

ORIGINAL RESEARCH

# Visualization of Experimental Bone Defects with Reduced-Radiation Dose Computed Tomography

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## ABSTRACT

**Introduction:** Orthopaedic efforts to date aiming to reduce radiation doses in computed tomography (CT) have been made solely for scoliosis imaging. In the present study, we examined whether a significant reduction of CT radiation dose affects the accuracy and reliability of visualizing experimental bone defects in a porcine model.

**Methods:** Six bicortical drill-hole defects of varying diameters were created in a random configuration in each of five porcine hindlimbs. Paired specimens were imaged by CT using a standard radiation dose, and doses sequentially reduced to 60%, 40%, 20%, and 10% of the standard dose. CT images were interpreted by three chief radiology residents blinded to the CT doses. The CT readings included the defect number, size, and location, and their interclass agreement was calculated.

**Results:** Bone defects were identified with 94.9%, 100%, and 77.0% accuracy. The average number of defects identified ranged from 6.2 to 6.4, with an interclass coefficient of 0.81. There was no association between CT dose and precision of identifying the defect number, size, and location.

**Discussion:** The study demonstrates the accuracy of reliably and precisely detecting bone defects as small as a 1.59-mm-diameter drill-hole using CT imaging with a radiation dose reduced to 10% of the standard dose.

**Keywords:** Computed tomography; Radiation dose reduction; Bone defects.

## INTRODUCTION

In musculoskeletal imaging, computed tomography (CT) visualizes structures in three

planes (axial, sagittal, and coronal), which can be reconstructed to depict a three-dimensional model of the anatomy [1]. Therefore, CT is more sensitive than plain radiography in the detection and delineation of fine bony anatomic details and, if present, lesions or other abnormalities [2]. Although the advantages of CT are substantial, they come with

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risks associated with a significantly increased dose of radiation compared with plain radiography. The radiation dose of single conventional CT imaging of the lumbar spine is greater than 200 chest X-rays [3]. A plain radiograph of the cervical spine is 0.04 mSv versus 3.24 mSv of its CT counterpart—an 81-fold increase [4]. The estimated effective dose of a lumbar CT examination is 5.6 mSv with an associated radiation-induced cancer risk of 1 in 3200 [5]. This cancer risk is dependent on subject age at exposure; the lifetime risk from a lumbar CT examination ranges from 20 per 10,000 scans for 3-year-olds to 3 in 10,000 for those 70 years of age [6]. Children are much more sensitive to the ill effects of CT radiation [2]. It has been established that pediatric CT examinations are justified when the benefits exceed the radiation risk [7]; however, the risk-benefit ratio can be optimized, in part, by reducing the radiation dose required to obtain the CT.

Several strategies have been proposed to reduce the CT-related radiation exposure in musculoskeletal imaging. Radiation reduction CT algorithms have been reported in orthopedic imaging, but the extent to which bone lesions can be adequately assessed with this technique has yet to be established. This is an important consideration because CT has proven very valuable in identifying the particular characteristics of bone defects, essential for establishing the differential diagnosis [8,9]. Furthermore, repeated CT examinations can be highly useful in determining if a defect is responding to treatment. However, as noted above, the radiation dose from standard CT scans is considerable and minimizing the radiation dose of each examination could help achieve a more favorable risk-benefit ratio.

The objective of this study was to determine if extremity CT radiation dose could

be reduced without affecting the qualitative and quantitative analyses of bone defects of variable size in a porcine model. The study hypothesis was that long bone defects of varying sizes and locations can be reliably detected and characterized using CT imaging with a radiation dose as low as 10% of that typically utilized.

## MATERIALS & METHODS

Five paired adult porcine hindlimb specimens were obtained fresh and maintained frozen at  $-4^{\circ}\text{C}$ . The specimens were thawed to room temperature and the femurs and tibias in both limbs of each pair were surgically exposed through straight mid-lateral incisions that extended from the proximal femur to the distal tibia. The surgical approach in all specimens consisted of a muscle-splitting dissection to expose the lateral femur and tibia cortex. Bicortical circular defects of varying diameters were created in the ipsilateral femur and tibia of each pair in a random longitudinal configuration, while the contralateral limb was left intact and served as a control. Bicortical defects of varying diameters were created by drill bits of the following diameters: 1.59 mm, 1.98 mm, 2.38 mm, 2.78 mm, 3.18 mm, and 3.57 mm (Figure 1). In addition to this longitudinal variation, the single bicortical defect in each horizontal plane was positioned randomly. A total of six defects were made throughout the femur and tibia in each experimental specimen. The soft tissues were closed with 0 Vicryl suture.

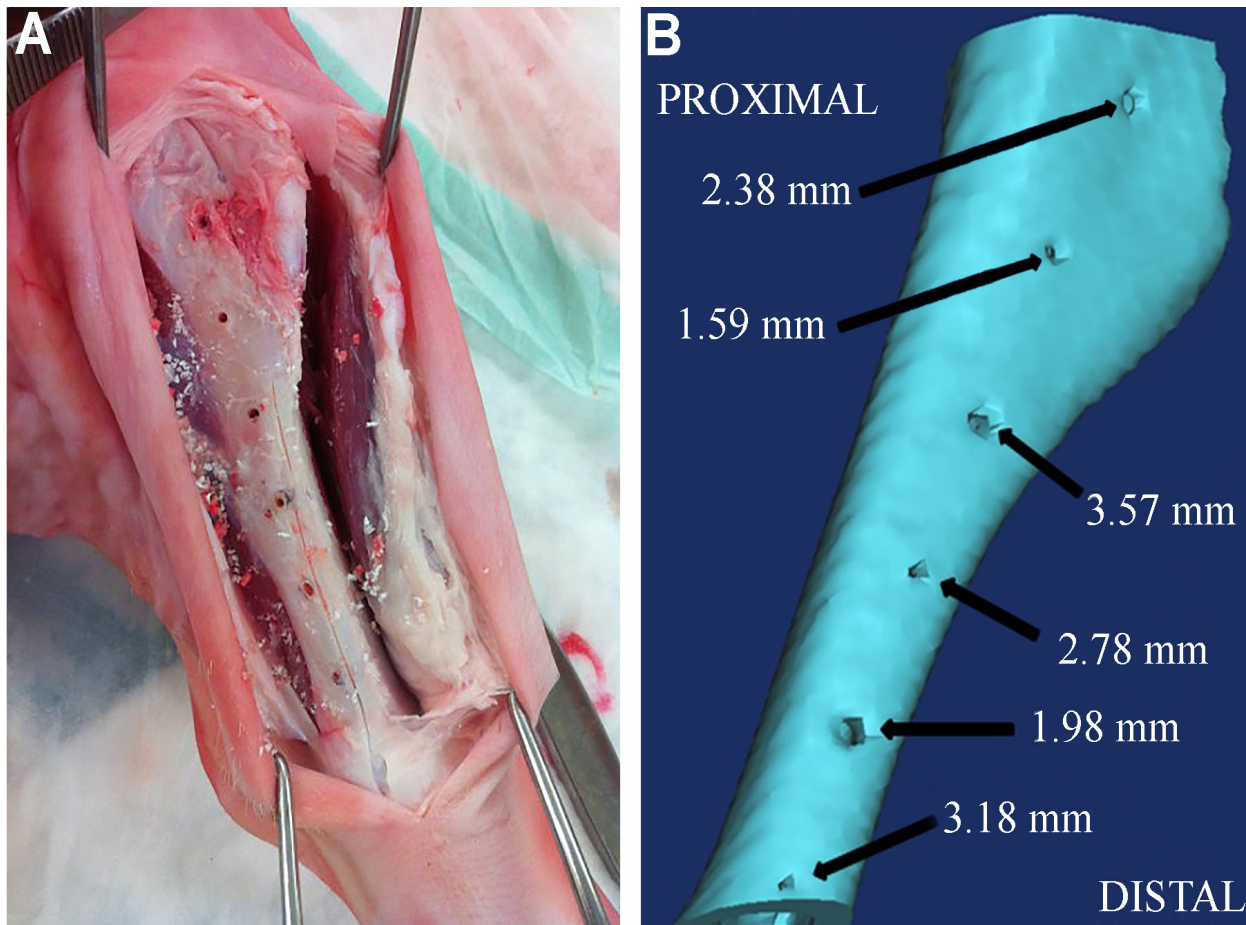
All porcine specimens were kept frozen until they were thawed for CT imaging. CT was performed with the hindlimbs of each pair (experimental and control) positioned adjacent to each other

to simulate the typical noise and scatter of the real-life setting.

CT imaging (Somatom Definition Flash 128-slice CT Scanner, Siemens Inc., Munich, Germany) was performed utilizing 1-mm slice thickness. The initial scanning was performed with the standard radiation dose of 120 kV for lower extremity scanning. Subsequent scans were performed at radiation doses of 3.6 mGy at 100 kV, 80 kV, and 70 kV. The amperage (mA) was manually adjusted to reduce the dose from 100% to 60%, 40%, 20%, and 10% of the standard dose (Figure 2). The coronal scans were then uploaded to a flash drive. The flash drive contained the proper protocol to read the scans.

Three radiology residents (PGY4)

blindly reviewed all scans in regard to the radiation doses, CT scanning protocols, and bone defect configurations for each scan. The scans were assessed with the ImageJ program (NIH; <http://imagej.nih.gov>). Detailed scan review instructions were communicated to the radiology residents both verbally and in writing. The reviewers were asked to indicate the coronal slice that permitted defect detection, and the total number of defects detected in each scan. The diameter of each defect was determined by the reviewers by using the measuring tools of the ImageJ program. Finally, the reviewers were asked to qualitatively assess the ease with which the defects were detectable to a tenth of a millimeter.

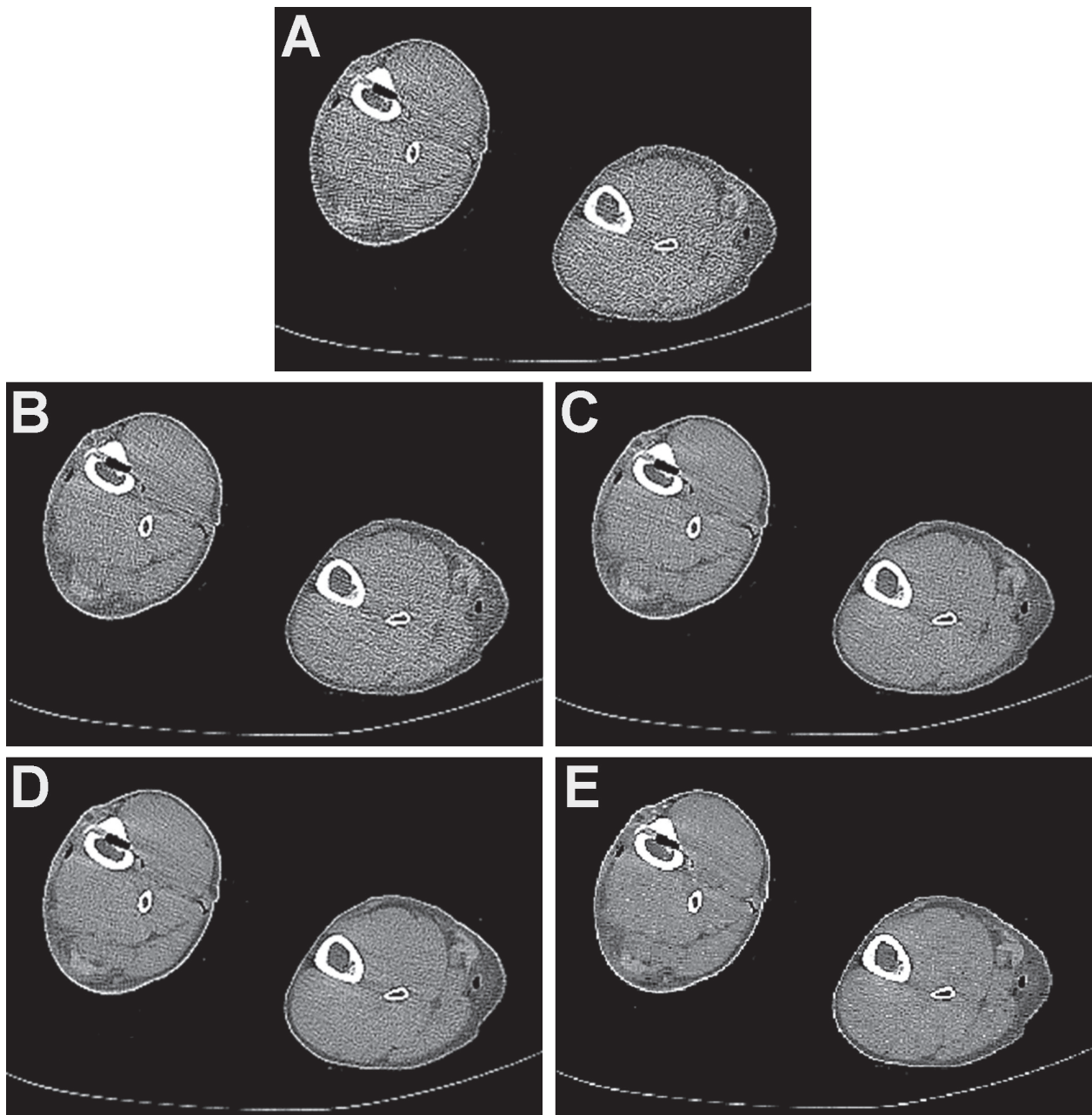


**Figure 1.** Photograph of cadaveric porcine tibia with six bicortical bone defects (A). A three-dimensional model of porcine tibia created with Mimics 14.01 computer software from CT images (B). The six different-size bone defects are labeled.



The abilities of each reviewer to identify the presence of a defect and determine the size of the defect, and the ease with which they were able to do so, were determined. The reliability of radiology defect assessments among the three reviewers was analyzed qualitatively and quantitatively. The interclass correlation coefficient (ICC)

for the ease of defect detection was estimated using a generalized linear mixed model with a logit link and binominal distribution. For the actual number of defects detected, the ICC was estimated from a general linear mixed model. The accuracy of defect size assessment was determined by calculating the difference between the observed



**Figure 2.** An example of CT imaging of paired, experimental (left) and intact (right) porcine hindlimb specimens. The experimental specimen has a 3.57-mm-diameter drill-hole defect. CT imaging was obtained at the standard radiation dose (100%) (A), and at doses reduced to 60% (B), 40% (C), 20% (D), and 10% (E) of the standard dose.

and the actual size of the defect. A linear mixed model was constructed to test the impact of dose on the precision adjusted for power (120 kV, 100 kV, 80 kV, and 70 kV), actual size of defects, and the location of defects. All tests were two-sided with alpha of 0.05 and were performed with the use of SAS 9.3 statistical software.

## RESULTS

Reviewers 1, 2, and 3 were able to detect 94.9%, 100%, and 77.0% of all defects (Figure 3), which are summation of all the doses. An ICC was 0.58 as estimated by generalized linear mixed model with a log rank and binominal distribution. The actual average numbers of defects identified by the three radiologists were between 6.2 and 6.4 per specimen with an ICC of 0.81 estimated by a linear mixed model. The numbers of correctly identified defects were 100, determined by comparing the correct site of defect from the reviewer's location of the defects.

Reviewers 1, 2, and 3 correctly identified 87.2%, 66.2%, and 85.1% of the defects (Figure 4).

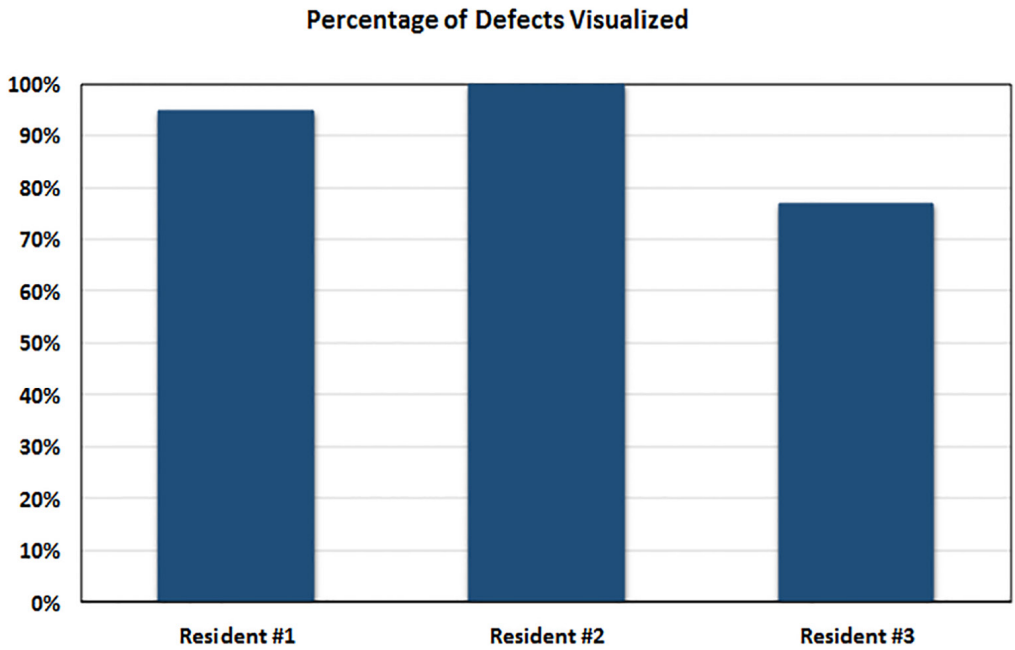
## DISCUSSION

Computed tomography is the preferred imaging modality for many musculoskeletal conditions [5]. Recently, however, the merits of CT have been challenged owing to the risks for adverse long-term effects, including carcinogenic effects, from the excessive radiation exposure associated with this imaging technique [9]. The acute effects include skin erythema, hair loss, and possibly desquamation of the skin, although this would almost never be seen after a CT examination

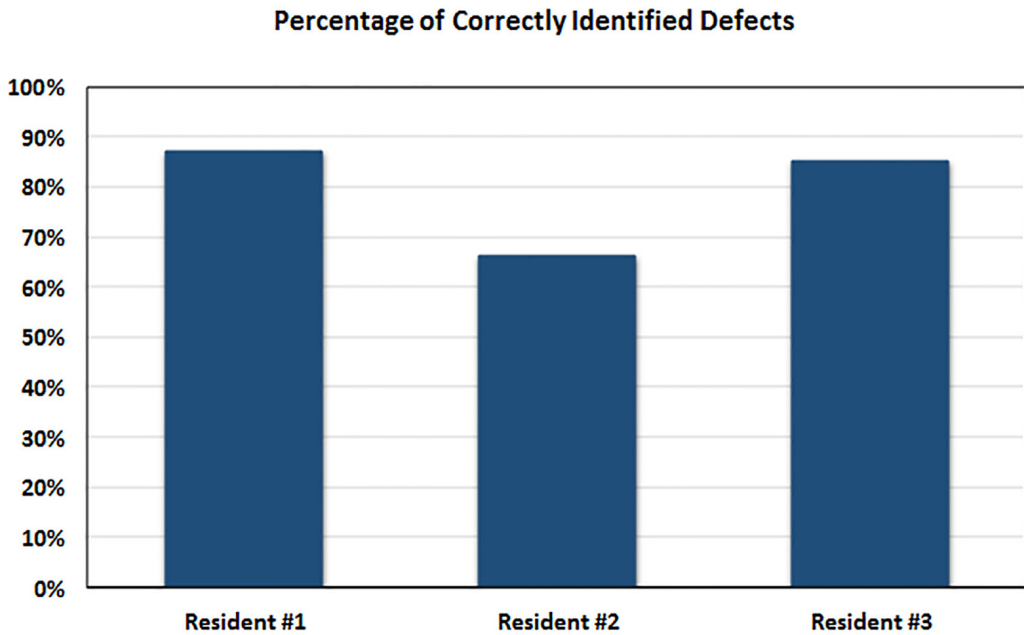
owing to radiation safety protocols. The effects of CT radiation are estimated from the effective dose and depend on the radiosensitivity of the organs; highly radiosensitive organs are the thyroid, stomach, bone marrow, lung, and breast [9]. CT of the pelvis has an effective dose of approximately 7.5 mSv, which with the accumulation of additional radiation from other studies can increase lifetime risk for cancer [9].

There have been several reported efforts to decrease CT radiation dose to decrease lifetime risks [9]. In the orthopaedic realm, work has been done to reduce the CT radiation required for the accurate evaluation of pedicle screw placement in younger patients following spinal surgery for scoliosis [10]. Low-dose CT protocols exist that demonstrate acceptable inter- and intraobserver reliability in spine instrumentation assessment [10]. However, efforts to decrease CT radiation in adolescent idiopathic scoliosis have not been expanded to other orthopedic applications. There has been some radiology interest in decreasing radiation exposure by employing low-dose radiation software, but these efforts have generally been limited to certain manufacturing companies [8]. To date, however, no studies have focused on extremities to determine if a reduced CT radiation dose can provide reliable quantitative and qualitative assessments of limb bone defects of varying size.

In the present study, a 90% reduction of the standard CT radiation dose did not significantly compromise our radiology reviewers' ability to detect defects of varying size in a porcine animal model. The negative precision of the reviewers was likely due to the ill-defined margins of the defects with lower radiation doses. However, as the radiation dose decreased, there



**Figure 3.** Reviewers (residents) 1, 2, and 3 were able to detect 94.9%, 100%, and 77.0% of all bone defects, which was a summation of all the CT doses.



**Figure 4.** Reviewers (residents) 1, 2, and 3 correctly identified 87.2%, 66.2%, and 85.1% of bone defects of various size.

was not a statistically significant difference in the precision of defect measurement ( $p=0.7327$ ). Although the ICC, a qualitative measure of the ease of defect identification, was 0.58, the actual values for the ease of

detection, more dependent on the radiologists' subjective assessments, were 77%, 94.9%, and 100% for reviewers 1, 2, and 3.

The limitations of this study include its relatively small sample size, and the por-

cine hind limb bone model, which may not reflect all of the imaging challenges associated with human subjects (eg, size, geometry, mineral density). The CT scans were reviewed by PGY4 radiology residents and defect detection and size determination may have differed with more experienced radiology observers. Finally, the study determined the minimal CT radiation dose required for a meaningful assessment by decreasing the radiation dose to as low as 10% of the standard dose.

## CONCLUSIONS

This study demonstrates that long bone defects of varying size and location could be accurately assessed quantitatively and qualitatively by using CT images generated with radiation reduced to 10% of the standard dose in a porcine hindlimb model. The findings warrant clinical validation.

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