The use of intraoperative 3D-RX imaging in trauma surgery of the extremities

Conventional C-arm fluoroscopy in trauma surgery of the extremities often fails to reveal incorrect positioning of implants (i.e. screws, plates) and joint incongruencies. In such cases, the problems are only recognized on postoperative Computed Tomography (CT) scans. The wish for more detailed information on fracture reduction and implant position during surgery has led to the development of intraoperative 3D imaging. The BV Pulsera with 3D-RX makes it possible to obtain 3D images during the surgical procedure.

This type of imaging provides additional information, enabling the surgeon to recognize problems with fracture reduction and/or fixation during the operation, and can confirm adequate reduction and fixation. This is potentially of great value, as previously the surgeon would have to wait for the postoperative CT scan and, if necessary, plan a revision. With the intraoperative 3D-RX imaging, detailed information is obtained during or at the end of the procedure, allowing any necessary corrections to be made while the patient is still on the table.

The BV Pulsera with 3D-RX is a conventional C-arm with added 3D-RX (Rotational X-ray) functionality. The modification makes no restrictions on the use of the system for normal (2D) fluoroscopy imaging in addition to the 3D reconstruction (Figure 1).

The aim of the present study was to evaluate the feasibility and benefits of the intraoperative use of 3D-RX imaging during trauma surgery of the foot, ankle, elbow, hand and wrist. The study was performed in a Level-I trauma center within a university hospital (Academic Medical Center, Amsterdam). We describe the potential benefits and practical issues of using an intraoperative 3D-RX system, such as effective use of time, sterility and radiation dose.
Three clinical cases are presented below, and the added value of 3D-RX imaging in trauma surgery is discussed.

Materials and methods

The prototype 3D-RX system is a mobile C-arm unit (BV Pulsera, Philips Medical Systems, Best, the Netherlands), modified to provide a motorized rotational movement, and combined with a Philips 3D-RA workstation. A series of 251 projection images is acquired over a period of 30 seconds during a 200° rotation of the C-arm. The projection images are used to reconstruct a 3D data set. A fast Feldkamp reconstruction algorithm provides a full high-definition 3D set. The radiation exposure of each image in the scanning run is dynamically adjusted to provide the best combination of low dose and optimal image quality.

Depending on the size of the anatomical region of interest, we use either a 23 cm (9") or a 31 cm (12") image intensifier field. The reconstructed data set represents a sphere with a diameter of 12.5 or 18 cm (corresponding to the 9" or 12" field) with isotropic voxels. Depending on the field size, slices of 0.7 or 0.5 mm thick are obtained. This is more than sufficient to see the smallest gaps and steps. With the 3D-RX system, it is possible to see contrast differences of about 50 Hounsfield Units (HU). Here again, this is more than adequate, as the typical bone/soft tissue contrast is 1000 HU. The contrast resolution is, however, affected by any metal implants included in the reconstruction, as a large quantity of metal in the image field will decrease the contrast.

The extremity is positioned on a radiolucent support, such as a carbon fiber surgery table extension, to allow rotational imaging (Figures 1, 2). Precise positioning is achieved using laser pointers aligned with the isocenter of the rotation.

The second step is a pair of low-dose anteroposterior and lateral X-ray images, taken to confirm the alignment of the system with the patient’s anatomy.

Next, the run of 251 projection images is acquired. After reconstruction, the 3D-RX data set can be viewed on a 3D-RA workstation in the operating room. Both volume rendering and slice images are available. Coronal, sagittal, and axial slices are reconstructed as standard. Optimal visualization settings and reformattting of the slices are intuitive, and can be easily done by the radiographic technician.

3D-RX imaging has been used in 35 patients to date (Table 1). Application of the 3D-RX system was dependent on the anticipated complexity of the fracture, but also on the availability of the system at the time.

Before positioning the C-arm, a sterile bag (such as the type normally used to cover the image intensifier or an instrument table) is placed over the operation zone by the surgeon and instrument nurse. The extremity, tabletop and drapes are then inside the bag. With this technique, the operation zone can be kept sterile. After the rotational run has been acquired, the bag is removed.

For ankle and foot surgery, a standard table (AlphaMaquet, Maquet, Baambrugge, the Netherlands) can be used. As long as the foot is not in line with the table side rails no metal artifacts will appear in the image. However, to achieve this, the patient often has to be positioned as far as possible towards the foot-end of the table. A carbon-fiber tabletop is therefore preferred and used whenever possible.

<table>
<thead>
<tr>
<th>Extremity</th>
<th>No. of patients</th>
</tr>
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<tbody>
<tr>
<td>Distal radius fracture</td>
<td>12</td>
</tr>
<tr>
<td>Carpal fracture</td>
<td>1</td>
</tr>
<tr>
<td>Elbow fracture</td>
<td>2</td>
</tr>
<tr>
<td>Ankle fracture</td>
<td>7</td>
</tr>
<tr>
<td>Metatarsal fracture</td>
<td>5</td>
</tr>
<tr>
<td>Calcaneus fracture</td>
<td>8</td>
</tr>
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</table>
For hand and wrist surgery we use the RADIUS table extension (Liftac AG, Zurich, Switzerland). This table extension, which we helped to develop, is a specially designed arm support consisting of a simple free-hanging carbon plate, with all-round access allowing rotational X-ray imaging. The table extension has proved to be very practical (Figure 2). In addition to being radiolucent, it is also free of the floor, allowing unrestricted movement of the operating table.

Results

Three representative cases are described below.

Case 1: Ankle

The first case is a 43 year old female patient with a bimalleolar Weber type C fracture of the left ankle. She was admitted for surgery. After repositioning and fixation of the fracture, the ankle was examined under fluoroscopy (Figure 3). Everything appeared to be in the correct position, but 3D imaging was performed as an additional check. The 3D slice images (Figure 4) showed clear subluxation of the talus and an excessively tight connection between the fibula and the tibia. After immediate revision, the ankle was examined again under fluoroscopy (Figure 5) and a new 3D run was acquired (Figure 6). The 3D run showed that the talus and fibula were now correctly positioned.

Case 2: Elbow

This case is a 32 year old male patient who sustained a luxation fracture of the right elbow after a bicycle accident (Figure 7). We reduced the luxation, and made a further check with conventional radiography and a CT scan (Figure 8). The radiographs showed a fracture of the radius head, while the CT scan also showed fracture of the coronoid process. We admitted the patient and performed surgery immediately (Figure 9). We stabilized the head of the radius with a locking compression plate (LCP), and reconstructed the coronoid process with a Mitek anchor. The collateral ligaments were also fixed with a Mitek anchor. Postoperative fluoroscopy showed correct positioning, and the 3D scan confirmed correct positioning of the screws and anchors (Figure 10). After that we closed the wound.

Case 3: Hand

The third case is a young male of 28 years old who had fallen on his left hand. A preoperative radiograph and CT scan showed a fracture of the hamate bone (Figure 11). Anatomical repositioning and fixation appeared to be the best treatment. After reduction of the fracture we succeeded in inserting a k-wire through the
hamate bone in a minimally invasive procedure. Fluoroscopy was unable to confirm successful reduction of the fracture. The 3D scan (Figure 12) confirmed correct reduction and a screw was inserted over the wire.

**Discussion**

The time required for the 3D-RX examination covers two phases. The first phase, comprising sterile coverage, alignment and acquisition, takes about three minutes. Surgery can then continue while the images are processed. A 3D dataset with 0.5 or 0.7 mm thick slices in all directions is reconstructed directly on a workstation in the operating room. Processing and appropriate display (with reformatting if necessary) is done by the technician and takes approximately three minutes.

The average operating time for the 35 patients in our group was 100 minutes. An average of 1.7 3D-RX scans were performed per procedure, representing a very small increase of about five minutes in the operating time. The system is able to produce standard fluoroscopic images as well as 3D reconstructions. During scanning, pulsed acquisition is used in order to avoid motion artifacts. The short pulses of radiation also ensure low dose, which is further reduced by automatic voltage control (typically in the range of 50-80 kV).

The maximum equivalent doses for hand/wrist and foot/ankle scans are shown in Table 2.

In foot/ankle surgery, the larger field (18 cm diameter sphere) is generally used in order to cover the whole region of interest. For hand surgery, the smaller field (12.5 cm diameter sphere) is used in order to obtain larger detail.

Trauma surgery frequently uses metal implant materials such as Kirschner wires, screws, and titanium (locking) plates to reduce and stabilize fractures. In fluoroscopy these highly attenuating implants obscure details. In 3D imaging techniques, such as CT and 3D-RX, typical metal artifacts are encountered. Although the artifacts are less disturbing in 3D-RX than in standard CT, they can nevertheless cause significant deterioration in the image quality in the form of contrast loss and streak artifacts, which can affect the ability to judge the reduction and position of implants.

3D-RX imaging should be avoided where too much metal is present, such as more than five Kirschner wires in one fracture fragment, or the use of Steinmann pins, due to the reduced...
image quality and the relatively high radiation dose resulting from the automatic adjustment. The presence of metal artifacts in the 3D-RX images mostly affects the volume rendering. The reformatting is much less affected and still shows great detail.

3D-RX imaging allows the surgeon to obtain images with a quality close to that of a CT scan during the operation. Consequently, a higher level of certainty about the operative result can be obtained before the skin is closed. We have found that, in a number of cases, the 3D-RX images led to an adjustment of the reduction and/or the position of one or more implants. Fluoroscopy, performed each time before the 3D-RX image was obtained, had failed to reveal the incorrect positioning. Apart from two cases, in which the images were seriously affected by extensive metal artifacts, the 3D-RX images had significant added value, either by confirming the proper reduction and implant position, or by revealing surgical failure.

**Conclusion**

The 3D-RX system provides accurate and highly detailed intraoperative images. Previously, we had to wait for the results of a post-operative CT scan, but now the surgeon can adequately check the operative result while the patient is still on the table. This is a major advantage, particularly with the increasing use of less invasive operation techniques, which no longer provide a direct view of fragments and implants. 3D-RX could therefore enhance the efficiency and cost-effectiveness of trauma surgery by obtaining optimal imaging of fracture reduction and fixation during the operation, thereby avoiding technical failures.

In our view, the extra surgery time is fully justified by the added precision, as well as the potential saving of the additional time that would be needed for repeat procedures. The radiation dose is low and the experience gained with this system has overcome initial practical issues such as sterility and the presence of metal artifacts. The contrast and spatial resolution are fully adequate for showing all the detail required for trauma surgery. The extra time is considered to be a minor delay, and the use of a carbon fiber tabletop and arm extension allow uncompromised handling and image quality.

We believe that intraoperative 3D rotational imaging has the potential to decrease the number of repeated surgical procedures, and has therefore become a standard procedure in our hospital during surgery of complex joint fractures of the extremities. We strongly recommend the use of 3D-RX during all intraarticular fractures of the extremities during trauma surgery. Nevertheless, more studies are needed to confirm the anticipated benefits.

N.B. The BV Pulsera with 3D-RX is not yet licensed for use in Canada.

### Table 2. Equivalent radiation dose figures for three modalities [1]

<table>
<thead>
<tr>
<th>Modality</th>
<th>Hand</th>
<th>Foot</th>
</tr>
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<tbody>
<tr>
<td>3D-RX</td>
<td>6.4 µSv</td>
<td>10.5 µSv</td>
</tr>
<tr>
<td>Plain image</td>
<td>0.17 µSv</td>
<td>0.7 µSv</td>
</tr>
<tr>
<td>CT</td>
<td>70 µSv</td>
<td>2 mSv</td>
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</table>

**Reference**