

Good Operative Effects of Patellofemoral Arthroplasty Combined With the Tibial Tubercle Transfer for Isolated Patellofemoral Arthritis Patients With an Increased Tibial Tuberosity-trochlear Groove Distance

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Abstract

Purpose: The objective of present study was to investigate the operative effect of patellofemoral arthroplasty combined with the tibial tubercle transfer for isolated patellofemoral arthritis patients with an increased tibial tuberosity-trochlear groove distance (>20mm).

Methods: A prospective study was performed between November 2012 and December 2017. Finally, thirty-six cases, with a mean age of 61.1 ± 7.3 years, were admitted to our study. A total of 17 patients underwent patellofemoral arthroplasty combined with tibial tubercle transfer, and 19 patients underwent patellofemoral arthroplasty only. All eligible patients had CT scans preoperatively and at 12 months follow-up, to assess the stability of the patellofemoral joint on axial slices. In addition, the demographic and clinical features of all the patients were asked. Knee balance was assessed with the single leg stance test and timed get up and go, and functionality was evaluated with stair climbing test and the Western Ontario and McMaster Universities Osteoarthritis Index score. ($P > 0.05$)

Results: Preoperatively, the data regarding the knee balance and functionality were not significantly different between the two Groups ($P > 0.05$). Many measurements showed significant differences between the two groups at the last follow-up. Significant differences were seen in well-known measurements such as the SLST (Group I, 28.9 s (SD 7.5); Group II, 20.3 s (SD 5.9); $p < 0.001$), TGUG (Group I, 13.4 s (SD 3.2); Group II, 16.8 s (SD 3.1); $p < 0.001$), and SCT (Group I, 18.6 s (SD 6.8); Group II, 24.5 s (SD 8.7); $p < 0.001$). Additionally, the median WOMAC score was improved from 62.7 (SD 11.2) preoperatively to 25.7 (SD 8.2) one year postoperatively in Group I and from 64.1 (SD 10.7) to 36.2 (SD 9.7) in Group II, which were also significantly different between the groups.

Conclusion: For such special IPA patients with an increased TT-TG (>20mm), the combined operation of PFA combined with TTT can better restore the involitional relationship of patellofemoral joint and further improve the balance and function of knee joint.

Introduction

Isolated patellofemoral arthritis (IPA) is a common condition affecting the middle-aged and the elderly [1]. It is estimated that approximately 10% of patients older than 40 years presenting with knee pain have radiographic evidence of IPA [1]. Isolated degeneration of the patellofemoral articulation has also been reported in 24% of women and 11% of men greater than 55 years who present with symptomatic knee arthritis [2]. When looking at patients older than 60 years, the disease was present in 34% of women and 19% of men according to some studies [1, 3]. Noble and Hamblen [3] reported patellofemoral osteoarthritis in 79% of 100 cadavers aged ≥ 65 years. Therefore, given the prevalence of this disease, we should attach great importance to the treatment of IPA.

IPA is associated with various etiologies, including objective patellar instability (33%), post-traumatic lesions (9%), and chondrocalcinosis (9%), although most cases remain idiopathic (49%) [4]. Patellar dislocation, included in patellar instability, is a significant risk factor to results in subsequent IPA

according to some studies [5-8]. In addition, it has been demonstrated that 78% of patients with IPA present concomitant signs of trochlear dysplasia, which could be an underlying cause of cartilage wear [4]. The significant trochlear dysplasia is seen in 55% of patients with patellofemoral arthritis [9-15]. Furthermore, the importance of trochlear dysplasia as a major predisposing factor for patellar dislocation has been recognized for many years [16, 17]. Fithian et al. [16] and Dejour et al. [18] reported that 85% and 96% of patients with patellar dislocation, respectively had trochlear dysplasia. Thus, IPA is not rare associated with patellar dislocation.

Niu et al. [19] have proven that early patellar dislocation not only results in eventual patellofemoral arthritis but also can lead to tibial tubercle lateralization and an increased tibial tuberosity-trochlear groove distance (TT-TG). The tibial tubercle, attached to the patellar tendon, is an important structural bone marker in terms of the Q angle and TT-TG, which reflect limb alignment. Its position affects the convolution of the patellofemoral joint. Lateralization of the tibial tuberosity can cause patellar dislocation; if lateralization of the tibial tubercle increases, then the Q angle, TT-TG, and external vector force of the patella also increase [19]. Most studies have confirmed that externalization of the tibial tubercle is a potential cause of patellofemoral instability [20-24].

The normal TT-TG distance measured on computed tomography (CT) scans is between 10 and 20 mm and more than 20 mm is the operative indication of tibial tubercle transfer (TTT) [18]. For elderly patients, the surgical "gold standard" for IPA has traditionally been patellofemoral arthroplasty (PFA), which literature has demonstrated to provide good long-term outcomes [25-27]. However, for IPA patients, there has been at least a 5% rate of patellar subluxation after PFA at a long-term follow-up [28]. This suggests a greater rate of dislocation in IPA patients with an increased TT-TG (>20mm) and a large quadriceps-angle (Q-angle) (>20°) [18]. Recently, numerous studies suggested that one of the reasons for the failure of patellofemoral arthroplasty is the subluxation or dislocation of the patella [29-31]. Theoretically, for severe patellofemoral track deformity that cannot be corrected (such as abnormal large Q-angle and positive J-sign), the simple soft-tissue balancing procedures in patellofemoral joint replacement is often not able to achieve satisfactory results, and it is usually necessary to combine the technique of tibial tubercle transfer. To the authors' knowledge, there are no published studies that investigate the operative effect of PFA combined with TTT for IPA patients with an increased TT-TG (>20mm). Therefore, we believe that for such special patients, this combined operation may be more effective to avoid patellar instability and improve knee function than PFA alone. The purpose of this study was to investigate the operative effect of PFA combined with TTT for IPA patients with an increased TT-TG (>20mm).

Data And Methods

Clinical background

The authors prospectively studied a consecutive series of 41 patients who received PFA combined with TTT and PFA alone by the senior surgeon between 2012 and 2017. All patients had provided written

informed consent for their participation in the study, which was approved in advance by our institutional reviewboard.

The inclusion criteria were as follows: (1) the age of patient was between 50 and 70; (2) patients who had a history of noninflammatory IPA with persistent pain and impairment despite conservative treatment; (3) patients with cartilage damage of greater than grade II; (4) patients with patellar subluxation or dislocation; (5) patients with an increased TT-TG (>20mm); (5) patients with a large Q-angle (>20°). The exclusion criteria were the presence of (1) tibiofemoral osteoarthritis; (2) systemic inflammatory arthropathy; (3) post-traumatic osteoarthritis; (4) patella baja; (5) psychogenic pain; (6) concomitant cruciate ligament or collateral ligament injury.

Among our 41 patients, 2 patient was lost, and 3 others met one or more exclusion criteria, leaving 36 patients (31 women and 5 men) aged 61.1 ± 7.3 years with complete data for this study. A total of 17 patients underwent patellofemoral arthroplasty combined with tibial tubercle transfer, and 19 patients underwent patellofemoral arthroplasty only. The Consolidated Standards of Reporting Trials (CONSORT) flowchart showing the selection of patients is shown in Figure 1. All eligible patients had CT scans preoperatively and at 12 months follow-up, to assess the stability of the patellofemoral joint on axial slices. In addition, the demographic and clinical features of all the patients were asked. Balance was assessed with the single leg stance test (SLST) and timed get up and go (TGUG), and functionality was evaluated with stair climbing test (SCT) and the Western Ontario and McMaster Universities Osteoarthritis Index score (WOMAC).

Operative technique

All patients received the Avon Patellofemoral prosthesis (Stryker Orthopaedics, Mahwah, New Jersey) (Figure 2). The procedure of PFA was performed in a manner consistent with previously published reports [32, 33]. The critical principles in successful patellofemoral arthroplasty for the treatment of isolated patellofemoral arthritis are as follows: the use of a muscle-sparing approach, appropriate placement of the femoral cutting guide (avoidance of retroversion or internal rotation), careful attention to avoid femoral notching, avoiding overtensioning of the patellofemoral retinaculum (through repairing the patella and releasing tension on the lateral retinaculum), patellar medialization (to avoid medial impingement), and careful soft tissue balancing.

The following are the main principles of successful tibial tubercle transfer for the treatment of patellofemoral arthritis proposed by Saleh et al. in 2005 [34] (Figure 2): (1) restoration or maintenance of the proper balance of the extensor mechanism; (2) transfer of a painful and degenerated area to a less loaded articular surface and reduction of the load on the lateral aspect of the patella through medial transfer of the tibial tuberosity; (3) relief of pain caused by the patellar retinaculum.

Assessment

The diagnosis of isolated patellofemoral arthritis was confirmed by preoperative radiographs (in anteroposterior, lateral and merchant views) (Figure 3). The diagnosis of patellar dislocation was confirmed by a patellar apprehension test (>1.5cm) [35] and CT of the patellofemoral joint with the non-weight-bearing knee in full extension [36] (Figure 4). Arthroscopic assessment was used to identify chondral lesions and concomitant pathology before performing operative techniques in all patients.

All patients underwent CT to assess the stability of the patellofemoral joint, preoperatively and at final follow-up, on a particular axial image which was established at the point with the greatest epicondylar width based on measurements on axial slices [36, 37]. All data were measured using Sante DICOM Viewer Free (64-bit) version 5.2 (Santesoft, Inc. Athens, Greece), which has an accuracy of 0.01° for angles and 0.01 mm for distance [38]. In order to minimize errors of measurement, all measurements were performed under the same conditions by two authors (YW and GY). After an interval of three weeks, one measured the 36 samples again and the intra and interobserver reliabilities were determined using intra-class correlation coefficients (ICCs).

SLST was used to evaluate static balance. The patients were instructed to stand on one foot and bend the other leg from hip and knee. This leg should not touch the other leg, and the balance is held for as long as possible. The test was performed by the affected leg with three repeats and the highest performance was recorded. If the bended leg touches the supportive leg or the foot touches the floor or the arms get support from anywhere, the test is failed [39, 40]. TGUG is a test used to assess dynamic balance. For the test, the person is asked to sit and stand up from a standard chair and walk a distance of approximately 3 metres, turn around and walk back to the chair and sit down again. The time begins with the instruction and ends with sitting down again. We repeated the test 2 times and found the mean value. The values below than 20 s are within normal limits for transfer and mobility; however, the values greater than 30 s means that the risk of dependence and falling is increased, and the elderly person needs assistance during daily activities and uses assistive devices for ambulation [39, 41].

In SCT, the patients were asked to climb up and down the ten step stairway, and this involves alternatively placing climbing up and down as fast as possible onto a step that was 19 cm high and 27 cm deep. We repeated the test two times to prevent tiredness and found the mean value [39, 41, 42]. In addition, the Western Ontario and McMaster Universities Osteoarthritis Index score (WOMAC; 0 to 100, 0 being the best score) [25, 43] was also collected to evaluate the knee functionality.

Statistical analysis

Sample size was calculated by Raosoft, Inc. Minimal clinically important difference was considered 15 % of maximal score for WOMAC for Total knee arthroplasty (TKA) by Escobar et al. [39, 44]. With a change 15 % in WOMAC score, the estimated sample size required to detect a statistically significant difference between groups, at a 10 % significance level with a power of 90 %, was 35 patients.

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) version 16.0 (SPSS, Chicago, Illinois). The Kolmogorov–Smirnov test was used to test the normality of numerical

data. Levene's test was used to assess the homogeneity of the data. All numerical variables showed a normal distribution or equal variance. Differences between the two groups were analysed with a two-sample Student's *t*-test. The differences of gender (female/male), leg (right/left) and the apprehension sign were analyzed using Pearson's chi-squared test. Numerical data are shown as mean and standard deviation, and categorical data as numbers with percentages. A *p*-value of < 0.05 was considered statistically significant.

Results

Demographic features of the groups were presented in Table 1. Statistically significant difference was not found between the two groups in comparison with demographic characteristics.

Table 1
The comparison of demographic characteristics of the groups

Indexes	Group I (n = 17)	Group II (n = 19)	<i>p</i> value
Age (year)	60.8 ± 7.2	61.3 ± 7.5	n.s.
Length (cm)	158.1 ± 6.4	159.6 ± 5.8	n.s.
Weight (kg)	73.7 ± 10.8	72.5 ± 11.7	n.s.
BMI (kg/m ²)	29.5 ± 4.2	28.5 ± 3.4	n.s.
Gender (F/M)	15/2	16/3	
DS (R/L)	14/3	15/4	
<i>Age, Length, Weight</i> and <i>BMI</i> were calculated using student's <i>t</i> -test. The Gender and <i>DS</i> was compared by Pearson's chi-squared test. N.s.: <i>p</i> > 0.05			
<i>BMI</i> body mass index; <i>F</i> female, <i>M</i> male; <i>DS</i> dominant side, <i>R</i> right, <i>L</i> left			

Evaluation indexes of patellofemoral joint stability.

The intra and inter observer intra-class correlation coefficients were high for all measurements (Table 2). Preoperatively, there were also no statistically significant differences between the patellofemoral joint stability in the two groups (n.s.) (Table 3). Additionally, all patients in both groups had a patellar lateral shift that exceeded 1.5 cm with a hard end point for the apprehension test, with no significant difference. At the final follow-up, these parameters were significantly different between the two groups, such as the Q-angle (Group I, 10.09° (SD 1.05); Group II, 16.68° (SD 1.95); *p* < 0.001), the tibial tuberosity-trochlear groove distance (Group I, 7.95 mm (SD 1.64); Group II, 15.59 mm (SD 3.08); *p* < 0.001), the congruence angle (Group I, 9.46° (SD 1.27); Group II, 14.93° (SD 2.62); *p* < 0.001), the patellar tilt angle (Group I, 9.83° (SD 1.29); Group II, 15.17° (SD 1.87); *p* < 0.001), the patellar lateral shift (Group I, 8.52 mm (SD 1.31); Group II, 13.72 mm (SD 2.41); *p* < 0.001) (Table 4). Additionally, 5 patients in Group II had a patellar lateral

shift that exceeded 1.5 cm. However, all patients in Group I had a patellar lateral shift that less than 1.5 cm for the apprehension test, with a significant difference between the two groups.

Table 2
Intra-observer and inter-observer agreement of geometric measurements with 95% confidence intervals.

Measurement	Intra-observer			Inter-observer		
	ICC	95%CI for ICC		ICC	95%CI for ICC	
Lower	Upper	Lower	Upper			
Pre-Group I- Q-angle	0.835	0.475	0.988	0.810	0.417	0.977
Pre-Group I-TT-TG	0.954	0.891	0.980	0.819	0.574	0.923
Pre-Group I-CA	0.938	0.855	0.974	0.701	0.291	0.873
Pre-Group I-PTA	0.965	0.916	0.985	0.835	0.612	0.930
Pre-Group I-PLS	0.991	0.978	0.996	0.907	0.781	0.961
Post-Group I- Q-angle	0.891	0.691	0.942	0.821	0.552	0.913
Post-Group I-TT-TG	0.902	0.768	0.958	0.908	0.782	0.961
Post-Group I-CA	0.735	0.375	0.888	0.710	0.317	0.877
Post-Group I-PTA	0.943	0.865	0.976	0.868	0.689	0.944
Post-Group I-PLS	0.985	0.964	0.994	0.899	0.761	0.957
Pre-Group II- Q-angle	0.967	0.926	0.981	0.852	0.624	0.949
Pre-Group II-TT-TG	0.945	0.871	0.977	0.763	0.440	0.899
Pre-Group II-CA	0.968	0.925	0.987	0.922	0.815	0.967
Pre-Group II-PTA	0.954	0.892	0.981	0.793	0.513	0.912
Pre-Group II-PLS	0.996	0.991	0.998	0.992	0.982	0.997
Post-Group II- Q-angle	0.971	0.926	0.989	0.851	0.714	0.935
Post-Group II-TT-TG	0.911	0.791	0.962	0.801	0.530	0.915
Post-Group II-CA	0.965	0.918	0.985	0.832	0.604	0.929
Post-Group II-PTA	0.952	0.886	0.979	0.776	0.473	0.905
Post-Group II-PLS	0.989	0.974	0.995	0.929	0.833	0.970

Table 3
Preoperative evaluation of patellofemoral joint stability

Indexes	Group I (n = 17)	Group II (n = 19)	p value
Q-angle (°)	21.97 ± 1.65	22.81 ± 1.72	n.s.
TT-TG (mm)	22.74 ± 2.53	23.18 ± 2.15	n.s.
CA (°)	22.59 ± 4.28	21.97 ± 3.84	n.s.
PTA (°)	21.83 ± 3.36	22.16 ± 2.95	n.s.
PLS (mm)	19.82 ± 3.61	19.37 ± 4.26	n.s.
Apprehension sign [n/N(%)]			
≥1.5cm	0/17(0)	0/19(0)	
≤1.5cm	17/17(100)	19/19(100)	
<i>Q-angle, TT-TG, CA, PTA and PLS</i> were calculated using student's t-test. The apprehension sign was compared by Pearson's chi-squared test. N.s.: $p > 0.05$			
<i>Q-angle</i> quadriceps-angle, <i>TT-TG</i> tibial tuberosity-trochlear groove distance, <i>CA</i> congruence angle, <i>PTA</i> patellar tilt angle, <i>PLS</i> patellar lateral shift			

Table 4
Patellofemoral joint stability at follow-up

Indexes	Group I (n = 17)	Group II (n = 19)	p value
Q-angle (°)	10.09 ± 1.05	16.68 ± 1.95	≤0.001
TT-TG (mm)	7.95 ± 1.64	15.59 ± 3.08	≤0.001
CA (°)	9.46 ± 1.27	14.93 ± 2.62	≤0.001
PTA (°)	9.83 ± 1.29	15.17 ± 1.87	≤0.001
PLS (mm)	8.52 ± 1.31	13.72 ± 2.41	≤0.001
Apprehension sign [n/N(%)]			
≥1.5cm	17/17(100)	14/19(74)	
≤1.5cm	0/17(0)	5/19(26)	
<i>Q-angle, TT-TG, CA, PTA and PLS</i> were calculated using student's t-test. The apprehension sign was compared by Pearson's chi-squared test. N.s.: $p > 0.05$			
<i>Q-angle</i> quadriceps-angle, <i>TT-TG</i> tibial tuberosity-trochlear groove distance, <i>CA</i> congruence angle, <i>PTA</i> patellar tilt angle, <i>PLS</i> patellar lateral shift			

Evaluation indexes of knee balance and functionality.

Preoperatively, the data regarding the knee balance and functionality were not significantly different between the two Groups (n.s.) (Table 5). Many measurements showed significant differences between the two groups at the last follow-up (Table 6). Significant differences were seen in well-known measurements such as the SLST (Group I, 28.9 s (SD 7.5); Group II, 20.3 s (SD 5.9); $p < 0.001$), TGUG (Group I, 13.4 s (SD 3.2); Group II, 16.8 s (SD 3.1); $p < 0.001$), and SCT (Group I, 18.6 s (SD 6.8); Group II, 24.5 s (SD 8.7); $p < 0.001$). Additionally, the median WOMAC score was improved from 62.7 (SD 11.2) preoperatively to 25.7 (SD 8.2) one year postoperatively in Group I and from 64.1 (SD 10.7) to 36.2 (SD 9.7) in Group II, which were also significantly different between the groups.

Table 5
Preoperative evaluation of knee balance and functionality

Indexes	Group I (n = 17)	Group II (n = 19)	p value
SLST (sec.)	5.6 ± 3.9	5.8 ± 3.7	n.s.
TGUG (sec.)	24.4 ± 5.3	25.9 ± 4.8	n.s.
SCT (sec.)	45.6 ± 17.8	48.3 ± 19.1	n.s.
WOMAC	62.7 ± 11.2	64.1 ± 10.7	n.s.
<i>SLST, TGUG, SCT and WOMAC</i> were calculated using student's t-test. N.s.: $p > 0.05$			
<i>SLST</i> single leg stance test, <i>TGUG</i> timed get up and go, <i>SCT</i> stair climbing test, <i>WOMAC</i> Western Ontario and McMaster Universities Osteoarthritis Index score			

Table 6
Follow-up results of knee balance and functionality

Indexes	Group I (n = 17)	Group II (n = 19)	p value
SLST (sec.)	28.9 ± 7.5	20.3 ± 5.9	⊠0.001
TGUG (sec.)	13.4 ± 3.2	16.8 ± 3.1	⊠0.001
SCT (sec.)	18.6 ± 6.8	24.5 ± 8.7	⊠0.001
WOMAC	25.7 ± 8.2	36.2 ± 9.7	⊠0.001
<i>SLST, TGUG, SCT and WOMAC</i> were calculated using student's t-test. N.s.: $p > 0.05$			
<i>SLST</i> single leg stance test, <i>TGUG</i> timed get up and go, <i>SCT</i> stair climbing test, <i>WOMAC</i> Western Ontario and McMaster Universities Osteoarthritis Index score			

Discussion

Correlational studies noted better outcomes in IPA patients with subluxation and dislocation after PFA, which were commonly associated with trochlear dysplasia [25, 26]. Marco Valoroso et al. [27] pointed out that PFA improves patellofemoral congruence by correcting trochlear dysplasia and standardizing radiological measurements as patellar tilt and TT-TG. However, for IPA patients, there has been at least a

5% rate of patellar subluxation after PFA at a long-term follow-up [28]. This suggests a greater rate of dislocation in IPA patients with an increased TT-TG (>20mm). In normal knees, the Q-angle is under 20° and the congruence-angle (CA) are close to 10° [36, 45]. The normal TT-TG distance, patellar lateral shift (PLS) and patellar tilt angle (PTA) are under 20 mm, 15 mm and 20°, respectively [18, 46-50]. Our results showed that both of the two surgical methods could improve the stability of patellofemoral joint. But compared with PFA, the standardizing radiological measurements of this combined operation were more in line with normal knee level. In addition, there were five patients with subluxation of the patella in Group II and none in Group I (Figure 5). Therefore, for such special patient, the stability of the patellofemoral joint can be significantly improved by the PFA combined with TTT, compared with PFA alone, with decreased recurrent instability.

SLST was used to evaluate static balance. Vuorenmaa et al. [51] found that time standing on one foot was 10.3 ± 14.7 s at the third month in unilateral TKA patients, which was a significant improvement over the preoperative evaluation results. In the study by Akbaba et al. [39], the SLST period increased from 3.5 ± 4.5 s to 44.2 ± 32.2 s for right leg and from 2.6 ± 2.4 s to 42.6 ± 32.5 s for left leg after bilateral TKA at the second month. In the current study, our data showed that the static balance of Group I is much higher than that of Group II after one year of surgery.

TGUG is a test used to assess dynamic balance. The values below than 20 s are within normal limits for transfer and mobility [39, 41]. Zeni et al. [52] reported that the TGUG period decreased from 8.7 ± 1.8 s to 6.7 ± 1.3 s at the second year for bilateral TKA. In the study by Akbaba et al. [39], the TGUG period decreased from 21.7 ± 11.2 s to 12.9 ± 2.9 s by effective rehabilitation training after two months of bilateral TKA. In the present study, more improvement was obtained for dynamic balance in Group I when compared to Group II at the first year after operation.

SCT is an important index to evaluate the function of knee joint and the number of stairs and application of SCT differ in the literatures. In the study by Akbaba et al. [39], it was found that the SCT (10 stairs) results were pre-operative 49.1 ± 24.5 s, first month 34.9 ± 20.5 s, second month 17.5 ± 7.2 s after bilateral TKA. Marcus et al. [53] found that the SCT (10 stairs) period was pre-operative 17.2 ± 6.8 s and sixth week 9.2 ± 3.9 s following the eccentric exercise programme in TKA patients. Zeni et al. [52] showed that the duration of SCT (12 steps) decreased from 16.8 ± 5.7 s to 10.0 ± 1.9 s in bilateral TKA patients. Heiberg et al. [54] reported that the SCT duration of 8 stairs was 14 ± 5 s in the pre-operative period and was 6 ± 2 s at the post-operative third month. In our study, the duration of SCT (10 steps) decreased from 45.6 ± 17.8 s preoperatively to 18.6 ± 6.8 s postoperatively in Group I and from 48.3 ± 19.1 s to 24.5 ± 8.7 s in Group II after one year of surgery. The results showed that with the combined operation of PFA combined with TTT, the climbing up and down period decreased significantly when compared to PFA alone.

In addition, the WOMAC score is also a widely accepted index of knee function evaluation. Kim et al. [55] demonstrated that WOMAC values decreased at the sixth month in the groups with or without passive range of motion (ROM) when compared to the pre-operative period. Akbaba et al. [39] reported that WOMAC pain, stiffness and function values decreased at the second month when compared to the pre-

operative period in TKA patients. Walls et al. [56] and Rooks et al. [57] revealed a similar decrease in the WOMAC score. In our study, the median WOMAC score was improved from 62.7 ± 11.2 preoperatively to 25.7 ± 8.2 one year postoperatively in Group I and from 64.1 ± 10.7 to 36.2 ± 9.7 in Group II. Our results showed that the WOMAC score of the combined surgery is better than that of PFA alone.

Through the above discussion, we can draw the following conclusions. Firstly, both of the two surgical methods could improve the stability of patellofemoral joint and function of knee joint when compared to the pre-operation. Secondly, it also shows that for such special IPA patients with an increased TT-TG ($>20\text{mm}$), the combined operation of PFA combined with TTT can better restore the involuntional relationship of patellofemoral joint and further improve the balance and function of knee joint. Therefore, for such special IPA patients, this combined operation may be more effective to avoid patellar instability and improve knee function than PFA alone.

Abbreviations

IPA: Isolated patellofemoral arthritis;

TT-TG: tibial tuberosity-trochlear groove distance;

CT: computed tomography;

TTT: tibial tubercle transfer;

PFA: patellofemoral arthroplasty;

CONSORT: Consolidated Standards of Reporting Trials;

SLST: single leg stance test;

TGUG: timed get up and go;

SCT: stair climbing test;

WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index score;

ICCs: intra-class correlation coefficients;

Q-angle: quadriceps-angle;

CA: congruence-angle;

PLS: patellar lateral shift;

PTA: patellar tilt angle;

TKA: Total knee arthroplasty;

SPSS: Statistical Package for the Social Sciences;

ROM: range of motion;

Declarations

Ethics approval and consent to participate

The present study was approved by the Academic Ethics Committee of the Third Hospital of Hebei Medical University. The trial was conducted in accordance with the Declaration of Helsinki. All participants will be provided information about the study and enrolled into the trial if they meet all eligibility criteria and voluntarily sign an informed consent statement.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used during the current study available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Fei Wang contributed to the conception of the study; Conglei Dong, Chao Zhao contributed significantly to the analysis and wrote the manuscript; Ming Li, Huijun Kang and Kang Piao collected the data; Kuo Hao, Chenyue Xu and Maozheng Wei helped perform the analysis with constructive discussions. The authors read and approved the final manuscript.

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Figures

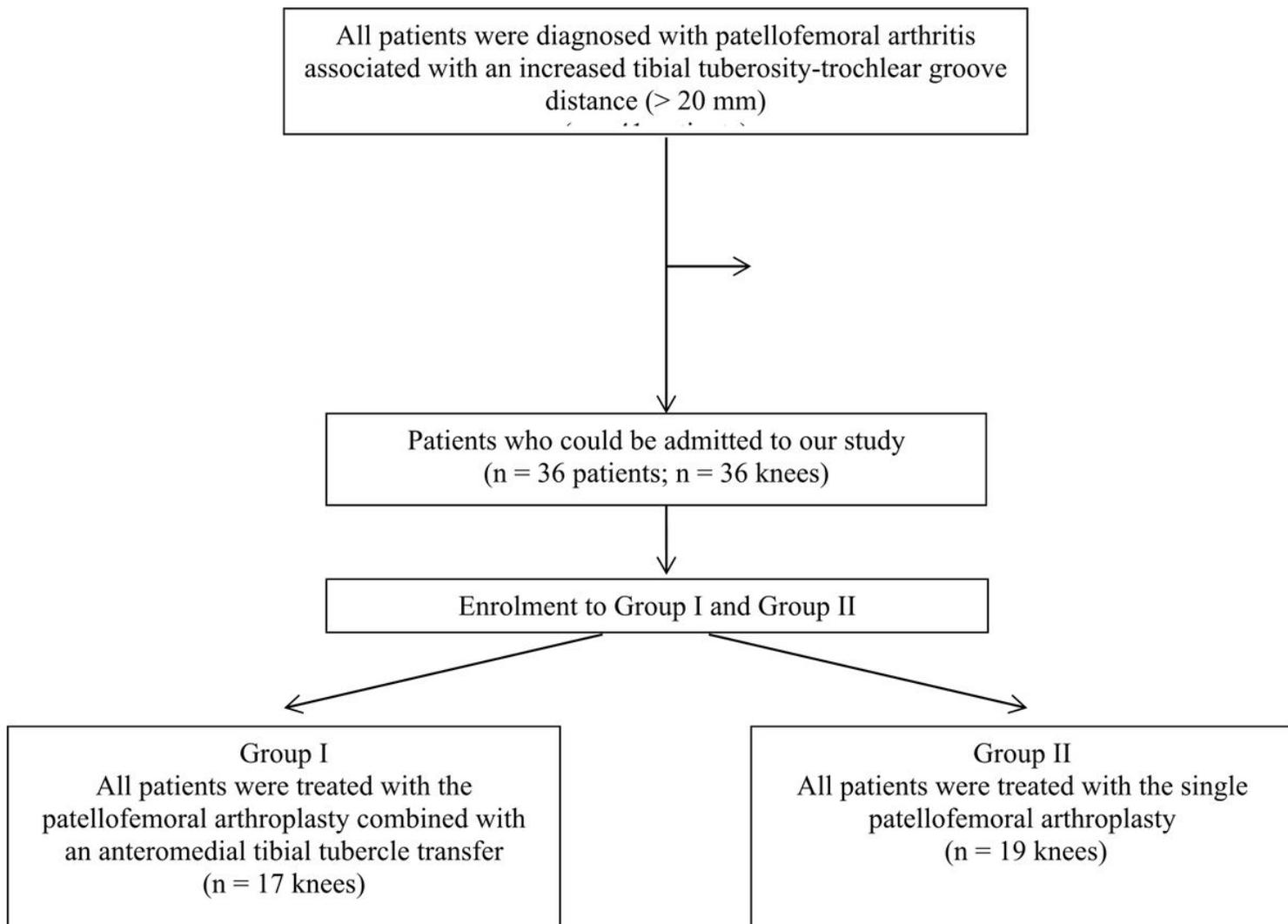


Figure 1

Consolidated Standards of Reporting Trials (CONSORT) flowchart of patient selection.

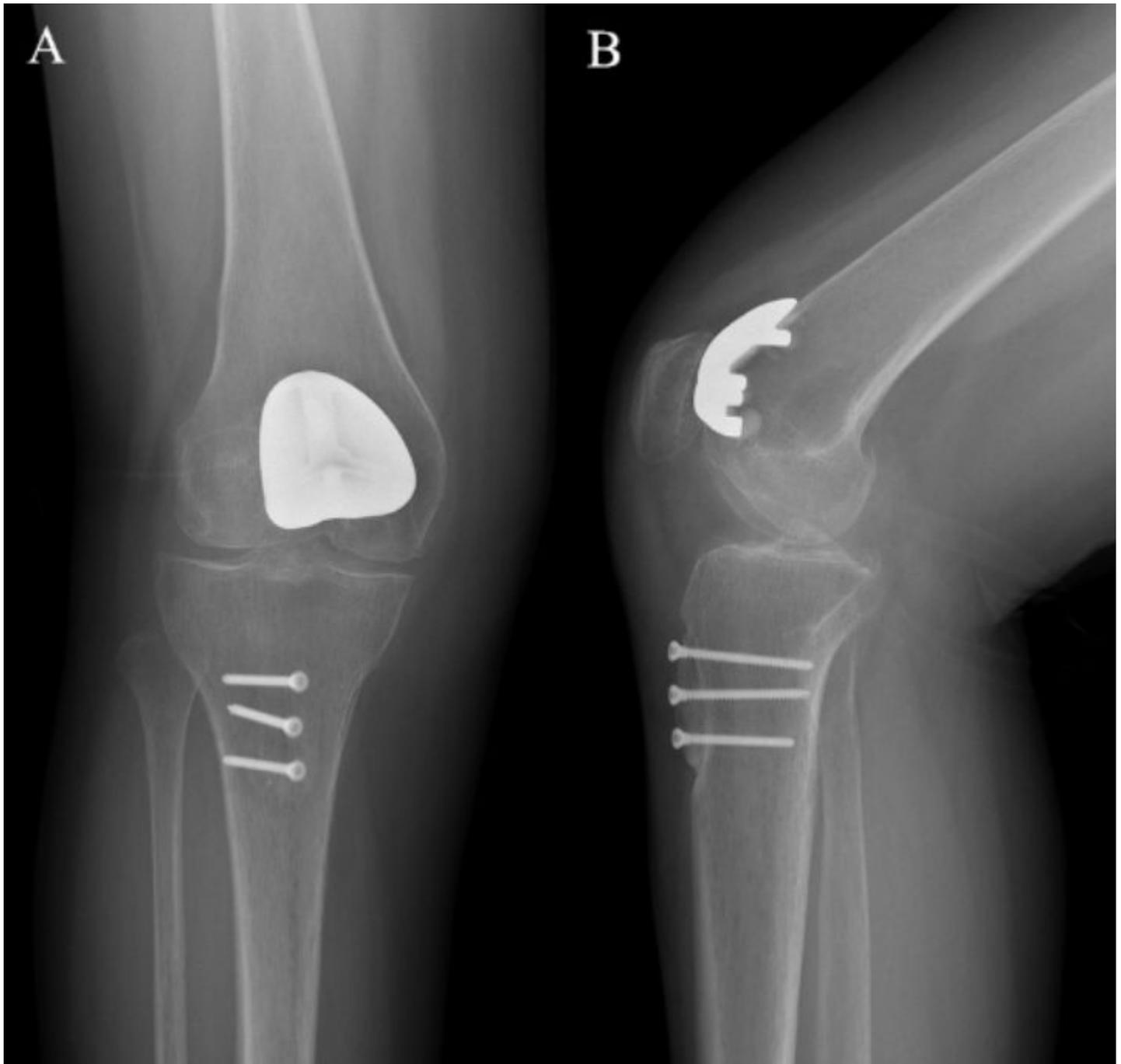


Figure 2

IPA patients with an increased TT-TG distance ($>20\text{mm}$) may have a good outcome with the patellofemoral arthroplasty combined with an anteromedial tibial tubercle transfer.

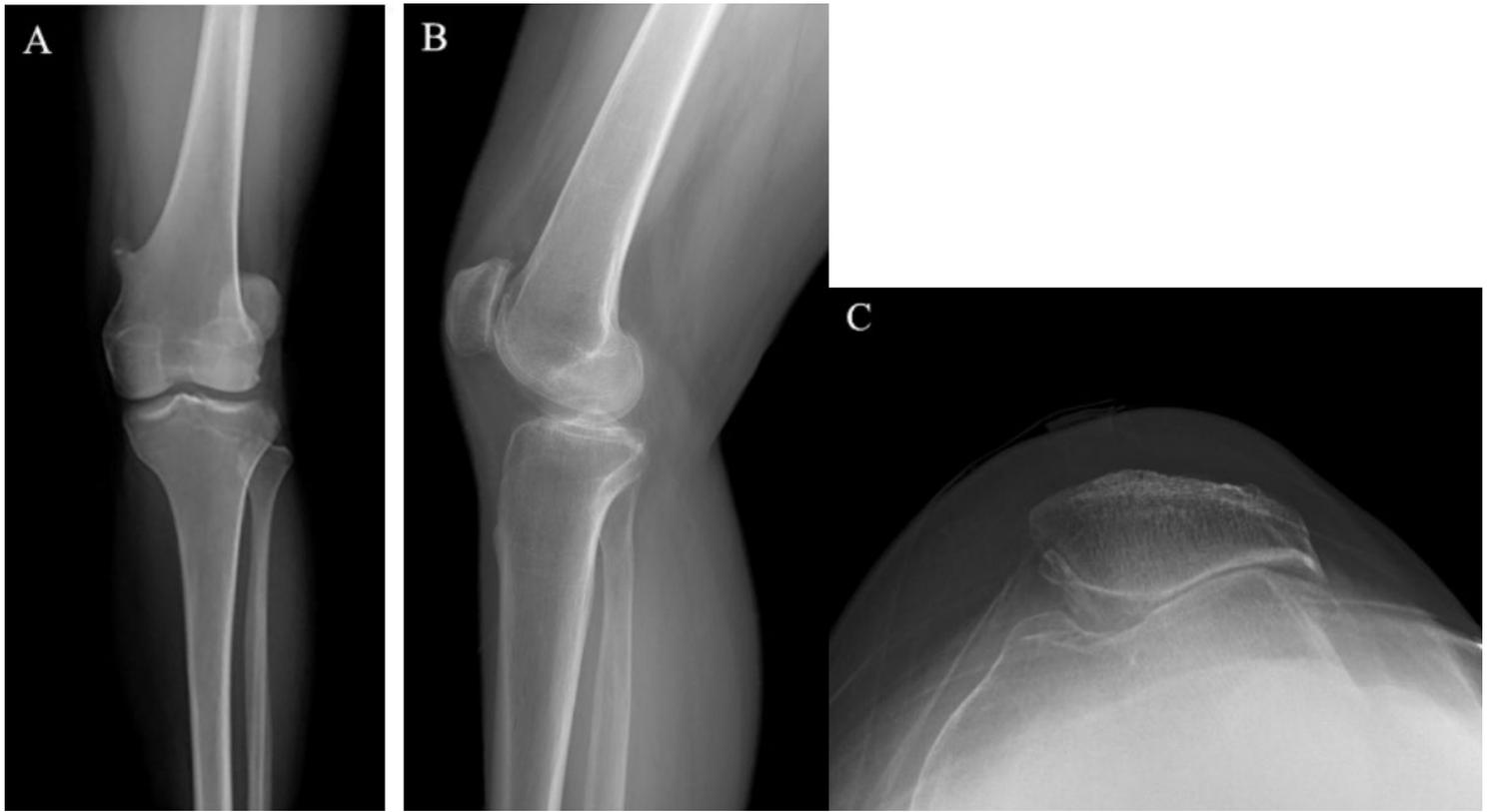


Figure 3

Pre-operative radiographs of a typical patient in A) anteroposterior, B) lateral and C) merchant views, showing evident osteoarthritis of the patellofemoral joint and mild osteoarthritis of the tibiofemoral joint.

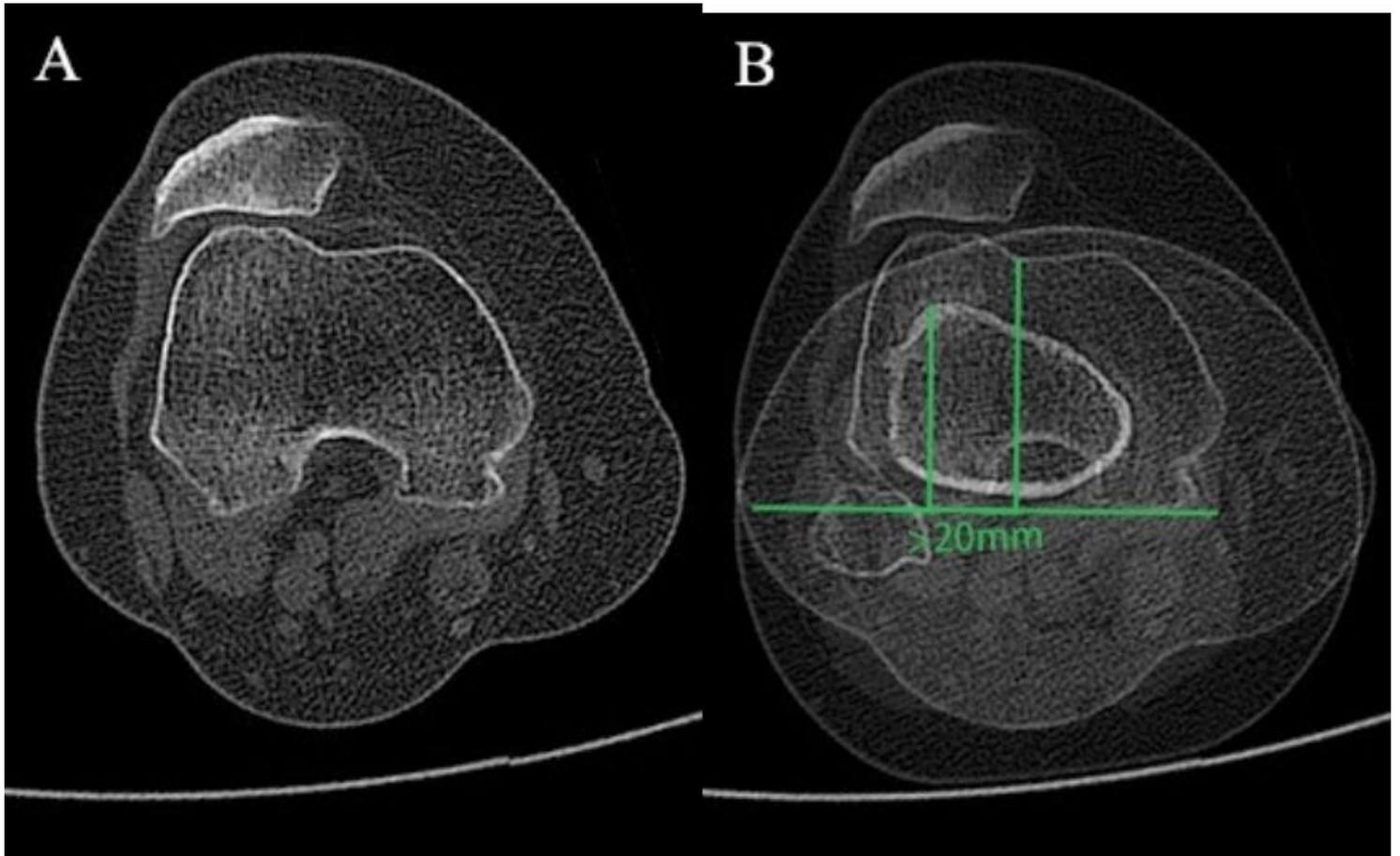


Figure 4

A) Diagnosis of patellar dislocation by transversal imaging of CT with the non-weight-bearing knee in full extension before operation. B) The normal TT-TG distance measured on computed tomography scans is less than 20 mm and more than 20 mm is the operative indication of tibial tubercle transfer.

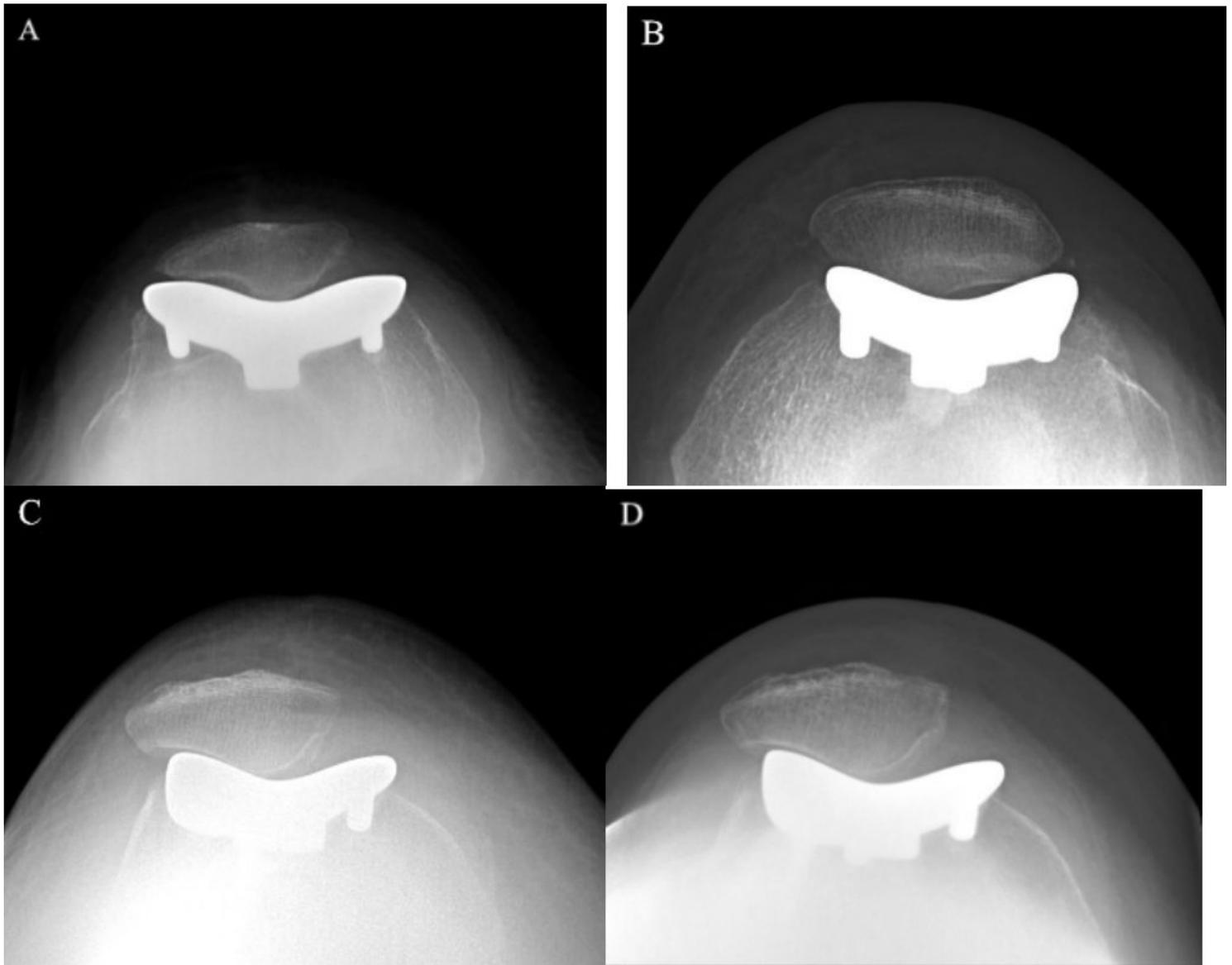


Figure 5

1) Post-operative merchant radiographs of some typical patients in A) and B), showing the good involutinal relationship of patellofemoral joint after the combined surgery. 2) Post-operative merchant radiographs of some typical patients in C) and D), showing the poor involutinal relationship of patellofemoral joint after the single PFA.