the risk of cartilage damage in the medial tibial plateau, while valgus alignment reduces this risk[44,45]. A significant association between malalignment and progression of OA has been reported, with varus alignment promoting progression in the medial compartment while leading to the progression of OA in the lateral compartment[45–48]. In patients with knee OA, varus alignment is caused by a more medial inclination of the tibial plateau and reduced valgus angulation of the distal femur compared to what is seen in healthy individuals[49,50]. In addition, Matsumoto *et al.*[51] found that the femur shifts from a medially bowed curvature to a laterally bowed arrangement with age. This change would reduce the condylar-shaft angle, shift the mechanical axis medially and potentially contribute

TABLE 3 Summary of compartment distribution of osteoarthritis in tibiofemoral joint in different studies (knees [%])

		Compartment involved		
	Gender	Medial	Lateral	M + L
Felson *et al.*[32] (K/L grade ≥2, JSN ≥1)				
Framingham, USA	Male	93 (32.3)	12 (4.2)	
	Female	153 (53.1)	30 (10.4)	
	Total	246 (85.4)	42 (14.6)	
Beijing, China	Male	103 (13.6)	83 (11)	
	Female	349 (46.1)	222 (29.3)	
	Total	452 (59.7)	305 (40.3)	
Wise *et al.*[33] (JSN ≥1)				
African American	Male	57 (18.7)	20 (6.6)	12 (3.9)
	Female	138 (45.2)	46 (15.1)	32 (10.5)
	Total	195 (63.9)	66 (21.6)	44 (14.4)
White	Male	542 (35.3)	59 (3.8)	30 (2)
	Female	676 (44)	183 (11.9)	45 (2.9)
	Total	1218 (79.3)	242 (15.8)	75 (4.9)
The present study (K/L grade ≥3)				
Nanjing, China	Male	16 (9.6)	2 (1.2)	14 (8.4)
	Female	96 (57.8)	10 (6)	28 (16.9)
	Total	112 (67.5)	12 (7.2)	42 (25.3)

In the study of Felson *et al.*[38], none of the knees showed osteoarthritis in both the medial and lateral compartments; two knees with isolated patellofemoral joint osteoarthritis in the present study are not included in this table

to the progression of medial OA. The high rate of medial compartment disease in our study may be due to the advanced OA seen at recruitment (K/L grade ≥3). This late stage of OA may also explain the relatively low prevalence of isolated medial OA with more compartments becoming involved as the disease progresses.

The indication for Oxford UKA has expanded. Initially, it was recommended for isolated medial or lateral compartment OA. Patients who were overweight (>82 kg), younger than 60 years, or maintained a high level of activity were thought to be contraindicated[52]. However, with increasing knowledge on knee kinematics and improved implant design, these conditions are no longer absolute contraindications[15,16]. In addition, various studies have shown that PFJ OA does not affect functional outcome or survivorship of the Oxford UKA, suggesting that co-existent PFJ OA should not be a contradiction for Oxford UKA[15,18,19,36,37]. However, a functionally intact ACL is still critical for the long-term outcome of medial UKA, and failure of UKA would be expected in those with ACL-deficient knees[53–55]. An intact ACL could maintain the stability of the knee and limit cartilage erosion of both the antero-medial tibial plateau and femoral condyle[56]. One reliable method to determine the structural integrity of the ACL is to observe the bone erosion pattern of the medial plateau on the lateral radiographs[57]. A modified Keyes classification was established and validated by Waldstein *et al.*[35], where grade 1 with no erosion on the tibial plateau observed on lateral X-ray film predicted a functionally intact ACL, while grade 2 with erosion extending to the posterior margin showed more than half incidence of ACL torn. There were 109 knees classified as grade 1 in the present study. Of these knees, 66 had isolated medial OA, and 15 showed co-existent PFJ OA, suggesting that 81 knees (48.2%) could be treated with medial UKA as an alternative to TKA. The true number of suitable candidates may be higher, because some functionally intact ACL are expected within the group of patients with a Keyes grade of 2. The applicability of UKA was also investigated in a UK population by Willis-Owen *et al.*[58]. By analyzing the preoperative antero-posterior weight-bearing, lateral in 45° of flexion and "Skyline" patella views of 200 consecutive knees, the authors found that 35.1% of knees had anteromedial compartment OA with or without medial PFJ OA, and were suitable for medial UKA. In addition, 25.1% knees had medial compartment OA with or without PFJ OA, may debatable for medial UKA. The incidence of UKA found in our study and reported by Willis-Owen *et al.*[58] is higher than that reported by Arno *et al.*[59], who identified 21% of 97 knees with medial OA as candidates for UKA. This discrepancy may be because Arno's study did not include patients with patellofemoral arthritis and included patients with genu varum of less than 10° instead of 15°.

Lateral compartment knee OA can be treated by lateral UKA with predictable, good long-term outcomes, as either fixed[60,61] or mobile bearing[62]. In the present study, 11 knees showed isolated lateral compartment OA with an intact ACL (Keyes grade 1). However, it is important to note that the method used to determine ACL integrity has not been validated in lateral OA. As such, it is not possible to determine if any or all of these 11 knees might have benefited from UKA without more information about the integrity of the ACL. Moreover, the effect of co-existent PFJ OA in outcomes of lateral UKA has not been reported.

Patellofemoral OA is a common condition[8,9], confirmed by the fact that it was present in 33.9% of the knees in our study. However, isolated PFJ OA (K/L grade ≥3) is rare, and was only found in 2 knees. This isolated PJF OA could be treated by PFJR as an alternative to TKA; however, strict selection criteria are critical for its success. There should be no significant degeneration in the tibiofemoral joint and a K/L classification of no more than grade 1[9]. Hence, neither of the 2 knees identified as isolated PFJ OA in the present study could be treated with PFJR, due to the presence of K/L grade 2 in the tibiofemoral joint.

There are limitations inherent to this retrospective study. Although all knees underwent TKA in our center, the intraoperative status of the ACL was not recorded. Because some of the patients with modified Keyes grade 2 might have had an intact ACL, the total number of patients suitable for UKA might be higher than reported. In contrast, the rate of indications for lateral UKA could be lower than what is estimated. Another limitation is that a skyline view of the knee is not routinely taken prior to TKA, and, thus, only limited views of the PFJ were available. Using a lateral radiograph to assess PFJ OA may be inadequate. However, because the severity of PFJ degeneration is not a contraindication to UKA, it may not have had a significant impact on the number of patients who fit the criteria for medial UKA.

Despite these limitations, our study has shown a high prevalence of medial compartment OA in Chinese patients undergoing TKA (91.7%). Many of these patients may be suitable for medial UKA (48.2%). A much smaller number of individuals were identified as suitable for lateral UKA (6.6%). To date, UKA is far less popular than TKA in China. This may be due to concerns regarding the learning curve associated with new surgical techniques. Zhang *et al.* report how well Chinese arthroplasty surgeons have adapted to handling the minimally invasive Oxford phase 3 medial UKA. They found that failure rates diminished rapidly after 16 cases, and satisfactory outcomes were achieved after approximately 25 cases[63]. In addition, good results can be expected when using UKA for more than 20% of overall knee arthroplasty, and the optional proportion was 40% to 60%[32].

This is the first time that the pattern of OA has been determined in a group of Chinese patients with symptomatic end-stage osteoarthritis. Many of the patients identified are suitable for partial knee arthroplasty. We encourage appropriately trained surgeons to expand the choices offered to patients by including partial knee arthroplasty as part of their treatment algorithm.

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