Early Detection of Fractures With Low-Dose Digital X-Ray Images in a Pediatric Trauma Unit

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At the Red Cross Trauma Unit, we treat approximately 8,000 children with trauma annually. The major cause of severe, debilitating trauma and death is motor vehicle crashes (MVCs). Children injured in MVCs typically present with multiple injuries and diagnosis can be difficult, especially if a concomitant head injury is present. Fractures are easily missed in children, particular when clinical signs are absent or the patient is comatose, intubated, or sedated.

Diagnostic errors in trauma departments are primarily attributable to inadequate radiographic practice, with missed fractures comprising the largest proportion of such errors. Radiography is not routinely performed on patients presenting with trauma. Decisions on whether to obtain radiographs and what parts of the anatomy to radiograph are based on departmental protocol, clinicians’ experience, patient history, and physical examination. Guly found that failure to perform radiography accounted for 13.4% of 953 diagnostic errors in 934 accident and emergency patients during a period of 4 years. In an earlier study, 55% of 39 fractures with delayed recognition were not radiographed at the time of admission to a trauma center. Routine, full-body radiography for trauma patients would eliminate some diagnostic errors and delays, but the risks of ionizing radiation, the time taken to obtain radiographs, and the costs involved prohibit such a practice in conventional screen-film radiography.

The risks associated with ionizing radiation are higher in pediatric patients than in adults; bone marrow, the thyroid gland, the breast, and the lung have been reported to be especially sensitive to radiation. Infante-Rivard et al. found increased risk of leukemia with increased number of X-ray examinations and expressed concern that diagnostic radiation doses in children are not adequately controlled. A significant breast cancer mortality risk has been shown in scoliosis patients who had multiple diagnostic X-rays when they were young. Shu et al. reported increased risk of leukemia and childhood cancer with increased number of X-ray examinations. The evidence of increased cancer risk with increased radiation exposure in children highlights the importance of limiting the frequency and dose of radiographic examinations while maximizing the detection of injuries in the pediatric trauma setting.

Computed radiography (CR) is replacing screen-film radiography. Dalla Palma et al. have shown that the total cost of CR is lower (by 20%) than that of conventional radiography when using 8 × 10 inch film as the output device for both the analog and the digital modalities. CR has the additional advantage that examinations are repeated less frequently because of over- or underexposure, but the disadvantage that patients often receive higher doses of radiation per examination. Digital radiography (DR) has been shown to have equivalent image quality to CR, with reduced radiation dose, although Willis and Slovis have reported that overexposure is common in both CR and DR. CR is currently more popular than DR because of high costs, lack of portability, and fragility of detector hardware in the latter. Reiner et al. have reported that the cross-over point at which DR costs become justifiable in replacing CR, is at CR capacity utilization rates close to 80%. In this small study, in a trial comparing CR and full body DR in a pediatric trauma unit, we report three cases in which full-body low-dose digital radiographs obtained revealed fractures that would otherwise initially have been missed using the standard CR protocol.

METHODS

The Trauma Unit at the Red Cross War Memorial Children’s Hospital houses a FujiFilm Computed Radiography FCR 5000 system (Fuji Photo Film Co., Ltd, Tokyo, Japan). In addition, a StatScan (Lodox Systems, [Pty] Ltd., Sandton, South Africa) low-dose linear slit scanning digital X-ray system was installed in 2004. Statscan is used primarily for...
trauma imaging and approved by the Food and Drug Administration in the United States. It produces high-quality digital X-ray images with low radiation exposure, approximately 2% to 72% of the standard conventional dose in adult trauma applications,\textsuperscript{11,12} and is capable of taking adult full-body X-ray images in 13 seconds. The X-ray source and detector banks are mounted on a C-arm that can be rotated around the patient trolley, enabling anteroposterior (AP) as well as lateral X-ray images to be taken, as well as images at any angle between 0 degrees and 90 degrees, without requiring the patient to be moved.\textsuperscript{13}

The pediatric settings for an AP full-body radiograph on Statscan are 90 kV at 160 mA. This technique setting is used for children weighing between 10 and 30 kg. The scan time is 10 seconds or less depending on the size of the child. Thus, the system has the potential to shorten emergency department length of stay for patients who require radiography.\textsuperscript{14} Higher kilovolt and milliampere settings are required in comparison to CR because of the thinly collimated X-ray beam (0.4 mm wide). However, Statscan delivers a lower dose because of the reduction in scatter. Don\textsuperscript{8} reported entrance skin exposure ranging from 0.20 mGy to 0.77 mGy on standard radiography of 5-year-old children. We have measured entrance skin exposure of 105 µGy on the Statscan pediatric full-body setting, and the following on our CR system at settings for a 3-year-old child: 819 µGy for skull, 71 µGy for chest, 192 µGy for abdomen, and 182 µGy for pelvis.

It is standard in our Trauma Unit to perform a CR “trauma series” protocol in patients presenting with multiple injuries, including a lateral cervical spine and an AP chest and pelvis X-ray. Additionally, radiographs of the long bones are obtained on indication (after clinical examination). Although CR is the standard method of obtaining radiographs in the Trauma Unit, a multiple-injury trial was started in January 2005, in which every child presenting after involvement in a MVC or demonstrating multiple injuries of any kind was scanned using the standard multiple-injury protocol on CR, as well as using Statscan to screen for missed pathological findings. The standard multiple-injury protocol for Statscan is an AP full-body scan and a lateral cervical spine scan.

RESULTS

We provide a short description of three patients that were examined both with CR and with Statscan, whose fractures would have been missed had only the CR protocol been used. A total of 20 children had been scanned in the multiple-injury trial at the time of writing this report.

Patient 1: Missed Distal Radius Fracture

A 7-year-old boy arrived in our Trauma Unit after being involved in a MVC as a pedestrian. At examination, he had a decreased level of consciousness, with a Glasgow Coma Scale score of 14/15. He suffered multiple lacerations and abrasions on the face and abdomen. He had difficulty speaking because of excessive swelling of the face and tongue; a mandible fracture was suspected. He was also noted to have monoparesis of the left arm. His blood pressure was normal and his ventilation was regular and undistressed.

Mobile CR images were taken at bedside of areas including the face, cervical spine, chest, and pelvis. These images revealed a symphyseal fracture of the mandible. Computed tomography (CT) of the head was also performed revealing a left parietal soft tissue swelling without intracranial pathological findings, whereas a CT of the abdomen revealed a contusion of the left lower lobe of the liver. The patient was prepared for theater, the lacerations debrided, and a deep tongue laceration was sutured.

After the initial critical period DR was ordered (according to our protocol). This scan revealed a right distal radius fracture that had not previously been diagnosed (Fig. 1). CR images were then ordered to confirm the fracture. The fracture was treated with a plaster cast. Physiotherapy was initi-
The child improved gradually, and the fracture healed well.

**Patient 2: Missed Humerus Fracture**

A 5-year-old girl was treated in our Trauma Unit after being involved in a MVC as a pedestrian. Her blood pressure and pulse rate were normal but her level of consciousness was slightly impaired, with a Glasgow Coma Scale score of 14/15. At clinical examination, there were signs of a compound fracture of the left lower leg as well as an obvious fracture of the left femur.

The left leg showed no clinical features of neurovascular compromise. CR images of the skull, cervical spine, chest, pelvis, left femur, and left lower leg were obtained. These revealed fractures of the left lower leg and femur. DR was ordered, according to our protocol. This image revealed a buckling of the proximal humerus (Fig. 2 [full-body image] and Fig. 3 [close-up of the left humerus]). There were no evident clinical signs of this particular fracture and no CR images had been ordered.

The patient was prepared for theater and an external fixator was fashioned on the lower leg; a sling was used to immobilize the fracture of the humerus. The child recovered fast and all fractures healed without complication.

**Patient 3: Missed Tibial Fracture**

An 8-year-old boy was admitted after a MVC (pedestrian). He had a normal level of consciousness and was hemodynamically normal. He complained about severe pain in the right leg. CR images were obtained of the right femur, right lower leg, and pelvis, but no fracture was diagnosed. In accordance with our protocol, DR was ordered. This revealed a subtle right tibial plateau fracture (Fig. 4). CR of the knee confirmed a tibial plateau fracture, indicative of an anterior cruciate ligament tear. The patient was treated with a plaster cast and the fracture recovered well.
DISCUSSION

Trauma is the leading cause of morbidity, mortality, and disability in childhood. Efficient, early detection of fractures will contribute to the containment of morbidity and mortality as a result of trauma. Radiographic examination of trauma patients has traditionally been limited to anatomic areas indicated by clinical examination and experience to be at risk of injury. Full-body scans are possible on CR if the child is smaller than the largest X-ray plate, but it is likely that one technique (kilovolt and milliapere) would not be acceptable for all anatomic parts. For example, thinner parts could be overexposed if the technique was set to penetrate the skull or abdomen. Capturing the entire body on good quality radiographs in CR and screen-film radiography would require multiple images. Although full-body radiographic coverage would facilitate the detection of fractures without associated clinical signs, the increased sensitivity of children to ionizing radiation and the increased scanning time required for multiple radiographs render full-body imaging in screen-film radiography and CR risky.

Although chest doses are slightly higher for Statscan than for CR, Statscan significantly reduces exposure to ionizing radiation when the skull, abdomen, and pelvis are examined. Statscan was found to be of great assistance in diagnosing otherwise missed fractures in the present study. It has the potential to satisfy the requirement of adequate radiographic coverage at minimal dose in pediatric trauma.

CONCLUSION

Full-body DR can be of significant value in the early detection of long-bone fractures, particularly in the multiply injured patient. Statscan is ideal for children because of the ability to assess life-threatening injuries immediately and because of its reduced X-ray dose.

REFERENCES