Intraoperative 3-Dimensional Imaging in Foot and Ankle Trauma—Experience With a Second-Generation Device (ARCADIS-3D)

Martinus Richter, MD, PhD and Stefan Zech, MD

Objective: Intraoperative 3-dimensional imaging with the first available device (ISO-C-3D; Siemens, Germany) has shown potential benefit in foot and ankle surgery. The aim of the study was to assess the clinical use of the second-generation device (ARCADIS-3D; Siemens) in comparison with earlier experience with the first-generation device.

Methods: In a matched pair study, the ISO-C-3D/ARCADIS-3D was used for intraoperative visualization after reduction/correction and internal fixation. The ISO-C-3D was used in 62 cases between January 1, 2003, and March 15, 2004, and the ARCADIS-3D was used in cases with similar fractures and arthrodesis location between September 1, 2006, and April 30, 2008. Potentially, changes in implant position and/or reduction were made after device use. Time spent and changes resulting from the use of ISO-C-3D/ARCADIS-3D were registered and analyzed.

Results: On average, the operation was interrupted for 440/320 seconds (ISO-C-3D/ARCADIS-3D), 120/60 seconds, on average, for the scan, and 210/180 seconds, on average, for evaluation of the images by the surgeon. In 39%/34% of the cases (24/21 of 62), the reduction and/or implant position was corrected during the same procedure after the ISO-C-3D/ARCADIS-3D scan.

Conclusions: Intraoperative 3-dimensional visualization with the ISO-C-3D/ARCADIS-3D can provide useful information that cannot be obtained from plain films or conventional C-arms. The second-generation device (ARCADIS-3D) provides faster scan and evaluation that reduces time spent. No other benefits were seen.

Key Words: intraoperative 3D imaging, deformities, hindfoot, mid foot, fracture dislocation

(*J Orthop Trauma* 2009;23:213–220)

INTRODUCTION

When using intraoperative fluoroscopy in foot and ankle trauma care, incorrect positioning of extraosseous and intra-articular screws and gaps or steps in joint lines frequently remain undiscovered and are only recognized on postoperative computed tomography (CT) scans.[1,2] A mobile C-arm with 3-dimensional imaging (ISO-C-3D; Siemens, Germany) was developed to better enhance the intraoperative recognition of problems with fracture reduction and fixation.[2] The conclusions of the first clinical experience using this device were that the intraoperative 3-dimensional visualization with the ISO-C-3D could provide useful information in foot and ankle trauma care that cannot be obtained from plain films or conventional C-arms alone.[2] The ISO-C-3D seemed to be most helpful in procedures with closed reduction and internal fixation and/or when axial reformations provide information that is not possible with a conventional C-arm and/or direct visualization during open reduction and internal fixation. The ISO-C-3D had the possibility of replacing a postoperative CT scan as 2-dimensional images for documentation can also be performed.[2] The radiation contamination that corresponded to 39 seconds fluoroscopy time with a conventional digital C-arm and the time spent with 440-second interruption of the surgical procedure have been criticized.[2] The second-generation device has been developed to minimize these problems and to improve handling. The aim of the study was to assess the clinical use of the new device (ARCADIS-3D; Siemens) in comparison with earlier experience with the first-generation device (ISO-C-3D; Siemens).

MATERIALS AND METHODS

Device

ISO-C-3D/ARCADIS-3D, are motorized mobile C-arms that provide fluoroscopic images during a 190-degree orbital rotation, resulting in a 119-mm data cube (Fig. 1). Multiplanar and 2-dimensional reconstructions can be obtained from these 3-dimensional data sets (Figs. 2A, 2B).

Setting

This clinical study was performed in a level I trauma center, which is also a university hospital (ISO-C-3D group, institution A), and a level II trauma center, which is also a university teaching hospital (ARCADIS-3D group, institution B). The surgical staff involved in the study consisted of experienced orthopaedic trauma surgeons and interns,

Accepted for publication December 11, 2008.
From the Department for Trauma, Orthopaedic and Foot Surgery, Coburg Medical Center, Coburg, Germany.
The authors did not receive grants or outside funding in support of their research or preparation of this article.
The devices that are the subject of this article are Food and Drug Administration approved.
Reprints: Prof Dr. med Martinus Richter, MD, PhD, Klinik für Unfallchirurgie, Orthopädie und Fusschirurgie, Klinikum Coburg, Ketschendorfer Strasse 33, 96450 Coburg, Germany (e-mail: info@foot-trauma.org).

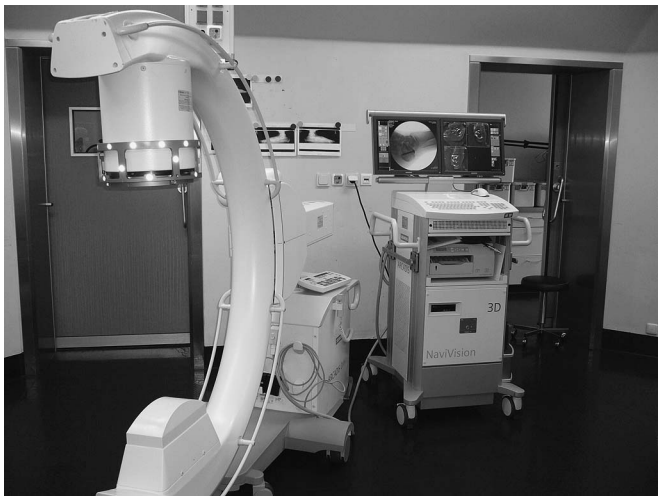

FIGURE 1. ARCADIS-3D device in the operating room.

residents, and fellows in training. The surgical procedures were exclusively performed not only by the head of the trauma department or the attending surgeons but also by residents.

The devices were always used after reduction, and positioning of implants was judged to be correct by the surgeon using a conventional C-arm. When incorrect reduction and/or implant positions were detected with the conventional C-arm, a correction of the reduction and/or implant was performed.

The surgical staff performed the conventional C-arm imaging. The ISO-C-3D/ARCADIS-3D imaging was performed either by the surgical staff or by a medical student who attended the ISO-C-3D study as part of his MD thesis. Seventeen surgeons were involved in the study (ISO-C-3D: 1 head of department, 4 attending surgeons, 2 senior residents, and 1 junior resident and ARCADIS-3D: 1 head of department, 4 attending surgeons, 3 senior residents, and 1 junior resident). Their level of experience with acute trauma and reconstructive foot and ankle surgery ranged from 15 cases (junior resident) to 500 cases (heads of department). None of the surgeons had prior experience with the ISO-C-3D in the ISO-C-3D group and with the ARCADIS-3D in the ARCADIS-3D group. Two surgeons from the ARCADIS-3D group had earlier experience with the ISO-C-3D. A sterile towel or a sterile plastic bag was used as a drape when the scanning procedure was performed.

After using the ISO-C-3D/ARCADIS-3D, the surgeon decided if changes need to be made when incorrect reduction and/or implant positions were detected. The necessary changes were made to achieve the goals of the surgical procedure, that is, anatomic reduction and optimal implant position. Based on the surgeons' experience, corrections were always made if there was thought to be a direct effect on the clinical outcome, that is, optimization of the reduction and/or position of the implant would improve the clinical outcome. After the corrections, a second ISO-C-3D/ARCADIS-3D scan was performed if any uncertainty regarding the correct reduction and/or implant position remained.

All patients who were treated at institution A between January 1, 2003, and March 15, 2004, were considered for inclusion into the ISO-C-3D group. All patients who were treated at the institution B between September 1, 2006, and April 20, 2008, were considered for inclusion into the ARCADIS-3D group.

Fractures of the pilon; isolated posterior malleolar fractures; talus, calcaneus, navicular, cuboid fractures; Chopart or Lisfranc fracture dislocations; isolated Weber C ankle fractures; and posttraumatic ankle and hindfoot arthrodeses were designated for inclusion in both groups. Matched pair cohorts for all cases were obtained with the exception of pilon and Weber C fractures. There were fewer pilon fractures in the ARCADIS-3D group than in the ISO-C-3D group and 3 more Weber C ankle fractures in the ARCADIS-3D group than in the ISO-C-3D group (Tables 1 and 2). No exclusion criteria were defined for either group.

Evaluation

A medical student who attended the surgeries recorded the times needed for each of the steps of the procedure (Table 3). The following steps were recorded and

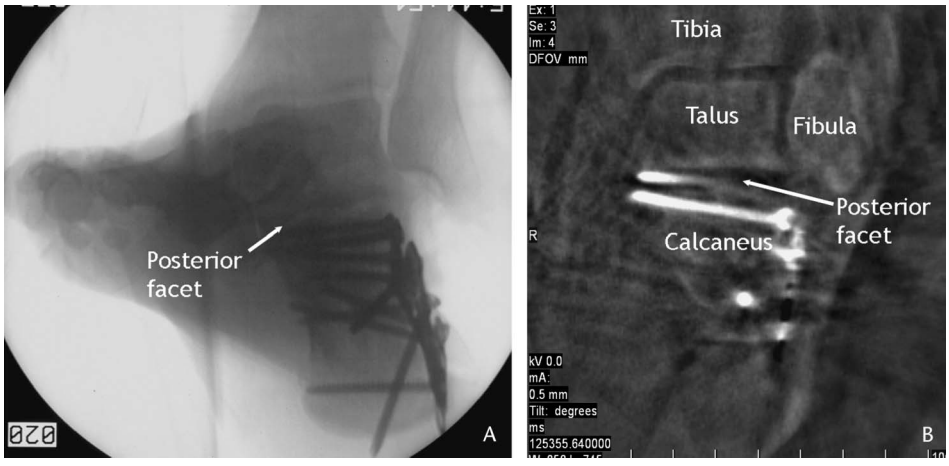

FIGURE 2. A, B, Calcaneus fracture after ORIF with plate and screws from the ISO-C-3D group. After evaluation with C-arm including Broden view (A), a correct reduction and implant position were confirmed by the surgeon. The ISO-C-3D-scan showed a screw penetrating the posterior facet medially (B), which was corrected at the same procedure. ORIF, open reduction and internal fixation.

timed: (1) preparation for the use of the ISO-C-3D/ARCADIS-3D in the operating room (ie, transfer of the device to the operating room, establishing connections, and turning on); (2) adjustment of the ISO-C-3D/ARCADIS-3D to the patient, including draping; (3) scan time (exclusively the scanning process); (4) calculation time of the ISO-C-3D/ARCADIS-3D device after the scan, before the images were visible on the screen; (5) evaluation time, that is, time spent by the surgeon choosing the views and planes on the screen and analyzing reduction and implant position; and (6) interruption time during the procedure for use of the ISO-C-3D/ARCADIS-3D (time for adjustment, scanning, and evaluation without preparing and calculating), including problems with the device. Measurements of both groups were compared between groups.

Statistical Analysis

The distribution of the fracture/arthrodesis location and the percentages of changes were compared with a χ^2 test, and the measured times were compared with a paired t test. The null hypothesis at the $P < 0.05$ level was that there is no difference between the groups.

Ethical Approval

The study was not approved by the ethical commissions of the responsible authority. Informed consent was not obtained from all subjects included in the study. The used devices (ISO-C-3D/ARCADIS-3D) were certified by the responsible authority for the executed usage.

RESULTS

Table 3 shows the time spent for the different steps. On average, the operation was interrupted for 440 seconds in the ISO-C-3D group (120 seconds, on average, for the scan and 210 seconds, on average, for evaluation of the images by the surgeon). In the ARCADIS-3D group, the operation was interrupted for 320 seconds on average (60 seconds, on average, for the scan and 180 seconds, on average, for evaluation). The net radiation time during a 100-image scan was 39.3 seconds for the ISO-C-3D and 19.6 seconds for ARCADIS-3D. In 1 case (2%) of the ISO-C-3D group, the software crashed during calculation and was restarted (summarized total calculation time 600 seconds). The reason for the crash could not be determined. The crash happened before the first software update at the very beginning of the study.

Consequences of ISO-C-3D/ARCADIS-3D Scan

ISO-C-3D

Using the ISO-C-3D scan, the position of the implant alone was corrected in 26% of cases (16 of 62), the reduction alone was corrected in 19% (12 of 62) of cases, and both implant position and reduction were corrected in 7% (4 of 62) of cases (Tables 1 and 2). A second ISO-C-3D scan was performed in 12 cases after the corrections (50% of cases in which corrections were performed). In none of those 12 cases were further corrections made after the second scan.

ARCADIS-3D

Using the ARCADIS-3D scan, the position of the implant alone was corrected in 26% (16 of 62) of cases, the reduction alone was corrected in 15% (10 of 62) of cases, and both implant position and reduction were corrected in 8% (5 of 62) of cases. A second ARCADIS-3D scan was performed in 14 cases after the corrections (66% of cases in which corrections were performed). In none of those 14 cases were further corrections made after the second scan.

The level of surgeon's experience did not differ between the ISO-C-3D group and ARCADIS-3D group (χ^2 test, $P > 0.05$). Table 4 indicates the changes made correlated with the surgeon's experience. The head of the department performed corrections in 31% and 36% of cases after ISO-C-3D/ARCADIS-3D use. The 4 attending surgeons who were involved in the study performed between 3 and 7 cases each and corrected reduction and/or implant position in 38% of their total cases in both groups (ISO-C-3D/ARCADIS-3D). The 2 senior residents performed a correction in 44% of cases in the ISO-C-3D group and 27% of cases in the ARCADIS-3D group. The junior residents performed 1 case in the ISO-C-3D group and 3 cases in the ARCADIS-3D group (without changes after ISO-C-3D use; 33% after ARCADIS-3D). The percentage of correction did not significantly differ between these groups (head of the department, attending surgeon, senior resident, and junior resident and ISO-C-3D versus ARCADIS-3D; χ^2 test, $P > 0.05$).

Statistical Analysis

The distribution of the fracture/arthrodesis location and the number of corrections after use of the ISO-C-3D/ARCADIS-3D did not differ between groups (χ^2 test, $P > 0.05$). The mean time spent for all steps of usage was lower for the ARCADIS-3D than for the ISO-C-3D (t test, $P < 0.05$). The null hypothesis was rejected for mean time spent and correlation between surgeons' experience versus changes and not rejected for fracture/arthrodesis location and the number/percentage of corrections.

DISCUSSION

A problem in foot and ankle trauma care can be the high percentage of joint fractures,[2–4] especially in the hindfoot and mid-foot region.[4,5] Long-term results in these cases are directly related to the accuracy of the initial reduction of the joint.[3,5] During operative foot and ankle trauma care, intraoperative visualization can be a problem, especially during closed or percutaneous procedures.[2,4,6,7] Different intraoperative C-arm views are standard and are equivalent to plain radiographs.[2,3,6] Unfortunately, postoperative CT scans may identify malpositions of the articular reduction not previously recognized intraoperatively.[1,2,8] A repeat procedure might be needed to correct the reduction and/or implant position.[2,3,8] It is in these cases that an intraoperative 3-dimensional imaging device is beneficial, very possibly improving clinical outcome.[2,8] Based on this study and others included in the literature, both the ISO-C-3D and the ARCADIS-3D seem to provide this additional necessary information intraoperatively.[1,2,9–12] The first device that was available was the ISO-C-3D with the

TABLE 1. Cases With ISO-C-3D Use

Diagnosis (Numbers)	No. Changes After ISO-C-3D Use			Description of Procedures and of Changes After ISO-C-3D Use
	In Total	Implant Position	Reduction	
Fractures (n = 50)				
Pilon (11)	4	2	3	All cases of ORIF with plates and screws
				Case 1: 1 screw that penetrated ankle corrected
				Case 2: 1 screw that penetrated ankle corrected and step in joint line corrected
				Cases 3 and 4: step of the ankle joint line corrected
Weber C (7)	3	2	2	All cases of CRIF with syndesmosis screw
				Case 1: reduction of distal fibula corrected
				Case 2: syndesmosis screw corrected
				Case 3: reduction of distal fibula and syndesmosis screw corrected
Dorsal Volkmann (1)	1	—	1	CRIF with 2 screws
				Step and gap in joint line corrected
Talus (3)	1	1	—	All cases of ORIF with screws, 1 screw that penetrated ankle joint corrected
Calcaneus (20)	7	5	3	ORIF with plate and screws
				Cases 1, 2, and 3: 1 screw that penetrated posterior facet corrected
				Case 4: 1 screw that penetrated calcaneocuboid joint corrected
				Cases 5 and 6: step in the posterior facet corrected
				Case 7: 1 screw that penetrated posterior facet and step in the posterior facet corrected
Navicular (1)	1	1	—	CRIF with screw
				One screw that penetrated talonavicular joint medially and plantarly corrected
Cuboid (1)	—	—	—	ORIF with screws
Lisfanc fracture dislocation (6)	2	1	1	Two cases of ORIF with tricortical bone autograft, plate, and screw and 4 cases of ORIF with screws/wires
				Case 1: 1 screw that penetrated talonavicular joint corrected
				Case 2: reduction of third metatarsal corrected to reduce flattening of the transverse arch
Posttraumatic osteoarthritis at the hindfoot with or without deformity (n = 12)				
Subtalar osteoarthritis (2)	1	1	—	Open cartilage removal, cancellous bone autograft, and 7.3-mm screws
				One screw that penetrated the ankle joint corrected
Subtalar osteoarthritis with deformity (10)	4	3	2	Open cartilage removal, correction, tricortical bone autograft, and 7.3-mm screws
				Case 1: 1 screw that penetrated the ankle joint corrected
				Case 2: 1 screw that penetrated joint between cuboid and fourth metatarsal corrected
				Case 3: hindfoot varus corrected
				Case 4: 1 screw that penetrated joint between cuboid and fourth metatarsal corrected; hindfoot varus corrected
In total (62), %	24/62 (39)	16/62 (26)	12/62 (19)	—

ORIF, open reduction and internal fixation; CRIF, closed reduction and internal fixation.

above-described benefits.[2] One important part of this study was to show the further development of this device (ARCADIS-3D), which solved some of the earlier problems, notably time spent obtaining the scan and radiation emitted.

We are aware that the first-generation device (ISO-C-3D) has been discontinued. We still believe that a comparison of the second-generation device (ARCADIS-3D) with the first-generation device was useful to indicate the advantages of the improvements.

Although it is true that we did not evaluate the impact of the changes on patient outcome, in more than one third of the cases in this study, intraoperative use of the ISO-C3D/ARCADIS-3D led to changes of reduction and/or implant positioning. This result did not differ between the ISO-C-3D and the ARCADIS-3D.

When reviewing the literature, there are situations where the use of ISO-C-3D/ARCADIS3D is especially helpful, such as in Weber C ankle and calcaneus fractures. Zwipp reported

TABLE 2. Cases With ARCADIS-3D Use

Diagnosis (Numbers)	No. Changes After ARCADIS Use			Description of Procedures and of Changes After ARCADIS Use
	In Total	Implant Position	Reduction	
Fractures (n = 50)				
Pilon (8)	2	2	0	All cases of ORIF with plates and screws
				Case 1: 1 screw that penetrated ankle corrected
				Case 2: 1 screw that penetrated ankle and the distal tibiofibular joint corrected
Weber C (10)	4	4	4	All cases of ORIF with syndesmosis screw
				All cases, reduction of distal fibula and syndesmosis screw corrected
Dorsal Volkmann (1)	0	—	—	CRIF with 2 screws
Talus (3)	1	1	—	All cases of ORIF with screws, 1 screw that penetrated subtalar joint corrected
Calcaneus (20)	6	4	3	ORIF with plate and screws
				Cases 1, 2, and 3: 1 screw that penetrated posterior facet corrected
				Case 4: 1 screw that penetrated calcaneocuboid joint corrected
				Cases 4, 5, and 6: step in the posterior facet corrected
Navicular (1)	1	1	—	CRIF with screw
				One screw that penetrated talonavicular joint medially and plantarly corrected
Cuboid (1)	—	—	—	ORIF with screws
Lisfanc fracture dislocation (6)	2	1	1	All cases of ORIF with screws/wires
				Case 1: 1 screw that penetrated talonavicular joint corrected
				Case 2: reduction of first and second metatarsal corrected to reduce flattening of the transverse arch
Posttraumatic osteoarthritis at the hindfoot with or without deformity (n = 12)				
Subtalar osteoarthritis (2)	1	1	—	Open cartilage removal, cancellous bone autograft, and 7.3-mm screws
				One screw that penetrated the ankle joint corrected
Subtalar osteoarthritis with deformity (10)	4	2	2	Open cartilage removal, correction, tricortical bone autograft, and 7.3-mm screws
				Cases 1 and 2: 1 screw that penetrated the ankle joint corrected
				Cases 3 and 4: hindfoot varus corrected
In total (62), %	21 (34)	16 (26)	10 (15)	—

ORIF, open reduction and internal fixation; CRIF, closed reduction and internal fixation.

a malposition of the distal fibula after closed reduction and fixation with a syndesmosis screw in 5 of 18 Weber C fractures, which was recognized with a postoperative CT.[13] He used a conventional C-arm and did not detect these malpositions intraoperatively. Revision surgery was performed in those 5 cases to improve the reduction.[13] During this same period, we recognized comparable malpositions in 2 of 7 Weber C fractures when using the ISO-C-3D intraoperatively and were able to correct the reduction during the procedure.[2] Later, Vasarhelyi et al reported on torsional side to side differences of more than 10 degrees on proximal and distal CT cuts of 61 ankle fractures, with ruptures of the syndesmotic complex. This CT technique correlated with the American Orthopaedic Foot and Ankle Society score and could help determine when early operative revision was indicated.[8] Again, we were able to recognize comparable malpositions in 4 of 10 Weber C fractures when using the ARCADIS-3D intraoperatively and were able to correct the reduction during the same procedure (Figs. 3A–D). Another important finding in our study was the high percentage of screws penetrating the joints when open reduction and internal fixation of calcaneus fractures were performed. Although the posterior facet and the calcaneocuboid joint were visible from the lateral side, we found screws penetrating these joints medially when we performed an intraoperative ISO-C3D/ARCADIS-3D scan in 5 of 20 cases. Both joints are oblique, and the posterior facet is especially difficult to visualize with a C-arm (Broden view).[4,6,7] In 3 of 20 cases, significant malreductions of the joint line of the posterior facet were also recognized with both ISO-C-3D and ARCADIS-3D and correction during the same operative procedure was possible. The ability to perform corrections intraoperative may in fact improve clinical outcome because Song et al[4] found nonanatomic reduction of the posterior facet, in 7 of 21 fractures using postoperative CT scans of Sanders type II calcaneus fractures.[14,15] They found a worse clinical outcome in those fractures in comparison with the remaining 14 fractures with anatomic reduction of the posterior facet without malposition.[15]

TABLE 3. Time Spent for Intraoperative ISO-C-3D/ARCADIS-3D Use

Step	Description of Step	ISO-C-3D/ARCADIS Time Spent (s) / Time Spent (min) Average	Minimum	Maximum
Preparing	Transfer of the device to the operating room, establishing of connections, and turning on	300/190*	150/120	600/600
		5.00/3.10	2.30/2.00	10.00/10.00
Adjustment	Draping with sterile towel or plastic bag and adjustment of device to the foot for the scan	180/120*	100/60	360/300
		3.00/1.50	1.40/1.00	6.00/5.00
Scanning	ISO-C-3D/ARCADIS scan alone	120/60*	100/60*	130/60*
		2.00/1.00	1.40/1.00	2.10/1.00
Calculation	Calculating time of device after the scan, before the images were visible on the screen	35/10*	30/10	600/10*
		0.35/0.10	0.30/0.10*	10.00/0.10
Evaluation	Choosing the views and planes on the screen and analyzing the reduction and implant position by the surgeon	210/180	120/60	360/300
		3.30/3.00	2.00/1.00*	6.00/5.00
Interruption of surgical procedure	Adjustment + scanning + evaluation	**440/320***	330/180*	700/600
		7.20/5.20	5.30/3.00	11.40/10.00

*t test, $P < 0.05$.

The statistical analysis of the surgeon's experience needs to be interpreted carefully as the junior residents only did 1 case with the first-generation system and 3 cases with the second-generation system. One remarkable point is that one of the senior residents of the ISO-C-3D group served as the head of the department of the ARCADIS-3D group, 3 years later. The personal experience of this individual was 27 cases in the ISO-C-3D group and more than 100 cases later with the ISO-C-3D before becoming part of the ARCADIS-3D group. This might be a bias due to the extensive experience of this individual before starting in the ARCADIS-3D. If so, the expectation would be that the extensive individual experience might decrease the percentage of insufficient reduction and/or implant position before the ARCADIS-3D use. This was not the case that proves the earlier conclusion that ISO-C-3D and ARCADIS-3D are helpful for all levels of experience.[2]

A major concern for new technical devices is the time added to a procedure. In our study, the operation was interrupted for 7.20 minutes on average for ISO-C-3D use, which was considered to be an acceptable time consumption.[2] Favorably, the time spent with the ARCADIS-3D was significantly lower with 5.20 minutes interruption of the operation in comparable cases. The net radiation time in our study was 39.3/19.6 seconds during a 100-image ISO-C-3D/ARCADIS scan.[2,10,11] Both devices measured radiation time. The amount of radiation contamination during that time depends on the volume and density of the radiated body and could not be determined. A comparison of the radiation

TABLE 4. Changes Made in Relation to Surgeons' Experience

Surgeon Status, ISO-C-3D/ARCADIS	No. Cases Contributed to Study, Single Surgeon an in Total ISO-C-3D ARCADIS	No. Changes After ISO-C-3D–ARCADIS Use, ISO-C-3D/ARCADIS In Total (%)	Implant Position (%)	Reduction (%)
Head				
n = 1	13	4/13 (31)	3/13 (23)	2/13 (15)
n = 1	28	10/28 (36)	7/28 (25)	5/28 (17)
Attending surgeons				
n = 4	7/6/5/3 = 21	8/21 (38)	5/21 (24)	4/21 (19)
n = 4	3/3/7/3 = 16	6/16 (38)	4/16 (25)	2/16 (13)
Senior residents				
n = 2	26/1 = 27	12/27 (44)	8/27 (29)	6/27 (22)
n = 3	8/4/3 = 15	4/15 (27)	4/15 (27)	2/15 (13)
Junior resident				
n = 1	1	0/1	0/1	0/1
n = 1	3	1/3 (33)	1/3 (33)	1/3 (33)
Total surgeons				
n = 8	62	24/62 (39)	16/62 (26)	12/62 (19)
n = 9	62	21/62 (34)	16/62 (26)	10/62 (25)

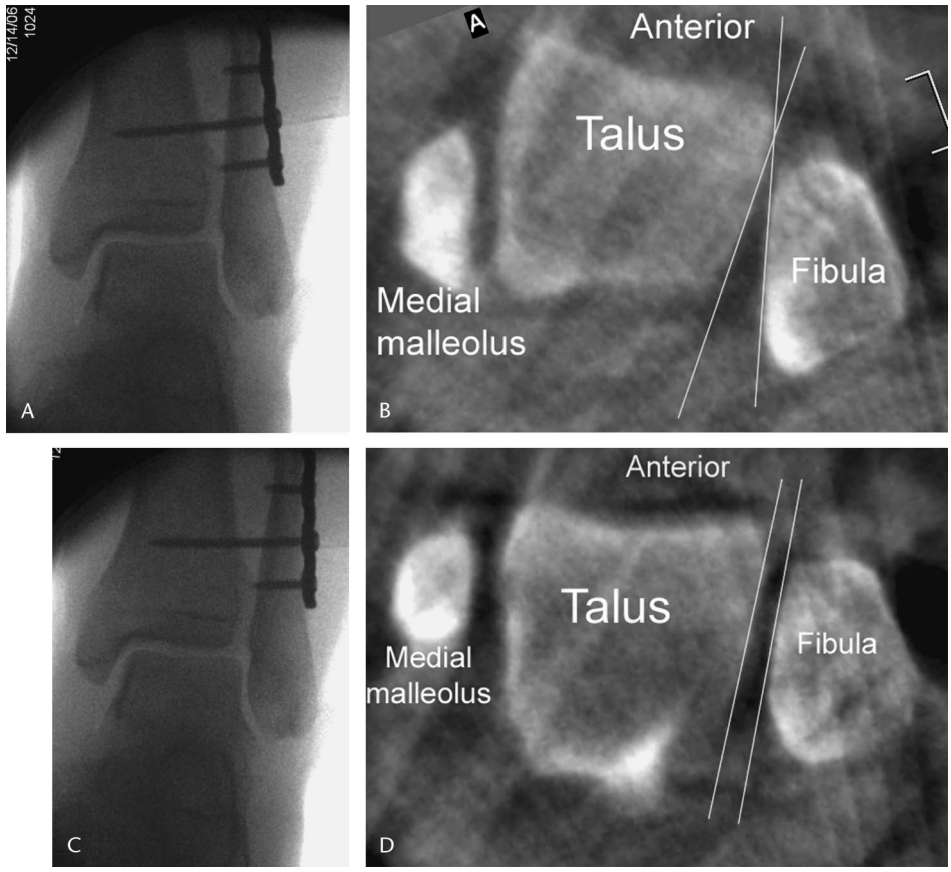

FIGURE 3. A–D, Weber C ankle from the ARCADIS-3D group. A, A C-arm image after ORIF including syndesmosis screw. B, The ARCADIS-3D scan shows a massive internal rotation of the distal fibula, leading to incongruency of the ankle joint. A, This was not recognized with the C-arm. C, After correction of the ORIF, the C-arm showed no significant difference. D, The ARCADIS-3D shows a correct rotation of the distal fibula and anatomic congruency of the ankle joint. ORIF, open reduction and internal fixation.

contamination with a standard CT scan would be interesting. However, to date, it is not possible to report the dose of a standard CT scan because there are so many different devices in use (single slice to 256 slices; many different manufacturers). Even with an actual 512-slice CT, the radiation contamination is not less than with ARCADIS-3D. We feel that it is more useful to compare the radiation contamination with 2-dimensional C-arm use. Of course, the radiation contamination depends on the body location, but this is true for both 3 and 2 dimensions. Therefore, the radiation time may be the best way to compare a 3-dimensional and a conventional 2-dimensional scan as reported above. We did not register the fluoroscopy times in control cases without 3-dimensional usage. The fluoroscopy times depend on the surgeon, whereas the 3-dimensional scan time is the same for all cases and is independent of surgeon's experience.

The biggest drawback of the ISO-C-3D/ARCADIS-3D is the cost. Although the ISO-C-3D is no longer available, it was twice as expensive as a conventional digital C-arm (price of ISO-C-3D was approximately €120,000/146,000 US $). To date, the ARCADIS-3D is available at a price of approximately €130,000 (200,000 US $). In addition, a carbon table for patient positioning is necessary for optimal image quality with the ARCADIS-3D (price of carbon table is approximately €40,000/64,000 US $). The higher financial expenditure for the use of the ARCADIS-3D may be offset by the likely reduction in the number of postoperative CT scans.

In this study, we did not obtain postoperative CT scans on a regular basis, as we did before the ISO-C-3D/ARCADIS-3D was available. Earlier studies have proven the comparable resolution of the ARCADIS-3D and the CT.[1,9–11] Because the technical features of the ISO-C-3D/ARCADIS-3D had been shown in previous studies, a comparison between ARCADIS-3D and CT was not performed during our study. The study was designed to discover the technical possibilities of the ISO-C-3D/ARCADIS-3D and how its use leads to modifications or corrections during a single surgical procedure.

A limiting factor in this study is that we do not know if we improved the surgical outcome by using a 3-dimensional device. Although we did not obtain objective outcome measures, it is clear to us that maximizing intraoperative outcomes is intuitively needed to obtain a good clinical result.

In conclusion, intraoperative 3-dimensional visualization using the ISO-C3D/ARCADIS-3D can provide useful information in foot and ankle trauma surgery that cannot be obtained from either plain films or conventional C-arms. The ISO-C-3D/ARCADIS-3D seems to be most helpful in procedures requiring closed reduction and internal fixation and/or when axial reformations provide information that is not possible to obtain with a conventional C-arm and/or direct visualization during open reduction and internal fixation. The ISO-C-3D/ARCADIS-3D has the possibility of replacing a postoperative CT scan as 2-dimensional images for documentation can also be performed. The second-generation device

(ARCADIS-3D) provides faster scan and evaluation that reduces time spent and provides less radiation contamination.

REFERENCES

1. Euler E, Wirth S, Linsenmaier U, et al. Vergleichende Untersuchung zur Qualität der C-Bogen-basierten 3D-Bildgebung am Talus. *Unfallchirurg*. 2001;104:839–846.
2. Richter M, Geerling J, Zech S, et al. 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: 259–266.
3. Zwipp H. Chirurgie des Fusses. Wien New York; Springer Berlin Heidelberg New York; 1994.
4. Zwipp H, Dahlen C, Randt T, et al. Komplextrauma des Fusses. *Orthopade*. 1997;26:1046–1056.
5. Richter M, Wippermann B, Krettek C, et al. Fractures and fracture dislocations of the midfoot—occurence, causes and long-term results. *Foot Ankle Int*. 2001;22:392–398.
6. Hansen STJ. *Functional Reconstruction of the Foot and Ankle*. Philadelphia, PA: Lippincott Williams & Wilkins; 2000.
7. Myerson MS, Fisher RT, Burgess AR, et al. Fracture dislocations of the tarsometatarsal joints: end results correlated with pathology and treatment. *Foot Ankle*. 1986;6:225–242.
8. Vasarhelyi A, Lubitz J, Gierer P, et al. Detection of fibular torsional deformities after surgery for ankle fractures with a novel CT method. *Foot Ankle Int*. 2006;27:1115–1121.
9. Kotsianos D, Rock C, Wirth S, et al. Frakturdiagnostik am Kniegelenk mit einem neuen mobilen CT-System (ISO-C-3D): Vergleich mit konventionellem Röntgen und Spiral-CT. *Rofo*. 2002;174:82–87.
10. 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;14:1590–1595.
11. 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;174:170–176.
12. 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;104:827–833.
13. Zwipp H. Techniken Syndesmoseninsuffizzienz [abstract]. Presented at: Videosymposium MHH Unfallchirurgie; March 25–26, 2004; Hannover, Germany.
14. Sanders R, Fortin P, Dipasquale T, et al. Operative treatment in 120 displaced intraarticular calcaneal fractures. Results using a prognostic computed tomography scan classification. *Clin Orthop Relat Res*. 1993; 290:87–95.
15. Song KS, Kang CH, Min BW, et al. Preoperative and postoperative evaluation of intra-articular fractures of the calcaneus based on computed tomography scanning. *J Orthop Trauma*. 1997;11:435–440.