Seminars in ROENTGENOLOGY

Imaging of Acetabular Fractures: A Phantom Study Comparing Radiation Dose by Radiography and Computed Tomography

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Introduction

Patients who suffer pelvis fractures due to high-mechanism trauma often receive multiple imaging studies during the course of their treatment, exposing them to high radiation doses.[1-3] For the initial work up of a high-mechanism trauma patient, computed tomography (CT) of the abdomen and pelvis is frequently obtained to identify the severity and scope of a patient's injuries.[4] The Judet-Letournel classification is still widely used for the classification of acetabular fractures. Although originally developed for radiography, this classification works well for CT.[5-8] The scheme divides acetabular injuries into multiple categories and aids the orthopedic surgeon in determining surgical approach.[9] The Judet system requires 3 radiographs: an antero-posterior (AP) view, and right and left obturator oblique views (Fig. 1). Inlet and outlet views of the pelvis are also obtained to aid the surgeon in determining the degree of reduction required (Fig. 1). These projections can be painful for a patient with acetabular trauma who must be rolled from side-to-side during the required positioning needed to obtain these views. 3D rendered reconstructions of CT imaging can simulate the standard Judet 5 views obtained using radiography. Studies have demonstrated equivalent or superior performance of 3D and virtual radiographs as compared to conventional radiography.[6,10-12] CT examinations are also arguably more comfortable for the patient, who can lay still in a supine position rather than being repositioned multiple times for radiographic views of the pelvis and can now be performed with lower radiation dose techniques.

Some clinicians may be reluctant to order CT due to anxiety from presumed added radiation dose over radiography; this anxiety is amplified given the common need for multiple radiographic and CT examinations of the pelvis during the course of treatment.[13,14] With the introduction of recent low dose CT techniques along with other potential benefits to the patient, this clinical dose paradigm merits further investigation.[15,16] The purpose of this study was to perform a comparative analysis of the radiation dose to an average sized adult between a 5-view pelvis radiograph series and a standard CT pelvis protocol.

Materials and Methods

Throughout the study, an anthropomorphic adult male phantom (CIRS ATOM Model 701; Norfolk, VA) was used to mimic patient attenuation and anatomy. The comparison of radiation dose was broken into 3 stages: (1) determination of radiation dose distribution resulting from a 5-view radiograph series; (2) measurement of multiple point doses resulting from a 5-view radiograph series; and (3) measurement of identical point doses resulting from a CT pelvis.

Because of the complex patient and x-ray tube positioning used throughout a 5-view pelvis radiograph series, we first determined where the cumulative x-ray beam was physically entering the phantom. To do so, the phantom was wrapped with radiochromic self-developing dosimetry film (Ashland, Inc. Gafchromic XR-RV3; Covington, KY) and multiple replicates (approximately 15) of a 5-view pelvis series were performed consecutively by an experienced technologist until the film was darkened adequately to visually assess the areas of highest dose. All radiograph acquisitions were performed with the phantom on a backboard in the same radiographic room (Philips Healthcare, Bucky TH; Cleveland, OH). The image receptor in all cases was a computed radiography (CR) imaging plate (Fujifilm Medical Systems, XG 5000 plate reader with ST-V1 imaging plate; Tokyo, Japan). The system automatic exposure control (AEC) was calibrated such that an exposure of 1 mR to the imaging plate resulted in a sensitivity number

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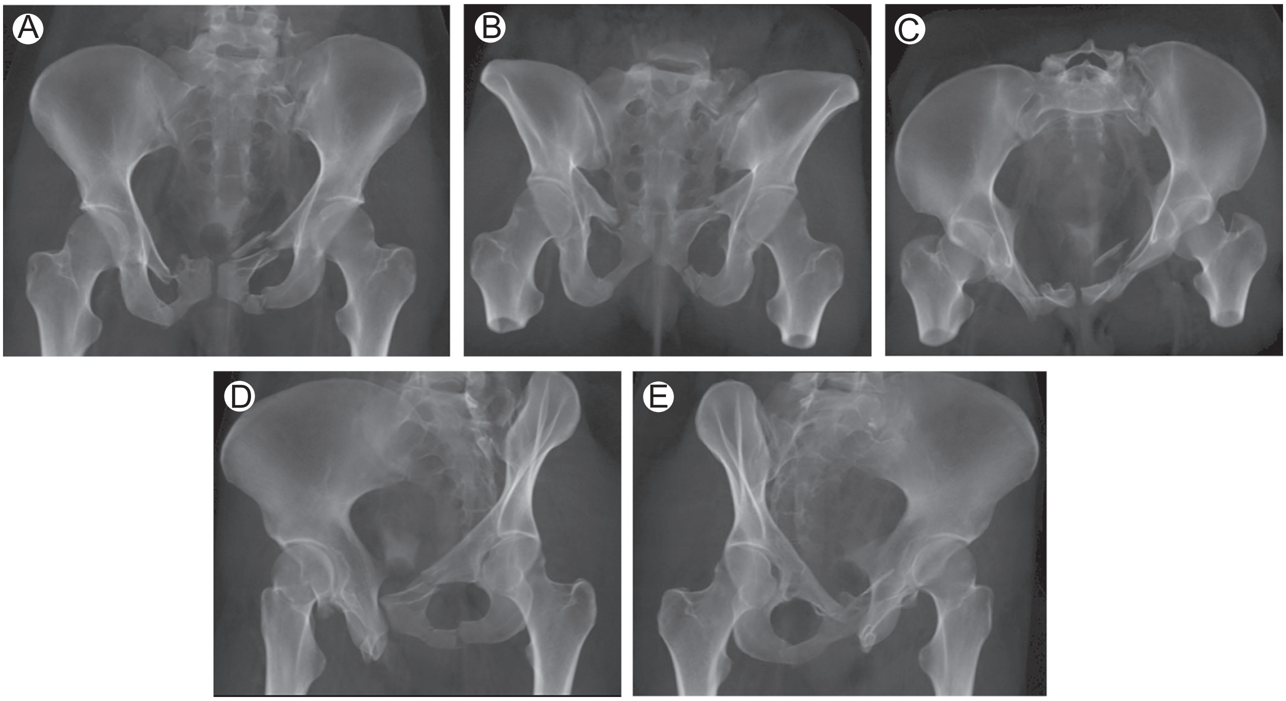


Figure 1 Reconstructed "ghost" images of the pelvis from CT data showing the 5 views in the pelvis series (A) AP, (B) outlet, (C) inlet, (D) Judet right posterior oblique, and (E) Judet left posterior oblique.

of 200, using manufacturer recommended methods. Clinical acquisition parameters were used throughout (bucky table, 80 kV, CR300 AEC sensitivity setting, and center AEC cell active). Figure 2 shows positioning of the phantom on the table along with a visual of the film darkening that resulted from repeated radiation exposures. This initial study identified the "hot regions" of the overlapping 5-view radiograph series, to help identify appropriate locations for subsequent point dose measurements.

Following the preliminary study, we placed 7 optically stimulated luminescence dosimeters (OSLD) (Landauer nanoDot OSLD; Glenwood, IL) around and within an axial slab of the "hot region" of the phantom at the following locations: anterior, posterior, right lateral, left lateral, right anterolateral, left anterolateral, and central or deep. Figure 3 shows the surface and interior locations of the 7 OSLDs, which included 2 different axial locations on the phantom. A total of 2 serially-acquired 5-view radiograph series were performed by 2 senior radiology technologists. OSLD sets were interchanged between the 2 series. Table 1 summarizes the acquisition techniques—including the AEC-selected mAs—for each acquired projection.

For the CT scan (Somatom Definition AS+; Siemens Medical, Germany), OSLDs were positioned at identical locations and 2 independent scans were performed by a CT technologist using our institutional standard bony pelvis protocol: PA and lateral topograms were performed so that a scan range from just above the iliac crests to just below the ischial tuberosities could be defined. As in the radiograph series, the phantom was positioned on the same backboard with the same overlying straps. The following parameters were used: automated tube current modulation (CareDose 4D), quality reference tube current of 170 mAs, attenuation based automated voltage selection (CarekV, position 3 with reference 120 kV), detector configuration 128 × 0.6 mm (nominal beam width 64 × 0.6 mm or 38.4 mm), pitch of 0.8, and tube rotation time of 0.5 seconds. The dose summary page from the CT scans is shown in Figure 4.

The results of the OSLD measurements were summarized in a readout report. Since the point dosimeters were positioned in the same physical location for the radiograph series and the CT scan, relative comparisons were made with respect to surface and central axis dose deposition for each imaging approach.

Effective dose (ED) was also calculated for both imaging methods. For the radiograph series, ED was estimated based on measured entrance skin dose (ESD) using a Monte-Carlo based simulation software (XDose v2.1 Clinical Data Interchange Standards Consortium 2009, using NRPB-SR262) that references a mathematical anthropomorphic hermaphroditic adult phantom. The simulation was performed assuming a pelvis AP projection, 80 kVp, 3.1 mm Al filtration, and measured OSLD anterior ESD. ED for the CT scan was estimated using 2 methods: (1) application of k-factors to the scan dose-length product (DLP); and (2) a Monte-Carlo based simulation software (CTExpo v1.7). The simulation software required an input of scanner model and technique parameters used during the scan. Organ dose estimates were generated using the Monte-Carlo based simulation methods for both the radiographic series and the CT scan.

Results

Table 2 summarizes the individual replicate and mean OSLD measurements resulting from the radiograph series and from

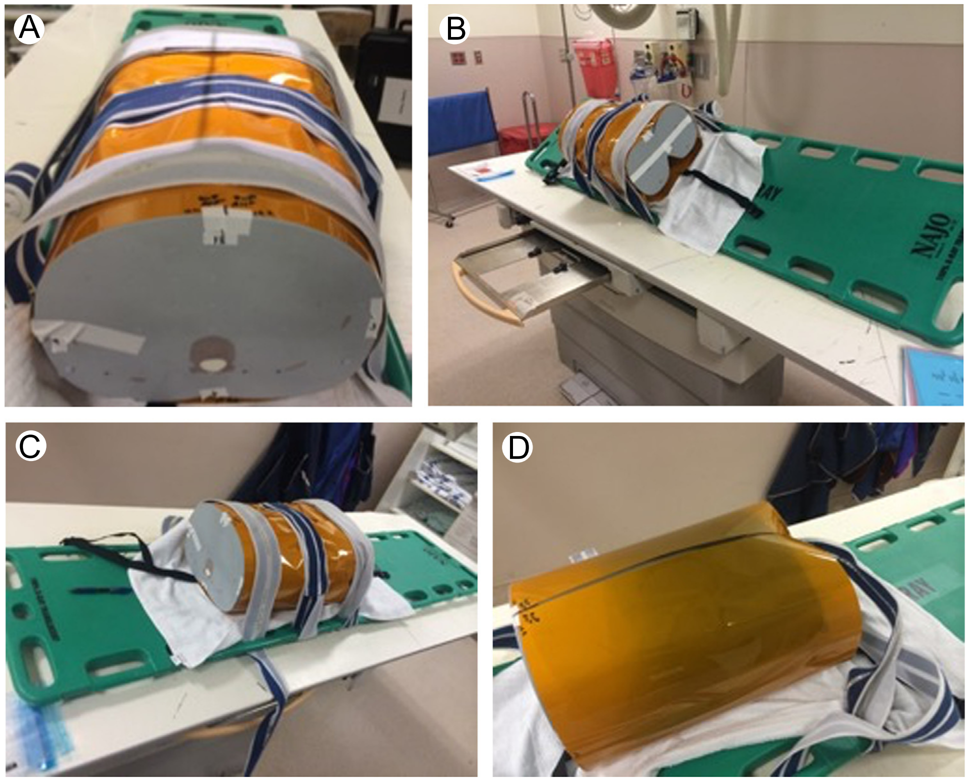


Figure 2 Experimental setup to assess the distribution of radiation dose from a 5-view pelvis radiograph series showing: (A) anthropomorphic phantom wrapped in radiochromic film; (B) phantom position for Judet view; (C) phantom position for AP and inlet or outlet views; and (D) darkened radiochromic film showing the distribution of radiation dose at skin entry for the cumulative examination. (Color version of figure is available online.)

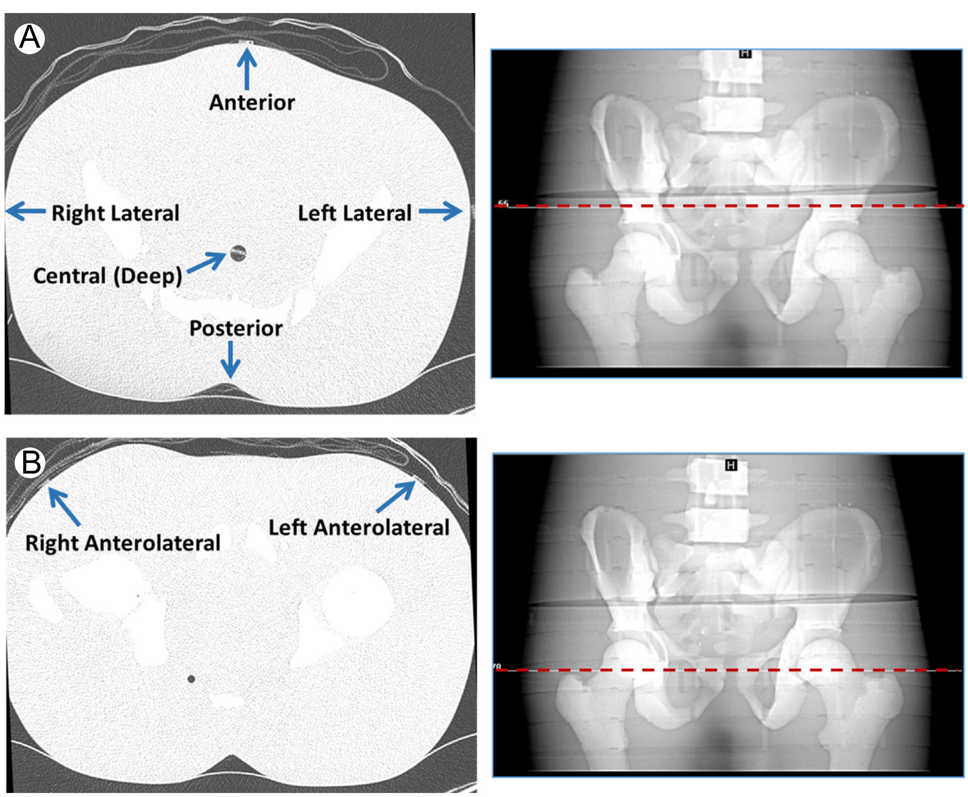


Figure 3 CT images obtained during the experiment show OSLD positioning on and within the phantom. Two axial slabs (A) and (B) were used through the pelvis with OSLDs in the following positions: anterior, right lateral, central (deep), posterior, left lateral, right anterolateral, and left anterolateral.

Table 1 Summary of Acquisition Techniques for 2 Replicates of 5-View Radiographic Pelvis Series. All Acquisitions Performed Under Automatic Exposure Control

Projection	kV	AEC Sensitivity	AEC Active Cell	Replicate 1 mAs	Replicate 2 mAs
Anterior-posterior	80	CR300	Center	52	47
Inlet	80	CR300	Center	99	93
Outlet	80	CR300	Center	125	109
Judet left down	80	CR300	Center	88	79
Judet right down	80	CR300	Center	110	105

the CT examination. As expected, the distribution of radiation dose around the phantom differed between radiography and CT. The radiograph series exhibited regions of concentrated dose around the periphery of the phantom, with mean point doses ranging from 52 mGy on the anterior surface down to 0.7 mGy on the posterior surface; the CT examination exhibited a much more uniform dose distribution around the phantom with mean point dose measurements ranging between 7 and 11 mGy. Deep or central dose measurements were comparable between the 2 imaging modalities with measured dose of approximately 4 mGy for each. Of particular note, the 5-view radiographs had a higher maximum ESD of 52 mGy at the anterior surface as compared to 11 mGy for the CT examination at the left antero-lateral position.

Using the aforementioned simulation methods, the ED of the radiograph series was estimated to be 8.6 mSv. For CT, the 2 presented calculation methods had an estimated ED of 2.3 mSv (AAPM TG96) and 4 mSv (CTExpo), respectively. This indicates that there is a dose savings in excess of 50% when using our institutional pelvis CT scan when compared to the 5-view pelvis radiograph series.

Table 3 presents organ doses from the Monte-Carlo based simulation methods. The comparison shows that organ doses for the selected anatomies of interest were lower for CT than the radiograph series in all cases. These differences were more apparent for superficial organs located at or near the radiographic beam entry, such as the testes and the urinary bladder. The result supports the higher radiographic entrance dose observed with the physical OSL dosimeter as compared to the deep organs.

Discussion

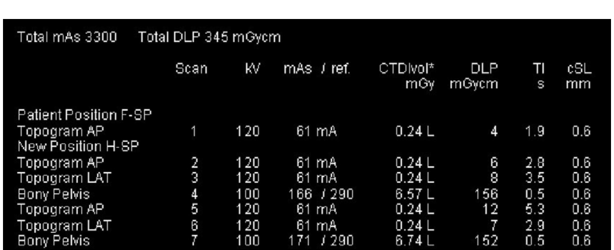
Our study demonstrates that the ED from a pelvis protocol CT scan can be lower than the ED of a 5-view pelvis radiograph series. Given this information, in addition to CT's greater sensitivity for fractures, superior evaluation of the soft tissues, better patient tolerance, and studies showing equivalent or superior performance of 3D virtual radiographs over conventional radiography,[17] we recommend CT with 3D reconstructions rather than 5-view radiography for the evaluation of acetabular and other pelvis fractures.

Although some may find this recommendation counter-intuitive, there are a number of potential reasons for the comparatively higher exposure with radiography. Compared to many other parts of the body, the pelvis is dense, comprised principally of large bony structures and dense soft tissues. Moreover, the steep obliquity of the inlet, outlet, and bilateral oblique projections results in a long x-ray path through the patient, requiring higher mAs when AEC is used to maintain detector exposure.

There are several limitations to this study. The comparison of 2 different imaging modalities with 2 different approaches, systems, and protocols is not trivial. ED is one of the primary comparators that we used to differentiate the 2 imaging approaches. Calculations of ED are not suitable for an individual patient or scan and are instead based upon standard patient simulated data.

The methods used to calculate ED have inherent assumptions that introduce increased uncertainty in the estimates. For the radiograph series, the simulation software offered a collection of single projection setups that do not fully mimic the more complex geometry used over the course of the 5-view acquisition. The simulated AP pelvis view best encapsulated the irradiated area of the anthropomorphic phantom that was used, but surely simplifies the irradiated volume measured in the phantom. The inputs to the radiographic simulation are also highly dependent on the positioning of the individual OSLDs, and susceptible to variation in positioning of the patient and x-ray tube by the technologist. This variability is also made evident in the different AEC-selected mAs values presented in Table 2. With the limited number of replicates that were possible in this study due to limited dosimeters, a full characterization of the radiographic technique variability could not be fully explored.

For both the radiographic and the CT simulation, there is discord between the mathematical model and underlying Monte-Carlo methods that are used by the simulation software and the physical anthropomorphic phantom that was used in this experiment. Even within the Monte-Carlo based simulations themselves, there is a degree of conflict since the



Total mAs 3300 Total DLP 345 mGycm

	Scan	kV	mAs / ref.	CTDIvol* mGy	DLP mGycm	TI s	cSL mm
Patient Position F-SP							
Topogram AP	1	120	61 mA	0.24 L	4	1.9	0.6
New Position H-SP							
Topogram AP	2	120	61 mA	0.24 L	6	2.8	0.6
Topogram LAT	3	120	61 mA	0.24 L	8	3.5	0.6
Bony Pelvis	4	100	166 / 290	6.57 L	156	0.5	0.6
Topogram AP	5	120	61 mA	0.24 L	12	5.3	0.6
Topogram LAT	6	120	61 mA	0.24 L	7	2.9	0.6
Bony Pelvis	7	100	171 / 290	6.74 L	152	0.5	0.6

Figure 4 Dose summary page for the CT scans.

Table 2 Summary of Phantom Point Dose Measurements From 2 Replicates Each of Radiographic Series and CT Acquisition

Dosimeter Position	Radiography Point Dose (mGy)			Computed Tomography Point Dose (mGy)		
	Replicate 1	Replicate 2	Mean	Replicate 1	Replicate 2	Mean
Anterior	53.92	49.24	51.58	7.89	10.78	9.34
Left anterior-lateral	49.75	50.14	49.95	10.25	11.29	10.77
Left lateral	23.07	19.96	21.52	9.29	11.31	10.30
Posterior	0.70	0.73	0.72	6.93	6.49	6.71
Right lateral	10.74	11.02	10.88	8.66	8.14	8.40
Right anterior-lateral	40.09	43.20	41.65	9.51	10.38	9.95
Central (deep)	4.23	4.00	4.12	4.23	4.50	4.37

underlying sex assignment (hermaphroditic, male, and female) that had to be selected. On the other hand, the approach to calculation and measurement presented in this study are broadly used in practice and in the literature, though the differences and limitations need to be clearly acknowledged when performing a comparison study.

Additionally, the comparison is specific to the individual systems and protocols that were defined as routine. On its surface, the comparison was arguably between an older CR technology and a relatively recent CT technology. Newer radiographic equipment may offer the opportunity to acquire images at a lower technique due to improvements in detector efficiency or via newer image processing methods. We believe that we cannot reduce our radiographic dose further without significant degradation in contrast to noise ratio, given the difficulty of interpreting underexposed images of the pelvis, particularly with larger patients.

We assumed a 5-view pelvis protocol in this study, when 3 views (AP, inlet, and outlet) may be sufficient in some clinical settings. One could postulate that the radiography dose for 3 views instead of 5 views would certainly decrease the ED differences presented above. On the other hand, it is plausible that adequate image quality is achievable at even lower CT dose levels than were used in this study, especially with the increased availability and use of iterative reconstruction methods.

Table 3 Estimated Organ Doses for the Pelvic Region

Organ	Radiography mGy	Computed Tomography mGy
Testicles	38.3	9.2
Ovaries	11.4	8.1*
Uterus	15.2	9.7*
Urinary bladder	25.7	8.6
Small intestine	13.5	7.2
ULI	15.6	7.6†
LLI	12.9	

ULI, upper large intestine; LLI, lower large intestine.

*Organ dose estimation for female reproductive organs from CT required simulation as female mathematical model. Other presented values are from male mathematical model to better align with the anthropomorphic phantom measurements.

†CT simulation presents organ dose over the entire large intestine.

Finally, the dose distribution differs significantly between radiography and CT. Although we did use *x*, *y*, and *z* automated tube current modulation on the CT scanner, which would result in some variation in the exposure in all planes, overall there was greater uniformity in radiation exposure to the pelvis with CT compared to the 5 radiographic projections.

When a CT is performed for the initial assessment of trauma, opportunistic retrospective 3D reconstructions can be performed using the available CT data, obviating the need for radiography altogether.[18] However, it has been our experience that repeat imaging is often requested to assess for interval changes in alignment after transfer from another facility, or following closed manipulation or reduction before surgical intervention, especially if some time has elapsed from the initial polytrauma CT and other life-saving interventions have been performed. Replacing radiography with CT is valuable in these settings. Patient comfort and ease of acquisition are 2 of the main reasons to consider CT over radiography. Patients with pelvis trauma or those recently postoperative can have a significant amount of pain, and positioning for the Judet views can be extremely uncomfortable. Additionally, the Judet series can be technically challenging to obtain with variable image quality and often the need to repeat images if the obliquity is insufficient; these issues are nearly eliminated with the use of CT. Routine postoperative CT imaging of the pelvis has also been suggested by some given the potential to detect radiographically occult complications.[19]

Based on the findings above, we would recommend CT over radiography. However, there are additional clinical practicalities to consider. CT is a higher cost examination and one must consider the availability of the CT scanner. Using CMS Technical and Professional component reimbursement rates a 3-view pelvis radiograph series is $42.95 (CPT 72190, technical $31.24, professional $11.71). This is approximately 1/5 the cost of a CT scan with 3D reconstructions. The noncontrast CT pelvis is $164.61 (CPT 72912, technical $106, professional $58.61) and the 3D reconstruction is $78.95 (CPT 76377, technical $36.19, professional $42.76). However, we noted during our experiment that image acquisition time for CT was much faster than radiography even with the added time required for the reconstructions. Lastly, we were performing this study at a major trauma center where CT scanner availability is less of a concern.

Conclusion

The use of CT in place of 5-view radiography of the pelvis for the assessment of acetabular fractures can be performed at a lower radiation dose. Additionally, using CT instead of radiography offers the potential to reduce pain associated with positioning an acutely injured patient, and can lead to greater soft tissue detail with more consistent results.

IRB Statement

No IRB review was required; this was a phantom study. No human subjects were involved.

References

1. Prasarn ML, Martin E, Schreck M, et al: Analysis of radiation exposure to the orthopaedic trauma patient during their inpatient hospitalization. Injury 43(6):757-761, 2012
2. Hui CM, MacGregor JH, Tien HC, et al: Radiation dose from initial trauma assessment and resuscitation: Review of the literature. Can J Surg 52 (2):147-152, 2009
3. Rohner DJ, Bennett S, Samaratunga C, et al: Cumulative total effective whole-body radiation dose in critically ill patients. Chest 144 (5):1481-1486, 2013
4. Caputo ND, Stahmer C, Lim G, et al: Whole-body computer tomographic scanning leads to better survival as opposed to selective scanning in trauma patients: A systematic review and meta-analysis. J Trauma Acute Care Surg 77(4):534-539, 2014
5. O'Toole RV, Cox G, Shanmuganathan K, et al: Evaluation of computed tomography for determining the diagnosis of acetabular fractures. J Orthop Trauma 24(5):284-290, 2010
6. Bishop JA, Rao AJ, Pouliot MA, et al: Conventional versus virtual radiographs of the injured pelvis and acetabulum. Skeletal Radiol 44 (9):1303-1308, 2015
7. Martinez CR, Di Pasquale TG, Helfet DL, et al: Evaluation of acetabular fractures with two- and three-dimensional CT. Radiographics 12 (2):227-242, 1992
8. Scheinfeld MH, Dym AA, Spektor M, et al: Acetabular fractures: What radiologists should know and how 3D CT can aid classification. Radiographics 35(2):555-577, 2015
9. Judet R, Judet J, Letournel E: Fractures of the acetabulum: Classification and surgical approaches for open reduction: Preliminary report. J Bone Joint Surg Am 46:1615-1646, 1964
10. Sinatra PM, Moed BR: CT-generated radiographs in obese patients with acetabular fractures: Can they be used in lieu of plain radiographs? Clin Orthop Relat Res 472(11):3362-3369, 2014
11. Abdelfattah AA, Moed BR: CT-generated radiographs in patients with pelvic ring injury: Can they be used in lieu of plain radiographs? J Orthop Surg Res 11(26):1-5, 2016
12. Pekmezci M, Kandemir U, Toogood P, et al: Are conventional inlet and outlet radiographs obsolete in the evaluation of pelvis fractures? J Trauma Acute Care Surg 74(6):1510-1515, 2013
13. Kim PK, Gracias VH, Maidment AD, et al: Cumulative radiation dose caused by radiologic studies in critically ill trauma patients. J Trauma 57 (3):510-514, 2004
14. Sharma OP, Oswanski MF, Sidhu R, et al: Analysis of radiation exposure in trauma patients at a level I trauma center. J Emerg Med 41(6):640-648, 2011
15. Kovacs WC, Yao J, Bluemke DA, et al: Opportunities to reduce CT radiation exposure, experience over 5 years at the NIH Clinical Center. Radiat Prot Dosimetry 175(4):482-492, 2017
16. Weir V, Zhang J: Clinical experience with radiation dose reduction of CT examinations using iterative reconstruction algorithms. Med Phys 43 (6):3368, 2016
17. Geijer M, El-Khoury GJ: Imaging of the acetabulum in the era of multidetector computer tomography. Emerg Radiol 14(5):271-287, 2007
18. Yun SJ, Jin W, Yoon SH, et al: Diagnostic performance of abdominal CT for diagnosis of pelvic fractures: Comparison with pelvic CT. Acta Radiol 57(10):1244-1250, 2016
19. Archdeacon MT, Dailey SK: Efficacy of routine postoperative CT scan after open reduction and internal fixation of the acetabulum. J Orthop Trauma 29(8):354-358, 2015