Original Article Clinics in Orthopedic Surgery 2015;7:483-489 • http://dx.doi.org/10.4055/cios.2015.7.4.483

Intraoperative Three-Dimensional Imaging in Calcaneal Fracture Treatment

Heui-Chul Gwak, MD, Jeon-Gyo Kim, MD*, Jung-Han Kim, MD, Sang-Myung Roh, MD

Department of Orthopaedic Surgery, Inje University Busan Paik Hospital, Inje University College of Medicine, Busan,
**Department of Orthopedics, District Hospital, Korea Army Training Center, Nonsan, Korea*

Background: To compare the effectiveness of intraoperative three-dimensional (3D) image and conventional two-dimensional (2D) fluoroscopic images, which are used in the treatment of acute calcaneal fractures.

Methods: We retrospectively analyzed 40 patients who suffered calcaneal fracture and underwent surgery at Inje University Busan Paik Hospital. The patients were divided into two groups. Only 2D fluoroscopy was used to evaluate 20 patients of group 1. On the other hand, 3D fluoroscopy was performed on the remaining 20 patients of group 2; 3D fluoroscopy was performed on these patients after they were extensively evaluated by 2D fluoroscopy during surgery. We reviewed the radiographic and clinical outcomes of these patients, whose average follow-up period was 42.6 months.

Results: In group 2, 3D fluoroscopy detected four cases (20%) of articular incongruence and screw misplacement. All these complicated cases were corrected during surgery. At the final follow-up session, the mean American Orthopedic Foot and Ankle Society (AOFAS) hind foot score was 78.3 (range, 65 to 95) in group 1 and 82.3 (range, 68 to 95) in group 2.

Conclusions: Intraoperative 3D imaging of calcaneal fractures is considered to be useful in evaluating the congruence of joints and the placement of implants.

Keywords: *Calcaneus, Fracture, Treatment, Three-dimensional imaging, Fluoroscopy*

In conventional calcaneal fracture surgery, surgeons evaluate the misplacement of implants and the congruence of the posterior facet using two-dimensional (2D) fluoroscopy. However, 2D fluoroscopy cannot completely elucidate the complex anatomy of the calcaneus. Therefore, if the image obtained by 2D fluoroscopy is unclear, then computed tomography (CT) is performed to obtain an accurate assessment of the calcaneus postoperatively. Recently, devices have been developed to perform intraoperative three-dimensional (3D) fluoroscopy; this novel technique has been extremely useful in assessing various types of fractures.[1-3] Compared to 2D fluoroscopy, 3D fluoroscopy is much more accurate and sophisticated, so the frequency of complications is lower in cases assessed by 3D fluoroscopy.[1-3]

The purpose of this study is to evaluate whether 3D fluoroscopy is actually useful in reducing calcaneal fractures and internal fixation during surgery. The clinical outcome of 3D fluoroscopy is compared with that of 2D fluoroscopy.

METHODS

The Ethics Committee of Inje University Busan Paik Hospital granted an approval for conducting this study. From March 2008 to September 2012, 40 patients had been diagnosed with joint-depression-type calcaneal fractures in Inje University Busan Paik Hospital. These patients had undergone surgery and were followed-up for at least two years. We retrospectively analyzed these patients in our study. The average follow-up period of these patients was 42.6 months (range, 24 to 82 months). The inclusion criteria of these patients were as follows: all the patients were

Received February 14, 2015; Accepted June 18, 2015
Correspondence to: Jeon-Gyo Kim, MD
Department of Orthopedics, District Hospital, Korea Army Training Center, 504 Deugan-daero, Yeonmu-eup, Nonsan 33011, Korea
Tel: +82-41-741-5420, Fax: +82-51-890-6129
E-mail: bluewhisle@gmail.com

aged 18 years and above. They had suffered closed unilateral fractures. So they were treated with internal fixation surgery. An extensile lateral approach was used while performing this surgery. Postoperatively, these patients reported for follow-up sessions for at least two years. CT scans were performed to assess the injured calcaneus in these follow-up sessions. The exclusion criteria included the following conditions: polytrauma of the injured foot, presence of severe medical diseases, open fracture and the presence of other concurrent fractures in both the lower extremities. The subjects were classified into two groups: groups 1 and 2. Group 1 included 20 patients on whom only 2D fluoroscopy was performed to evaluate surgical reduction and internal fixation. Group 2 included the remaining 20 patients on whom 3D fluoroscopy was performed after conducting all the courses of evaluation with 2D fluoroscopy. There was no significant difference in demographics of these two groups (Table 1). When these subjects reported for the first follow-up session, we performed simple radiography and CT on all the subjects, and the fractures were classified into different types using Sander's classification system.[4,5)]

The timing of the surgery was fixed after considering the various factors, such as combined injuries, the general condition of the body and the condition of the skin, etc. Surgery was performed after the swelling had subsided and skin wrinkles had appeared. The average time expended before surgery was 6.95 days (range, 1 to 21 days) in group 1 patients, while that of group 2 patients was 8.4 days (range, 1 to 23 days). But, there was no significant difference between the two groups in this regard ($p = 0.374$) (Table 1).

Table 1. Demographic Information on the Two Groups of Patients Who Underwent Surgery Using Only 2D Fluoroscopy and 3D Fluoroscopy, Respectively

Variable	Group 1 2D fluoroscopy (n = 20)	Group 2 3D fluoroscopy (n = 20)	*p*-value
Sex			0.751*
Male	13	12	
Female	7	8	
Age (yr)	42.5 (26–61)	40.5 (24–61)	0.575†
Body mass index (kg/m²)	24.8 (21.2–28.3)	24.5 (19.8–28.9)	0.700‡
Smoker	9	8	0.750*
Sanders type	1	0	0.484§
II	9	10	
III	8	9	
IV	3	1	
Time to operation (day)	6.95 (1–21)	8.4 (1–23)	0.374†

Values are presented as number or mean (range).
2D: two-dimensional, 3D: three-dimensional.
*Chi-square test. †Mann-Whitney *U*-test. ‡Student *t*-test. §Fisher exact test.

Surgery and Postoperative Treatment

In all cases, open reduction and internal fixation were performed using the extensile lateral approach. In both the groups of patients, the initial reduction of the fracture and the position of the implants were evaluated using 2D fluoroscopy. In some cases, the calcaneal fracture still required some correction. In such cases, 2D fluoroscopy was performed again after conducting the correction. In group 2, an additional round of 3D fluoroscopy was performed, and if there was a problem, 3D fluoroscopy was performed again after correction. After performing the surgery, a short leg splint was fixed at a neutral position on the ankle. A week after the surgery, subjects were asked to wear ankle boots or a short leg cast provided there was no problem with the wound. Eight to ten weeks after the surgery, the state of the fracture was assessed and then the subjects were allowed partial weight-bearing gait. Three months after the surgery, subjects were allowed full weight-bearing gait.

Intraoperative 3D Fluoroscopic Device

A 3D fluoroscopic device (ARCADIS Orbic; Siemens AG, Erlangen, Germany) was used to obtain a 3D image of the fracture; the position of the implants and the state of reduction, which were difficult to determine in the 2D image, were thoroughly evaluated using this 3D image.

Before performing the scanning process, the device was covered with a sterilized cap (Fig. 1). In a single scanning round, 100 fluoroscopic images were obtained as the device underwent a rotation of 190 degrees. After the scanning process, the precise images were modified in the coronal, axial and sagittal planes using a computerized system. Thus, these 3D fluoroscopic images were compared with the previous 2D fluoroscopic images. Based on these 3D images, we modified the reduction of the fracture and the position of the implants (Fig. 2).

Evaluation Method

We recorded the following parameters: total operative time, time expended in operating 3D fluoroscopy and the correction undertaken after performing 3D fluoroscopy.

Fig. 1. Three-dimensional fluoroscopy. (A) Draping was performed using a sterile cover for fluoroscopes. (B) The device performs a 190-degree orbital rotation within two minutes.

Fig. 2. Cases in which the screw was modified. (A, C) After evaluation with two-dimensional fluoroscopy, reduction and implant placement were checked by the surgeon. (B, D) Three-dimensional fluoroscopy showed a step-off and gap of the fracture site and wrong position of the screw (arrow), which were corrected.

The total operative time was defined as the time expended between skin incision and skin closure.

For radiographic evaluation, we measured Bohler's and Gissane's angle at a lateral view of the calcaneus *via* the picture archiving and communication system (PACS) system (Fig. 3). Each measurement was performed thrice, and then the mean of these measurements was obtained. The union time was also evaluated. It was defined as the time at which at least three planes showed union, so there was no pain and movement at the fracture site and the subject did not experience any pain while walking.

For clinical evaluation, the American Orthopedic Foot and Ankle Society (AOFAS) hind foot score and the pain visual analog scale (VAS) were measured at the final follow-up. Postoperative complications were also checked in all the subjects included in this study.

Fig. 3. Lateral radiograph of the calcaneus shows the measurements of the critical angle of Bohler's and Gissane's angle.

Statistical Analysis

The IBM SPSS ver. 21.0 (IBM Co., Armonk, NY, USA) statistical program was used performing statistical analysis. A normal distribution pattern was evinced when we compared all the continuous variables in this study. The postoperative Bohler's and Gissane's angles, period of bone union, and pain VAS score were analyzed using Student *t*-test, while the AOFAS hind foot score was analyzed using Mann-Whitney *U*-test. In each group, the improvements in Bohler's and Gissane's angle were analyzed by performing the paired *t*-test. The results were considered to be statistically significant when $p < 0.05$.

RESULTS

Lead Time

The total median operative time was 165 minutes (range, 50 to 280 minutes) and 130 minutes (range, 75 to 330 minutes) in groups 1 and 2, respectively. There was no statistically significant difference between the total operative times of the two groups ($p = 0.527$).

The median time expended in taking 3D fluoroscopy images was 415 seconds. It took a mean of 105 seconds (range, 70 to 145 seconds) to move and modify the device. It took 120 seconds to scan when the device rotated automatically through 190 degrees. Finally, it took a mean of 185 seconds (range, 125 to 140 seconds) to identify the image with the computerized system.

Surgical Procedures

There were four cases (20%) in which the screws were replaced after performing 3D fluoroscopy. Among the four cases, two cases were corrected for incongruence (Fig. 2A and B). The third case had a perforated screw in the articular cartilage (Fig. 2C and D), while the fourth case had a large screw that irritated the contralateral tendon. The screws were replaced in both these cases. Interestingly, 2D fluoroscopy could not detect these issues in any of the four cases. After the correction, 3D fluoroscopy was performed again; none of the cases required correction at this stage.

Evaluation Results

In group 1, Bohler's angle varied between 7.1° (range, 0.8° to 14.2°) to 23.5° (range, 17.2° to 29.5°) at the last follow-up. Moreover, Gissane's angle was from 90.2° (range, 72° to 109.5°) to 115.2° (range, 105.6° to 123.2°) at the last follow-up. This indicates that there were statistically significant improvements in subjects belonging to group 1 ($p = 0.001$ and $p = 0.003$, respectively). In group 2, Bohler's angle varied between 6.5° (range, 0.3° to 12.4°) to 22.9° (range, 15.3° to 30.2°) at the last follow-up, while Gissane angle's varied between 92.8° (range, 75.2° to 107.4°) to 117.3° (range, 109.2° to 126.8°) at the last follow-up. So, there were statistically significant improvements even in subjects belonging to group 2 ($p = 0.001$ and $p = 0.002$, respectively). At the last follow-up, no statistically significant difference was observed in Bohler's and Gissane's angles of the two groups ($p = 0.285$ and $p = 0.357$, respectively). The bone union was determined in all cases of group 1, except in one case of subtalar fusion due to infection. On the other hand, bone union was determined in all cases of group 2. The average union periods were 14.2 weeks (range, 8 to 20.28 weeks) and 13.1 weeks (range, 7.28 to 19.71 weeks) for groups 1 and 2, respectively. Thus, there was no significant difference between the average union periods of both the groups ($p = 0.452$).

At the last follow-up, the mean AOFAS hind foot scores were 78.3 (range, 65 to 95) and 82.3 (range, 68 to 95) in groups 1 and 2, respectively. Moreover, the mean pain VAS scores were 2.9 (range, 1 to 3) and 2.7 (range, 1 to 3) in groups 1 and 2, respectively. In both groups, these clinical scores indicated that the prognosis of the surgical treatment was good. There was no significant difference in the AOFAS hind foot score and the pain VAS of the two groups ($p = 0.694$ and $p = 0.562$) (Table 2).

In group 1, there were four cases of postoperative complications. The first two cases were of peroneal nerve injury, while the third case was of subtalar arthritis, which was confirmed by radiographic examination. The fourth

Table 2. Comparison of the Clinical and Radiographic Results of the Two Groups after Undergoing Surgical Treatment

Variable	Group 1 2D fluoroscopy (n = 20)	Group 2 3D fluoroscopy (n = 20)	*p*-value
Bohler's angle (°) at last follow-up	23.5 (17.2–29.5)	22.9 (15.3–30.2)	0.285*
Gissane's angle (°) at last follow-up	115.2 (105.6–123.2)	117.3 (109.2–126.8)	0.357*
Time to union (wk)	14.2 (8–20.28)	13.1 (7.28–19.71)	0.452†
AOFAS hind foot score	78.3 (65–95)	82.3 (68–95)	0.694†
Visual analog scale	2.9 (1–3)	2.7 (1–3)	0.562*

2D: two-dimensional, 3D: three-dimensional, AOFAS: American Orthopedic Foot and Ankle Society.
*Student *t*-test. †Mann-Whitney *U*-test.

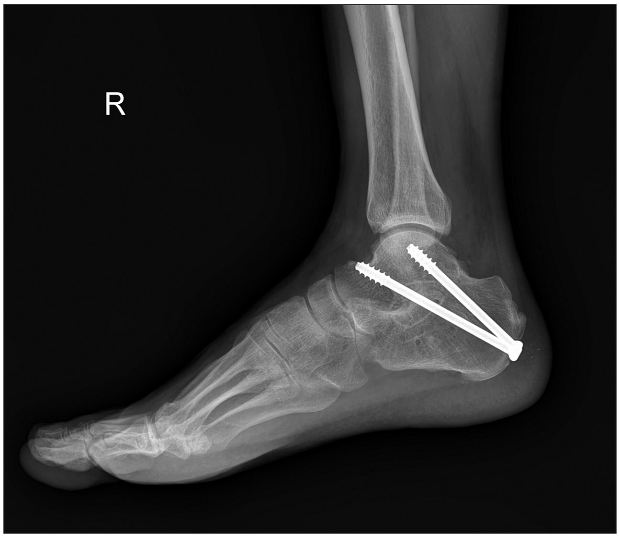

Fig. 4. A case with complication. After treating the deep infection, we performed subtalar fusion.

case was of deep infection. In the case of deep infection, subtalar fusion was performed after treating the infection with debridement (Fig. 4). In group 2, there was one case of peroneal nerve injury and another case of focal skin necrosis at the surgical wound; the focal skin necrosis was improved by performing extensive debridement. The wound was closed by surgical suture.

DISCUSSION

In the treatment of intra-articular calcaneal fractures, open reduction and internal fixation showed better results than conservative treatment in the long-term follow-up.[5-10] However 10% to 20% of the problems persisted even after performing open reduction and internal fixation. Among these complications, early foot arthritis and pain were the most common ones.[7,11,12] Therefore, the state of variable reduction should be precisely examined, especially with regards to the congruence in the posterior facet.[7,11] With regard to that in this case, Sanders et al.[13] have insisted that the step-off during surgery must be reduced by 3 mm or less, but other authors have suggested that a step-off that is more than 1 mm should be corrected.[14] Also, the posterior facet of the calcaneus was quite vulnerable to screw perforation. If such penetration is not detected intraoperatively, it may lead to a poor outcome.[15] The screw could penetrate the contralateral cortex, thereby irritating the opposite tendon.[14] Thus, screw misplacement and articular incongruities are usually not detected when surgery is performed using 2D fluoroscopy; however, they are easily detected by performing CT postoperatively.[14,16] The status of the reduction in the posterior facet can be determined with Broden's view intraoperatively, but there are limitations in this type of assessment as there is frequent overlapping of images. Recently, we found that arthroscopy could effectively tackle this problem. Although it is difficult to inspect the entire joint in a single view, the articular cartilage is probably injured in a narrow joint.[4)]

A new C-arm-based 3D imaging device has been introduced in recent studies. The 3D images produced with this novel device had better clarity and resolution as compared to 2D fluoroscopy that was performed intraoperatively; the quality of 3D images is comparable to that of CT scans.[2,17-19] The C-arm-based 3D imaging device can produce several 3D images as it automatically rotates through 190 degrees (Fig. 1). Moreover, it can also produce 2D images of high quality, so there is no need to conduct 2D fluoroscopy while performing surgery.

In group 2, screw misplacement and articular incongruities were avoided in 20% of all the cases with the help of 3D fluoroscopy. Note that, the complications of four cases were undetected by 2D fluoroscopy, which was performed while carrying out surgery. After performing 3D fluoroscopy on group two patients, we detected a significant number of complications. Therefore, the number of corrections performed in group two patients were significantly different from that performed in group 1 patients. Thus, these results indicate that 3D fluoroscopy can significantly compensate for the weaknesses of 2D fluoroscopy. Recently, several studies have reported about the use of 3D fluoroscopy during surgery.[20,21] Although it normally takes about 410 seconds to operate the device, it is a cost-effective measure to minimize the complications and further revisions associated with screw misplacements and articular incongruities. Actually, the results of this study indicate that there is no significant difference in the total operative times of the two groups. This indicates that there are no limitations to the use of 3D fluoroscopy.

All the radiological and clinical results were good in the two groups. Moreover, there were no statistically significant differences in the clinical results of the two groups. Subtalar arthritis did not develop in any of the patients included in group 2; however, this must be evaluated with a longer follow-up.

One of the limitations of this study is the fact that it is a retrospective study with a short follow-up period of about two years. Furthermore, we included a relatively small number of cases in this study. It was quite expensive to obtain 3D images with the novel device; the cost of the device was as high as 200,000 US dollars.

However, 3D fluoroscopy can also be performed in other types of orthopedic surgery. Hufner et al.[1] have reported that 3D fluoroscopy is a cost-effective procedure. Although the costs of 3D fluoroscopy are considerably high, it is economically viable as it minimizes the frequent revisions that are otherwise encountered with 2D fluoroscopy.[1] Nevertheless, the use of 3D fluoroscopy must further investigated in future studies.

In conclusions, an intraoperative 3D fluoroscopy can clearly detect misplacement of implants and articular incongruities during calcaneal fracture surgery. These complications are not usually detected by standard 2D fluoroscopy during surgery. Therefore, 3D fluoroscopic device is very useful in the surgical treatment of calcaneal fractures.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

REFERENCES

1. Hufner T, Stubig T, Gosling T, Kendoff D, Geerling J, Krettek C. Cost-benefit analysis of intraoperative 3D imaging. Unfallchirurg. 2007;110(1):14-21.
2. Richter M, Geerling J, Zech S, Goesling T, Krettek C. Intraoperative three-dimensional imaging with a motorized mobile C-arm (SIREMOBIL ISO-C-3D) in foot and ankle trauma care: a preliminary report. J Orthop Trauma. 2005;19(4):259-66.
3. Rubberdt A, Feil R, Stengel D, et al. The clinical use of the ISO-C(3D) imaging system in calcaneus fracture surgery. Unfallchirurg. 2006;109(2):112-8.
4. Gavlik JM, Rammelt S, Zwipp H. The use of subtalar arthroscopy in open reduction and internal fixation of intra-articular calcaneal fractures. Injury. 2002;33(1):63-71.
5. Sanders R, Gregory P. Operative treatment of intra-articular fractures of the calcaneus. Orthop Clin North Am. 1995;26(2):203-14.
6. Benirschke SK, Sangeorzan BJ. Extensive intraarticular fractures of the foot: surgical management of calcaneal fractures. Clin Orthop Relat Res. 1993;(292):128-34.
7. Bezes H, Massart P, Delvaux D, Fourquet JP, Tazi F. The operative treatment of intraarticular calcaneal fractures: indications, technique, and results in 257 cases. Clin Orthop Relat Res. 1993;(290):55-9.
8. Carr JB. Surgical treatment of the intra-articular calcaneus fracture. Orthop Clin North Am. 1994;25(4):665-75.
9. Leung KS, Yuen KM, Chan WS. Operative treatment of displaced intra-articular fractures of the calcaneum: medium-term results. J Bone Joint Surg Br. 1993;75(2):196-201.
10. Paley D, Hall H. Intra-articular fractures of the calcaneus: a critical analysis of results and prognostic factors. J Bone Joint Surg Am. 1993;75(3):342-54.
11. Zwipp H, Tscherne H, Thermann H, Weber T. Osteosynthesis of displaced intraarticular fractures of the calcaneus: results in 123 cases. Clin Orthop Relat Res. 1993;(290):76-86.
12. Sanders R, Fortin P, DiPasquale T, Walling A. Operative treatment in 120 displaced intraarticular calcaneal fractures: results using a prognostic computed tomography scan classification. Clin Orthop Relat Res. 1993;(290):87-95.
13. Sanders R, Fortin P, DiPasquale T, Walling A, Helfet D, Ross E. The results of operative treatment of displaced intra-ar-

ticular calcaneal fractures using a CT scan classification. In: Tscherne H, Schatzker J, eds. Major fractures of the pilon, the talus, and the calcaneus: current concepts of treatment. Berlin: Springer; 1993. 175-89.

14. Trepman E, Lutter LD, Brodsky JW. Highlights of the Fourteenth Annual Summer Meeting of the American Orthopaedic Foot and Ankle Society, Boston, Massachusetts, July 24-26, 1998. Foot Ankle Int. 1999;20(1):58-67.

15. Jordan C, Mirzabeigi E, Williams S. Determining the angle of screw placement for internal fixation of calcaneal fractures. J Orthop Trauma. 1999;13(1):47-50.

16. Euler E, Wirth S, Linsenmaier U, Mutschler W, Pfeifer KJ, Hebecker A. Comparative study of the quality of C-arm based 3D imaging of the talus. Unfallchirurg. 2001;104(9):839-46.

17. Kotsianos D, Wirth S, Fischer T, et al. 3D imaging with an isocentric mobile C-arm comparison of image quality with spiral CT. Eur Radiol. 2004;14(9):1590-5.

18. Rock C, Kotsianos D, Linsenmaier U, et al. Studies on image quality, high contrast resolution and dose for the axial skeleton and limbs with a new, dedicated CT system (ISO-C-3 D). Rofo. 2002;174(2):170-6.

19. Rock C, Linsenmaier U, Brandl R, et al. Introduction of a new mobile C-arm/CT combination equipment (ISO-C-3D): initial results of 3-D sectional imaging. Unfallchirurg. 2001;104(9):827-33.

20. Stockle U, Krettek C, Pohlemann T, Messmer P. Clinical applications: pelvis. Injury. 2004;35 Suppl 1:S-A46-56.

21. Wich M, Spranger N, Ekkernkamp A. Intraoperative imaging with the ISO C(3D). Chirurg. 2004;75(10):982-7.