Intraoperative Use of 3-D Fluoroscopy in the Treatment of Developmental Dislocation of the Hip in an Infant

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Confirming reduction of a developmental dislocation of the hip (DDH) through a spica cast is an imaging challenge. Computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound have been advocated.[1-11] Each of these modalities has its benefits and drawbacks. Ultrasound allows the hip to be visualized in the operating room but is operator-dependent and requires cutting a window in the posterolateral aspect of the cast—thereby weakening an area that is crucial in holding the reduction. MRI is useful for visualizing the hip, acetabulum, and soft-tissue structures through a spica cast, but MRI availability and cost, and the prolonged sedation required, make this modality prohibitive for routine use at many centers. CT provides excellent visualization of bony details and anatomical relationships but subjects patients to ionizing radiation. In addition, both MRI and CT require waiting for the patient to recover from general anesthesia before moving him or her from the operating room to the scanner. When the reduction is suboptimal, the patient must be returned to the operating room for repeat anesthesia and corrective action.

At our institution, we have begun using a 3-dimensional (3-D) fluoroscope (Siremobil Iso-C^{3D}; Siemens Medical Solutions, Erlangen, Germany) in the operating room to confirm reductions after application of spica casts. Similar to a conventional C-arm, this instrument is portable and can provide 2-D images useful for intraoperative arthrography. Unlike a standard fluoroscope, the 3-D fluoroscope automatically rotates 190° around an isocentric point on the patient. It obtains either 50 fluoroscopic images in 1 minute or 100 images in 2 minutes, depending on the desired level of anatomical detail. Specialized software then processes the images and reconstructs them to provide axial, coronal, and sagittal views of the anatomy. These images are of high quality and are comparable to those obtained with a CT scanner. The radiation dose for the 50-image cycle is equivalent to 20 seconds of standard fluoroscopy or approximately 0.77 mGy (77 mrad).[12] The radiation dose for the 100-image cycle is equivalent to 40 seconds of standard fluoroscopy or approximately 1.57 mGy (157 mrad).[12] We have found that the 50-image cycle provides adequate visualization of anatomical detail. To put the radiation dose in perspective, natural background radiation from the atmosphere is approximately 1 mrad per day.

The primary benefit of this instrument in the treatment of an infant with DDH is that it allows the surgeon to assess the reduction without taking the patient off the operating table, and corrective action can be taken without the risks associated with repeat anesthesia or the cost and inconvenience of a return trip to the operating room.

We present the case of an infant with DDH to illustrate the use of 3-D fluoroscopy in reduction imaging. We obtained informed consent from the patient's family to perform the procedure and publish the case data.

Case Report

An 8-month-old otherwise healthy girl with bilateral teratologic DDH underwent a right open hip reduction through an anterior approach with open adductor tenotomy, psoas

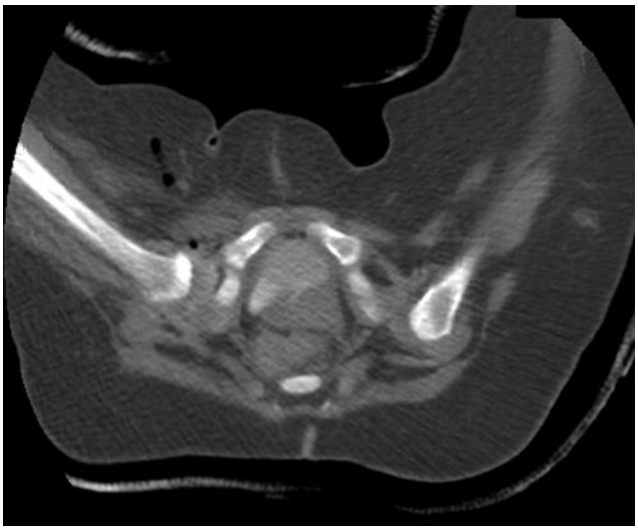

Figure 1. Computed tomography scan after initial surgery on right hip shows reduced right hip and unreduced left hip.

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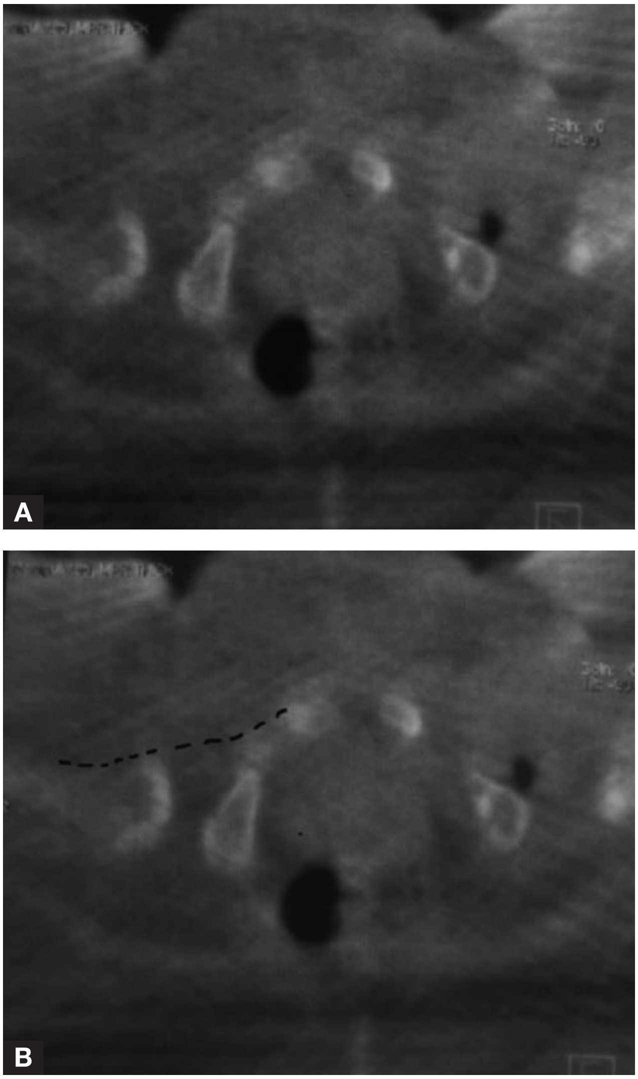

Figure 2. Intraoperative 3-dimensional fluoroscopic image shows (A) maintained reduction of right hip and (B) intact anterior Shenton's line (dashed line).

lengthening, and spica casting. During this procedure, Hypaque dye was used for an arthrogram, and fluoroscopic images were obtained to check reduction quality before closure. After closure of the right hip, it was judged that an attempt to perform the same procedure on the left hip at the same time would jeopardize the right hip reduction, and therefore the left hip was left dislocated, and a spica cast was applied. After application of the spica cast, new fluoroscopic images were checked in the operating room for continued reduction. Following the standard of care at our institution, we had a CT scan performed in the CT suite to ensure reduction of the hip in the spica cast (Figure 1).

Four weeks later, the child returned for open reduction of the left hip, with confirmation by 3-D fluoroscopy. First, general anesthesia was induced. Then, the 3-D fluoroscope was used to check the status of the right hip through the spica cast (Figures 2A, 2B), the cast was removed, and the right hip was examined and found to be clinically stable. Next, through an anterior approach, open reduction was

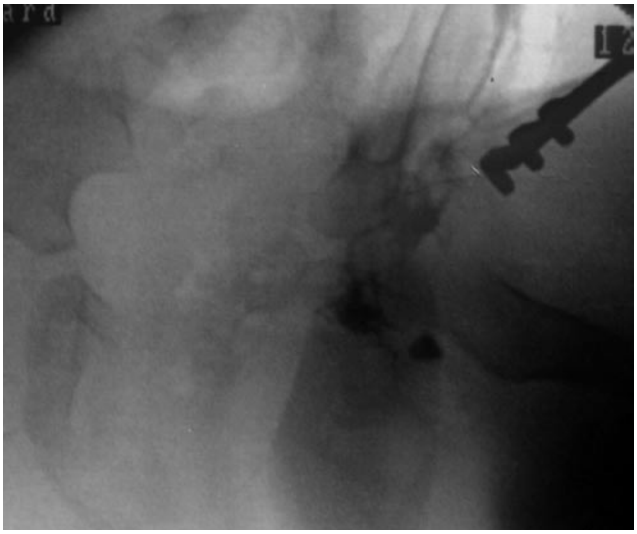

Figure 3. Intraoperative 2-dimensional fluoroscopic image obtained with 3-dimensional fluoroscope with intra-articular Hypaque dye after open reduction of left hip.

performed on the left hip, along with open adductor tenotomy and psoas lengthening. A Hypaque arthrogram was performed with the standard fluoroscopic function of the Siremobil Iso-C^{3D} used for reduction confirmation (Figure 3). After wound closure and application of the spica cast, the 3-D fluoroscope was again used in the operating room to confirm both hip reductions with the patient still under general anesthesia (Figures 4A, 4B). A postoperative CT scan was deemed unnecessary, as the 3-D fluoroscopic images were conclusive of reduction.

The medical physicist at our institution calculated the doses of ionizing radiation from the conventional CT scanner (used during the first procedure) and from the 3-D fluoroscope (second procedure). The dose from conventional CT was 19.3 mGy (1930 mrad) on the central axis; this dose was calculated using a kVp of 120 and an effective mAs of 91.5 for the study by using the median mAs for the 34 slices taken. The dose from the 3-D fluoroscope was 0.86 mGy (86 mrad) on the central axis, for a 50-image reconstructed study at 63 kVp and 56 mAs.

Discussion

Closed or open treatment of DDH with postoperative use of CT to assess reduction has been the standard of care at many institutions for the better part of 2 decades. Browning and colleagues[2] in 1982 were the first to mention this use for CT; they described using CT to confirm location and to assess acetabular anteversion in 5 infants with DDH. Since the early 1980s, several authors have advocated using CT to image children with DDH.[3,6-11] Various CT-based anatomical relationships have been described, including hip-abduction angle, acetabular anteversion, and lateral, anteroposterior displacement of the femoral metaphysis in relation to the acetabulum, including the commonly used modified anterior Shenton's line (a line drawn parallel to the pubic rami to its intersection on the proximal femoral metaphy-

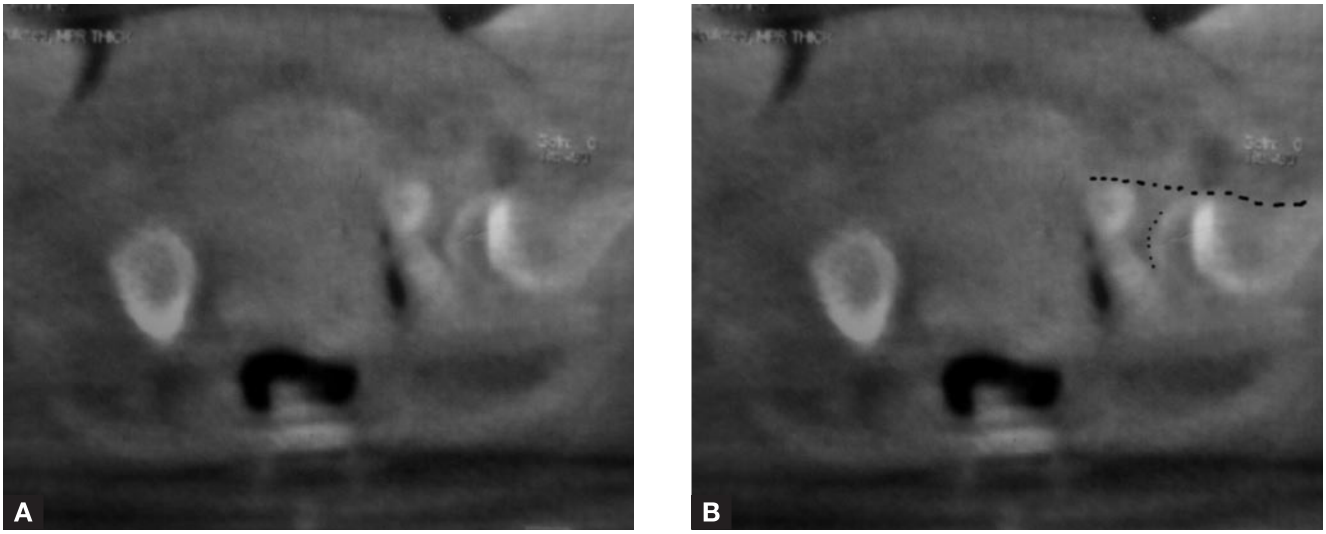

Figure 4. Intraoperative 3-D fluoroscopic image obtained after open reduction of left hip and application of spica cast shows **(A)** residual dye pooling and **(B)** intact anterior Shenton's line (dashed line) and outline of residual dye pooling (dotted line). Right hip reduction was also confirmed but is not pictured here.

sis), as described by Smith and colleagues in 1997.[7,8] Other imaging modalities have been described, including MRI and ultrasound. MRI has been advocated to evaluate DDH, particularly in children younger than 12 months, as cartilaginous and soft-tissue structures are directly visualized.[5,13] However, MRI availability and cost, and the prolonged sedation required, make this modality prohibitive for routine use at many centers. Likewise, ultrasound has been used to assess postreduction anatomical relationships; a window is cut in the posterolateral aspect of the spica cast so a transducer can be placed.[1] Like MRI, ultrasound has the benefit of not using ionizing radiation. With ultrasound, however, the "question arose as to whether the reduction could be lost by removal of the plaster plug, which was typically at the point where the cast was molded," wrote Harcke and Kumar,[14] who reported performing limited CT scans on all infants in rigid casts.

Use of 3-D C-arm fluoroscopy represents a significant advancement in the treatment of various orthopedic and neurosurgical ailments. Unlike the standard fluoroscope, the 3-D fluoroscope rotates automatically around an isocentric point on the patient. Specialized software processes the images and reconstructs them to provide axial, coronal, and sagittal views of the anatomy comparable to those obtained with a CT scanner. Wang and colleagues[15] reported 3-D fluoroscopy to be more sensitive (0.716 vs 0.608) but less specific (0.789 vs 0.937) than standard spiral CT in placing pedicle screws. Linsenmaier and colleagues[16] found no significant difference between 3-D fluoroscopy and spiral CT in accuracy of evaluation of placement of talar osteosynthesis screws. Similarly, Hott and colleagues,[17] reporting on 60 cranial and spinal procedures, wrote that 3-D fluoroscopy successfully confirmed postsurgical CT images in the first 20 cases and that, given the similarities in images, they decided to forgo postoperative CT scans in the other 40 cases.

We believe that 3-D fluoroscopic images are of sufficient quality to obviate the need for confirmatory postsurgical CT scans for patients treated for DDH. Intraoperative 3-D fluoroscopy can be used to differentiate a reduced hip from an unreduced hip with relative ease, and the process can be facilitated by drawing a modified anterior Shenton's line (Figure 5).

In the present case, our patient received ionizing radiation in (calculated) doses of 19.3 mGy (1930 mrad) from the conventional CT scanner and 0.86 mGy (86 mrad) from the intraoperative 3-D fluoroscope. Although the estimated risks of receiving ionizing radiation at these doses are negligible relative to the benefits garnered from CT images, dose reductions are desirable.[18] Boone and colleagues[19] described using size-dependent technique factors to limit radiation doses for pediatric patients. Had

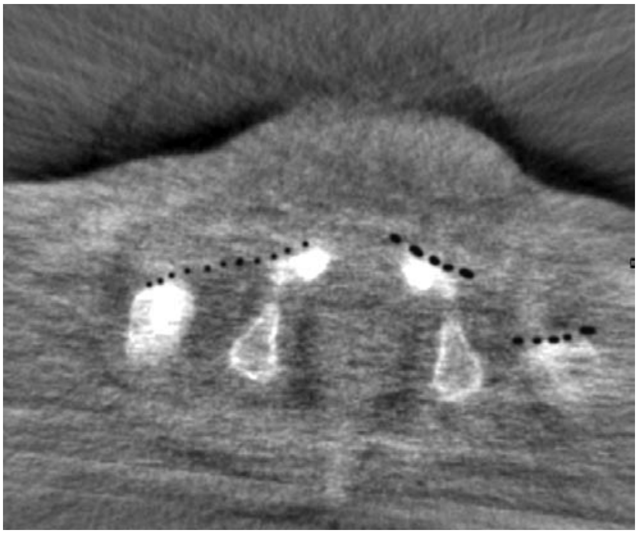

Figure 5. Intraoperative 3-D fluoroscopic image shows intact (right) and "broken" (left) anterior Shenton's line indicating reduced hip and unreduced hip, respectively.

such a limited CT scan been performed after our patient's first operation, the estimated dose would have been 2.31 mGy (231 mrad), approximately 3 times higher a dose than what 3-D fluoroscopy delivered, and with the much more significant disadvantage of removing the patient from the operating room.

Intraoperative 3-D fluoroscopy represents a significant advance in the treatment of DDH. It can be used to confirm reduction of hips in spica casts in the operating room, obviating the need for return trips there for repeat anesthesia for correction of inadequate reductions. In addition, the dose of ionizing radiation is small, equivalent to 20 seconds of fluoroscopy (or the dose received from ambient radiation over approximately 11 weeks), and less than the dose received from conventional CT. The 3-D fluoroscope is approximately twice the cost of a standard C-arm and approximately half that of a conventional CT machine; maintenance costs are similar to those for a standard 2-D C-arm and approximately 4 times less than those for a CT scanner. Ease of use and maneuverability of the 3-D fluoroscope make it readily adaptable to any operating room. Use of 3-D fluoroscopy for the treatment of DDH appears promising and has become routine at our institution.

Authors' Disclosure Statement and Acknowledgments

The authors report no actual or potential conflict of interest in relation to this article.

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This paper will be judged for the Resident Writer's Award.