

# Association between abnormal native tibial torsion and poorer clinical outcomes following robotic-assisted total knee arthroplasty: follow-up of at least two years

**Haoshen Wu**

The Affiliated Hospital of Qingdao University

**Wenzhe Wang**

The Affiliated Hospital of Qingdao University

**Nanyu Pang**

The Affiliated Hospital of Qingdao University

**Fan Chen**

The Affiliated Hospital of Qingdao University

**Chaoqun Yu**

The Affiliated Hospital of Qingdao University

**Feiyu Mu**

The Affiliated Hospital of Qingdao University

**Jihao Zhang**

The Affiliated Hospital of Qingdao University

**Luhao Wang**

The Affiliated Hospital of Qingdao University

**Haining Zhang**

**zhanghaining1976@126.com**

The Affiliated Hospital of Qingdao University

**Zian Zhang**

The Affiliated Hospital of Qingdao University

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## Research Article

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# Abstract

## Purpose

For patients treated with total knee arthroplasty (TKA), postoperative knee function and patient-reported outcomes may both be influenced by native tibial torsion. Accordingly, the study compared clinical outcomes of robotic-assisted total knee arthroplasty (RA-TKA) between patients with tibial rotational malalignment and those with normal tibial rotational alignment.

## Methods

From 2022 to 2023, the retrospective cohort included 382 patients who received RA-TKA using a functional alignment (FA) strategy for end-stage varus knee osteoarthritis (KOA). One surgeon performed all procedures. A TTA  $> 30^\circ$  defined the abnormal tibial torsion (ATT) group, whereas a TTA  $\leq 30^\circ$  defined the normal tibial torsion (NTT) group. Following 1:1 matching, each group comprised 77 patients. Clinical outcomes were evaluated with the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Oxford Knee Score (OKS), Knee Society Score (KSS) function, and Forgotten Joint Score (FJS); anterior knee pain (AKP) and patellofemoral crepitus were also recorded. Postoperative data collection occurred after patients reached the minimum 2-year follow-up.

## Results

Similar WOMAC, OKS, and KSS function scores were observed for the ATT and NTT groups at both the preoperative assessment and postoperative follow-up. Postoperative FJS was significantly lower for the ATT group relative to the NTT group ( $75.5 \pm 23.5$  vs.  $83.4 \pm 18.4$ ,  $P = 0.045$ ). The incidences in the ATT and NTT groups were 25% and 10%, respectively, for patellofemoral crepitus ( $P = 0.020$ ) and 19% and 8%, respectively, for AKP ( $P = 0.035$ ), with both outcomes occurring more frequently in the ATT group. Patient satisfaction was numerically higher in the NTT group (94%) than in the ATT group (84%), but the between-group difference was nonsignificant ( $P = 0.072$ ).

## Conclusion

Clinical outcomes improved after RA-TKA in both the ATT and NTT groups. At follow-up of at least 2 years, however, lower FJS was more likely among patients with ATT, who also had higher incidences of patellofemoral crepitus and AKP.

## Introduction

Rotational alignment is considered a critical factor in successful total knee arthroplasty (TKA); tibial component malrotation may adversely affect retropatellar pressure, knee kinematics, and extension

deficit, potentially leading to anterior knee pain (AKP), stiffness, and patient dissatisfaction[1-3]. Previous investigations of tibial component rotation have focused mainly on proximal tibial anatomy. However, growing evidence indicates that preoperative tibial torsion may also influence postoperative outcomes following TKA [4].

Tibial torsion describes the rotation of the proximal tibia with respect to the distal tibia and is measured as the angle between the transmalleolar axis and a line tangential to the proximal tibial posterior cortex. Earlier investigations have presented AKP, gait dysfunction, and patellar instability as possible consequences of excessive native tibial torsion [5-8]. Native tibial torsion exceeding 30° has been considered an indication for tibial derotation osteotomy (TDO) to address the biomechanical and functional consequences of abnormal tibial torsion [9,10]. However, setting tibial component rotation in TKA does not take the degree of preoperative tibial torsion into account. Although TKA corrects limb alignment and modifies the native knee anatomy intraoperatively, individual variations in native tibial torsion may still influence postoperative outcomes. This possibility warrants evaluation of TKA outcomes across patients with different degrees of preoperative tibial torsion.

Robotic-assisted techniques have increased the precision of bone resection and the accuracy with which anatomical landmarks are identified, thereby improving tibial component rotational alignment [11-14]. Nevertheless, few studies have investigated whether variation in preoperative tibial torsion influences postoperative clinical outcomes or the frequency of AKP and patellofemoral crepitus in recipients of robotic-assisted total knee arthroplasty (RA-TKA).

With at least 2 years of follow-up, we evaluated native tibial torsion in relation to clinical outcomes and patellofemoral symptoms, specifically AKP and patellofemoral crepitus. We hypothesized a possible association between abnormal preoperative tibial torsion and both poorer postoperative functional outcomes and more frequent patellofemoral symptoms after RA-TKA.

## Materials and Methods

### Study design and participants

The investigated cohort included 382 patients treated from May 2022 to November 2023 with RA-TKA under a functional alignment (FA) strategy for end-stage varus knee osteoarthritis (KOA). Exclusion was based on the following criteria: (1) valgus knee deformity (mechanical hip-knee-ankle angle (mHKA) > 180°) [15]; (2) absence of a minimum 2-year follow-up duration; (3) inflammatory arthritis; (4) flexion contracture > 20°; (5) a history of lower extremity fracture or surgery, and (6) periprosthetic joint infection or revision. In this study, native tibial torsion angle (TTA) greater than 30° was defined as abnormal tibial torsion (ATT) [10]. Based on these criteria, 91 patients were assigned to the ATT group (TTA > 30°). These patients were matched 1:1 with 189 patients who had normal tibial torsion (NTT) (TTA ≤ 30°). Matching was performed based on known key variables that influence postoperative outcomes of TKA, including age (±5 years), sex (exact match), body mass index (BMI) (±5 kg/m<sup>2</sup>), side (exact match), prosthesis (exact match for Stryker cruciate-retaining (CR) or posterior-stabilized (PS) Triathlon), and

mHKA ( $\pm 5^\circ$ ). After matching, each group contained 77 patients. The flowchart of the patient selection process was shown in Fig.1.

### **Surgical techniques**

In each TKA, a cemented CR or PS prosthesis was implanted through a standard medial parapatellar approach, with no patellar resurfacing. Both preoperative imaging and intraoperative evaluation were used to document the functional capacity and structural integrity of the posterior cruciate ligament (PCL), and these findings informed prosthesis selection [16,17]. Implant availability and the surgeon's preference were also considered. For preoperative planning, the Mako robotic platform planning software generated 3D models from computed tomography (CT) scans. This platform enables personalized planning, implant size adjustment, and position modification to adhere to FA principles [18]. For tibial implant rotation, the anteroposterior axis was defined by a line connecting the center of the posterior cruciate ligament attachment and the medial third of the tibial tubercle [19]. Using the preoperative CT-generated bone model, the location of the tibial implant's anteroposterior axis was first established and subsequently marked in the Mako robotic platform planning software. Prior to fixing the tibial trial component with pins, a navigation probe was used to accurately locate anterior-posterior axis of the tibial implant (Fig.2). An orthopedic surgeon highly experienced in FA RA-TKA performed all procedures at the same institution. Standardized rehabilitation was initiated for every patient on the day after surgery and delivered by the same treatment team.

### **Patient-reported outcome measures**

Both patients and the independent evaluator who collected patient-reported outcome measures (PROMs) remained blinded to group assignment. Before surgery, the PROMs collected were the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), the Oxford Knee Score (OKS), and the Knee Society Score (KSS) function [20]. At follow-up, patient satisfaction and patellofemoral symptoms were evaluated alongside the WOMAC, OKS, KSS function, and the Forgotten Joint Score (FJS) [21].

The assessed patellofemoral symptoms were AKP and patellofemoral crepitus. AKP was assessed by determining whether patients reported pain in the anterior region of the operated knee during stair climbing as well as low chair-rising activities [22]. Patellofemoral crepitus was assessed by asking whether patients noticed crackling or abnormal popping anteriorly in the operated knee while moving through the mid-range of motion [23].

Patients used a five-point Likert scale to rate satisfaction, selecting very satisfied, satisfied, neutral, dissatisfied, or very dissatisfied. Dichotomization yielded two groups: very satisfied or satisfied responses constituted the satisfied group, while neutral, dissatisfied, or very dissatisfied responses constituted the dissatisfied group [24]. All assessments were independently performed by the same trained clinician to ensure consistency and reliability of the results. Patients were followed for 24 to 35 months.

## Alignment measures

Two independent observers measured the mHKA using preoperative standing full-leg radiographs and the TTA using preoperative axial CT scans. The medial angle formed by the femoral mechanical axis and the tibial mechanical axis constituted mHKA. TTA denotes the lateral angular difference between the proximal and distal portions of the tibial axis. At the proximal level, a tangent drawn along the posterior tibial cortex immediately proximal to the fibular head established the tibial axis (Fig.3a); at the distal level, the axis was established by connecting the centers of the tibia and fibula on axial CT images at a level corresponding to the transmalleolar axis (Fig.3b) [25]. The two independent observers worked independently, using Centricity<sup>TM</sup> universal viewer zero footprint to measure the angles. Between-observer consistency for the radiographic measurement methods was assessed using intraclass correlation coefficients (ICCs). The average of the measurements obtained from the two observers was used for the subsequent analysis. Excellent consistency was supported by intra-observer ICCs and inter-observer ICCs that each exceeded 0.9.

## Statistical analysis

R version 4.4.1 was used for data matching and analysis;  $p < 0.05$  defined statistical significance. Patient matching was implemented with the MatchIt package using a 1:1 nearest neighbor matching algorithm without replacement. Continuous variables were first assessed for normality using the Shapiro–Wilk test; Student's t-test was then used for normally distributed variables, and the Wilcoxon rank-sum test for variables with a non-normal distribution. Categorical outcomes were compared through the use of the chi-square test.

The sample-size calculation was performed with PASS 15. Effect-size inputs were taken from Clement et al.'s FJS study [26]: 13.7 points for the minimal clinically important difference (MCID) and 30 points for the standard deviation. With these assumptions, a group size of 77 patients was required to identify a clinically significant difference in FJS at 80% statistical power and an  $\alpha$  of 0.05.

## Results

Of the 154 patients analyzed, 77 were in the ATT group and 77 were in the NTT group. TTA was the only baseline characteristic showing a significant between-cohort difference ( $34.9 \pm 4.3$  vs.  $21.7 \pm 5.5$ ,  $P < 0.001$ ) (Table 1).

Preoperative comparison of the two groups showed no significant difference in WOMAC ( $49.4 \pm 5.8$  vs.  $49.3 \pm 5.5$ ,  $P = 0.967$ ), OKS ( $40.1 \pm 5.3$  vs.  $39.9 \pm 5.4$ ,  $P = 0.603$ ), or KSS function ( $42.1 \pm 14.9$  vs.  $46.4 \pm 15.6$ ,  $P = 0.073$ ) (**Table 2**).

At the minimum 2-year follow-up, FJS was  $75.5 \pm 23.5$  in the ATT group and  $83.4 \pm 18.4$  in the NTT group; the ATT score was significantly lower ( $P = 0.045$ ). Differences across the study groups remained nonsignificant for WOMAC ( $9.9 \pm 6.1$  vs.  $8.8 \pm 4.7$ ,  $P = 0.450$ ), OKS ( $14.9 \pm 3.3$  vs.  $14.3 \pm 2.1$ ,  $P = 0.802$ ),

or KSS function ( $83.8 \pm 17.0$  vs.  $86.0 \pm 15.4$ ,  $P = 0.580$ ) (Table 2). From the preoperative assessment to the minimum 2-year follow-up, both groups showed significant improvements in WOMAC, OKS, and KSS function scores (Table 3).

Postoperatively, patellofemoral crepitus occurred in 25% of the ATT group versus 10% of the NTT group ( $P = 0.020$ ); AKP occurred in 19% of the ATT group versus 8% of the NTT group ( $P = 0.035$ ). Both outcomes were significantly more frequent in the ATT group. Postoperative satisfaction was 84% in the ATT group versus 94% in the NTT group; the resulting difference was not statistically significant ( $P = 0.072$ ) (Table 2).

## Discussion

The principal finding was that the between-group difference in FJS, although statistically significant, did not reach the widely accepted MCID. Patellofemoral crepitus and AKP affected significantly greater proportions of patients in the ATT group than in the NTT group. Patient dissatisfaction was likewise more frequent in the ATT group, whereas the other PROMs showed no statistically significant between-group differences.

Our findings provide clinically relevant evidence for managing individuals with excessive tibial torsion who undergo TKA for end-stage varus KOA. Although TDO has been recommended when native tibial torsion is greater than  $30^\circ$  [9,10], most patients who also have KOA and excessive tibial torsion receive TKA alone rather than TKA combined with TDO. Drexler et al. [27] combined TKA with TDO in 10 KOA patients whose native TTA exceeded  $45^\circ$  and who had concomitant patellar instability; postoperative complications occurred in 50%. These complications are associated with nonunion at the osteotomy site, arthrofibrosis, and the additional surgical trauma caused by the osteotomy procedure. In our cohort, the ATT and NTT groups had comparable postoperative OKS, WOMAC and KSS function. The between-group difference in postoperative FJS fell short of the MCID despite the higher score observed in the NTT group relative to the ATT group. Collectively, the findings suggest that additional TDO for preoperative ATT may not be necessary during primary TKA.

According to Panni et al.'s systematic review [28], excessive internal rotation of the tibial component was associated with greater susceptibility to AKP and poorer functional outcomes after TKA; in contrast, external rotation appeared not to affect outcomes. Several studies used the Akagi line to define tibial component rotation; this line connects the midpoint of the PCL insertion to the medial border of the tibial tubercle [18,29]. Compared with the Akagi line, a line joining the medial one-third of the tibial tubercle to the central portion of the PCL insertion has been reported to prevent internal rotation more effectively. Lützner et al. [30] found that positioning the landmark at the medial third of the tibial tubercle improved femorotibial rotational alignment relative to placement at the medial border. When the tibial component has a greater degree of internal rotation, postoperative outcomes after TKA may be adversely affected; the distal tibia may also show a further increase in external rotation relative to the component. Future

work is therefore needed to verify whether tibial component placement based on the Akagi line results in poorer clinical outcomes in patients with ATT.

Among the patellofemoral symptoms examined, this study assessed the relationship of preoperative ATT to postoperative AKP and patellofemoral crepitus. According to Erkocak et al. [6], AKP may occur more frequently when excessive external tibial torsion is present, although this condition is not considered a direct cause. Our findings add evidence that preoperative ATT is associated with more frequent postoperative AKP after TKA. However, the mechanisms that could account for this association were not established in the present study. Clarifying the underlying causes of AKP among patients with ATT requires additional research. Patellofemoral crepitus was significantly more frequent among patients with ATT than among those with NTT. Previous studies suggest that patellofemoral crepitus can often be managed nonoperatively and that symptoms may improve or resolve over time [31,32]. Nevertheless, our findings indicate that ATT may be one potential factor associated with patellofemoral crepitus after TKA.

Several limitations warrant consideration. First, the cohort was restricted to patients who had varus KOA and underwent FA RA-TKA without patellar resurfacing. Consequently, applicability of the findings may be limited when other alignment strategies or surgical techniques are used or when valgus deformities are present. Second, our study population consisted exclusively of Asian patients. Previous research has indicated that native tibial torsion is generally greater in Caucasian populations compared to Asians [33], which should be considered when extrapolating these results to other ethnic groups. Third, the relatively short 2-year follow-up indicates a need for studies with longer observation periods to determine whether outcomes differ over time between the ATT and NTT groups. Fourth, whether implant design influenced postoperative outcomes was not specifically examined. CR and PS implants have yielded comparable clinical outcomes in previous studies [34,35]. In the present study, CR and PS implants were exactly matched, and the same intraoperative tibial rotational reference axis was used for both implant designs. Nevertheless, whether ATT has different effects on the outcomes of CR and PS implants remains unclear. Larger studies are needed to clarify whether ATT may influence outcomes across different implant designs. Fifth, our study did not include postoperative CT assessment of component rotational alignment, which limited the ability to evaluate the exact rotational relationship between the tibia and the tibial component. Sixth, AKP and patellofemoral crepitus were assessed as self-reported binary (yes/no) outcomes without severity grading, which may limit the precision of symptom evaluation. Finally, variations in femoral component rotational alignment were not evaluated for their impact on postoperative outcomes. Previous studies have shown that abnormal femoral component rotation is not associated with adverse outcomes after TKA [36,37]. Therefore, under the precise conditions of RA-TKA, variations in femoral component rotational parameters are unlikely to have significantly influenced our results.

## Conclusion

Patients with ATT and those with NTT both showed improved clinical outcomes after RA-TKA. However, after at least 2 years of follow-up, lower FJS was more likely among patients with ATT, who also had higher incidences of patellofemoral crepitus and AKP.

## Declarations

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### Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

### Author Contributions

Haoshen Wu and Wenzhe Wang: Writing – original draft; Nanyu Pang: Writing – review & editing; Fan Chen: Formal analysis; Chaoqun Yu: Baseline data curation; Feiyu Mu: Investigation (patient follow-up); Jihao Zhang and Luhao Wang: Investigation (radiographic and CT measurements); Zian Zhang and Haining Zhang: Conceptualization, Methodology, Supervision. All authors have read and approved the final manuscript.

### Ethics approval

*This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of the Affiliated Hospital of Qingdao University (QYFY WZLL 50286).*

### Consent to participate

Informed consent was obtained from all individual participants included in the study.

### Consent to publish

Not applicable.

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## Tables

| <b>Table 1.</b> Demographic characteristics between groups with abnormal and normal tibial torsion                                                          |                                        |                                      |         |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------|--------------------------------------|---------|
|                                                                                                                                                             | Abnormal tibial torsion group (n = 77) | Normal tibial torsion group (n = 77) | P value |
| Age (years)                                                                                                                                                 | 68.4 ± 4.6                             | 68.5 ± 3.9                           | 0.940   |
| Sex                                                                                                                                                         |                                        |                                      | 1.000   |
| Women                                                                                                                                                       | 60 (78%)                               | 60 (78%)                             |         |
| Men                                                                                                                                                         | 17 (22%)                               | 17 (22%)                             |         |
| BMI (kg/m <sup>2</sup> )                                                                                                                                    | 27.8 ± 3.4                             | 27.9 ± 3.2                           | 0.756   |
| Side                                                                                                                                                        |                                        |                                      | 1.000   |
| Left                                                                                                                                                        | 40 (52%)                               | 40 (52%)                             |         |
| Right                                                                                                                                                       | 37 (48%)                               | 37 (48%)                             |         |
| Prosthesis                                                                                                                                                  |                                        |                                      | 1.000   |
| CR                                                                                                                                                          | 40 (52%)                               | 40 (52%)                             |         |
| PS                                                                                                                                                          | 37 (48%)                               | 37 (48%)                             |         |
| mHKA (°)                                                                                                                                                    | 173.5 ± 3.0                            | 172.8 ± 2.7                          | 0.280   |
| TTA (°)                                                                                                                                                     | 34.9 ± 4.3                             | 21.7 ± 5.5                           | <0.001  |
| Follow-up (months)                                                                                                                                          | 28.9 ± 2.9                             | 28.5 ± 2.8                           | 0.384   |
| Abbreviation: BMI = body mass index; CR = cruciate-retaining; PS = posterior-stabilized; mHKA = mechanical hip-knee-ankle angle; TTA = tibial torsion angle |                                        |                                      |         |

| <b>Table 2.</b> Clinical outcomes between groups with abnormal and normal tibial torsion                                                                                                                          |                                           |                                         |                |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|-----------------------------------------|----------------|
|                                                                                                                                                                                                                   | Abnormal tibial torsion group<br>(n = 77) | Normal tibial torsion<br>group (n = 77) | <i>P</i> value |
| WOMAC                                                                                                                                                                                                             |                                           |                                         |                |
| Preoperative                                                                                                                                                                                                      | 49.4 ± 5.8                                | 49.3 ± 5.5                              | 0.967          |
| Postoperative                                                                                                                                                                                                     | 9.9 ± 6.1                                 | 8.8 ± 4.7                               | 0.450          |
| OKS                                                                                                                                                                                                               |                                           |                                         |                |
| Preoperative                                                                                                                                                                                                      | 40.1 ± 5.3                                | 39.9 ± 5.4                              | 0.603          |
| Postoperative                                                                                                                                                                                                     | 14.9 ± 3.3                                | 14.3 ± 2.1                              | 0.802          |
| KSS function                                                                                                                                                                                                      |                                           |                                         |                |
| Preoperative                                                                                                                                                                                                      | 42.1 ± 14.9                               | 46.4 ± 15.6                             | 0.073          |
| Postoperative                                                                                                                                                                                                     | 83.8 ± 17.0                               | 86.0 ± 15.4                             | 0.580          |
| FJS                                                                                                                                                                                                               |                                           |                                         |                |
| Preoperative                                                                                                                                                                                                      | NA                                        | NA                                      | NA             |
| Postoperative                                                                                                                                                                                                     | 75.5 ± 23.5                               | 83.4 ± 18.4                             | 0.045          |
| Patellofemoral symptoms                                                                                                                                                                                           |                                           |                                         |                |
| Patellofemoral crepitus                                                                                                                                                                                           | 19 (25%)                                  | 8 (10%)                                 | 0.020          |
|                                                                                                                                                                                                                   | 15 (19%)                                  | 6 (8%)                                  | 0.035          |
| Satisfaction                                                                                                                                                                                                      |                                           |                                         | 0.072          |
| Satisfied                                                                                                                                                                                                         | 65 (84%)                                  | 72 (94%)                                |                |
| Dissatisfied                                                                                                                                                                                                      | 12 (16%)                                  | 5 (6%)                                  |                |
| Abbreviation: WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index; OKS = Oxford Knee Score; KSS = Knee Society Score; FJS = Forgotten Joint Score; AKP = anterior knee pain; NA = not assessed |                                           |                                         |                |

**Table.3** Comparison of preoperative and postoperative clinical outcomes within the abnormal and normal tibial torsion groups

|                 | Abnormal tibial torsion group (n = 77) |               |                | Normal tibial torsion group (n = 77) |               |                |
|-----------------|----------------------------------------|---------------|----------------|--------------------------------------|---------------|----------------|
|                 | Preoperative                           | Postoperative | <i>P</i> value | Preoperative                         | Postoperative | <i>P</i> value |
| WOMAC           | 49.4 ± 5.8                             | 9.9 ± 6.1     | <0.001         | 49.3 ± 5.5                           | 8.8 ± 4.7     | <0.001         |
| OKS             | 40.1 ± 5.3                             | 14.9 ± 3.3    | <0.001         | 39.9 ± 5.4                           | 14.3 ± 2.1    | <0.001         |
| KSS<br>function | 42.1 ± 14.9                            | 83.8 ± 17.0   | <0.001         | 46.4 ± 15.6                          | 86.0 ± 15.4   | <0.001         |

Abbreviation: WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index; OKS = Oxford Knee Score; KSS = Knee Society Score

## Figures

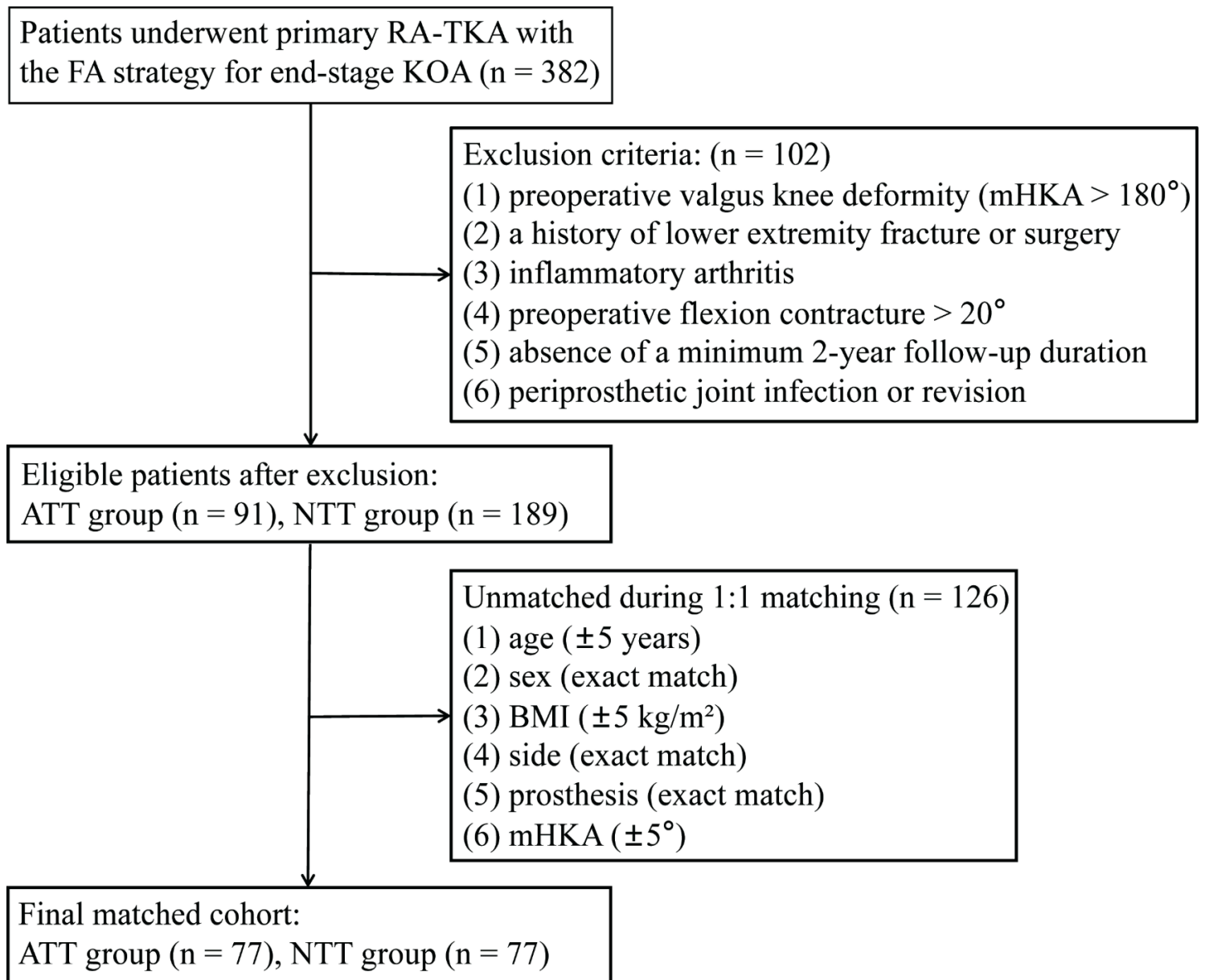


**Figure 1**

Flowchart of the patient selection process in the study.

RA-TKA = robotic-assisted total knee arthroplasty; KOA = knee osteoarthritis; mHKA = mechanical hip-knee-ankle angle; BMI = body mass index; ATT = abnormal tibial torsion; NTT = normal tibial torsion

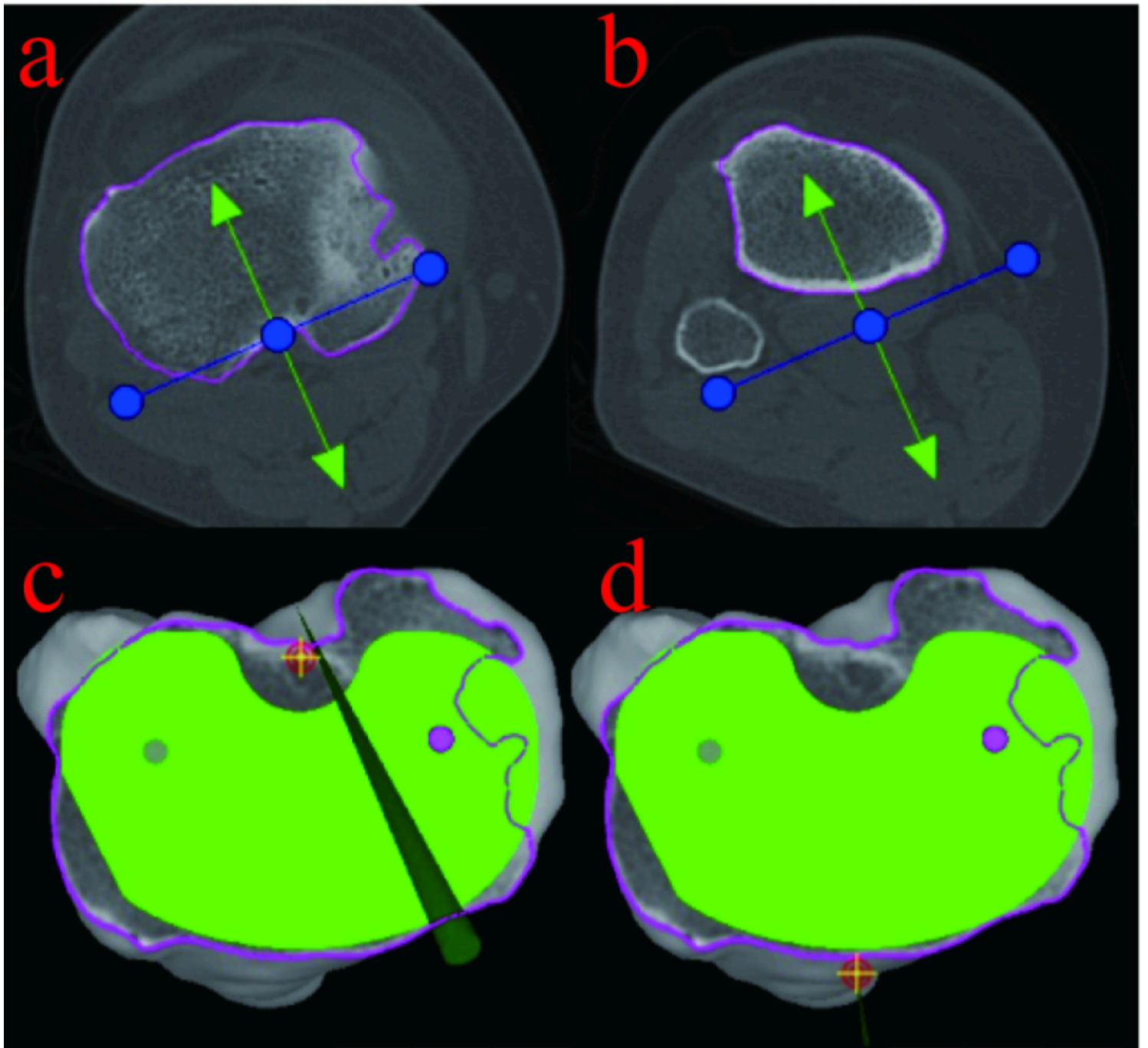


**Figure 2**

Display of landmarks and axes for tibial component rotational alignment in the Mako robotic platform planning software.

**a, b** Green lines indicate the anteroposterior axis of the tibial component. Blue lines are perpendicular to the green lines, and the central blue dot represents the midpoint of the perpendicular lines. The central blue dot is positioned at the pivot point of the posterior cruciate ligament. **b** The anterior direction of the green arrow points toward the medial one-third of the tibial tubercle. **c, d** The green regions represent the planned tibial component position based on the anteroposterior axis. Red circles, generated from the midpoint of the yellow crosshair, indicate the probe localization areas. **c** The yellow crosshair midpoint is

located at the midpoint of the posterior edge of the tibial component. **d** The yellow crosshair midpoint is located at the midpoint of the anterior edge of the tibial component.

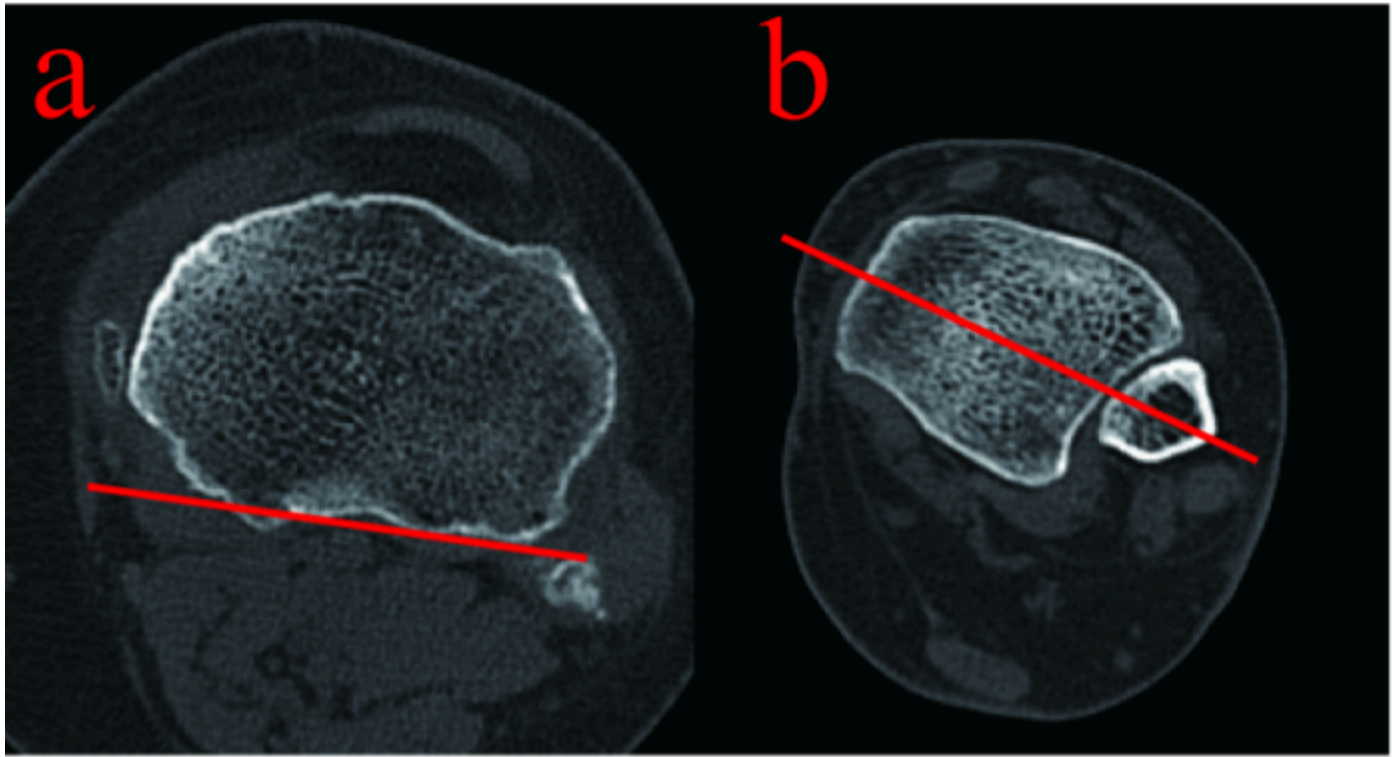


**Figure 3**

The measurement of tibial torsion angle on the axial computed tomographic scan images.

Red lines indicate the proximal tibial axis (a) and distal tibial axis (b) used to calculate the tibial torsion angle. The tibial torsion angle was defined as the lateral angle between these two axes.