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RESEARCH

Changes in coronal tibiofemoral subluxation before and after medial unicompartmental knee arthroplasty: an observation for ten years

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Abstract

Introduction Residual coronal tibiofemoral subluxation (CTFS) can cause peripheral contact between the implant components after medial unicompartmental knee arthroplasty (UKA), resulting in premature failure. The aim of this study was to investigate the changes in CTFS before and after surgery.

Methods Fifty-nine knees of 51 patients who underwent fixed-bearing medial UKA were retrospectively analyzed. CTFS was measured using anteroposterior knee radiographs in the standing position and under valgus stress before surgery and at two weeks and one, five, and 10 years after surgery. The preoperative and postoperative alignment of the knee and tibial component inclination angle (TCIA) were also evaluated.

Results Mean preoperative CTFS decreased significantly from 4.6 ± 1.5 mm in the standing position to 3.3 ± 1.1 mm under valgus stress and to 3.5 ± 1.4 mm in the standing position immediately after surgery. No changes in mean CTFS were observed during the 10-year follow-up period. The CTFS at 2 weeks after surgery was strongly correlated positively with the CTFS at the 10-year follow-up and the preoperative CTFS under valgus stress. The postoperative medial proximal tibial angle (MPTA) was strongly correlated negatively with the two-week postoperative CTFS, while TCIA was significantly correlated positively with that.

Conclusions Residual CTFS after medial UKA did not change during the mid-term follow-up period, which was predictable to some extent based on the observations noted using the preoperative valgus stress radiographs. Close attention should be paid to patients with severe uncorrectable preoperative CTFS and small MPTA values when considering the indications for medial UKA.

Level of evidence IV.

Keywords Coronal tibiofemoral subluxation · Knee osteoarthritis · Medial unicompartmental knee arthroplasty · Peripheral contact

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Introduction

Unicompartmental knee arthroplasty (UKA) is becoming an increasingly popular alternative to total knee arthroplasty (TKA) owing to the faster recovery rate [1], better functional outcomes [2, 3], higher satisfaction rate [4, 5], and other benefits of minimally invasive surgical techniques such as UKA compared to those of TKA [6, 7]. However, many registration systems have shown that mid- or long-term survival rates are worse after UKA as compared with those after TKA [8, 9].

In patients with varus knee osteoarthritis (OA), various degrees of coronal tibiofemoral subluxation (CTFS) are observed using anteroposterior (AP) knee radiographs [10–13]. In CTFS, the femoral condyles shift medially relative to the tibial plateau, and appropriate congruence of the tibiofemoral joint is lost. Nam et al. demonstrated that the degree of CTFS observed preoperatively decreased immediately after fixed-bearing medial UKA [14]. However, when the CTFS persists after the medial UKA, peripheral contact between the femoral component and the tibial polyethylene insert can occur; this is because the tibial polyethylene insert used for conducting the fixed-bearing UKA usually has a flat surface in the mediolateral orientation [15]. Recent studies have shown that excessive CTFS can lead to poor clinical outcomes, increase the risk of lateral compartment OA, and cause unknown postoperative pain due to intercondylar impingement after fixed-bearing UKA [16–18]. Furthermore, peripheral contact between the femoral and tibial components after medial UKA can cause anteromedial wear of the polyethylene tibial inserts and loosening or subsidence of the tibial implants [19, 20].

Regarding the indications and preoperative planning of medial UKA for good mid- or long-term results, information on the postoperative course of residual CTFS and preoperative and postoperative factors affecting residual CTFS would be useful. However, whether residual CTFS improves or worsens after medial UKA and whether preoperative radiographic assessments can be used to predict the severity of postoperative CTFS remain unclear. Furthermore, the risk factors contributing to a high degree of postoperative residual CTFS are unknown. The purpose of this study was to investigate changes in residual CTFS after medial UKA and identify preoperative and postoperative radiographic parameters of the knee and alignments of the tibial implant that can affect the degree of residual CTFS after surgery.

Materials and methods

Patients

The study protocol was reviewed and approved by the institutional review board and was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. All patients provided informed consent for participation. We reviewed prospectively collected data of patients who underwent primary fixed-bearing medial UKA between January 2012 and August 2014 at our institute. A total of 74 UKA procedures were performed during this period. Fifteen knees did not have the necessary documentation to be included in the analysis because of death (n = 3) or loss to follow-up (n = 12), leaving 59 knees. The median age of the patients was 72 years (range, 55–91 years), and 40 knees of women and 19 knees of men were included. We retrospectively analyzed each patient's preoperative and postoperative radiographic data obtained during a yearly follow-up at the outpatient clinic. The inclusion criteria were varus knee OA at stages I–III according to the Kellgren–Lawrence classification and secondary medial knee OA with spontaneous osteonecrosis of the knee (SONK). The exclusion criteria included flexion contracture of more than 10°, uncorrectable varus deformity of the knee, previous knee surgery or rheumatoid arthritis, and presence of pain in the lateral compartment or patellofemoral joint. The minimum follow-up period was 10 years, and no cases of revisions, due to any reason, were observed during this period. In all procedures performed by two senior surgeons (M.A. and S.A.), a fixed-bearing UKA implant (Zimmer Unicompartmental High-Flex Knee System, Zimmer Inc., Warsaw, IN, USA) was implanted through a medial mini-skin incision. The operation was performed using the "tibia-cut first and spacer block" technique. The anterior cruciate ligament (ACL) status was checked to ensure that the ACL functioned in all 59 knees. The medial collateral ligament was carefully protected throughout the procedure, and no soft tissue release was performed along the medial side.

Radiographic evaluation

AP knee radiographs in the standing position and under valgus stress were obtained one month before surgery. Standing AP hip-to-ankle radiographs were obtained one month before and two weeks after surgery. Postoperative standing AP knee radiographs were obtained at two weeks and one, three, and six months after surgery and every year thereafter. CTFS was defined as the subluxation of the proximal tibia relative to the distal femur on the lateral edge of the femorotibial joint. CTFS was measured as described by Ogawa et al. [21] and was measured as the distance between a line drawn perpendicular to the ground and passing through the most lateral point of the lateral femoral condyle and a second line drawn perpendicular to the ground and passing through the most lateral point of the lateral tibial condyle, ignoring changes caused by osteophytes (a in left panel of Fig. 1a). CTFS was measured using preoperative AP knee radiographs in the standing position, radiographs with valgus stress, and two-week, one-, five-, and 10-year postoperative radiographs. The hip–knee–ankle angle (HKAA), femorotibial angle (FTA), and medial proximal tibial angle (MPTA) were measured using preoperative and two-week postoperative standing AP knee radiographs. The tibial component inclination angle (TCIA) was measured using two-week postoperative standing knee AP radiographs. The HKAA was defined as the angle between the mechanical axes of the femur and tibia (varus, positive; valgus, negative). The FTA was defined as the angle between the anatomical axes of the tibia and femur. The MPTA was defined as the angle between the tangent of the medial and lateral

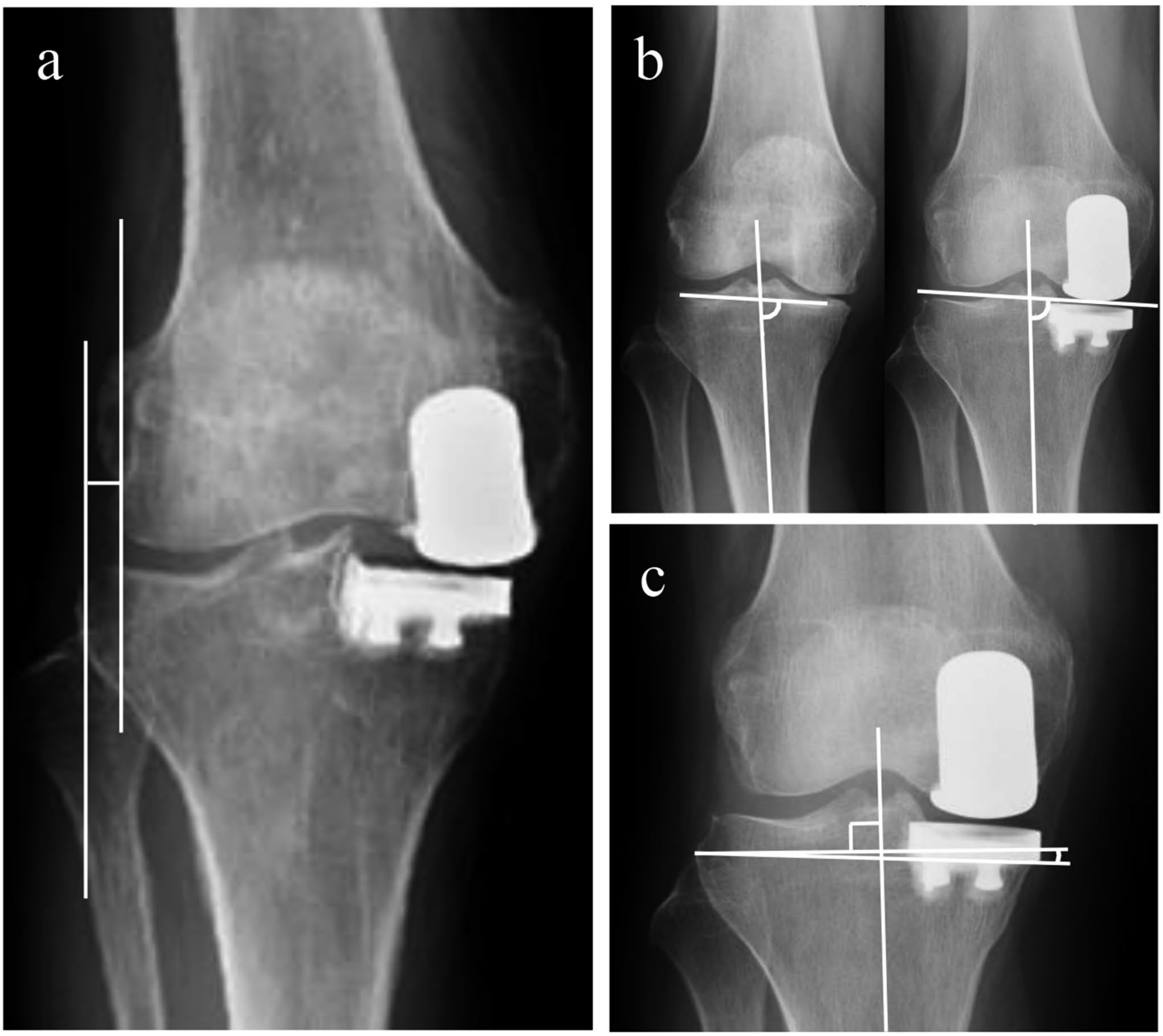

Fig. 1 Radiographic assessment of measured outcome parameters. (**a**) Coronal tibiofemoral subluxation (CTFS) is defined as the distance between a line drawn perpendicular to the ground and passing through the most lateral point of the lateral femoral condyle and another line drawn perpendicular to the ground and passing through the most lateral point of the lateral tibial condyle. (**b**) Distance between the medial edge of the tibial insert and the contact point between the femoral and tibial component. Medial proximal tibial angle (MPTA), defined as the angle between the tangent of the medial and lateral tibial plateau and the mechanical axis of the tibia. For the calculation of postoperative MPTA, tibial articular surface was defined as the line connecting the contact point between the femoral and tibial implants and the lateral midpoint of the joint space. (**c**) Tibial component inclination angle (TCIA), defined as the installation angle of the tibial component relative to the mechanical axis of the tibia

tibial plateaus and the mechanical axis of the tibia. Regarding the postoperative MPTA, the tibial articular surface was defined as the line connecting the contact point between the femoral and tibial implants and the lateral midpoint of the joint space (Fig. 1b). The TCIA was defined as the tibial component angle relative to the mechanical axis of the tibia (Fig. 1c).

Statistical analysis

To determine the inter- and intra-observer reliabilities of the radiographic measurements, all parameters were measured twice, with a one-month interval, by two observers. The inter- and intra-observer reliabilities of all radiographic measurements were evaluated using intraclass correlation coefficients (ICCs). ICCs for inter- and intra-observer reliabilities for radiographic measurements ranged from 0.82 to 0.96 (Table 1).

We compared the mean CTFS values obtained from six observations (preoperative, preoperative under valgus stress, and two-week and one-, five-, and 10-year postoperative) using analysis of variance (ANOVA) along with Sidak's post hoc test. The correlation between the two-week and 10-year postoperative CTFS values was examined to determine whether the postoperative residual CTFS improved or worsened. The correlation between the preoperative CTFS under valgus stress and two-week postoperative CTFS was examined to determine whether postoperative residual CTFS could be predicted preoperatively. The correlation between the preoperative and two-week postoperative CTFS values in the standing position was examined to determine whether preoperative CTFS could affect the degree of CTFS immediately after surgery. Furthermore, to determine the effects of the degree of residual CTFS on postoperative changes in CTFS, we analyzed the correlation between the two-week postoperative CTFS and the change in CTFS over 10 years, with positive values for improvement. A Pearson's correlation analysis was performed for these variables. To identify preoperative and postoperative radiographic parameters that can affect the degree of postoperative residual CTFS, correlations between the immediate postoperative CTFS and alignment parameters (preoperative and postoperative FTA, HKAA, and MPTA and postoperative TCIA) were examined. Furthermore, multivariate regression analysis for immediate postoperative CTFS was performed using the alignment parameters that were statistically significant in the correlation analysis mentioned above.

All data are presented as means and standard deviations (SDs). We used BellCurve for Excel (Social Survey Research Information Co., Ltd., Tokyo, Japan) to perform the statistical analyses. p-values of less than 0.05 were considered statistically significant.

Table 1 Intraclass correlation coefcients of radiographic measurements

	Inter-observer	Intra-observer
CTFS	0.82	0.89
FTA	0.89	0.91
HKAA	0.94	0.96
Preoperative MPTA	0.92	0.94
Postoperative MPTA	0.89	0.93
TCIA	0.83	0.87

CTFS: Coronal tibiofemoral subluxation, FTA: Femorotibial angle HKAA: Hip knee ankle angle, MPTA: Medial proximal tibial angle

TCIA: Tibial component inclination angle

Results

The mean preoperative CTFS was 4.6 ± 1.5 mm in the standing position, which decreased significantly to 3.3 ± 1.1 mm under valgus stress ($p < 0.01$). The mean two-week postoperative CTFS was 3.5 ± 1.4 mm, which was significantly lower than the preoperative value ($p < 0.01$). The mean CTFS values in the standing position at two weeks and one, five, and 10 years postoperatively were 3.5 ± 1.4, 3.4 ± 1.3, 3.3 ± 1.2, and 3.2 ± 1.1 mm, respectively. No significant differences were observed between the mean preoperative CTFS under valgus stress and the mean postoperative CTFS at two weeks and one, five, and 10 years (Fig. 2).

A strong correlation was observed between the two-week and 10-year postoperative CTFS values ($r = 0.89$; $p < 0.0001$). The two-week postoperative CTFS was significantly correlated with the preoperative CTFS under valgus stress ($r = 0.76$; $p < 0.0001$), preoperative CTFS in the standing position ($r = 0.67$; $p < 0.0001$), and degree of change in CTFS over 10 years ($r = 0.6$; $p < 0.0001$) (Table 2).

Univariate regression analysis indicated significant negative correlations between the two-week postoperative CTFS and preoperative (r = -0.68; $p < 0.0001$) and postoperative MPTA values (r = -0.62; $p < 0.0001$). In addition, a significant correlation was observed between the two-week postoperative CTFS and TCIA ($r = 0.55$; $p < 0.0001$) (Table 2). These variables (preoperative MPTA, postoperative MPTA, and TCIA) were further analyzed using a multivariate regression analysis. Preoperative MPTA had the strongest correlation with two-week postoperative CTFS ($p = 0.001$), followed by TCIA ($p = 0.003$) (Table 3).

Discussion

The main finding of this study was that residual CTFS after medial UKA remained almost unchanged during the 10-year follow-up period, which could be predicted to some extent

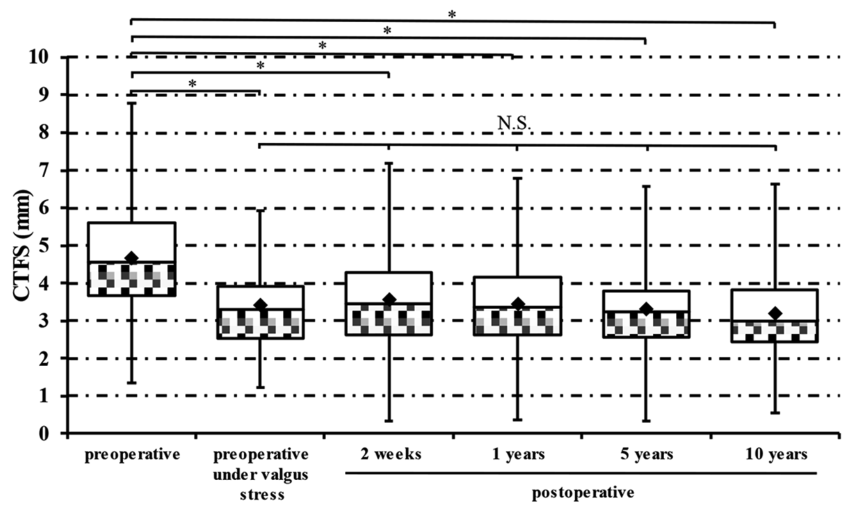

Fig. 2 Box and whisker plot for preoperative CTFS, CTFS under valgus stress, and postoperative CTFS (at two weeks and one, five, and 10 years after surgery). Bottom borders of the box represent the 25th and 75th percentiles; the bar in the box is the median and the rhombus (♦) in the box is the mean. The ends of the whiskers represent the minimum and maximum of all data. *$P<0.01$

Table 2 Radiographic parameters and correlations between the 2-week postoperative CTFS and each parameters

		Mean (SD)	r	*p*
CTFS (mm)	Preoperative	4.6±1.5	0.67	<0.0001
	Preoperative under valgus stress	3.3±1.1	0.75	<0.0001
	10-year postoperative	3.2±1.1	0.89	<0.0001
	Amount of changes over 10 years	0.3±0.64	0.6	<0.0001
FTA (°)	Preoperative	180.2±3.45	0.33	0.02
	Preoperative under valgus stress	177.4±2.55	0.25	0.06
	Postoperative	175.9±2.4	0.26	0.04
HKAA (°)	Preoperative	6.0±3.13	0.34	0.02
	Postoperative	1.3±3.24	0.35	0.02
MPTA (°)	Preoperative	85.1±2.61	-0.68	<0.0001
	Postoperative	86.8±2.69	-0.62	<0.0001
TCIA (°)		4.0±2.6	0.55	<0.0001

CTFS: Coronal tibiofemoral subluxation, FTA: Femorotibial angle, HKAA: Hip knee ankle angle MPTA: Medial proximal tibial angle, TCIA: Tibial component inclination angle, r: correlation coefficient

Table 3 Multivariate regression analysis using the 2-week postoperative CTFS as a dependent variable

	β	t	*p*	95%CI
Preoperative MPTA	-0.42	-3.29	0.001	-0.37–-0.09
Postoperative MPTA	-0.18	-1.35	0.17	-0.18–-0.23
TCIA	0.30	3.11	0.003	0.05–0.27

CTFS: Coronal tibiofemoral subluxation, MPTA: Medial proximal tibial angle, TCIA: Tibial component inclination angle, β: standardized partial regression coefficient, CI: confidence interval

using the preoperative valgus stress radiographs. Among the preoperative and postoperative radiographic parameters, preoperative MPTA had the greatest effect on postoperative residual CTFS.

The mean CTFS in the standing position decreased from 4.6±1.5 mm preoperatively to 3.5±1.4 mm immediately after surgery. This result corroborates those obtained in a study by Nam et al., in which the mean CTFS decreased from 4.5 mm preoperatively to 2.3 mm postoperatively [14]. The mean difference between preoperative and postoperative CTFS in the present study was only 1.3 mm, and the mean residual CTFS in the present study was larger than that in the previous report [14]. We adopted the method described by Ogawa et al. [21] for the measurement of CTFS because it overcomes the difficulty of drawing the tibial shaft line on a tibia with varus deformity, which is often seen in Asian populations [22–25]. This difference in measurement methods may explain the differences between the results of our study and those of the study conducted by Nam et al. [14]. The method had ICC values of (inter: 0.82; intra:0.89) in this study, and those of (inter: 1.0; intra:0.947) shown in the study of Springer et al. [26] which utilized the same method, indicated the high reproducibility of that.

Postoperative residual CTFS was almost unchanged during the 10-year follow-up period, and the mean change in CTFS over 10 years was only 0.3 mm. In contrast, CTFS immediately after surgery had a weak but statistically significant correlation with the change in CTFS over 10 years ($r=0.6$; $p<0.0001$). This means that the severity of residual CTFS observed immediately after surgery may decrease slightly during the follow-up period. The reason for this phenomenon is unknown, but a possible explanation is the postoperative dissolution of soft tissue contractures in the knee over time. Previous studies have suggested that peripheral contact between the implant components can cause wear of the tibial polyethylene and progressive subluxation of the implant [8, 19]. This discrepancy between the results of our study and those of previous studies can be explained in part by the improvement in quality of the polyethylene used for contemporary UKA [27–29]. In this study, the tibial insert was manufactured using modern technologies to improve its mechanical properties and prevent the oxidative degradation of polyethylene. The manufacturing process included the use of a calcium stearate-free resin powder, net-shaped compression molding, and polyethylene crosslinking/sterilization using X-ray radiation after inert gas packing. Other explanations for the decrease in the degree of residual CTFS after contemporary UKA may be the use of modern surgical techniques and instruments to reconstruct the anatomical shape and alignment of the knee and good postoperative knee stability with physiological kinematics attributable to bicruciate ligament retaining [30–32]. Although wear of the polyethylene tibial inserts or subsidence of tibial implants was not observed in this study, residual CTFS may have increased over the postoperative course.

The results of the present study revealed that postoperative residual CTFS was strongly correlated with preoperative CTFS in the standing position and under valgus stress, which is consistent with the findings of previous studies [17, 33]. This implies that in cases with severe preoperative CTFS, the severity of postoperative CTFS tends to be high, because of which peripheral contact between the femoral component and tibial insert is likely to occur. Close attention should be paid to patients with severe preoperative CTFS in the standing position and under valgus stress when considering the indications for medial UKA and positioning of the femoral component during surgery. For preoperative templating of the femoral component, the AP knee radiographic data obtained under valgus stress should be considered because the data can be used to predict the presence of postoperative residual CTFS to some extent.

Among the angular parameters of the preoperative and postoperative knee and implant alignments, the preoperative and postoperative MPTA and TCIA were determined to be factors affecting postoperative residual CTFS. Nakayama et al. conducted a finite element model analysis and reported that joint line obliquity induces excessive shear stress on the articular cartilage after high tibial osteotomy (HTO) [34]. Furthermore, Ogawa et al. reported that the opening-wedge HTO procedure affects the postoperative CTFS, which is significantly correlated with changes in the MPTA [20]. In the standing position, a low MPTA may cause a medial shift of the femoral condyle on the tibial plateau owing to an increase in the shear force. This idea is supported by the results of the present study, which showed that preoperative MPTA had a moderately negative correlation with preoperative CTFS in the standing position ($r = 0.58$; $p < 0.0001$). Multivariate regression analysis revealed that TCIA was another factor affecting postoperative residual CTFS. The varus inclination of the tibial implant can also increase the shear force because the polyethylene insert has a flat surface. Inoue et al. reported that valgus inclination of the tibial component may increase the risk of medial tibial condylar fractures after medial UKA, owing to stress concentration in the medial tibial metaphyseal cortex [35]; varus inclination of the tibial component that is higher than the original slope should be avoided, as this may increase the severity of residual CTFS.

The present study has several limitations. First, this was a retrospective radiographic review. Therefore, prospective observational studies should be conducted to obtain robust evidence. Second, the assessments in this study were performed using standing AP knee radiographs, which are subject to rotational errors that may affect the accuracy of the results. However, the radiographs were obtained under strict rotational control of the extremities, and the rotational errors seemed negligible. Third, clinical follow-up data of patients has not been obtained adequately in this study, and clinical follow-up study should be necessary to confirm the clinical significance of residual CTSF. Finally, the observation period was limited to 10 years. We cannot exclude the possibility that postoperative CTFS may increase after long-term service of the implants. A long-term follow-up study is necessary to determine the degree of alleviation of residual CTFS after contemporary medial UKA.

Conclusions

The residual CTFS after medial UKA did not change during the 10-year follow-up period. Postoperative residual CTFS may be predicted to some extent using preoperative AP knee radiographs obtained under valgus stress. Close attention should be paid to patients with severe uncorrectable preoperative CTFS and small MPTA values when considering the indications for medial UKA.

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Author contributions KY and SA designed this experiment. KY, AM and KN did the data collection. KY and TH did the data analysis. KY wrote the original manuscript. MA, SM and KG reviewed and edited the manuscript. All authors read and approved the manuscript.

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Data availability Data are available upon request by contacting the corresponding author.

Declarations

Competing interests The authors declare no competing interests.

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