J Orthop Sci (2014) 19:125–131
DOI 10.1007/s00776-013-0475-1

ORIGINAL ARTICLE

Usefulness of intraoperative three-dimensional imaging in fracture surgery: a prospective study

Sang Won Moon · Ji Wan Kim

Received: 27 March 2013 / Accepted: 16 September 2013 / Published online: 4 October 2013

Abstract
Background Since its introduction, intraoperative three-dimensional (3D) imaging has enabled the analysis of articular fractures and implant positions during fracture surgery. The purpose of this study was to evaluate the usefulness of intraoperative 3D imaging in locating anatomic structures, correcting errors, and preventing revision surgery.
Methods Between March 2010 and November 2012, intraoperative 3D imaging was used during surgery for 109 fractures in 101 patients. Fluoroscopy was performed with the Iso-C3D^{TM} (Siemens, Erlangen, Germany). We recorded the number of intraoperative revisions for adjustment of fracture reduction and correction of implant position for these fractures.
Results Cases comprised intra-articular fractures (55 %), disruptions of the posterior pelvic ring (33 %), and syndesmotic injury (12 %). The intraoperative revision rate was 9.2 % (10/109). When considered by fracture site, the revision rate was highest for syndesmotic injury (23.1 %), followed by iliosacral fixation (8.3 %) and intra-articular fractures (6.6 %). We changed the implant position in six cases, corrected the articular reduction in one case, and revised the malreduction of syndesmosis in three cases. No postoperative infection occurred in any of these cases.
Conclusions Intraoperative 3D imaging is useful for correcting errors and may prevent a second operation. Three-dimensional imaging may be especially helpful in intra-articular fractures, iliosacral screw fixation, and syndesmotic injury.

S. W. Moon · J. W. Kim (✉)
Department of Orthopaedic Surgery, Haeundae Paik Hospital
Inje University, 1435 Jwa-dong, Haeundae-gu, Busan 612-862,
Republic of Korea
e-mail: bakpaker@hanmail.net

Introduction

Many techniques have been developed for fracture surgery. Minimally invasive plate osteosynthesis (MIPO), which was introduced in 1997 [1], has become popular and has had excellent results [2, 3]. Intraoperative fluoroscopic imaging is a useful modality for fracture surgery and has become a major step forward in controlling fracture reduction and implant positioning. It is particularly useful during intramedullary nailing and MIPO [4]. However, in fracture surgery using conventional 2D fluoroscopy, there is frequent failure in detecting suboptimal positioning of implants and joint incongruities [5, 6]. Incorrect implant positioning, which is easy to overlook under 2D fluoroscopic visualization, can cause damage to major blood vessels or nerves [7]. This error can be detected on postoperative CT scans, but another operation is necessary to correct it. The introduction of intraoperative 3D imaging has enabled analysis of articular fracture or implant position. The purpose of this study was to demonstrate the usefulness of intraoperative 3D imaging in fracture surgery.

Materials and methods

Patients

Between March 2010 and November 2012, 3D imaging was used intraoperatively during surgery for 109 fractures in 101 patients: 61 men and 40 women with an average age

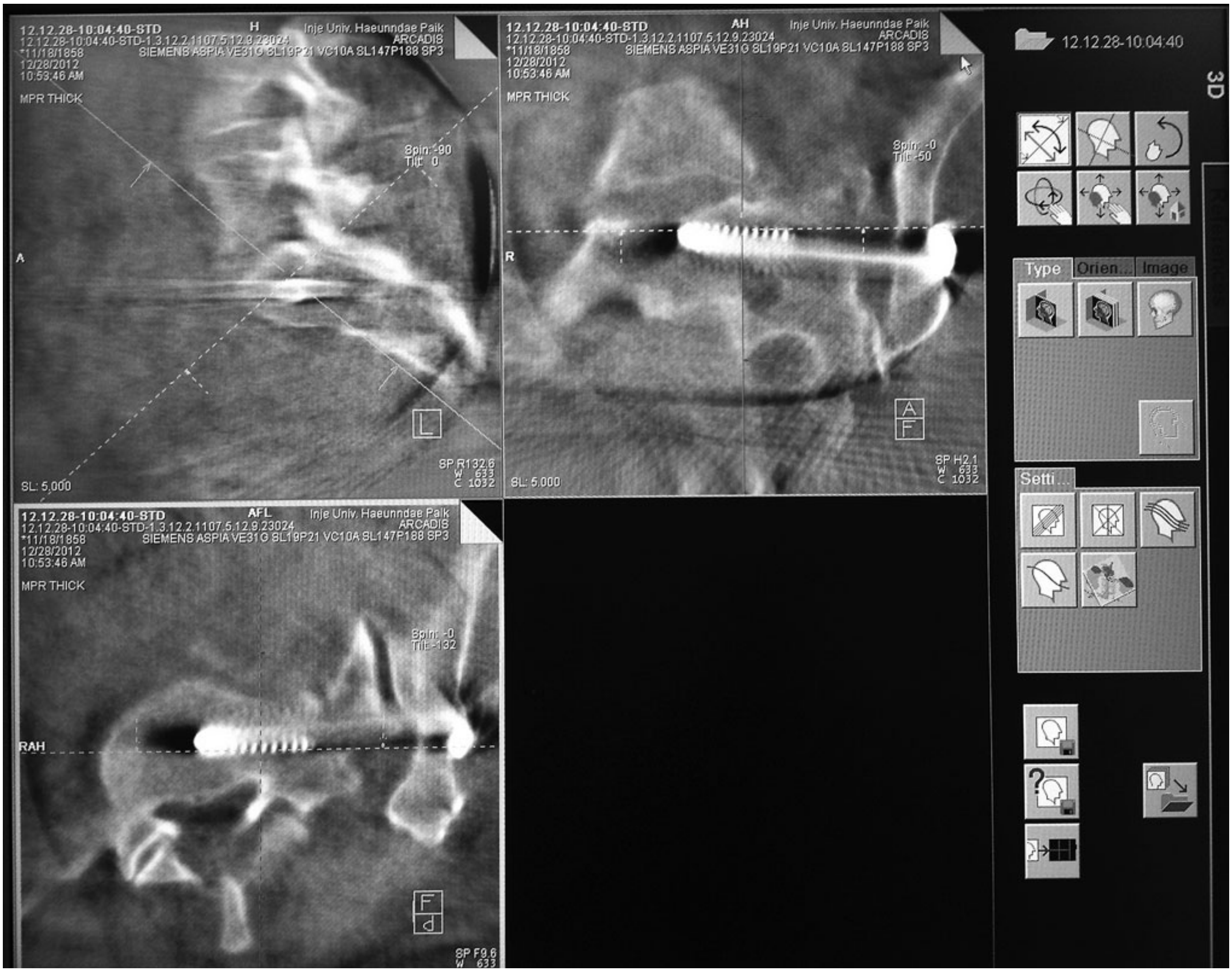

Fig. 1 Monitor view of Iso-C3D images showing multiplanar reconstructions of the pelvis

of 48.0 (range 18–79) years. Included cases were disruptions of the posterior pelvic ring (36); ankle fractures with syndesmotic injury (13); and intra-articular fractures (60) of the acetabulum (27), distal radius (15), tibial plateau (9), pilon (4), calcaneus (2), distal femur (1), patella (1), and olecranon (1). All operations were performed by a single orthopedic trauma surgeon at a level I trauma center.

Device and technique

All patients were positioned on a carbon-fiber radiolucent table (VIWAS, Maquet, Germany). Fluoroscopy was performed with the Iso-C3D™ (Siemens, Erlangen, Germany), which consists of two units: a modified C arm that provides conventional 2D-projection imaging, and a workstation that allows 3D reconstruction of the automatically acquired isotropic data set. The anatomic region of interest (ROI) was centered within the isocenter of the C arm on anteroposterior (AP) and lateral views. The operative field was covered by an extra layer of sterile sheets to ensure sterility during scanning. The C arm automatically acquired 2D frames in 62 s through a 190° scan; the 3D data set, a cube of 123 cm^3, was simultaneously generated. The 3D images were immediately displayed, similar to computed tomography (CT), in the form of coronal, sagittal, and axial planes (Fig. 1). All surgical staff exited the operating room during the scan.

Evaluation

The incidence of intraoperative revision and postoperative infection was analyzed. Approval for this study was obtained from our institutional review board.

Results

Ten of 109 (9.2 %) fractures were judged to require revision intraoperatively after Iso-C3D image evaluation

Table 1 Revision cases with iso-C3D use

Case	Age	Sex	Fracture site	Procedure	Revision details
1	57	Male	Syndesmosis	Transfixing screw fixation	Malreduction of distal tibiofibular joint and its correction
2	24	Male	Pilon	ORIF	Change of malpositioned screw
3	68	Female	Distal radius	ORIF	Change of malpositioned screw
4	61	Male	Tibial plateau	ORIF	Insufficient reduction and its correction
5	55	Male	Pelvic ring	Iliosacral screw fixation	Change of malpositioned screw
6	18	Female	Pelvic ring	Iliosacral screw fixation	Change of malpositioned screw
7	68	Female	Pelvic ring	Iliosacral screw fixation	Change of malpositioned screw
8	20	Male	Syndesmosis	Transfixing screw fixation	Malreduction of distal tibiofibular joint and its correction
9	50	Female	Syndesmosis	Transfixing screw fixation	Malreduction of distal tibiofibular joint and its correction
10	45	Male	Acetabulum	ORIF	Removal of malpositioned screw

ORIF open reduction/internal fixation

Table 2 Correction rate in relation to fracture site

Fracture site	Cases	Revision cases
Syndesmosis injury	13	3 (23.1 %)
Pelvis posterior ring injury (iliosacral screw fixation)	36	3 (8.3 %)
Acetabulum	27	1 (3.7 %)
Distal radius	15	1 (6.7 %)
Tibial plateau	9	1 (11.1 %)
Pilon	4	1 (25 %)
Other (calcaneus, distal femur, patella, olecranon)	5	0 (0 %)
Total	109	10 (9.2 %)

(Table 1). When considered by fracture site, the revision rate was highest for syndesmotic injury (23.1 %), followed by iliosacral fixation (8.3 %). The revision rate of intra-articular fractures was 6.6 % (Table 2). We changed the implant position in six cases (Fig. 2), corrected the articular reduction in one (Fig. 3), and revised the malreduction of syndesmosis in three (Fig. 4). None of the errors requiring intraoperative revision were seen on 2D fluoroscopic imaging. After the revisions, an Iso-C3D scan was repeated in all cases. Among three cases of malpositioned iliosacral screws, only one had paresthesia of the buttock, without motor deficit, and the symptom was resolved. There was no postoperative infection.

Discussion

Our data indicate the value of an intraoperative 3D imaging system. We identified unacceptable reduction or inappropriate screw position requiring revision in 9.2 % of cases. It is useful to detect a potentially unfavorable surgical outcome and reduce the number of revision surgical procedures, but standard 2D intraoperative fluoroscopy does not always enable precise identification of joint incongruity and periarticular implant position [8]. Multiplanar imaging is more accurate than standard 2D intraoperative fluoroscopy in the assessment of many articular fractures [9, 10], and several studies have reported the value of intraoperative 3D imaging [11–13]. Based on our experience, intraoperative 3D imaging may be especially useful for the following fractures:

1. Syndesmosis malreduction: We reduced syndesmosis by using a large, pointed clamp without overcompression

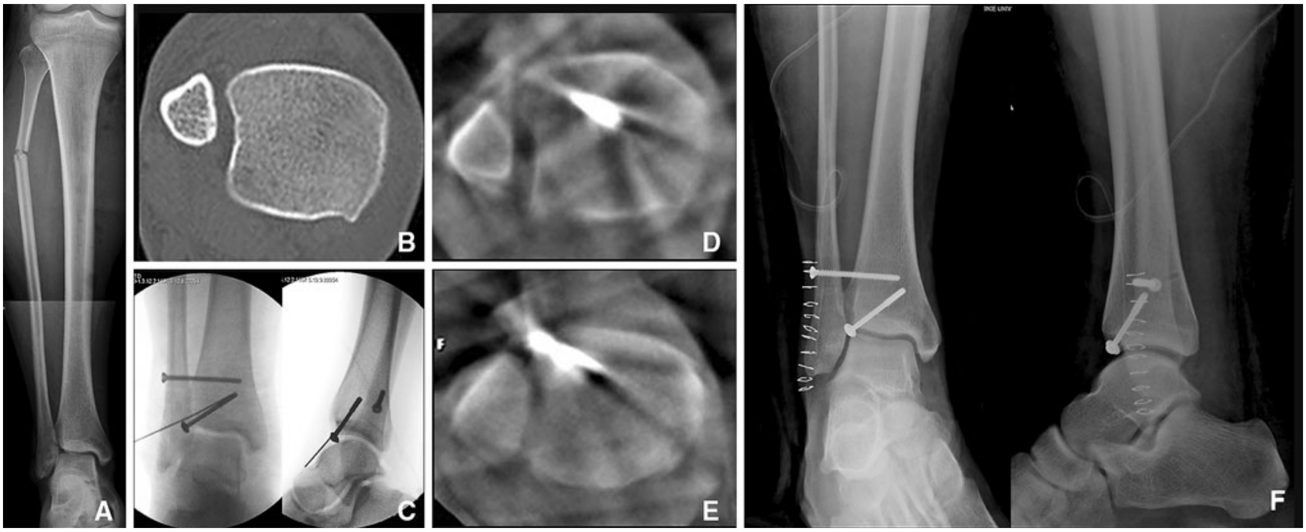

Fig. 2 **a** Maisonneuve fracture with Chaput fracture. **b** Axial computed tomography (CT) image showing incongruence of distal tibiofibular joint. **c** C-arm image obtained after open reduction and screw fixation. **d** Intraoperative 3D image showing anterior translation of the fibula and increased gap of posterior incisura. **e** Intraoperative 3D image showing correct reduction. **f** Postoperative radiograph

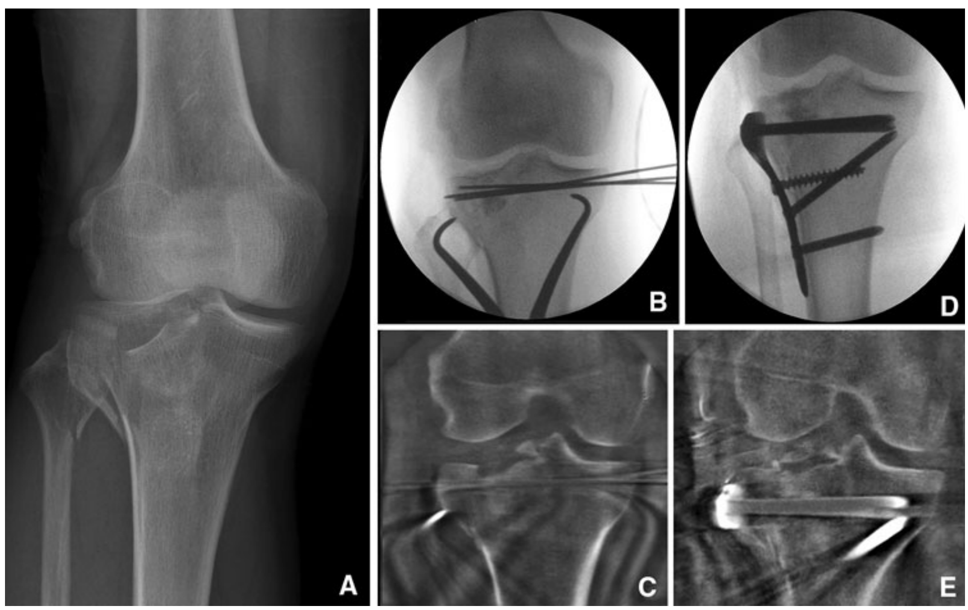

Fig. 3 **a** Tibial plateau fracture. **b** C-arm image obtained after open reduction and provisional K-wire fixation. **c** Intraoperative 3D image showing depression of articular fragment. **d** C-arm image obtained after revision. **e** Intraoperative 3D image showing satisfactory reduction

in the neutral position of the ankle joint and fixed it with a 3.5-mm cortical screw 2.5 cm proximal to the ankle joint. Syndesmosis reduction was evaluated radiographically intraoperatively in mortise and talar-dome lateral images. We revised 23.1 % of syndesmosis surgeries. Several papers report that 16–52 % of syndesmoses were noted to be malreduced postoperatively [14, 15]. Sagi et al. [8] reported a syndesmosis malreduction rate of 39 % despite treatment by experienced orthopedic trauma surgeons. Syndesmosis malreduction can lead to ankle arthritis, but it is difficult to obtain an accurate syndesmosis reduction because findings of intraoperative 2D fluoroscopy assessing malreduction may be unreliable [8]. Summers et al. suggested a reliable method for intraoperative 2D fluoroscopy evaluation using mortise and talar-dome images of the uninjured ankle in the operating room [16]. However, they agreed that CT is a more reliable method and that their method is not indicated in patients with injuries to both ankles. Several authors continue to support the use of postoperative CT for evaluating syndesmosis malreduction [14, 15]. According to Miller et al. [17], small malreductions will likely not be evident with standard intraoperative fluoroscopy and could be an indication for intraoperative CT. However, intraoperative 3D imaging

Fig. 4 Fracture of posterior wall of the acetabulum. **a** Pelvic anteroposterior radiograph showing widening of left hip joint space after reduction of posterior hip dislocation. **b** Axial computed tomography (CT) image demonstrating incarcerated fragment in the hip joint and posterior wall fracture. **c** The screw penetrating the hip joint was detected using intraoperative 3D imaging; the screw was removed

makes it possible to confirm reduction of syndesmosis, and if malreduction is evident, to perform immediate revision.

2. Iliosacral screw fixation: We reduced the posterior ring by skeletal traction or joystick technique with an external fixator. A guide wire was inserted in the safety zone and confirmed in the lateral view of the sacrum, followed by pelvic inlet and outlet views. The final confirmation was performed by intraoperative 3D imaging, which facilitated correction of 8.3 % of these fractures. Rates of iliosacral screw malposition after implantation under fluoroscopic guidance range from 2 % to 15 % [18, 19], with an incidence of neurologic injury between 0.5 % and 7.7 % [20]. Zwingmann et al. reported that complete intraosseous screw position was found in 42 % of cases using the conventional technique, which is significantly less than the 81 % seen using a 3D image intensifier in combination with a navigation system. Moreover, the revision rate was significantly less in the group in whom the navigation system was used (1.6 %) than in the conventional group (19 %) [21]. Zwingmann et al. [21] identified some causes of screw malpositioning: (1) the process of interpolation, which is associated with inherent errors, must be performed by surgeons, because visualization via an image intensifier is possible in only one plane at a time; (2) exact anatomic knowledge or extensive surgical experience is required for the procedure. Ebraheim et al. [22] cited the following causes for screw malpositioning: difficulties in radiographic interpretation because of patient obesity and intestinal gases, and variations in the anatomy of the posterior pelvis.

3. Acetabular fracture: Results of an experimental study with fresh–frozen cadavers revealed that only 18 of 24 screws were correctly identified using a conventional C arm and that 23 of 24 screws were correctly identified using the Iso-C3D [23]. Atesok et al. [24] reported an acetabular intraoperative revision rate of 9 %, or one of 11 patients, and von Recum et al. [25] reported a revision rate of 14.7 %, or 15 of 102 patients. While reporting the causes of malpositioning, some researchers suggested that the discrepancy between radiographic and clinical results in some patients may be due to traumatic cartilage injury, which itself remains poorly understood, or the inability to accurately detect articular incongruity using conventional 2D radiography [26]. Norris et al. reported that the anatomic nature of the acetabulum is such that direct visualization of the joint surface to assess reduction and the status of intra-articular implants is rarely possible, indicating surgeons are usually completely dependent on 2D fluoroscopy during surgery. A fluoroscopic view along the axis of a screw is often necessary to confirm its extra-articular positioning; it is frequently not feasible to obtain this view because of obstructing factors such as soft tissues and the surgical table [27].

4. Tibial plateau fracture: Restoration of articular congruity is an essential operative goal of treating tibial plateau fractures. Periarticular plates are now commonly used to fix tibial plateau fractures, but a periarticular plate with fixed screw trajectory can put the popliteal artery at risk due to anterior plate translation or posterior liftoff [7]. Under 2D imaging, lateral imaging is sometimes not truly lateral, so the penetrating screw can be concealed. In particular, the most posterior screw can penetrate the posterior cortex of the tibia and cause arterial injury [7]. However, intraoperative 3D imaging is better than standard

Fig. 5 **a** Trimalleolar fracture. **b** Coronal computed tomography (CT) image showing posterior malleolus displacement. **c** Percutaneous screw fixation was planned (*arrow*) using CT imaging. **d**, **e** Intraoperative 3D image showing the exact screw position and length

intraoperative fluoroscopy for confirmation of plate position and assessment of screw trajectory and length in order to avoid posterior penetration and vascular injury.

5. Distal radius fracture: The increasing use of volar plates for distal radius fractures has resulted in mechanical injury of the extensor pollicis longus (EPL) secondary to drill-bit penetration or rupture from prominent dorsal screws [28]. Evaluation of the depth of a screw using standard intraoperative fluoroscopy may be difficult, as Lister's tubercle or dorsal bone fragments may screen screw protrusion into the third extensor compartment [29]. Benson et al. [29] recommended using either shorter screws or leaving the implicated plate holes unfilled, as well as considering open assessment of the third extensor compartment; however, intraoperative 3D imaging can be a good alternative for evaluating screw protrusion.

6. Calcaneal fracture: Rapid deterioration of the joint, and most likely severe pain and disability, will develop if the reduction is inadequate or screws protrude into the joint [30]. In a series of calcaneal fractures, Rubberdt et al. [31] found that in 19.5 % of cases, an implant or reduction was changed based on Iso-C3D data.

7. Percutaneous cannulated screw fixation: Accurate direction and length of screws should be planned thoroughly using preoperative CT images, and correct positioning of the guide wire can be confirmed with an intraoperative 3D image (Fig. 5e).

The disadvantages of Iso-C3D imaging are radiation contamination and infection risk. The net radiation time in our study was 62 s. Radiation contamination is comparable with that of a standard CT scan, and the time corresponds to fluoroscopy time using a conventional C arm [11]; therefore, radiation contamination is not a cause for concern. Infection can be avoided with sterile draping of the scanning arm before the scanning procedure. A limitation of our study is the relatively small number of cases (109), which is not sufficient to support a definitive intraoperative revision rate. However, the study's main strengths are that it was designed as a prospective study and that all operations were performed by a single orthopedic trauma expert. This minimizes bias and provides a definitive revision rate.

Conclusion

Fracture surgery under 3D imaging incurred a revision rate of 9.2 %. Intraoperative 3D imaging is a valid tool for error correction, which prevents a second operation. Three-dimensional imaging may be especially useful in intra-articular fracture, iliosacral screw fixation, and syndesmotic injury.

Acknowledgments This work was supported by the 2012 Inje University research grant.

Conflict of interest None.

References

1. Krettek C, Schandelmaier P, Tscherne H. New developments in stabilization of dia- and metaphyseal fractures of long tubular bones. Orthopade. 1997;26:408–21.
2. Hasenboehler E, Rikli D, Babst R. Locking compression plate with minimally invasive plate osteosynthesis in diaphyseal and

distal tibial fracture: a retrospective study of 32 patients. Injury. 2007;38:365–70.

3. Zhiquan A, Bingfang Z, Yeming W, Chi Z, Peiyan H. Minimally invasive plating osteosynthesis (MIPO) of middle and distal third humeral shaft fractures. J Orthop Trauma. 2007;21:628–33.
4. Geerling J, Kendoff D, Citak M, Zech S, Gardner MJ, Hufner T, Krettek C, Richter M. Intraoperative 3D imaging in calcaneal fracture care-clinical implications and decision making. J Trauma. 2009;66:768–73.
5. Catalano LW 3rd, Barron OA, Glickel SZ. Assessment of articular displacement of distal radius fractures. Clin Orthop Relat Res. 2004;(423)79–84.
6. Edwards CC 2nd, Haraszti CJ, McGillivary GR, Gutow AP. Intra-articular distal radius fractures: arthroscopic assessment of radiographically assisted reduction. J Hand Surg Am. 2001;26:1036–41.
7. Dee M, Sojka JM, Daccarett MS, Mormino MA. Evaluation of popliteal artery injury risk with locked lateral plating of the tibial plateau. J Orthop Trauma. 2011;25:603–7.
8. Sagi HC, Shah AR, Sanders RW. The functional consequence of syndesmotic joint malreduction at a minimum 2-year follow-up. J Orthop Trauma. 2012;26:439–43.
9. Borrelli J Jr, Goldfarb C, Catalano L, Evanoff BA. Assessment of articular fragment displacement in acetabular fractures: a comparison of computerized tomography and plain radiographs. J Orthop Trauma. 2002;16:449–56 (discussion 56–7).
10. Chan PS, Klimkiewicz JJ, Luchetti WT, Esterhai JL, Kneeland JB, Dalinka MK, Heppenstall RB. Impact of CT scan on treatment plan and fracture classification of tibial plateau fractures. J Orthop Trauma. 1997;11:484–9.
11. 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;19:259–66.
12. Stockle U, Konig B, Schaffler A, Zschernack T, Haas NP. Clinical experience with the Siremobil Iso-C(3D) imaging system in pelvic surgery. Der Unfallchirurg. 2006;109:30–40.
13. Wich M, Spranger N, Ekkernkamp A. Intraoperative imaging with the ISO C(3D). [Der Chirurg; Zeitschrift fur alle Gebiete der operativen Medizen]. 2004; 75:982–87.
14. Gardner MJ, Demetrakopoulos D, Briggs SM, Helfet DL, Lorich DG. Malreduction of the tibiofibular syndesmosis in ankle fractures. Foot Ankle Int (American Orthopaedic Foot and Ankle Society [and] Swiss Foot and Ankle Society). 2006;27:788–92.
15. Miller AN, Carroll EA, Parker RJ, Boraiah S, Helfet DL, Lorich DG. Direct visualization for syndesmotic stabilization of ankle fractures. Foot Ankle Int (American Orthopaedic Foot and Ankle Society [and] Swiss Foot and Ankle Society). 2009;30:419–26.
16. Summers HD, Sinclair MK, Stover MD. A reliable method for intraoperative evaluation of syndesmotic reduction. J Orthop Trauma. 2013;27:196–200.
17. Miller AN, Barei DP, Iaquinto JM, Ledoux WR, Beingessner DM. Iatrogenic syndesmosis malreduction via clamp and screw placement. J Orthop Trauma. 2012;27(2):100–6.
18. Hinsche AF, Giannoudis PV, Smith RM. Fluoroscopy-based multiplanar image guidance for insertion of sacroiliac screws. Clin Orthop Relat Res. 2002;(395)135–44.
19. Templeman D, Schmidt A, Freese J, Weisman I. Proximity of iliosacral screws to neurovascular structures after internal fixation. Clin Orthop Relat Res. 1996;(329)194–98.
20. van den Bosch EW, van Zwienen CM, van Vugt AB. Fluoroscopic positioning of sacroiliac screws in 88 patients. J Trauma. 2002;53:44–8.
21. Zwingmann J, Konrad G, Mehlhorn AT, Sudkamp NP, Oberst M. Percutaneous iliosacral screw insertion: malpositioning and revision rate of screws with regards to application technique (navigated vs. Conventional). J Trauma. 2010;69:1501–6.
22. Ebraheim NA, Haman SP, Xu R, Stanescu S, Yeasting RA. The lumbosacral nerves in relation to dorsal S1 screw placement and their locations on plain radiographs. Orthopedics. 2000;23:245–7.
23. Kendoff D, Gardner MJ, Citak M, Kfuri M Jr, Thumes B, Krettek C, Hufner T. Value of 3D fluoroscopic imaging of acetabular fractures comparison to 2D fluoroscopy and CT imaging. Arch Orthop Trauma Surg. 2008;128:599–605.
24. Atesok K, Finkelstein J, Khoury A, Peyser A, Weil Y, Liebergall M, Mosheiff R. The use of intraoperative three-dimensional imaging (ISO-C-3D) in fixation of intraarticular fractures. Injury. 2007;38:1163–9.
25. von Recum J, Wendl K, Vock B, Grutzner PA, Franke J. Intraoperative 3D C-arm imaging. State of the art. Der Unfallchirurg. 2012;115:196–201.
26. Borrelli J Jr, Ricci WM, Steger-May K, Totty WG, Goldfarb C. Postoperative radiographic assessment of acetabular fractures: a comparison of plain radiographs and CT scans. J Orthop Trauma. 2005;19:299–304.
27. Norris BL, Hahn DH, Bosse MJ, Kellam JF, Sims SH. Intraoperative fluoroscopy to evaluate fracture reduction and hardware placement during acetabular surgery. J Orthop Trauma. 1999;13:414–7.
28. Lee HC, Wong YS, Chan BK, Low CO. Fixation of distal radius fractures using AO titanium volar distal radius plate. Hand Surg. 2003;8:7–15.
29. Benson EC, DeCarvalho A, Mikola EA, Veitch JM, Moneim MS. Two potential causes of EPL rupture after distal radius volar plate fixation. Clin Orthop Relat Res. 2006;451:218–22.
30. Myerson M, Quill GE Jr. Late complications of fractures of the calcaneus. J Bone Joint Surg. American volume 1993; 75:331–41.
31. Rubberdt A, Feil R, Stengel D, Spranger N, Mutze S, Wich M, Ekkernkamp A. The clinical use of the ISO-C(3D) imaging system in calcaneus fracture surgery. Der Unfallchirurg. 2006;109:112–8.