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Are orthopedic surgeons able to detect 3 mm and 5 mm joint step off on fluoroscopy?

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Abstract. – OBJECTIVE: The aim of this study was to examine whether joint step-off created experimentally at 3 mm and 5 mm in the tibial lateral plateau can be accurately evaluated by orthopedic surgeons on fluoroscopic images.

PATIENTS AND METHODS: A lateral tibia plateau fracture was created experimentally on above-the-knee amputated material. Using a ruler, step-off at 3 mm and then at 5 mm was made on the joint surface, then joint and lateral fluoroscopy images were obtained. These images were evaluated by 316 orthopedic surgeons. The surgeons were asked whether the joint congruence in the plateau fracture required surgical correction. The same question was asked again after 3 months, and all the responses were recorded.

RESULTS: In the first measurements for 3 mm joint step-off, 77 (24.4%) orthopedic surgeons stated that surgical correction was necessary, and for 5 mm, 118 (37.3%) surgeons stated that surgical correction was necessary. In the 3rd month, the need for surgical correction was stated by 144 (45.6%) surgeons for 3 mm, and by 176 (55.7%) surgeons for 5 mm (p=0.001)

CONCLUSIONS: Fluoroscopy is not a reliable method to determine articular step-off. Methods such as arthroscopic or open joint surface evaluation should be applied in the operating room.

Key Words:
Joint surgery, Tibia plateau, Articular depression.

Abbreviations
CT: computed tomography; MRI: magnetic resonance imaging.

Introduction

Fractures of the tibial plateau are common injuries that are often observed and usually occur in the fifth and sixth decades of life[1,2]. It is difficult to diagnose lateral tibial plateau fractures on direct radiographs and fluoroscopic images[3]. This is because the medial and lateral of the tibial plateau are generally superimposed, and X-rays and fluoroscopy images of foot rotation can be misleading for surgeons[4-6]. Therefore, tibial plateau fractures are one of the fractures most likely to be overlooked by orthopedic surgeons[7].

There are studies in the literature that have investigated fractures related to other joint surfaces in respect of the risk of being overlooked on X-rays by surgeons. Determining joint congruence in tibia plafond fractures through direct radiographs has been found to be challenging[8]. In another study[9] of acetabulum fractures, it was determined that after checking and confirming joint congruence on fluoroscopic images intraoperatively, postoperative computed tomography (CT) scans were taken, and joint step-off of ≥2 mm was determined in most patients.

Acceptable joint step-off in tibial plateau fractures is <3 mm and step-off of ≥3 mm must be surgically corrected[10]. Correct anatomical reduction of the fracture reduces evolution into osteoarthritis and the future need for joint replacement[11]. However, this 3 mm limit is thought to be difficult to determine on direct radiographs. In a previous study[12], surgeons were asked to measure joint step-off and migration on direct radiographs and in the responses given, agreement was not determined in the desired range for evaluation of this step-off on direct radiographs[12]. To decide whether or not joint correction is necessary during the operation, fluoroscopic imaging is a method frequently used by surgeons. However, there are insufficient studies evaluating the ability of surgeons to measure joint step-off on fluoroscopic images.

The aim of this study was to examine whether joint step-off created experimentally at 3 mm and 5 mm in the tibial lateral plateau can be accurately evaluated by orthopedic surgeons on fluoroscopic images, and to evaluate inter and intraobserver reliability.

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Patients and Methods

The images obtained for the study were evaluated by orthopedic surgeons. The surgeons were asked if the joint congruence in the plateau fracture required surgical correction according to the joint anterior-posterior and lateral fluoroscopy images. The fluoroscopy images were saved in JPEG format and compiled into a PowerPoint presentation. This presentation was initially delivered via computer to surgeons who we were able to meet face-to-face. For those we could not meet in person, it was sent via email. All responses received from the surgeons were carefully recorded. The question was asked again three months later and the answers from all the surgeons were once again documented.

The study included 316 orthopedic surgeons. Inclusion criteria were (1) at least 5 years of orthopedic experience, and (2) practicing in the field of lower extremity surgery. Exclusion criteria were (1) less than 5 years of orthopedic experience, (2) not practicing in the field of lower extremity surgery, and (3) did not respond when questioned the second time. All the surgeons who participated were blinded to the study.

Above-the-knee amputate material was used to create 3 mm and 5 mm joint step-off experimentally on the lateral tibial plateau. The case selected was a 56-year-old male patient with a history of trauma with grade 3-4 gonarthrosis and osteonecrosis, but no other deformity in the knee joint, which was applied with above-the-knee amputation. The amputation was performed as the patient was found to have vascular obstruction caused by Buerger disease. The amputate material was taken from the right-side lower extremity of the patient and was obtained for the study immediately after the amputation surgery.

A 15 cm skin incision was made with an anterior approach over the right knee of the amputate material. The patella was everted medially by making a parapatellar arthrotomy. In this way, the whole joint surface of the tibial plateau was exposed. The lateral and medial menisci were excised. The lateral tibial plateau was marked, and 2.5 cm distal from the lateral tibial plateau joint surface was marked, then using a 1 mm thickness knife mounted on a saw (Stryker Inc., Michigan, USA), it was aimed to create a Schatzker-type 2[13] depressed fracture model to be formed of the whole lateral condyle including the lateral eminence. An oblique vertical osteotomy line was formed (Figure 1). Using a ruler 3 mm step-off was created, and the joint surface was stabilized with 2 radiolucent pins (Inion, Tampere, Finland). In this status, fluoroscopic images were taken of the joint (anterior-posterior image taken from 10° cephalic to caudal) and laterally (fluoroscope: Genoray Co. Ltd, ZEN-2090, Gyenoggi-do, South Korea) (Figure 2). For the 5 mm step-off, the osteotomy line was made in the same way, and the same images were taken.

Statistical Analysis

Data obtained in the study were analyzed statistically using NCSS software (Number Cruncher Statistical System). Descriptive statistical methods were used (frequency, percentage) in evaluations of the data. In the comparisons of quantitative data, the McNemar test, Cohen's Kappa test, and diagnostic screening tests were applied (sensitivity, specificity, PKV, NKV). A value of $p<0.05$ was accepted as statistically significant. Interobserver and intraobserver agreements were evaluated with the Cohen's Kappa test. Kappa values were interpreted as <0: no agreement, 0.00-0.20: insignificant (poor), 0.21-0.40: low agreement (moderate), 0.41-0.60: moderate agreement (moderate), 0.61-0.80: significant agreement (good), and 0.81-1.00: almost complete agreement (very good)[14]. A power analysis was performed prior to the study, and the sample size was determined to be 239 using a simple random sampling method to achieve 80% power with a 95% confidence interval and $\alpha=0.05$ level. However, considering potential losses, it was anticipated to be more appropriate to take the sample size as 319.

Results

In the first measurements for 3 mm joint step-off, 77 (24.4%) orthopedic surgeons stated that surgical correction was necessary, and for 5 mm, 118 (37.3%) surgeons stated that surgical correction was necessary. In the 3rd month, the need for surgical correction was stated by 144 (45.6%) surgeons for 3 mm, and by 176 (55.7%) surgeons for 5 mm (Table I).

No agreement was seen between the responses of the surgeons on day 0 and at 3 months related to 3 mm step-off ($p=0.001$). When the responses given at the two-time points were examined in detail, it was seen that of the 77 surgeons who stated on day 0 that reduction correction was necessary, at 3 months, a correction was stated to be necessary by 30 and not necessary by 47. Of the

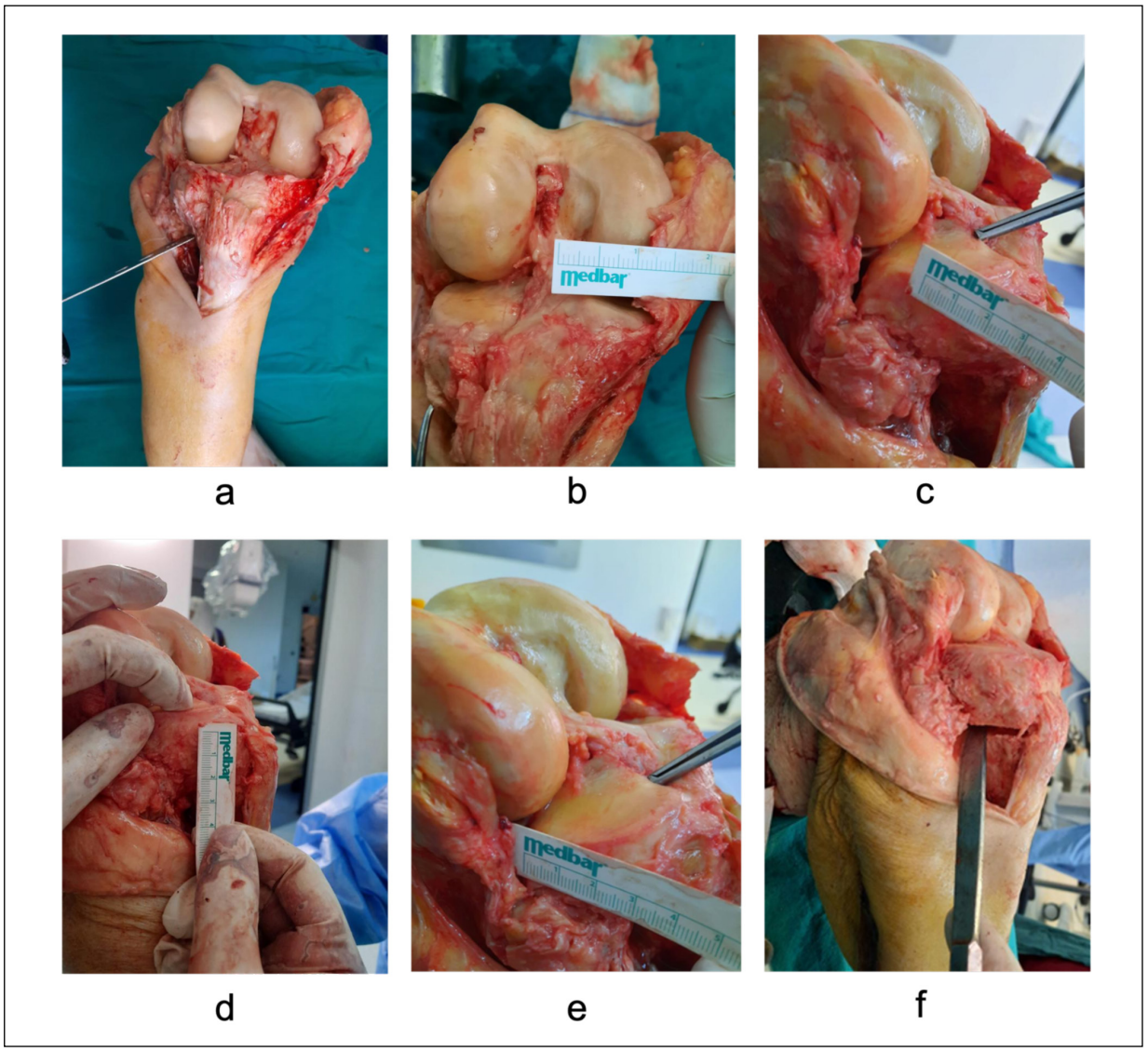

Figure 1. **a**, The defined osteotomy line. **b**, Creation of step-off in the lateral tibial plateau following osteotomy. **c**, Image of the joint after 3 mm joint step-off. **d**, Lateral image of the knee after 3 mm joint step-off. **e**, Image of the joint after 5 mm joint step-off. **f**, Lateral image of the knee after 5 mm joint step-off.

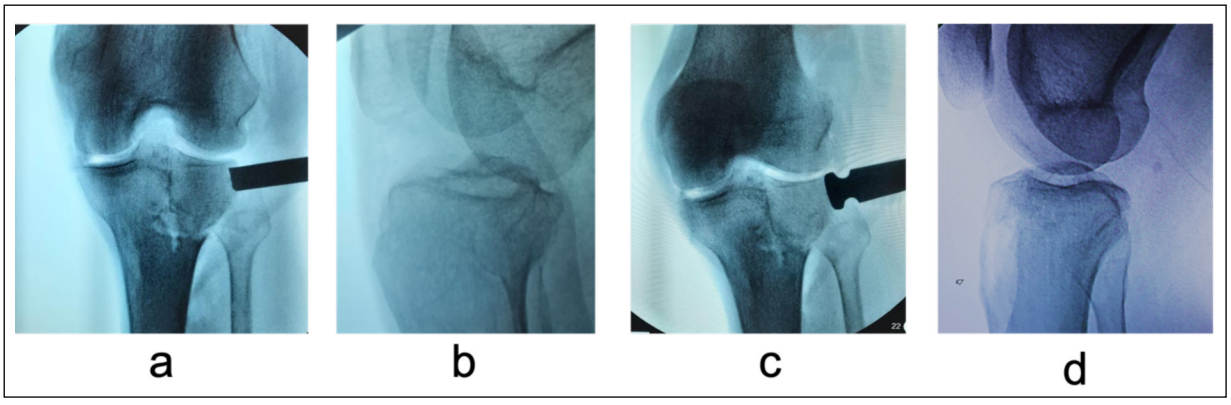

Figure 2. **a**, Joint radiograph taken with 3 mm joint step-off. **b**, Lateral knee radiograph taken with 3 mm joint step-off. **c**, Joint radiograph taken with 5 mm joint step-off. **d**, Lateral knee radiograph taken with 5 mm joint step-off.

Table I. Distribution of responses to joint step-off models.

	Correction is not necessary		Correction is necessary	
	n	%	n	%
Day 0 3 mm	239	75.6%	77	24.4%
Day 0 5 mm	198	62.7%	118	37.3%
3rd month 3 mm	172	54.4%	144	45.6%
3rd month 5 mm	140	44.3%	176	55.7%

239 surgeons who stated on day 0 that reduction correction was not necessary, at 3 months, correction was again stated to be not necessary by 125, and necessary by 114 (Cohen's Kappa agreement coefficient: -0.067).

No agreement was seen between the responses of the surgeons on day 0 and at 3 months related to the 5 mm step-off (p=0.001). When the responses given at the two-time points were examined in detail, it was observed that out of the 118 surgeons who indicated on day 0 that a reduction correction was required, 60 surgeons stated that correction was still necessary after 3 months, while 58 surgeons believed that correction was not necessary. Out of the 198 surgeons who stated on day 0 that reduction correction was not necessary, correction was again stated to be not necessary by 82 at 3 months, and necessary by 116 (Cohen's Kappa agreement coefficient: -0.070).

No agreement was seen between the responses of the surgeons on day 0 related to the 3 mm and 5 mm step-off (p=0.001). When the responses related to both 3 mm and 5 mm joint step-off given on day 0 were examined in detail, it was seen that of the 77 surgeons who stated on day 0 that reduction correction was necessary for 3 mm step-off, 26 stated that correction was necessary for the 5 mm joint step-off, and 51 that it was not necessary. Of the 239 surgeons who stated on day 0 that reduction correction was not necessary for 3 mm step-off, 147 stated that correction was not necessary for 5 mm joint step-off, and 92 stated that it was necessary (Cohen's Kappa agreement coefficient: -0.040).

No agreement was seen between the responses of the surgeons at 3 months related to 3 mm and 5 mm step-off (p=0.006). When the responses related to both 3 mm and 5 mm joint step-off given at 3 months were examined in detail, it was seen that of the 144 surgeons who stated at 3 months that reduction correction was necessary for 3 mm step-off, 96 stated that correction was necessary for the 5 mm joint step-off, and 48 that it was not necessary. Of the 172 surgeons who stated that reduction correction was not necessary for 3 mm step-off, 92 stated that correction was not necessary for 5 mm joint step-off and 80 stated that it was necessary (Cohen's Kappa agreement coefficient: 0.198) (Table II).

Discussion

To obtain good results in tibial plateau fractures, the determination of joint congruence is very important. Despite options such as CT for orthopedic surgeons to evaluate this joint congruence preoperatively and postoperatively, fluoroscopic imaging is generally used for intraoperative evaluation. To evaluate the joint surface in gonarthrosis and implant indications, the use of radiographs is validated in the literature, while for anatomic reduction, it is not sufficient[15]. In this

Table II. Evaluation of the compatibility of the responses given.

	3 mm	5 mm	Day 0	3rd month
	Day 0-3rd month	Day 0-3rd month	3 mm-5 mm	3 mm-5 mm
Mc Nemar Test	0.001*	0.001*	0.001*	0.006*
Kappa Values	-0.067	-0.070	-0.040	0.198
Results	n (%)	n (%)	n (%)	n (%)
Those who did not change their minds	155 (49.1%)	142 (44.9%)	173 (54.7%)	188 (59.5)
Those who changed their minds	161 (50.9%)	174 (55.1%)	143 (45.3%)	128 (40.5%)

*p<0.05.

study, joint step-off was created in above-the-knee amputate material, and orthopedic surgeons were asked twice, at day 0 and after 3 months, whether a correction of the joint surface was necessary. The reliability of fluoroscopy was tested by the different answers obtained to the same questions asked at different times.

There are studies[16-18] showing that joint step-off can be overlooked on direct radiographs and fluoroscopy. Kiel et al[16] evaluated plateau fractures that had been previously overlooked and reported that the use of magnetic resonance imaging (MRI) and CT were useful in preventing these fractures from being overlooked. Zhang et al[17] investigated inter and intraobserver agreement of proximal tibial morphology on CT and radiographs and found that CT was more reliable in the determination of tibial morphology. In a study by Ozkut et al[18], arthroscopic evaluation was reported to provide better results in the evaluation of joint step-off in tibial plateau fractures than fluoroscopic evaluation. Other joint surfaces such as the tibial plafond, distal radius, and acetabulum have been investigated in the literature, and there are studies[8,9,19] suggesting that X-ray beams are not reliable in the determination of joint step-off. In the current study, intraoperative fluoroscopic imaging was determined not to be reliable in the determination of joint step-off of the tibial lateral plateau. This result suggests that more detailed scanning tools and arthroscopic or open examination of the joint surface are necessary to make more consistent decisions during the operation.

In a cadaver study by Haller et al[20] in which tibial plateau fractures were created, it was reported that 90% of surgeons noticed step-off at 2 mm and 5 mm, but when there was no step-off in the joint, the accuracy of the surgeons fell to 62%. In addition, on AP and lateral radiographs, the interobserver agreement for 5 mm joint step-off was excellent but was determined to be poor for 2 mm. In the current study, no agreement was found for joint step-off of 3 mm and 5 mm. In both studies[20], the reliability was not at the desired level. Moreover, the intraobserver agreement was examined in the current study, and no agreement was determined for either a 3 mm or 5 mm joint step-off. In other studies[8,9,16,17,19], conducted on the tibial plateau and other joints, X-rays have been found to be inconsistent in the estimation of joint step-off, and the current study was seen to be more consistent with the literature. Unlike the study by Haller et al[20], the step-off in the current study was created with the appearance of a natural fracture. It was also aimed to obtain standardization by asking each surgeon about the same image. Asking a greater number of orthopedic surgeons strengthened the results of this study.

Generally, it is believed that joint step-off of >2 mm in tibial plateau fractures requires correction, but there are some differences in literature[21,22]. Although some studies[23,24] have shown that minimal joint step-off is not important to obtain a good result, Parkkinen et al[25] investigated lateral tibial plateau fractures and showed that significantly more post-traumatic osteoarthritis developed in patients with >2 mm joint step-off. In a cadaver study by Oeckenpöhler et al[26], lateral tibial plateau fracture modelling was created, and it was shown that joint step-off of 1 mm did not create an increase in pressure in the joint, whereas an increase in pressure in the joint was formed with ≥2 mm joint step-off. In the current study, 2 different joint step-off models of 3 mm and 5 mm were created to see whether or not there was a reliable joint step-off limit on fluoroscopic images. At baseline, it was decided that correction was necessary by 77 (24.4%) surgeons for 3 mm step-off and by 118 (37.3%) surgeons for 5 mm step-off. At 3 months, 144 (45.6%) surgeons decided that correction was necessary for 3 mm, and 176 (55.7%) for 5 mm step-off. At both time points it was observed that more surgeons recommended correction for the 5 mm step-off than for the 3 mm. This demonstrates that 5 mm joint step-off is more noticeable than 3 mm.

No agreement was found between the responses of the surgeons related to 3 mm and 5 mm joint step-off at day 0 and at 3 months. This shows that a substantial proportion of the surgeons who decided that correction was necessary for 3 mm joint step-off decided that it was not necessary for 5 mm. This major inconsistency may provide evidence that 3 mm and 5 mm joint step-off cannot be differentiated by surgeons on fluoroscopic images. In addition, the changes in responses could have been affected by the psychological status of the surgeons at the time of responding, whether they were within working hours and their operating workloads.

There are studies examining the outcomes of percutaneous techniques. Elsøe et al[27], in their evaluation of 28 patients with lateral tibial plateau fractures treated using the percutaneous technique, noted the emergence of arthrosis symptoms in 8 patients following an average follow-up period of 2.5 years. Similarly, Vendeuvre et al[28], having treated 30 cases of lateral tibial plateau fractures with the percutaneous technique, re-

ported that 47% of the patients had residual joint step-off up to 2 mm. In our study, we demonstrated that fluoroscopy failed to identify 3 mm and 5 mm joint step-offs fully. Consequently, it can be said that the use of percutaneous techniques in joint surgery, where fluoroscopy is the only method used for assessing joint displacement, is open to complications.

Limitations

There were some limitations to this study, primarily that it was a cadaver study and had all the inherent limitations of cadaver studies. Secondly, only joint line and lateral fluoroscopic images were used, but joint line radiographs have been shown to be more effective in determining joint congruence than normal anterior-posterior radiographs[29]. In addition, as the orthopedic surgeons in the study did not have the opportunity to see the preoperative CT scans, this prevented them from having an idea of where attention should be paid, and this could have affected the results. Finally, the time was not recorded at which the surgeons evaluated the fluoroscopic images, and therefore, factors such as workload and fatigue could not be evaluated.

Our study demonstrates that relying solely on fluoroscopy for joint surface assessment in the operating room can lead to complications such as arthritis. Evaluation of small step-offs, particularly those of 3 mm and 5 mm, requires methods such as open surgery or arthroscopy-assisted surgery. The use of more advanced imaging methods produced with technology superior to fluoroscopy in the future could yield better results in the operating room.

Conclusions

The results of this study demonstrated that the use of fluoroscopy is not a reliable method in the determination of articular step-off, and to obtain good results, orthopedic surgeons should attempt methods such as arthroscopic or open joint surface examination in the operating room. This study clearly demonstrated that orthopedic surgeons could not differentiate between 3 mm and 5 mm joint step-off on fluoroscopic images.

Ethics Approval

Approval for this study was granted by the Ethics Committee of Kayseri Erciyes University (protocol No.: 2021/8).

Informed Consent

Informed consent was obtained from all subjects (orthopedic surgeons). All methods were carried out in accordance with relevant guidelines and regulations. Also, informed consent was obtained from the legal guardian/next of kin of the patient who was undergone above-knee surgery for the usage of the cadaver.

Availability of Data and Materials

The datasets generated and/or analyzed during the current study are not publicly available due to the ethical and confidentiality policy but are available from the corresponding author upon reasonable request.

Conflict of Interest

There is no competing interest in this study.

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