Mobile C-arm-Based Flat-Detector Computed Tomography: An Evaluation for Use in Orthopedic Trauma Surgery

Introduction
Recent innovations in mobile C-arm technology have made intraoperative flat-panel detector cone-beam computed tomography (FD-CT) a viable option for orthopedic trauma surgeons. This technology provides the surgeon with the opportunity to obtain tomographic images akin to conventional CT images during surgery in the OR. Intraoperative FD-CT using a mobile C-arm has the potential capability to improve the accuracy of fracture reductions, assure the correct placement of implants and facilitate navigation. To assess image quality and operative workflow of intraoperative mobile C-arm-based FD-CT, six experienced orthopedic traumatologists evaluated this technology using the Ziehm Vision RFD 3D mobile C-arm.

Methods
A 65-year-old male human cadaveric specimen was the subject for the evaluation. In a standard operating room, the specimen was positioned in the supine position on a radiolucent operating table. The Ziehm Vision RFD 3D mobile C-arm was positioned over the joints of the lower extremity and the pelvic region. The Ziehm Vision RFD 3D captured a full 3D dataset of the specimen using Ziehm Imaging’s patented SmartScan technology. SmartScan is a technology that uses a combination of rotational and translational motion to provide the equivalent of 180 degree of angular information in the Ziehm Vision RFD 3D’s compact dimensions.

Before intervention FD-CT images were obtained of the ankle, foot, knee and pelvis. Once the technique was satisfactory, a Weber type C bimalleolar ankle fracture and a split depressed lateral tibial plateau fracture were created. The fractured joints were imaged and the 3D images created. These images were assessed by the surgeons to determine their radiographic quality and if the appropriate information was available. The fractures were repaired in a standard fashion using plates and screws. The metaphyseal defect in the lateral tibial plateau fracture was filled with calcium phosphate cement. Using the standard fluoroscopic images of the Ziehm flat-panel detector, iliosacral screws were inserted across the right sacroiliac joint and a screw was placed into the left superior pubic ramus (anterior column screw) of the pelvis. After the fixation was completed the joints were imaged again and the reconstructed 3D images were evaluated to assess image quality, metal artifacts, adequacy of reduction and implant position [Fig. 1].

![Fig. 1: The reconstructed tomographic images from the Ziehm Vision RFD 3D (upper) and CT (lower) confirm the placement of the anterior column screw.](image-url)
A postoperative CT scan was acquired to serve as control for the standard of care.

Results

Workflow
The Ziehm Vision RFD 3D has 33” of vertical free space for access to the specimen and a footprint of only 63”H 32”W 75”L which leaves ample space in the OR for positioning and maneuverability. The Ziehm Vision RFD 3D uses flat-panel detector technology for image acquisition.

The 30cm x 30cm flat-panel detector provided a generous field of view (FOV) for the assessment of the lower extremities and especially the pelvis. Here it was particularly valuable for the sacroiliac and ramus medullary screws [Fig. 2]. It took approximately 60 seconds to acquire up to 400 fluoroscopic images and about 30 seconds for the reconstruction of a 3D volume.

The system allowed the surgeons to place their implants using standard fluoroscopic images. Exact implant position was confirmed using the 3D capabilities of the Ziehm Vision RFD 3D. This was particularly useful when concern for intraarticular screws was present. The ability to produce tomographic images of the fracture reduction enhanced the surgeons’ ability to determine the accuracy of the reduction using the 3D dataset.

Ease of Use
Using the full motorization, which includes movement capabilities in all 4 axes of the Ziehm Vision RFD 3D, the surgeons were able to precisely position the C-arm for image capture directly from the Remote Vision Center (touchscreen) mounted on the C-arm or the Position Control Center (joystick) mounted to the side of the OR table.

Image Quality
The variable isocentric design of the Ziehm Vision RFD 3D provides the ability to image shoulders, hips and off-centered anatomy. The 25kW generator on the Ziehm Vision RFD 3D provides the necessary power to penetrate even thick tissue near the pelvis and sacroiliac joints. The Ziehm Vision RFD 3D delivered high quality images comparable to CT images while offering a surgeon the capability to make hardware adjustments directly in the OR. The 4 Slice CT system was only used for postoperative scans. The reconstructed slices of the 3D volume provided the most reliable information as to reduction and implant position [Fig. 3 & 4].
Fig. 3: A bimalleolar fracture has been malreduced and stabilized. The reconstructed images from the Ziehm Vision RFD 3D confirm the screw positions and malreductions. The volume rendered 3D image provides an overall assessment of fixation.

Fig. 4: A split depressed tibial plateau fracture has been malreduced and stabilized. The reconstructed images from the Ziehm Vision RFD 3D confirm the screw positions and malreductions. The volume rendered 3D image provides an overall assessment of fixation.

A volume rendering of the 3D dataset was most useful in the preoperative phase to determine fracture morphology. Using the innovative Ziehm iterative reconstruction algorithm (ZIR), metal artifacts were strongly reduced even in smaller joints with multiple screws near the articular surface. Even here fracture reduction and implant position assessment was still possible.

Dose

All fluoroscopic images which were used for 3D reconstruction were acquired at standard fluoroscopic dose values (0.5 µGy/s detector entrance dose).

Discussion

Image quality and workflow have stayed at the forefront of the challenges faced by solutions for intraoperative imaging. In 2002 the first mobile C-arm with 2D and 3D capabilities entered the market. However there was still a large potential for improving the existing technology. Mobile C-arms that offer both 2D and 3D intraoperative capabilities can be very large in size due to their isocentric design. Isocentric design can limit range of motion and also minimize utility for orthopedic and trauma applications as they may not be able to image off-centered anatomy including shoulders and hips. Mobile C-arms may also use image intensifiers for image acquisition whose images are known to suffer from imperfections and distortion.

Other intraoperative solutions currently available, only offer single modality imaging which could be difficult for a hospital or surgeon to justify financially and can prove to be problematic for smaller operating rooms.

Postoperative CT scans are standard for many orthopedic and trauma procedures to confirm hardware and implant placement and intraarticular fracture reduction. CT scans provide suitable 3D information for assessment but potentially require a patient to come back the following day after surgery, receive additional radiation, and undergo a revision surgery if adjustment is needed. Adequate 2D and 3D intraoperative image quality could give a surgeon the capability to do minimally invasive surgery, which reduces blood loss, risk to patient, hospital stays and recovery times. In addition, surgeons could be more confident about success of the surgery in the OR and without the delay of waiting for a postoperative CT.
An imaging solution that offers 2D and 3D modalities, a compact design, versatility across applications and exceptional image quality could emerge as the standard of care for intraoperative imaging in orthopedic and trauma surgery.

Conclusion
The initial simulated experience with intraoperative mobile C-arm-based FD-CT was excellent. The ability to obtain images of peripheral joints was easy and effective. The quality of the images was assessed to be equivalent to conventional CT scans allowing the surgeon to determine fracture reduction and implant position within the OR prior to the end of the operative procedure.

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1 The Ziehm Vision RFD 3D is not cleared for sale in the US.
2 When original medical images are reproduced they will always lose a certain amount of detail.
3 Patent: DE 102013013552 B3