The Ideal Location of the Lateral Hinge in Medial Closing Wedge Osteotomy of the Distal Femur

Analysis of Soft Tissue Coverage and Bone Density

Tae Woo Kim,* MD, PhD, Myung Chul Lee,† MD, PhD, Jae Ho Cho,‡ MD, PhD, Jong Seop Kim,* MD, and Yong Seuk Lee,*§ MD, PhD
Investigation performed at the Department of Orthopaedic Surgery, Seoul National University Bundang Hospital, Seongnam, Republic of Korea

Background: Although an appropriate hinge position to prevent unstable lateral hinge fractures is well established in medial opening wedge high tibial osteotomy, the position during medial closing wedge distal femoral osteotomy has not been elucidated.

Purpose/Hypothesis: The purpose was to evaluate the ideal hinge position that would prevent an unstable lateral hinge fracture during biplanar medial closing wedge distal femoral osteotomy based on soft tissue coverage and bone density around the hinge area. The hypothesis was that the ideal hinge position could be clarified by analyzing soft tissue coverage and bone density around the lateral hinge area.

Study Design: Controlled laboratory study.

Methods: In 20 cadaveric knees (mean age, 70.3 ± 19.2 years), the femoral attachment of the gastrocnemius lateral head was quantitatively analyzed as a soft tissue stabilizer using digital photography and fluoroscopy. Then, medial closing wedge distal femoral osteotomy was performed, locating the lateral hinge either inside (group 1) or outside (group 2) the femoral attachment of the gastrocnemius lateral head, and the incidence of unstable lateral hinge fractures was compared between the 2 groups. Cortical bone density around the lateral hinge was measured using Hounsfield units on 30 computed tomography scans and reconstructed as a 3-dimensional mapping model. The transitional zone with low bone density was regarded as the safe hinge position with an increased capacity for bone deformation.

Results: The upper and lower margins of the femoral attachment of the gastrocnemius lateral head were 9.1 ± 0.9 mm above and 8.0 ± 1.4 mm below the upper border of the lateral femoral condyle, respectively, and the femoral attachment of the gastrocnemius lateral head was widest in the anteroposterior dimension 0.4 ± 1.7 mm above the upper border of the lateral femoral condyle. The incidence of unstable lateral hinge fractures during osteotomy was significantly decreased in group 1 compared with group 2 (group 1: 0/10; group 2: 5/10; $P = .01$). An isolated transitional zone with low bone density was observed in all 30 knees and located 1.3 ± 0.8 mm above the upper border of the lateral femoral condyle. Bone density of the transitional zone with low bone density was significantly lower than surrounding femoral cortices ($P < .001$).

Conclusion: Only the upper border of the lateral femoral condyle can be recommended as an ideal hinge position to prevent unstable lateral hinge fractures during biplanar medial closing wedge distal femoral osteotomy based on soft tissue coverage and bone density.

Clinical Relevance: When the hinge is positioned at the upper border of the lateral femoral condyle during biplanar medial closing wedge distal femoral osteotomy, the risk of unstable hinge fractures can be minimized.

Keywords: medial closing wedge distal femoral osteotomy; lateral hinge; unstable fracture; gastrocnemius lateral head; bone density

Medial closing wedge distal femoral osteotomy has gained popularity as a viable treatment option for the correction of valgus alignment in active young patients with lateral compartmental osteoarthritis.[3,14,22-24,32] It also can be a treatment option for patellar dislocations combined with valgus alignment.[5,8] While long-term follow-up data

The American Journal of Sports Medicine
2019;47(12):2945–2951
DOI: 10.1177/0363546519869325

are deficient, the survival rate of medial closing wedge distal femoral osteotomy has been reported as up to 89.9% at 10-year follow-up.[4] However, even if closing wedge osteotomy has a stable configuration after correction, correction loss, delayed union, and nonunion are important concerns in medial closing wedge distal femoral osteotomy.[7,13] These can be caused by unstable osteotomy configurations and unstable lateral hinge fractures, resulting in functional disability such as stiffness and the loss of correction, which requires a reoperation.[30] Therefore, to optimize the clinical outcomes of medial closing wedge distal femoral osteotomy, the prevention of unstable lateral hinge fractures is important.

Many studies have been performed to determine the safe zone to prevent unstable lateral hinge fractures in medial opening wedge high tibial osteotomy (MOW-HTO).[18,21,25,29] Han et al[10] defined the safe zone as an area from the tip of the fibular head to the circumference line of the fibular head, where the lateral capsule and the tibialis anterior muscle attach as a soft tissue stabilizer. Bone properties around the lateral hinge also can affect the incidence and pattern of hinge fractures. Lee et al[15] analyzed bone density around the proximal tibiofibular joint through the measurement of Hounsfield units (HUs) on 3-dimensional (3D) computed tomography (CT) scans and emphasized the risk of lateral hinge fractures during MOW-HTO with incomplete osteotomy. Bone density is also known to be correlated with elastic modulus and stiffness, which can determine the capacity for deformation.[1,11] Thus, soft tissue coverage and bone density around the hinge area can play an important role in the prevention of unstable displacement during osteotomy.

Current studies on the surgical technique of medial closing wedge distal femoral osteotomy simply suggest that the proper lateral hinge position is just above the lateral femoral condyle.[2,17,27,33] A recent cadaveric study only reported inferior stability in the supracondylar hinge compared with the lateral condylar hinge.[19] However, solid evidence on the appropriate hinge area is lacking. Therefore, this study evaluated the ideal hinge position based on soft tissue coverage and bone density. The purposes of this study were to (1) analyze the soft tissue stabilizer by cadaveric experiments, (2) evaluate the transitional zone with low bone density around the lateral hinge area using cortical mapping of HUs, and (3) determine the ideal hinge position to prevent unstable lateral hinge fractures. The hypothesis of this study was that the ideal hinge position could be clarified by analyzing soft tissue coverage and bone density around the lateral hinge area.

METHODS

Analysis of Soft Tissue Stabilizer

In our pilot test, cadaveric dissection showed a fascia-like femoral attachment of the gastrocnemius lateral head that covered the posterolateral cortex of the distal femur, where the lateral hinge in medial closing wedge distal femoral osteotomy is usually located (Figure 1). Therefore, the femoral attachment of the gastrocnemius lateral head was defined as a soft tissue stabilizer and quantitatively analyzed. Then, medial closing wedge distal femoral osteotomy was performed using 2 different hinge positions (inside or outside the femoral attachment of the gastrocnemius lateral head) to compare the incidence of unstable hinge fractures and confirm the role of the femoral attachment of the gastrocnemius lateral head as a soft tissue stabilizer. These cadaveric specimens were donated for university anatomy education, and approval from the institutional review board was obtained.

Quantitative Analysis of Femoral Attachment of Gastrocnemius Lateral Head. Twenty cadaveric knees (mean age, 70.3 ± 19.2 years; 7 female, and 3 male donors) were evaluated. The femoral attachment of the gastrocnemius lateral head on the lateral femoral condyle was identified, and digital photographs of this area were taken with lateral and posterior views (LUMIX DMC-GX7; Panasonic). The mediolateral (ML) dimension and the total height of the femoral attachment of the gastrocnemius lateral head were measured using the posterior view. The anteroposterior (AP) dimension of the femoral attachment of the gastrocnemius lateral head and the point at which the femoral attachment of the gastrocnemius lateral head showed the widest AP dimension were evaluated in the lateral view using ImageJ software (National Institutes of Health). A 10 mm–diameter round metal pin was used for the calibration of measurements (Figure 2). Two independent examiners (T.W.K., J.H.C.) measured each parameter twice at a time interval of 3 weeks.

Fluoroscopic Analysis of the Femoral Attachment of Gastrocnemius Lateral Head. Because medial closing wedge distal femoral osteotomy is usually performed under fluoroscopic guidance, the extent of the femoral attachment of the gastrocnemius lateral head was evaluated using fluoroscopic images. After guide pins were inserted at the upper and lower margins of the femoral attachment of the gastrocnemius lateral head, fluoroscopic images of the distal femur in the AP view were obtained (GE Healthcare) and transferred to a picture archiving and communication system

§Address correspondence to Yong Seuk Lee, MD, PhD, Department of Orthopaedic Surgery, Seoul National University Bundang Hospital, 166 Gumi-ro, Bundang-gu, Seongnam-si, Gyeonggi-do 463-707, Republic of Korea (email: smcos1@hanmail.net, smcos1@snu.ac.kr).

*Department of Orthopaedic Surgery, Seoul National University Bundang Hospital, Seongnam, Republic of Korea.

†Department of Orthopaedic Surgery, Seoul National University Hospital, Seoul, Republic of Korea.

‡Department of Orthopaedic Surgery, Hallym University Medical Center, Chuncheon, Republic of Korea.

One or more of the authors has declared the following potential conflict of interest or source of funding: Funding was received from the Seoul National University Bundang Hospital Research Fund (grant No. 09-2018-002) and the National Research Foundation of Korea (NRF-2017R1D1A1A09000509). AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

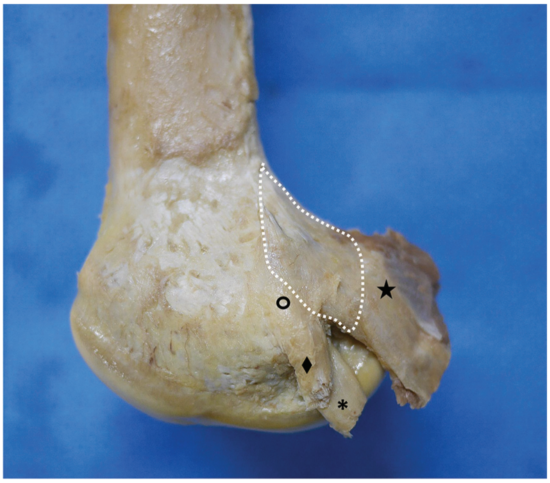

Figure 1. Soft tissue attachments on the posterolateral aspect of the distal femur. Dotted area indicates the femoral attachment of the gastrocnemius lateral head. ★, gastrocnemius lateral head; ◆, lateral collateral ligament; ✱, popliteus; ●, lateral femoral epicondyle.

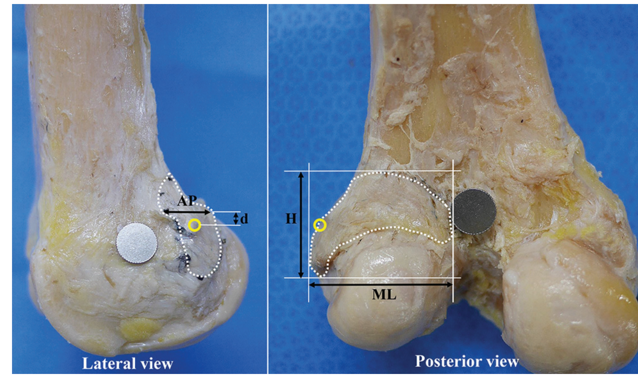

Figure 2. Quantitative analysis of the femoral attachment of the gastrocnemius lateral head (FA-GNLH) on digital photographs. Dotted area, FA-GNLH; yellow circle, upper border of the lateral femoral condyle; AP, anteroposterior dimension of the FA-GNLH; d, distance between the upper border of the lateral femoral condyle and the point at which the AP dimension of the FA-GNLH is widest; H, height of the FA-GNLH; ML, mediolateral dimension of the FA-GNLH.

with digital imaging and communications in medicine (DICOM) files. The height and cortical distance of the upper and lower margins of the femoral attachment of the gastrocnemius lateral head were measured from the upper border of the lateral femoral condyle (Figure 3). The upper border of the lateral femoral condyle was defined as the most prominent point at which the metaphyseal and epiphyseal cortices intersected. The ML dimension and the total height of the distal femur were also measured to evaluate the correlation between the distal femoral dimension and the extent of the femoral attachment of the gastrocnemius lateral head. All parameters were also measured twice by the same 2 independent examiners with a time interval of 3 weeks.

Biplanar Medial Closing Wedge Distal Femoral Osteotomy. Biplanar medial closing wedge distal femoral osteotomy was performed to investigate whether the femoral attachment of the gastrocnemius lateral head can be a soft tissue stabilizer against unstable lateral hinge fractures during medial closing wedge distal femoral osteotomy. In each pair of distal femur specimens, one side was randomly allocated to either group 1 (hinge inside the femoral attachment of the gastrocnemius lateral head) or group 2 (hinge outside the femoral attachment of the gastrocnemius lateral head), with the contralateral side allocated to the other group. In group 1, the lateral hinge was located at the upper border of the lateral femoral condyle, where the femoral attachment of the gastrocnemius lateral head was nearly the widest in the AP dimension. In group 2, the lateral hinge was located 15 mm above the upper border of the lateral femoral condyle, which was not covered by the femoral attachment of the gastrocnemius lateral head. Biplanar medial closing wedge distal femoral osteotomy was performed as described by Lobenhoffer et al[17] with 5 to 10 mm of a lateral cortical hinge. Medial and posterior cortices were resected with an electric saw, and the osteotomy end was precisely finished using an osteotome. The closing gap was also determined as 8 mm based on the mean value of the osteotomy gap (7.6 mm) in Lobenhoffer et al's study. The incidence and stability of lateral hinge fractures were then compared between the 2 groups. An unstable hinge fracture was defined as cortical breakage of the lateral hinge with displacement.

Statistical Analysis. Statistical analysis was performed using SPSS version 25.0 (IBM). All data were described as mean ± SD for continuous variables. A power analysis was performed with a 50% difference in the incidence of hinge fractures between the 2 groups, and the sample size was determined to be 10 knees in each group (α = .05, β = 0.80). Differences in the continuous variables were analyzed with the Student t test. Correlations between continuous variables were analyzed using the Pearson correlation model. Differences in categorical variables were analyzed using the Pearson chi-square test. Statistical significance was set at $P < .05$. Interobserver and intraobserver reliability were assessed with the intraclass correlation coefficient.

Analysis of Bone Density Around Hinge Area

Cortical bone density around the hinge area was measured with HUs on CT scans as previously described,[6,9] and the transitional zone with low bone density was evaluated using 3D cortical mapping of HUs.

Study Population. Thirty CT scans of the knee (mean age, 55.3 ± 9.2 years; 22 female, 8 male) obtained from patients who had undergone MOW-HTO for the treatment of medial compartment osteoarthritis were retrospectively analyzed. All CT scans were obtained to evaluate the postoperative osteotomy configuration of the proximal tibia on postoperative day 3. Exclusion criteria were as follows: major trauma (fracture, ligament injury), prior surgery, infection, severe inflammation, inherent bony deformity of the distal femur, and osteoporosis. Except for excluded

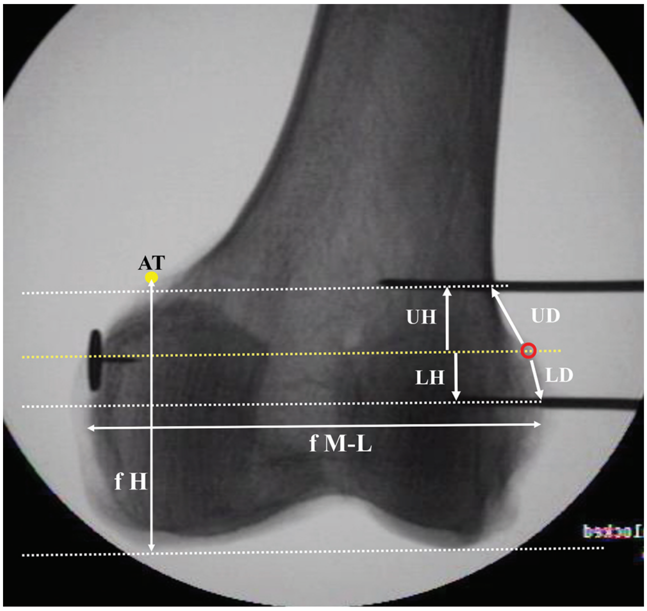

Figure 3. Fluoroscopic analysis of the upper and lower margins of the femoral attachment of the gastrocnemius lateral head. Red circle, upper border of the lateral femoral condyle; yellow dot, adductor tubercle; f H, height of the distal femur; f M-L, mediolateral dimension of the distal femur; LD, lower cortical distance; LH, lower height; UD, upper cortical distance; UH, upper height.

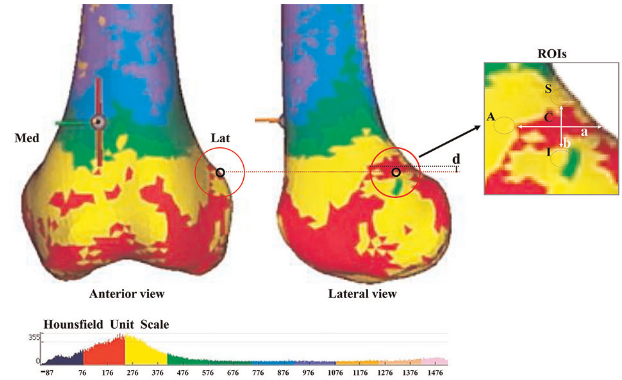

Figure 4. Cortical mapping of Hounsfield units in a 3-dimensional distal femoral model and evaluation of the transitional zone with low bone density (TZ-LBD). Black circle, upper border of the lateral femoral condyle; red circle, isolated TZ-LBD around the lateral hinge; a, anteroposterior dimension of the TZ-LBD; b, superoinferior dimension of the TZ-LBD; d, distance between the upper border of the lateral femoral condyle and the TZ-LBD; ROIs, 5-mm regions of interest for Hounsfield units (A, anterior cortex; C, center of the TZ-LBD; I, inferior cortex; S, superior cortex).

patients, the CT scans were from patients who were consecutively enrolled from January 2017 to December 2018. This study received approval from the institutional review board (B-1903-531-102).

Analysis of Cortical Bone Density. A CT scanner (SOMATOM Definition [Siemens]; MX8000, Brilliance-64, or iCT [Philips]) was used for all knee joint scans. Collected images were saved in DICOM files and imported into Mimics 21.0 software (Materialise). Initially, cortical bone of the distal femur was isolated from other bony structures and 3D-reconstructed through segmentation and remesh processes. Then, the HUs of each cortical segment were matched to a prepared 3D femoral model using finite element analysis.[6,9,16] Thus, the 3D HU mapping model of the distal femur was created, and HUs were visualized using different color scales (interval: 200 HUs, in order of red, yellow, green, and blue). In our pilot test, an isolated transitional zone with low bone density was observed at the posterolateral cortex of the distal femur adjacent to the upper border of the lateral femoral condyle. Therefore, the center of the transitional zone with low bone density was defined as the point at which the AP dimension of the transitional zone with low bone density was the widest, and the distance between the upper border of the lateral femoral condyle and the center of the transitional zone with low bone density was measured (Figure 4). In addition, the AP and superoinferior (SI) dimensions of the transitional zone with low bone density were measured, and the statistical difference in HUs between the transitional zone with low bone density and the surrounding cortices (anterior, superior, and inferior) was evaluated with 5-mm regions of interest. The estimated transitional zone with low bone density was considered to be the safe hinge position in terms of the capacity for cortical deformation.

Statistical Analysis. An a priori power analysis was performed with the assumption that bone density differences more than 200 HUs were significant, with an SD of 80 HUs between the transitional zone with low bone density (red zone) and surrounding cortices (yellow zone). Thirty cases were sufficient for a statistical comparison (α = .05, β = 0.95). Statistical analysis was performed using SPSS version 22.0.

RESULTS

Analysis of Soft Tissue Stabilizer

In the quantitative analysis of the femoral attachment of the gastrocnemius lateral head using digital photographs, the ML dimension, total height, and AP dimension were 28.7 ± 2.2 mm, 19.2 ± 1.7 mm, and 13.4 ± 2.3 mm, respectively. The AP dimension of the femoral attachment of the gastrocnemius lateral head was widest 0.4 ± 1.7 mm above the upper border of the lateral femoral condyle. In the fluoroscopic analysis of cadaveric knees, the upper and lower margins of the femoral attachment of the gastrocnemius lateral head were 9.1 ± 0.9 mm above and 8.0 ± 1.4 mm below the upper border of the lateral femoral condyle, respectively. The cortical distances between the upper or lower margins of the femoral attachment of the gastrocnemius lateral head and the upper border of the lateral femoral condyle were 11.8 ± 1.3 mm and 9.1 ± 1.4 mm, respectively (Table 1). The cortical distance of the upper

TABLE 1
Fluoroscopic Analysis of Upper and Lower Margins of FA-GNLH[a]

Extent of FA-GNLH and Femoral Condyle Dimension, mm	Mean ± SD
Height of upper margin	9.1 ± 0.9
Cortical distance of upper margin	11.8 ± 1.3
Height of lower margin	8.0 ± 1.4
Cortical distance of lower margin	9.1 ± 1.4
ML dimension of distal femur	80.3 ± 5.1
Height of distal femur	44.8 ± 3.4

[a]FA-GNLH, femoral attachment of gastrocnemius lateral head; ML, mediolateral.

margin was significantly related to the ML dimension and total height of the distal femur (ML dimension: $R = 0.673$, $P < .05$) (Table 2). The intraclass correlation coefficient of all parameters measured on digital photographs and fluoroscopic images was over 0.8.

After biplanar medial closing wedge distal femoral osteotomy with an 8-mm closing gap, 2 hinge fractures occurred in group 1 (hinge inside the femoral attachment of the gastrocnemius lateral head), and all were stable with soft tissue anchorage. On the contrary, 6 hinge fractures occurred in group 2 (hinge outside the femoral attachment of the gastrocnemius lateral head), and 5 of 6 fractures were unstable (Figures 5 and 6). There was a significant difference in the incidence of unstable lateral hinge fractures between the 2 groups (0 in group 1 and 5 in group 2; $P = .01$).

Analysis of Bone Density Around Hinge Area

In the bone density analysis of the distal femur through 3D cortical mapping of HU, an isolated shallow transitional zone with low bone density was observed around the upper border of the lateral femoral condyle of the posterolateral femoral cortices on all 30 CT scans (Figure 4). The center of the transitional zone with low bone density was located 1.3 ± 0.8 mm above the upper border of the lateral femoral condyle in the posterolateral femoral cortex and corresponded well with the point at which the femoral attachment of the gastrocnemius lateral head was widest in the AP dimension (0.4 ± 1.7 mm above the upper border of the lateral femoral condyle). The AP and SI dimensions of the transitional zone with low bone density were 19.2 ± 2.3 mm and 10.0 ± 0.6 mm, respectively. HUs of the transitional zone with low bone density were significantly lower than those of anterior, superior and inferior cortices, respectively (transitional zone with low bone density, 184 ± 32 HU; anterior, 345 ± 78 HU; superior, 389 ± 82 HU; inferior, 422 ± 45 HU; $P < .001$).

DISCUSSION

The principal findings of this study were that (1) the femoral attachment of the gastrocnemius lateral head broadly covered the posterolateral femoral condyle and served as a soft tissue stabilizer against unstable lateral hinge fractures during biplanar medial closing wedge distal femoral osteotomy and (2) an isolated transitional zone with low bone density was observed consistently on the posterolateral femoral condyle in the 3D HU cortical mapping model. Interestingly, the cortical area at which the AP dimension of the femoral attachment of the gastrocnemius lateral head was the widest (0.4 ± 1.7 mm above the upper border of the lateral femoral condyle) and the location of the transitional zone with low bone density (1.3 ± 0.8 mm above the upper border of the lateral femoral condyle) were very close to each other. In this area, cortical breakage can be reduced with an increased capacity for plastic deformation. Also, even if breakage occurred, the femoral attachment of the gastrocnemius lateral head can stabilize the broken hinge without displacement. Therefore, only the upper border of the lateral femoral condyle can be recommended as an ideal hinge position to prevent unstable displacement during medial closing wedge distal femoral osteotomy based on soft tissue coverage and bone density.

The supracondylar area of the lateral femoral condyle is known to have few soft tissue attachments available to stabilize hinges in medial closing wedge distal femoral osteotomy.[20] However, during cadaveric dissection, a fascia-like femoral attachment of the gastrocnemius lateral head was observed that covered the posterolateral cortices of the distal femur (see Figure 1). Although various anatomic studies on muscular and neurovascular structures of the gastrocnemius exist,[12,26,31] anatomic information regarding the origin of the gastrocnemius lateral head is rare. To our knowledge, this is the first study that quantitatively analyzed the femoral attachment of the gastrocnemius lateral head at the supracondylar areas of the distal femur. In this study, the upper and lower margins of the femoral attachment of the gastrocnemius lateral head were 9.1 mm above and 8.0 mm below the upper border of the lateral femoral condyle, respectively, and the extent of the femoral attachment of the gastrocnemius lateral head was correlated with the ML dimension of the distal femur ($R = 0.673$, $P < .05$). Also, the AP dimension of the femoral attachment of the gastrocnemius lateral head was 13.4 ± 2.3 mm and was widest at 0.4 ± 1.7 mm above the upper border of the lateral femoral condyle.

The role of the femoral attachment of the gastrocnemius lateral head as a soft tissue stabilizer was proven during biplanar medial closing wedge distal femoral osteotomy in our cadaveric study. In 2 cases of cortical hinge fractures in group 1 (hinge inside the femoral attachment of the gastrocnemius lateral head), we observed soft tissue anchorage of the femoral attachment of the gastrocnemius lateral head that prevented displacement of hinge fractures (Figure 6). On the contrary, 5 of 6 cortical hinge fractures in group 2 (hinge outside the femoral attachment of the gastrocnemius lateral head) were unstable without soft tissue anchorage. Considering that the proximal tibiofibular joints and ankle syndesmosis are known to be soft tissue stabilizers against unstable hinge fractures during high tibial osteotomy and supramalleolar osteotomy, respectively,[10,20] the femoral attachment of the

TABLE 2
Relationship Between FA-GNLH Parameters and Distal Femoral Dimension[a]

	Height of Upper Margin	Cortical Distance of Upper Margin	Height of Lower Margin	Cortical Distance of Lower Margin
ML dimension of distal femur				
r value	0.664	0.134	–0.274	–1.47
P value	.01	.647	.365	.616
Total height of distal femur				
r value	0.585	0.213	0.46	0.152
P value	.028	.465	.881	.603

[a]Differences in variables were analyzed with the Pearson correlation model. FA-GNLH, femoral attachment of gastrocnemius lateral head; ML, mediolateral.

Figure 5. Comparison of hinge fractures after biplanar medial closing wedge distal femoral osteotomy between the inside and outside the femoral attachment of the gastrocnemius lateral head (FA-GNLH) groups. (A) Inside FA-GNLH group without a hinge fracture. (B) Outside FA-GNLH group with an unstable hinge fracture.

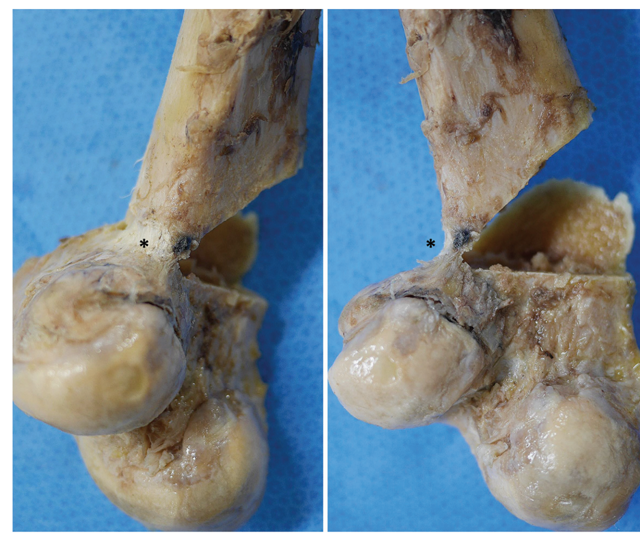

Figure 6. Soft tissue anchorage (*) of the femoral attachment of the gastrocnemius lateral head (FA-GNLH) that prevents displacement of a lateral hinge fracture after medial closing wedge distal femoral osteotomy in the inside FA-GNLH group.

gastrocnemius lateral head also can be suggested as a soft tissue stabilizer that can prevent unstable hinge fractures during medial closing wedge distal femoral osteotomy.

Another remarkable finding of this study was that an isolated transitional zone with low bone density was observed 1.3 ± 0.8 mm above the upper border of the lateral femoral condyle in the posterolateral femoral cortex through 3D cortical mapping of HU. In addition, it corresponded well with the cortical area at which the AP dimension of the femoral attachment of the gastrocnemius lateral head was widest. In this area, cortical bone density was lower than that in the lateral femoral epicondyle, gastrocnemius tubercle, and proximal metaphyseal bone. The transitional zone with low bone density in our study is very similar to the intact posterolateral cortical bridge after medial closing wedge distal femoral osteotomy in the cadaveric study by Nha et al.[20] In that study, the intact cortical bridge observed on 3D CT scans was suggested as a hinge stabilizer against unstable lateral hinge fractures. Therefore, the transitional zone with low bone density can be suggested as a cortical hinge in which the risk of hinge fractures can be reduced by an increased capacity for deformation.

There are also some limitations in our study. First, biplanar medial closing wedge distal femoral osteotomy was performed after dissection of the femoral attachment of the gastrocnemius lateral head, and therefore, possible other soft tissue stabilizers of lateral hinge fractures might have been stripped away. However, this study concentrated on the femoral attachment of the gastrocnemius lateral head as a soft tissue stabilizer, and the femoral attachment of the gastrocnemius lateral head was preserved well with the surrounding periosteum before osteotomy. Second, bone density analysis was performed using different knee

CT scans. However, we used early osteoarthritic knees with similar conditions. Third, a stability assessment was performed subjectively after osteotomy. However, existence of cortical breakage and displacement was clear and easily agreed between participants of the experiment because the degree of stability was too different between the 2 groups. Fourth, there could be more factors that can affect stability during osteotomy such as surgical techniques and osteotomy gaps. As in previous studies, incomplete osteotomy in MOW-HTO can result in unstable lateral hinge fractures.[18,21] Increased osteotomy gaps also can increase the risk of hinge fractures in opening or closing wedge high tibial osteotomy.[28] However, the clinical relevance of our study is that the proper hinge location based on soft tissue coverage and bone density can reduce the risk of unstable displacement during medial closing wedge distal femoral osteotomy.

CONCLUSION

Only the upper border of the lateral femoral condyle can be recommended as an ideal hinge position to prevent unstable lateral hinge fractures during biplanar medial closing wedge distal femoral osteotomy based on soft tissue coverage and bone density.

REFERENCES

1. Bayraktar HH, Morgan EF, Niebur GL, Morris GE, Wong EK, Keaveny TM. Comparison of the elastic and yield properties of human femoral trabecular and cortical bone tissue. *J Biomech*. 2004;37(1):27-35.
2. Brinkman JM, Freiling D, Lobenhoffer P, Staubli AE, van Heerwaarden RJ. Supracondylar femur osteotomies around the knee: patient selection, planning, operative techniques, stability of fixation, and bone healing. *Orthopade*. 2014;43(suppl 1):S1-S10.
3. Buda R, Castagnini F, Gorgolini G, Baldassarri M, Vannini F. Distal femoral medial closing wedge osteotomy for degenerative valgus knee: mid-term results in active patients. *Acta Orthop Belg*. 2017;83(1):140-145.
4. Chahla J, Mitchell JJ, Liechti DJ, et al. Opening- and closing-wedge distal femoral osteotomy: a systematic review of outcomes for isolated lateral compartment osteoarthritis. *Orthop J Sports Med*. 2016;4(6):2325967116649901.
5. Chang CB, Shetty GM, Lee JS, Kim YC, Kwon JH, Nha KW. A combined closing wedge distal femoral osteotomy and medial reefing procedure for recurrent patellar dislocation with genu valgum. *Yonsei Med J*. 2017;58(4):878-883.
6. Daalder MA, Venne G, Sharma V, Rainbow M, Bryant T, Bicknell RT. Trabecular bone density distribution in the scapula relevant to reverse shoulder arthroplasty. *JSES Open Access*. 2018;2(3):174-181.
7. Edgerton BC, Mariani EM, Morrey BF. Distal femoral varus osteotomy for painful genu valgum: a five-to-11-year follow-up study. *Clin Orthop Relat Res*. 1993;288:263-269.
8. Frings J, Krause M, Akoto R, Wohlmuth P, Frosch KH. Combined distal femoral osteotomy (DFO) in genu valgum leads to reliable patellar stabilization and an improvement in knee function. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(12):3572-3581.
9. Genisa M, Shuib S, Rajion ZA, Arief EM, Hermana M. Density estimation based on the Hounsfield unit value of cone beam computed tomography imaging of the jawbone system [published online October 11, 2018]. *Proc Inst Mech Eng H*. doi:10.1177/0954411918806333
10. Han SB, Lee DH, Shetty GM, Chae DJ, Song JG, Nha KW. A "safe zone" in medial open-wedge high tibia osteotomy to prevent lateral cortex fracture. *Knee Surg Sports Traumatol Arthrosc*. 2013;21(1):90-95.
11. Hart NH, Nimphius S, Rantalainen T, Ireland A, Siafarikas A, Newton RU. Mechanical basis of bone strength: influence of bone material, bone structure and muscle action. *J Musculoskelet Neuronal Interact*. 2017;17(3):114-139.
12. Kaplan N, Fowler X, Maqsoodi N, DiGiovanni B, Oh I. Operative anatomy of the medial gastrocnemius recession vs the proximal medial gastrocnemius recession. *Foot Ankle Int*. 2017;38(4):424-429.
13. Kazemi SM, Minaei R, Safdari F, Keipourfard A, Forghani R, Mirzapourshafiei A. Supracondylar osteotomy in valgus knee: angle blade plate versus locking compression plate. *Arch Bone Joint Surg*. 2016;4(1):29-34.
14. Kim YC, Yang JH, Kim HJ, et al. Distal femoral varus osteotomy for valgus arthritis of the knees: systematic review of open versus closed wedge osteotomy. *Knee Surg Relat Res*. 2018;30(1):3-16.
15. Lee YS, Won JS, Oh WS, Park HG, Lee BK. Lateral tibial bone mineral density around the level of the proximal tibiofibular joint. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(7):1678-1683.
16. Lin ZL, Li PF, Pang ZH, et al. Influence of regional difference in bone mineral density on hip fracture site in elderly females by finite element analysis. *Cell Biochem Biophys*. 2015;73(2):405-412.
17. Lobenhoffer P, Kley K, Freiling D, van Heerwaarden R. [Medial closed wedge osteotomy of the distal femur in biplanar technique and a specific plate fixator]. *Oper Orthop Traumatol*. 2017;29(4):306-319.
18. Nakamura R, Komatsu N, Fujita K, et al. Appropriate hinge position for prevention of unstable lateral hinge fracture in open wedge high tibial osteotomy. *Bone Joint J*. 2017;99(10):1313-1318.
19. Nha KW, Chang YS, Shon OJ, et al. Where is the target point to prevent cortical hinge fracture in medial closing-wedge distal femoral varus osteotomy? *J Knee Surg*. 2019;32(3):274-279.
20. Nha KW, Lee SH, Rhyu IJ, et al. Safe zone for medial open-wedge supramalleolar osteotomy of the ankle: a cadaveric study. *Foot Ankle Int*. 2016;37(1):102-108.
21. Ogawa H, Matsumoto K, Akiyama H. The prevention of a lateral hinge fracture as a complication of a medial opening wedge high tibial osteotomy: a case control study. *Bone Joint J*. 2017;99(7):887-893.
22. Rosso F, Margheritini F. Distal femoral osteotomy. *Curr Rev Musculoskelet Med*. 2014;7(4):302-311.
23. Sherman SL, Thompson SF, Clohisy JCF. Distal femoral varus osteotomy for the management of valgus deformity of the knee. *J Am Acad Orthop Surg*. 2018;26(9):313-324.
24. Sternheim A, Garbedian S, Backstein D. Distal femoral varus osteotomy: unloading the lateral compartment. Long-term follow-up of 45 medial closing wedge osteotomies. *Orthopedics*. 2011;34(9):e488-e490.
25. Takeuchi R, Ishikawa H, Kumagai K, et al. Fractures around the lateral cortical hinge after a medial opening-wedge high tibial osteotomy: a new classification of lateral hinge fracture. *Arthroscopy*. 2012;28(1):85-94.
26. Tashjian RZ, Appel AJ, Banerjee R, DiGiovanni CW. Anatomic study of the gastrocnemius-soleus junction and its relationship to the sural nerve. *Foot Ankle Int*. 2003;24(6):473-476.
27. van Heerwaarden R, Brinkman JM, Pronk Y. Correction of femoral valgus deformity. *J Knee Surg*. 2017;30(8):746-755.
28. van Raaij TM, Brouwer RW, de Vlieger R, Reijman M, Verhaar JA. Opposite cortical fracture in high tibial osteotomy: lateral closing compared to the medial opening-wedge technique. *Acta Orthop*. 2008;79(4):508-514.
29. Vanadurongwan B, Siripisitsak T, Sudjai N, Harnroongroj T. The anatomical safe zone for medial opening oblique wedge high tibial osteotomy. *Singapore Med J*. 2013;54(2):102-104.
30. Vena G, D'Adamio S, Amendola A. Complications of osteotomies about the knee. *Sports Med Arthrosc Rev*. 2013;21(2):113-120.
31. Walton Z, Armstrong M, Traven S, Leddy L. Pedicled rotational medial and lateral gastrocnemius flaps: surgical technique. *J Am Acad Orthop Surg*. 2017;25(11):744-751.
32. Wylie JD, Jones DL, Hartley MK, et al. Distal femoral osteotomy for the valgus knee: medial closing wedge versus lateral opening wedge. A systematic review. *Arthroscopy*. 2016;32(10):2141-2147.
33. Wylie JD, Maak TG. Medial closing-wedge distal femoral osteotomy for genu valgum with lateral compartment disease. *Arthrosc Tech*. 2016;5(6):e1357-e1366.