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Radiation dose reduction in pediatric computed-tomography-guided musculoskeletal procedures

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Abstract

Background—Computed-tomography-guided interventions are attractive for tissue sampling of pediatric bone lesions; however, it comes with exposure to ionizing radiation, inherent to CT and magnified by multiple passes during needle localization.

Objective—We evaluate a method of CT-guided bone biopsy that minimizes ionizing radiation exposure by lowering CT scanner tube current (mAs) and voltage (kVp) during each localization scan.

Materials and methods—We retrospectively reviewed all CT-guided bone biopsies (n=13) over a 1-year period in 12 children. Three blinded readers identified the needle tip on the reduced-dose CT images (mAs=50, kVp=80) during the final localization scan at biopsy and rated the image quality as high, moderate or low.

Results—The image quality of the reduced-dose scans during biopsy was rated as either high or moderate, with needle tip visualized in 12 out of 13 biopsies. Twelve of 13 biopsies also returned sufficient sample for a pathological diagnosis. The average savings in exposure using the dose reduction technique was 87%.

Conclusion—Our results suggest that a low mAs and kVp strategy for needle localization during CT-guided bone biopsy yields a large dose reduction and produces acceptable image quality without sacrificing yield for biopsy diagnosis.

Keywords

Radiation dose; CT-guided interventions; Musculoskeletal procedures; Image Gently; Children

Introduction

Image-guided interventions are a routine part of establishing the diagnosis of benign and malignant pediatric musculoskeletal lesions and help guide timely management [1, 2]. In comparison to open biopsy, image-guided interventions are minimally invasive and confer several advantages including low morbidity, low complication rate and cost savings [3]. Pediatric bone lesions often present a broad differential diagnosis and require direct tissue sampling. When CT is the best image-guided approach, the challenge is to balance image quality with dose reduction strategies to minimize exposure to ionizing radiation, a topic that

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Conflicts of interest None

has become paramount given the growing awareness among referring physicians and families [4, 5].

CT is often the modality of choice over radiation-free imaging (US and MRI) and reduced-radiation dose techniques (fluoroscopy) when accessing deep or purely osseous lesions without significant soft-tissue components [6–8]. This is well described and developed in the adult population, and a recent study has shown that accuracy of CT-guided biopsies in children ranges 80–90%, similar to that seen in the adult population [6, 9]. Factors identified to improve accuracy include providing on-site pathology, optimizing needle choice, and visualizing needle tip position within the lesion.

Optimized scanner tube current and voltage settings are vital to maximize accuracy while allowing for the lowest possible radiation. Despite studies in adults focused on minimizing radiation dose levels in CT-guided biopsies [9], we know of no previous studies that focus solely on the pediatric population for examining dose reduction strategies and how they affect musculoskeletal biopsy results. We demonstrate the feasibility of performing CT-guided biopsies of various bone lesions with acceptable image quality and diagnostic accuracy (biopsy yield) using the lowest possible scanner settings for tube current and voltage.

Materials and methods

With IRB approval, we retrospectively reviewed all CT-guided bone biopsies (n=13) performed at a single institution over a 1-year period in 12 children (mean age 11.9 years, range 2.8–18.0 years) using dose-reduction strategies.

CT imaging using the reduced-dose biopsy technique was performed on an MDCT scanner (Sensation 64; Siemens, Erlangen, Germany). First, dose-reduction strategies were considered during all aspects of the procedure including minimizing the number of passes and the imaging performed for initial target identification and trajectory planning for needle placement. For example, if prior imaging showed the lesion with some certainty then reduced-dose imaging was used upfront for trajectory planning and initial needle placement. If a first-pass diagnostic CT scan was required, then diagnostic settings were applied using dose adjustments for the child’s weight [10, 11]. For subsequent low-dose CT guidance the scanner tube current and voltage settings were lowered as much as possible, with most scans operating at the lowest settings allowed by the manufacturer (mAs=50, kVp=80), automatic exposure control off, collimation 0.6 mm, reconstructed slice thickness 1 mm, scan area in Z-axis=10 mm). The dose report was reviewed and recorded for each study, recording mAs, kVp and volume CT dose index ($CTDI_{vol}$). All bone biopsies were performed with a 14-gauge Ackermann biopsy needle set (Cook Medical, Bloomington, IN). The size of each lesion was calculated by taking the greatest cross-sectional area of the lesion in the x-y axis (axial plane) by using the caliper tool on the PACS workstation.

The impact of this dose reduction technique for CT biopsy was evaluated in several ways. Three blinded readers, who had no prior knowledge of the cases and who were not involved in the performance of the procedures (a pediatric radiologist, pediatric radiology fellow and radiology resident), retrospectively reviewed the last localization scan documenting needle placement in the lesion. This confirmation scan of needle localization was evaluated for (1) whether the biopsy needle and bone lesion could be visualized with the needle tip located in the lesion (Yes/No) and (2) image quality, which was rated as high, moderate or low. Images with high quality showed sufficient detail of the lesion to form an adequate differential diagnosis for the lesion. Images with moderate quality showed the lesion but without sufficient detail to form an adequate differential diagnosis. Images that were rated as either high or moderate in quality also had to show the tip of the needle in relationship to the lesion. Images with low quality were inadequate to demonstrate either the anatomical location of the lesion or the tip of the needle in relationship to the lesion.

For each study, the tube current, voltage, and $CTDI_{vol}$ for each scan/pass were obtained from the DICOM header and dose report provided by the scanner. We evaluated the impact of this dose-reduction technique using several calculations. For the purposes of this study we defined dose as the $CTDI_{vol}$ reported by the scanner. The total radiation exposure (TE) for the examination was calculated as the $CTDI_{vol}$ for the initial diagnostic scan + the sum of the scans performed at the reduced dose. The estimated potential total exposure from the procedure (eTE) if the dose-reduction technique was not employed was calculated as the $CTDI_{vol}$ of the initial diagnostic scan multiplied by the number of scans performed. The percentage of dose reduction in a single scan using the reduced-dose technique was calculated as 100 * (1 − $CTDI_{vol}$ of a single reduced-dose scan / $CTDI_{vol}$ of the diagnostic scan). The estimated percentage reduction in dose of the total biopsy procedure was calculated as 100 * (1 − TE/eTE).

Results

We reviewed 13 cases encompassing a variety of malignant and benign pathologies (Table 1). Biopsy locations included the tibia (n=4) and the spine (n=2), femur (n=3), and pelvis (n=4). One child had both spine and pelvic biopsies. Indications for biopsy were as follows: five osteoid osteomas, two sclerotic lesions, two lytic lesions, two marrow lesions seen only on MRI, one periostitis and one osteomyelitis. Of note, all pathologically confirmed osteoid osteomas had a complete response after radiofrequency ablation.

The image quality of the reduced-dose images was rated as either high (Fig. 1) or moderate (Fig. 2) in 12 out of 13 biopsies (tables 2 and 3). Only one case was rated by one reader as low image quality; in this case the reader thought the needle tip and lesion could not be confirmed (Fig. 3). In this case, CT had been performed for initial localization of the anterior pubic ramus with three scans and the remainder of the biopsy performed by feel; this biopsy, ID 11, required three scans total. The biopsy had returned diagnostic results on pathological analysis. Of note, lesions of the tibia and femur were all rated as high with the exception of a single case of a tibial lesion, which was rated by one reader as moderate. All cases of the spine and pelvis were rated as moderate with the exception of the one low pelvic lesion, as described above. Twelve of 13 biopsies returned a sufficient sample for a pathological diagnosis. All children had uncomplicated recoveries from the biopsy.

Final localization scans were all performed with the lowest possible tube voltage allowed by the manufacturer (80 kVp), and tube currents that ranged 50–60 mAs. Percentage reduction in $CTDI_{vol}$ of the final localization scan compared to the initial scan was tabulated for each case where an initial scan was performed (9/13 cases). Four children did not need an initial diagnostic scan to localize or characterize the lesion at the start of the biopsy because the lesion was readily detectible on the scout or had been characterized on a prior cross-sectional imaging examination. The results describing exposure at each scan, the total exposure for each biopsy, and the percentage of dose reduction (savings) using the reduced-exposure biopsy technique are presented in Table 4.

Discussion

We demonstrate a savings in the amount of ionizing radiation delivered during CT-guided bone interventions in children while maintaining acceptable image quality for adequate tissue sampling. CT-guided biopsies using a reduced-dose technique led to pathological diagnosis of various benign and malignant lesions in approximately 92% of cases, which is similar to prior reported studies [6, 12–14]. Moreover this reduced-dose technique led to an average reduction in $CTDI_{vol}$ of 87% from the diagnostic scan to the last localization scan showing placement of the needle in the lesion. This is in concordance with related studies focused on reduced-dose CT-guided lung biopsy [13, 15]. Ninety-two percent of cases were performed with the lowest tube current and voltage settings allowed by the manufacturer; nonetheless further dose savings may be possible with future technology. Moreover in the one case that did not return an adequate sample for pathological diagnosis, clinical management was not changed because the biopsy results from the lesion returned round blue cell tumor, presumed to be a metastasis from the more fully characterized primary tumor, which was a rhabdomyosarcoma.

Precise needle localization is imperative to avoid critical structures, optimize diagnostic yield for pathological diagnosis and maintain vital structures in the setting of tumor with the potential for limb-sparing surgery [16]. In our study all CT images except a solitary case by one out of three readers clearly visualized the needle tip in the target and had image quality rated as high or moderate, with the single low-image-quality case still yielding diagnostic results on pathology. These rates of pathological yield are in concordance with recent studies from both the pediatric [6, 12] and adult populations. For instance, one frequently cited study in adults demonstrated a 93% needle biopsy and 80% fine needle aspiration accuracy rate with a less than 1% complication occurrence [9]. A 2007 study in children [12] demonstrated a successful biopsy rate of 76% using primarily a US-guided technique, with CT fluoroscopy as a backup method if the lesion was not well visualized because of its depth or lack of a soft-tissue component.

Although our sample size is small our data suggest that lesions of the long bones (tibia and femur) are easier to characterize on reduced-dose exams, yielding a high rating for image quality in all but one case by a single reader. Comparatively lesions of the axial skeleton (spine and pelvis) are more difficult to characterize on reduced-dose exams, yielding only moderate image-quality ratings and in one instance for a pelvic lesion, low image quality. These differences suggest, as expected, that sites with more adjacent tissues and at a greater depth are more difficult to characterize on reduced-dose studies. Nonetheless biopsy yields and scans were sufficient for effective diagnosis on pathology.

It is important to note that scanner parameters for CT-guided interventions are variable and non-standardized, ranging from 200 mAs to 400 mAs and 100 kVp to 140 kVp [7, 17], with an average dose estimate equivalent to 4–6 years of background radiation exposure. Limited studies in adults suggest that CT fluoroscopy doses could be as low as 3.2 cGy using 10 mAs and 140 kVp [7]. Given the typically long life expectancy of children, minimizing radiation exposure is vital and has recently commanded wide attention from state and federal regulatory bodies, the news media, patients, families and providers alike with widely publicized campaigns such as Image Gently™ [4, 5].

The number of passes at a particular dose depends on many factors including the location (difficulty of access), the procedure (biopsy vs. biopsy + radiofrequency ablation) and operator experience; many of the biopsies in this study were performed with a trainee. This study suggests that the reduced-dose technique does not result in a large increase in scans and needle passes resulting from lower image quality. Seven scans were needed on average to complete the biopsies in this study. An estimate on the number of passes added by the reduced-dose technique can be calculated from the following data: 10 biopsy passes are required at the reduced-dose setting of 0.65 mGy to deliver the same dose as one scan at the average diagnostic dose of 6.5 mGy (number of additional biopsy passes = diagnostic $CTDI_{vol}$/ reduced-dose $CTDI_{vol}$ = 10). Therefore, even if a few extra needle passes were performed using the reduced-exposure technique, the dose savings is still substantial and may negate the potential increase in a small number of needle passes and scans resulting from lower image quality.

As a corollary to the above calculations, the data appear to support that the reduced-dose settings confer a dramatic reduction in exposure and greatly increase the number of available passes one can perform while still working at an overall lower dose than at the higher-dose setting. Using the data presented here, it can be calculated that a very large number of extra scans at the reduced dose would need to be performed to approach the exposure of one pass at the diagnostic scan dose. For example if it is assumed that one can perform a biopsy at the higher-exposure settings with half the number of passes than at the reduced-dose setting, then the total exposure at the high setting would be 24.1 mGy (7.4 / 2 passes * 6.5 mGy). This is almost three times higher than our average total dose of 8.7 mGy.

Our study suggests that we can reliably obtain adequate specimens with similar accuracy as has been reported for higher-dose techniques [6, 9]. Combinations of strategies are likely to help minimize dose in addition to lowering the tube current and voltage. These strategies could include the use of breast/gonad shielding (controversial), needle trajectory planning off CT scout images, foregoing high-dose localization scans, using infrequent intermittent thick-slice imaging, limiting needle passes, and intermittent CT fluoroscopy.

Limitations to this study include its retrospective design, the small sample size, variability in the lesions and locations sampled, and that the reduced-dose technique was performed only in the hands of one radiologist. The method used to measure dose is also imprecise because the study relied on the $CTDI_{vol}$ provided by the scanner; $CTDI_{vol}$ is a metric to provide a standardized method to estimate and compare the radiation output of different CT scanners and does not account very well for variability in patient size and composition. Also, technical factors on the CT scanner limited the level to which dose could be reduced to 50 mAs and 80 kVp, so we could not test further savings in dose or test what the threshold might be where poor image quality limits the acceptable performance of the biopsy. This study, however, can pave the way for future prospectively designed research with multiple radiologists.

Conclusion

Our results demonstrate the feasibility that a reduced-dose CT-guided biopsy method is safe and accurate and significantly decreases the dose of ionizing radiation delivered to children. The method reported here may be translated to other CT-guided interventions outside the musculoskeletal system, and dose reduction needs to be balanced with acceptable image quality for safe and accurate performance of the image-guided procedure.

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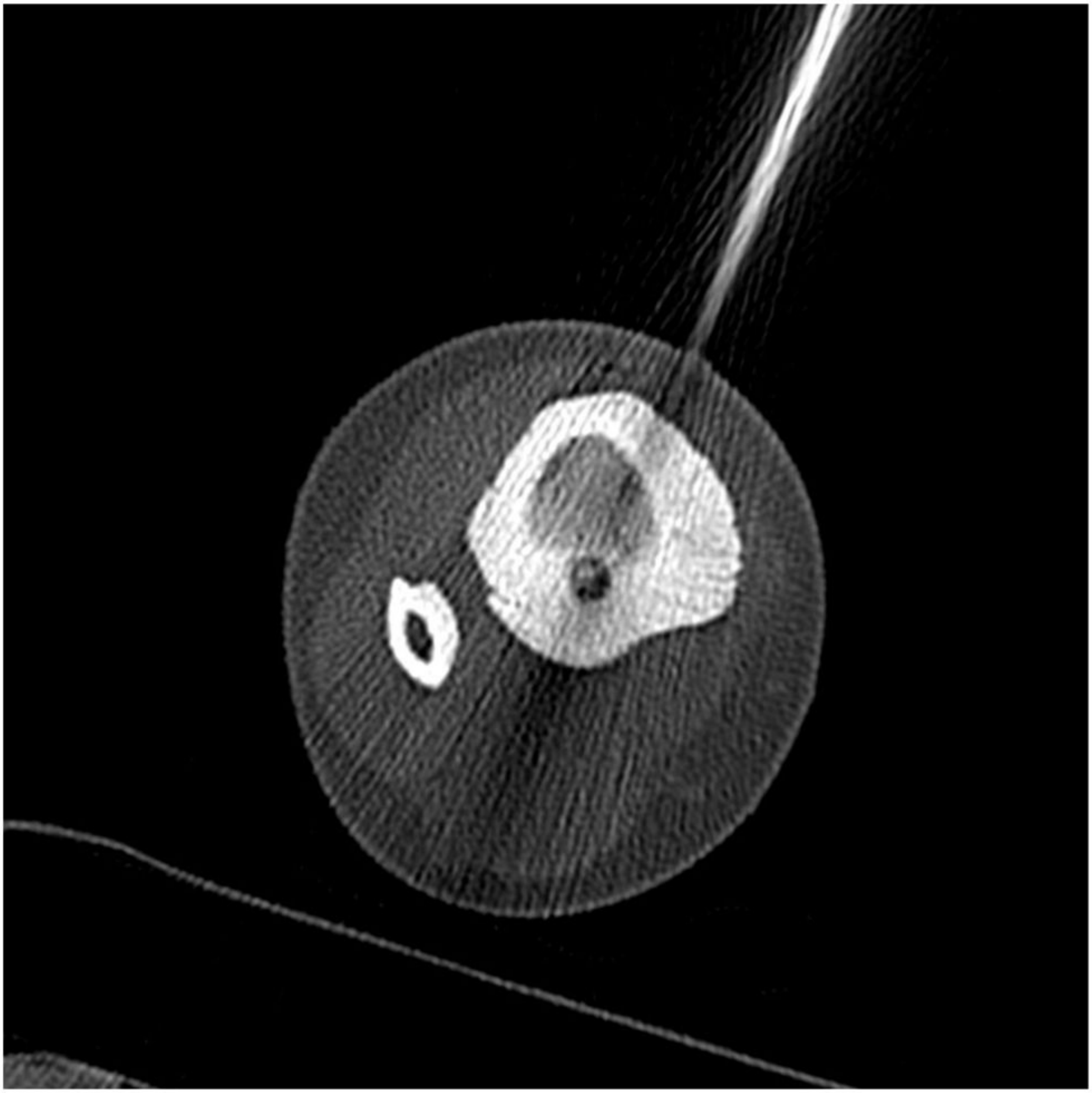

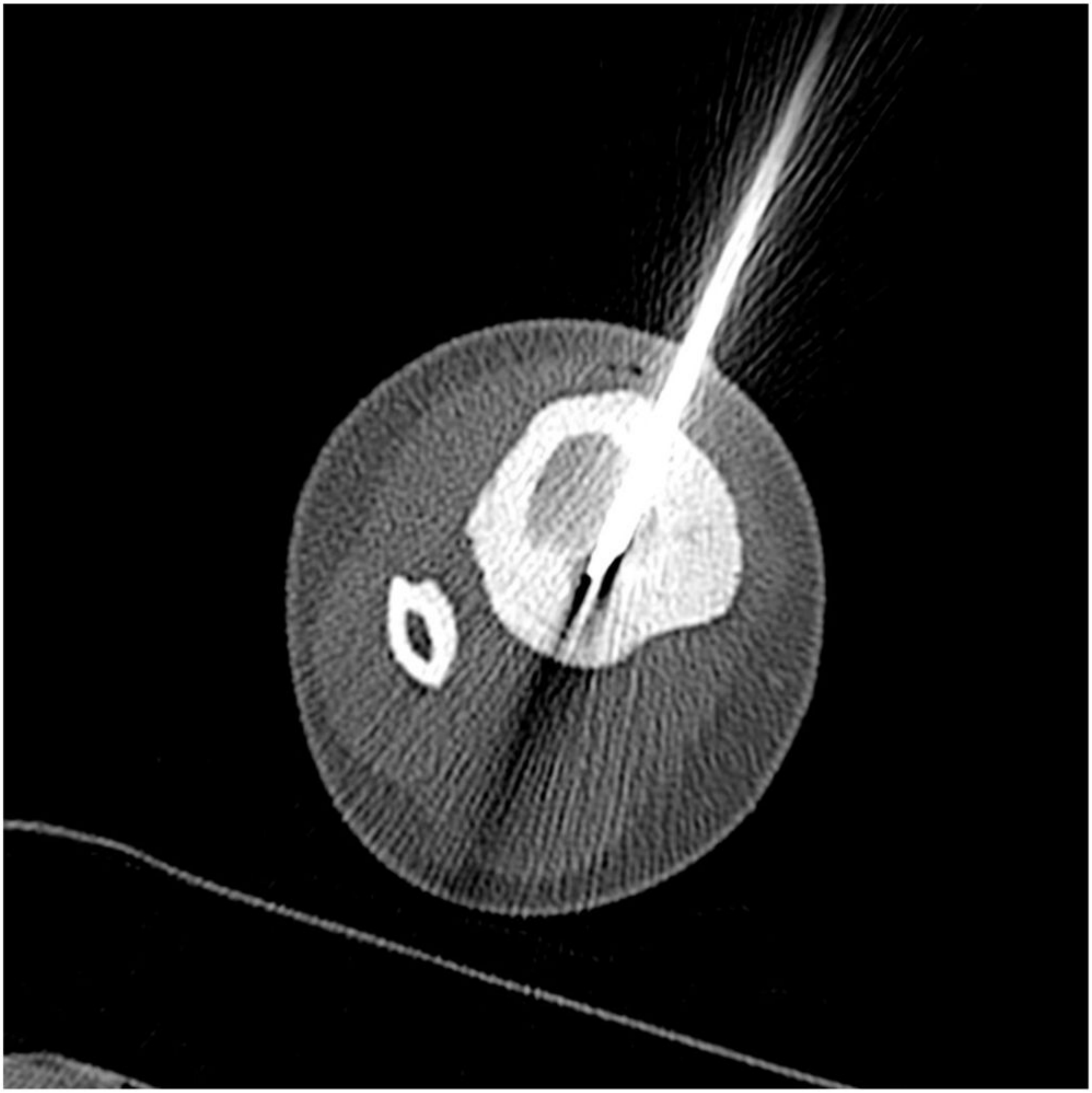

Fig. 1.
High image quality for reduced-dose images (mAs=50, kVp=80) during the final pass of the biopsy scan in a 15-year-old girl with osteoid osteoma (biopsy ID 04). Image quality on this biopsy was rated as high, with the nidus of lesion (**a**) and the biopsy needle tip clearly visualized (**b**)

Fig. 2.
Moderate image quality for reduced-dose images (mAs=52, kVp=80) during the final pass of the biopsy scan in a 9-year-old girl with suspected metastatic rhabdomyosarcoma (biopsy ID 02). **a** The diagnostic scan (kVp=100, mAs=338) performed during the planning portion of the procedure clearly shows the lytic lesion in the ilium. **b** However, the reduced-dose image (kVp=80, mAs=52) shows only the anatomy of the ilium and needle tip but not the lytic lesion

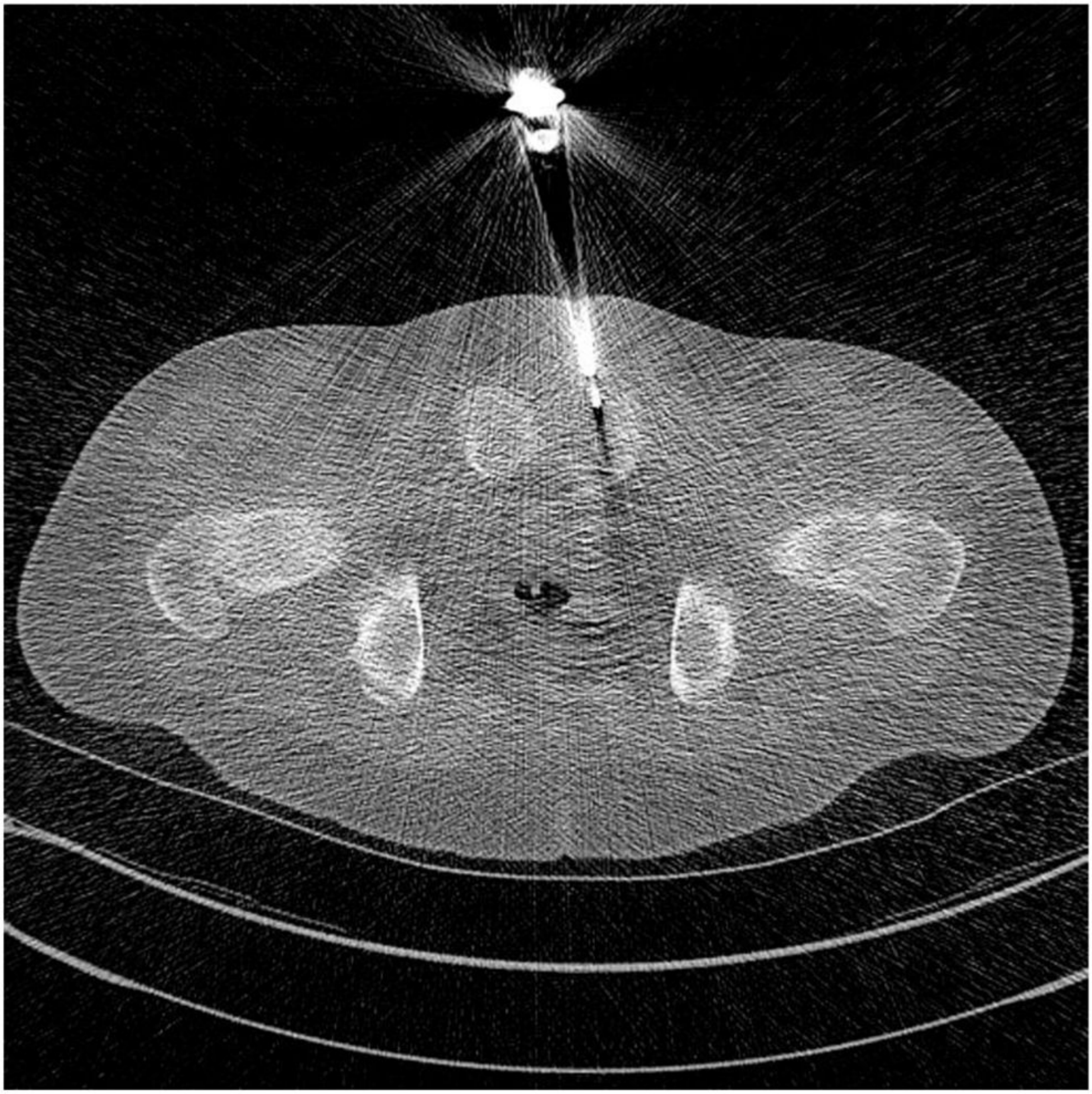

Fig. 3.
Low image quality for reduced-dose images (mAs=50, kVp=80) during the final pass of the biopsy scan in an 11-year-old with suspected osteomyelitis (biopsy ID 11). One of the three readers rated the image quality as low

Table 1

Overview of cases reviewed. Lesion size was estimated as the greatest area of the lesion on axial images

Biopsy ID	Sample sufficient?	Lesion type	Biopsy location	Lesion area (cm^2)	Biopsy result
02	No	Lytic lesion	Pelvis	5.3	Round blue cells*
04	Yes	Osteoid osteoma	Tibia	0.4	Osteoid osteoma
05	Yes	Osteoid osteoma	Femur	0.3	Osteoid osteoma
06	Yes	Osteoid osteoma	Tibia	0.2	Non-ossifying fibroma
07	Yes	Osteoid osteoma	Femur	0.4	Normal bone
08	Yes	Osteoid osteoma	Tibia	0.9	Osteoid osteoma
09	Yes	Sclerotic lesion	Spine	0.8	Metastatic GBM
10	Yes	Sclerotic lesion	Pelvis	1.0	Metastatic GBM
11	Yes	Osteomyelitis	Pelvis	2.4	Inflammation
12	Yes	Lesion only on MRI	Spine	2.8	Leukemia
14	Yes	Lytic lesion	Tibia	0.9	Treated neuroblastoma
15	Yes	Marrow	Pelvis	2.9	Normal bone
17	Yes	Periostitis	Femur	1.0	Negative for cells
				1.5±1.5 mean±SD	

*Histology showed round blue cell tumor, confirming a likely metastasis from known primary but insufficient sample size for further characterization

GBM glioblastoma multiforme

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Table 2

Subjective analysis of reduced-dose images

			Image quality			Lesion visualized			Needle tip visualized		
Biopsy ID	**Lesion type**	**Reader:**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
02	Lytic lesion		M	M	M	N	Y	N	Y	Y	Y
04	Osteoid osteoma		H	H	H	Y	Y	Y	Y	Y	Y
05	Osteoid osteoma		H	H	H	Y	Y	Y	Y	Y	Y
06	Osteoid osteoma		H	H	M	Y	Y	Y	Y	Y	Y
07	Osteoid osteoma		H	H	H	Y	Y	Y	Y	Y	Y
08	Osteoid osteoma		H	H	H	Y	Y	Y	Y	Y	Y
09	Sclerotic lesion		H	H	H	Y	Y	Y	Y	Y	Y
10	Sclerotic lesion		M	H	H	Y	Y	Y	Y	Y	Y
11	Osteomyelitis		M	M	L	Y	N	N	Y	Y	N
12	Lesion only on MRI		M	M	M	N	N	N	Y	Y	Y
14	Lytic lesion		H	M	H	Y	N	Y	Y	Y	Y
15	Marrow		M	M	M	N	N	N	Y	Y	Y
17	Periostitis		H	H	H	Y	Y	Y	Y	Y	Y

Image quality = high (H), moderate (M), low (L). *Y* yes, *N* no

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Table 3

Comparison of blinded readers’ scoring of image quality on reduced-dose images

n=13 cases	Reader 1	Reader 2	Reader 3
High	8	8	8
Moderate	4	5	5
Low	1	0	0

Table 4

Dose reduction analysis

		Single-pass exposure					Total CTDIvol		
		Initial Dx scan		Reduced dose					
Biopsy ID	No. scans	kVp/mAs	CTDIvol	kVp/mAs	CTDIvol	Single-pass % dose reduction	Estimated high dose	Actual dose	Total estimated % reduction
02	9	100/338	6.13	80/52	0.30	95%	55.17	8.53	85%
04	7	80/50	1.84	80/50	1.84	‡0%	12.88	12.88	‡0%
05	7	100/83	6.69	80/50	1.84	72%	40.14	15.89	60%
06	6	120/196	4.70	80/54	0.31	93%	28.20	6.25	78%
07	6	120/165	10.14	80/50	0.82	92%	60.84	14.24	77%
08	6	120/136	4.34	80/51	0.44	90%	26.04	6.54	75%
09	11	80/50	0.45	80/50	0.45	‡0%	4.95	4.95	‡0%
10	9	120/346	11.52	80/60	0.45	96%	103.68	15.12	85%
11	3	80/50	0.51	80/50	0.51	‡0%	2.04	2.04	‡0%
12	12	120/400	10.11	80/51	0.34	97%	121.32	13.85	89%
14	8	100/58	0.79	80/50	0.30	62%	6.32	2.89	54%
15	10	120/127	3.73	80/50	0.49	87%	37.30	8.14	78%
17	6	80/46	0.35	80/50	0.37	‡−6%	2.10	2.20	‡−5%
		Mean±SD	6.5±3.5		0.7±0.6	87±12%	38.5±38.3	8.7±5.1	76±11%

‡In these four patients the initial scan was performed at the reduced exposure settings; an initial diagnostic scan was unnecessary because the lesion was readily detectible or localized on the scout and did not need further characterization by a diagnostic-quality CT. Only the nine biopsies that included a diagnostic scan are used to calculate the mean±SD for the CTDIvol of the initial diagnostic scan and the single-pass and total estimated percentage dose reduction.

Dx diagnostic