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# Radiation Dose Reduction in CT-Guided Spine Biopsies Does Not Reduce Diagnostic Yield

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## ABSTRACT

**BACKGROUND AND PURPOSE:** CT-guided biopsy is the most commonly used method to obtain tissue for diagnosis in suspected cases of malignancy involving the spine. The purpose of this study was to demonstrate that a low-dose CT-guided spine biopsy protocol is as effective in tissue sampling as a regular-dose protocol, without adversely affecting procedural time or complication rates.

**MATERIALS AND METHODS:** We retrospectively reviewed all patients who underwent CT-guided spine procedures at our institution between May 2010 and October 2013. Biopsy duration, total number of scans, total volume CT dose index, total dose-length product, and diagnostic tissue yield of low-dose and regular-dose groups were compared.

**RESULTS:** Sixty-four patients were included, of whom 31 underwent low-dose and 33 regular-dose spine biopsies. There was a statistically significant difference in total volume CT dose index and total dose-length product between the low-dose and regular-dose groups ( $P < .0001$ ). There was no significant difference in the total number of scans obtained ( $P = .3385$ ), duration of procedure ( $P = .149$ ), or diagnostic tissue yield ( $P = .6017$ ).

**CONCLUSIONS:** Use of a low-dose CT-guided spine biopsy protocol is a practical alternative to regular-dose approaches, maintaining overall quality and efficiency at reduced ionizing radiation dose.

**ABBREVIATIONS:** CTDIvol = volume CT dose index; DLP = dose-length product; kVp = peak kilovoltage; mGy = milligray

Imaging-guided biopsy is a commonly used method to obtain a tissue diagnosis in suspected cases of malignancy. In particular, CT guidance is often used for precise localization of a lesion before and during biopsy. It provides the operator with great anatomic detail for biopsy planning and execution and allows for confirmation of needle placement into the area of concern. CT guidance is the preferred method of biopsy for osseous lesions within the vertebrae.<sup>1-4</sup> Even though CT guidance has become increasingly used for various procedures, there is concern over the amount of radiation exposure to the patient.<sup>5-8</sup>

Radiation dose reduction is commonly used in routine diagnostic CT scanning. Pediatric patients and patients who receive

multiple scans for acute disease follow-up, chronic conditions, and screening purposes often undergo CT with modified scanning protocols to reduce dose.<sup>9-14</sup> This type of protocol modification has also been used in CT-guided interventions to limit radiation dose when performing multiple scans during the procedure.<sup>8,15-18</sup> Given the increased desire to reduce radiation dose to patients, we transitioned our protocols for CT-guided spine biopsies to use a lower dose.

The purpose of this study was to demonstrate that a low-dose protocol for CT-guided spine biopsies is as effective in tissue sampling without an increase in procedural time or an increase in complication rates compared with our legacy higher-dose approaches.

## MATERIALS AND METHODS

After obtaining Institutional Review Board approval, we retrospectively reviewed all patients who underwent CT-guided spine procedures at our institution between May 2010 and October 2013. The total number of charts reviewed was 132.

Patients who underwent disk space aspirations and biopsies for suspected diskitis/osteomyelitis were excluded because of limited availability of surgical pathology data as most specimens were

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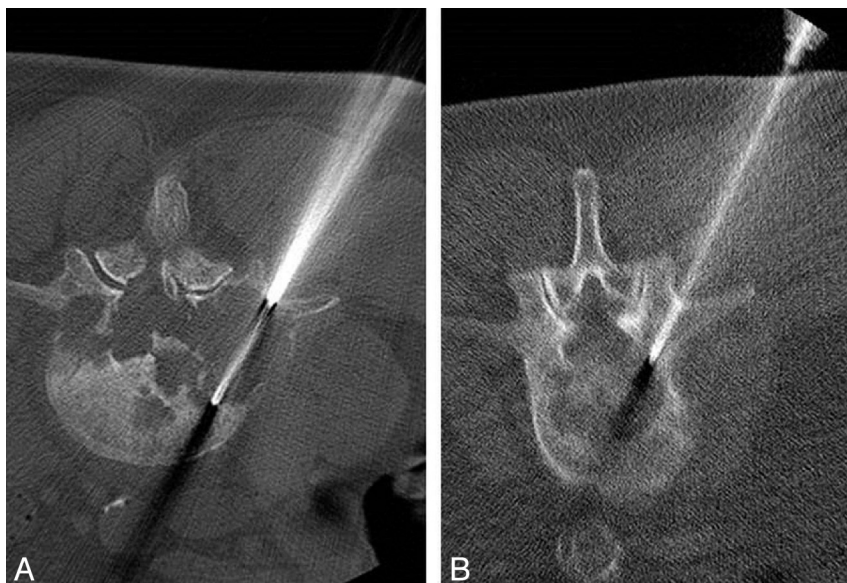
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**FIG 1.** A, Axial CT performed with the regular-dose technique (kVp 120, mAs 250) demonstrates a biopsy needle within a lytic lesion in L3 vertebral body. B, Axial CT performed with the low-dose technique (kVp 80, mAs 60) demonstrates a biopsy needle within a lytic lesion in L2 vertebral body. Both the lesion and the biopsy needle including its tip are sufficiently conspicuous.

only submitted for microbiology analysis. CT-guided pain management procedures such as facet cyst ruptures and epidural injections were also excluded. Patients for whom dose reports were not available in our institution's PACS were excluded.

Ultimately, 64 patients were included in this analysis. Two lesions were biopsied in 2 patients and 1 lesion in the remaining 62 patients, yielding a total of 66 lesions. All the biopsies were performed by 1 Certificate of Added Qualification–certified neuro-radiologist (A.H.D.) with 6 years of experience. The low-dose protocol was initiated in February 2012 and has been almost exclusively used since November 2012.

### Procedure

All CT-guided spine biopsies were performed on a 4-channel CT scanner (Volume Zoom; Siemens, Erlangen, Germany) or 8-section CT scanner (LightSpeed Ultra; GE Healthcare, Milwaukee, Wisconsin) in helical mode based on availability. The 8-section scanner was used to guide 50 biopsies (78.1%) and 4-section scanner for the remaining 14 biopsies (21.9%). CT fluoroscopy was not available. Patients all followed a standard course for these biopsies. Each was positioned prone for the procedures. Vital signs were monitored. Mild to moderate conscious sedation was used in 60 patients (93.8%), monitored anesthesia care in 2 patients (3.1%), and local anesthetic only in 2 patients (3.1%). A Fast Find Grid (Webb Manufacturing, Philadelphia, Pennsylvania) was placed over the general biopsy site for localization. In each patient, 1 preprocedure CT scan was obtained using a regular-dose protocol (120 peak kilovoltage [kVp]) and 200 mAs for planning. Skin was prepped and draped in normal sterile fashion. One percent lidocaine was infiltrated into tissues for local and deep anesthesia. An 11-, 12-, or 13-gauge bone biopsy needle set (Osteo-Site; Cook, Bloomington, Indiana, or Bonopty; AprioMed, Londonderry, New Hampshire) was advanced into the lesion

with CT images obtained after each needle advancement. Once the needle was confirmed within the lesion, CT scans were performed after each biopsy pass. In each patient, 1 final postbiopsy scan was obtained after the needle was removed using regular-dose parameters to assess for postprocedural complications. Patients were then transferred to a recovery area to be monitored before discharge or return to their hospital room.

### Data Collection and Scanning Parameters

Data from PACS and dose reports were collected, including age, sex, location, and characteristics of lesion biopsied, kVp, mAs, pitch, volume CT dose index (CTDIvol) per series (milligray [mGy]), CTDIvol total (mGy), scan range (mm), dose-length product (DLP) per series (mGy·cm), total DLP (mGy·cm), number of biopsy-guiding scans, number of pre- and postbiopsy diagnostic scans, number of needle passes, total number of scans,

duration of each biopsy (defined as time from the first prebiopsy scan to last postbiopsy scan), and complications. Pathology results were obtained for each patient from electronic medical records.

Low-dose biopsies were defined as those with a kVp of 80 and mAs of 40–60. Regular-dose biopsies were defined as those with a kVp of 120 and mAs >200. Scans performed at kVp and mAs parameters outside the above-mentioned criteria of low-dose or regular-dose biopsies were classified based on average CTDIvol (CTDIvol <10 mGy for low dose; CTDIvol >10 mGy for regular dose) as previously described by Kröpil et al.<sup>19</sup> They defined low-dose CTs as having a CT dose index <10 mGy. For example, 2 patients whose biopsies were started as low-dose protocol were switched to regular-dose protocol at the operator's discretion because of insufficient conspicuity of subtle lesions and were classified as "regular-dose" because the average CTDIvol was 17.1 mGy in one and 20.3 mGy in the other. Figure 1 demonstrates representative images from regular-dose and low-dose CT-guided spine biopsies.

Diagnostic tissue yield was classified as "positive for malignancy," "specific benign diagnosis," and "negative for malignancy without a specific benign diagnosis." Lesions were classified as lytic, sclerotic, or mixed. The location of lesions was recorded as cervical, thoracic, lumbar, or sacral.

Age, biopsy duration, total number of scans (including prebiopsy and postbiopsy scans), total CTDIvol (including that used for prebiopsy and postbiopsy scans), and total DLP (including that used for prebiopsy and postbiopsy scans) of low-dose and regular-dose groups were compared using an unpaired *t* test (GraphPad Prism software; GraphPad Software, San Diego, California). Diagnostic tissue yield and the distribution of lesions by type and location of low-dose and regular-dose biopsies were



compared using Fisher exact test (GraphPad Software).  $P$  value < .05 was considered statistically significant.

## RESULTS

Of the 64 patients who underwent CT-guided spine biopsies from 2010 to 2013, 29 patients (45.3%) underwent the procedure using a low-dose protocol and 35 patients (54.7%) using a regular-dose protocol. Table 1 demonstrates the mean and ranges for age, number of scans, duration of procedure, total CTDIvol, and total DLP for low-dose protocol; Table 2 denotes the same for regular-dose protocol.

### Demographics

There was no significant difference between the 2 groups in patient age ( $63.86 \pm 13.67$  years for low dose versus  $59.49 \pm 14.6$

years for regular dose;  $P = .2239$ ) or in sex distribution (14 of 29 or 48.3% women for low dose versus 19 of 35 or 54.3% women for regular dose;  $P = .802$ ).

### Dose and Scanning Time

There was a statistically significant difference between low-dose and regular-dose groups in total CTDIvol ( $69.47 \pm 24.76$  mGy for low dose versus  $285.2 \pm 132.6$  mGy for regular dose;  $P < .0001$ ) and total DLP ( $601.5 \pm 237.7$  mGy·cm for low dose versus  $1541 \pm 648.1$  mGy·cm for regular dose;  $P < .0001$ ) (Fig 2).

There was no significant difference in total number of scans obtained ( $11.38 \pm 4.354$  for low dose versus  $12.46 \pm 4.527$  for regular dose;  $P = .3385$ ) and duration of procedure ( $34.31 \pm 12.19$  minutes for low dose versus  $38.17 \pm 8.92$  minutes for regular dose;  $P = .149$ ) between the 2 groups (Fig 2).

Several outliers were noted, falling greater or less than 2 standard deviations from the mean. One patient in the low-dose group who had 2 lesions (one mixed and one sclerotic) biopsied had significantly more scans, longer duration of the procedure and higher total DLP than average. Two patients in the regular-dose group had significantly more scans than average (25 and 29) because of difficulty in accessibility of small vertebral body lesions, which resulted in significantly higher than average total CTDIvol (761.86 mGy) in one and total DLP (3062.46 mGy·cm) in the other.

### Biopsy Results

There was no significant difference between the 2 groups in the proportion of cases positive for malignancy (20 of 29 or 69.0% for low dose versus 21 of 35 or 60% for regular-dose;  $P = .6017$ ), those with a specific benign diagnosis (2 of 29 or 6.9% for low dose versus 6 of 35 or 17.1% for regular dose;  $P = .2754$ ), and those

whose pathology was negative for malignancy without a specific benign diagnosis (7 of 29 or 24.1% for low dose versus 8 of 35 or 22.9% for regular dose;  $P = 1.00$ ).

Of the 66 lesions that were biopsied, 39 (59.1%) were lytic, 15 (22.7%) were sclerotic, and 12 (18.2%) were mixed. There was no statistically significant difference in lesion type between the low-dose and regular-dose groups ( $P$  values ranging from .1174 to .7694).

Most of the lesions that underwent biopsy were located within the lumbar spine (29 of 66; 44%). This was followed by the thoracic spine (28 of 66; 42.4%), sacrum (7 of 66; 10.6%) and cervical spine (2 of 66; 3%). There was no statistically significant difference in the location of lesions between the low-dose and regular-dose groups ( $P$  values ranging from .4334 to 1.00).

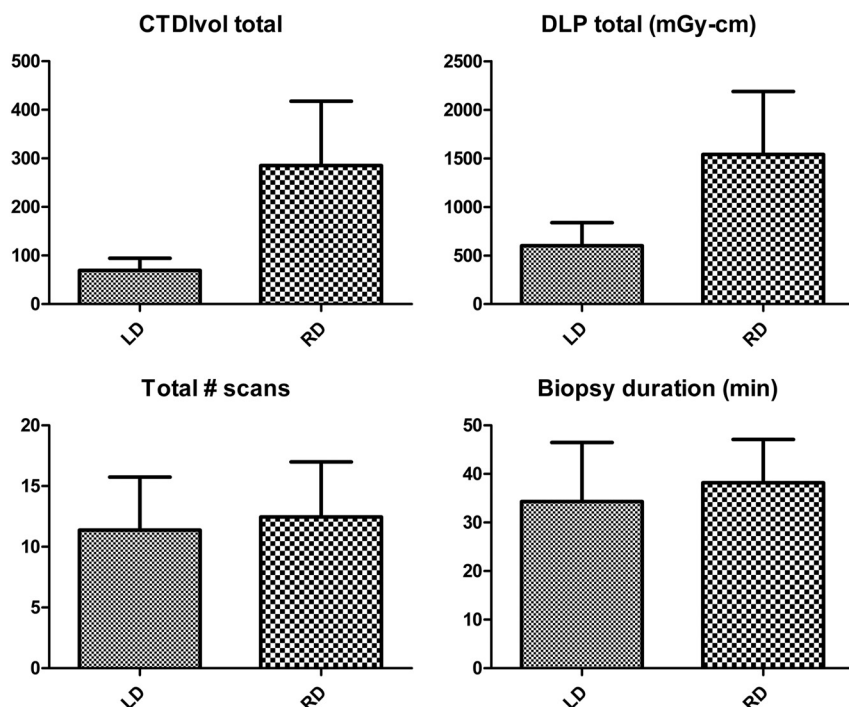
There were sufficient specimens for diagnosis in all patients in both biopsy groups. Overall, there was only 1 minor complication characterized by bleeding from the cannula, which was successfully

**Table 1: Low-dose biopsy group results**

	Range	Mean $\pm$ Standard Deviation
Age (years)	29–87	$63.86 \pm 13.67$
Total number of scans	5–22	$11.38 \pm 4.354$
Duration (minutes)	19–76	$34.31 \pm 12.19$
Total CTDIvol (mGy)	29.98–147.9	$69.47 \pm 24.76$
Total DLP (mGy·cm)	239.3–1206	$601.5 \pm 237.7$

**Table 2: Regular dose biopsy group results**

	Range	Mean $\pm$ Standard Deviation
Age (years)	24–86	$59.49 \pm 14.6$
Total number of scans	6–29	$12.46 \pm 4.527$
Duration (minutes)	21–58	$38.17 \pm 8.92$
Total CTDIvol (mGy)	98.77–761.9	$285.2 \pm 132.6$
Total DLP (mGy·cm)	523.6–3062	$1541 \pm 648.1$



**FIG 2.** Graphs of means with standard deviations comparing radiation dose (total CTDIvol and DLP), total number of scans, and biopsy duration between low-dose and regular-dose groups.



treated with Gelfoam (Pfizer, New York, New York), in a low-dose group patient whose biopsy yielded metastatic renal cell carcinoma. No major complications were reported.

## DISCUSSION

Imaging guidance for biopsy is a commonly used procedure in patients with imaging findings concerning for malignancy. In particular, CT guidance has been used for biopsy of a variety of sites within the body.<sup>1-4,8,15,16,20-23</sup> This is largely attributed to an improved ability of the operator to identify the lesion and plan a trajectory for biopsy. CT-guided biopsy has been shown to be an effective tool in identifying pathology with relatively low risk and cost compared with open biopsy.<sup>4,22,24</sup> However, a frequently cited concern with CT scanning is the potential consequences of ionizing radiation, and there is much emphasis on limiting radiation to as low as reasonably achievable to obtain the necessary results whenever possible.<sup>8,25</sup>

Previous studies have demonstrated the utility of a low-dose CT technique for a variety of interventional procedures. Meng et al<sup>15</sup> performed biopsies of lung lesions at lower doses and found that a reduction in the measure of radiation dose, CT dose index, and DLP were possible without sacrificing diagnostic yield. Smith et al<sup>8</sup> were able to reduce the radiation dose to the chest during CT-guided percutaneous lung biopsies by greater than 95% (from DLP of 677.5 mGy·cm to 18.3 mGy·cm) without decreasing technical success or patient safety. Pediatric CT-guided bone biopsies have been performed using lower mAs and kVp techniques producing acceptable image quality and providing similar diagnostic yield compared with standard techniques.<sup>16</sup> A low-dose CT protocol has also been used in spinal pain interventions. One study found that a change in CT parameters to lower radiation dose resulted in an 86% reduction in total DLP (from 1458 mGy·cm to 199 mGy·cm) for CT-guided spine injection procedures for pain.<sup>17</sup> Artner et al<sup>18</sup> demonstrated that the dose related to CT-guided sacroiliac joint injections can be significantly reduced to levels of pulsed fluoroscopy without compromising needle placement into the joint.

In this study, we found a significantly reduced radiation dose as expressed by CTDIvol and DLP in patients undergoing CT-guided spine biopsies using a low-dose protocol compared with a regular-dose protocol. There was no significant difference in the total number of biopsy scans, procedure time, or in the diagnostic yield between the groups. To our knowledge, this is the first study demonstrating a significantly reduced patient exposure to ionizing radiation during CT-guided spine biopsies without sacrificing the quality, efficiency, and diagnostic yield of the procedure.

Although there was a significantly lower radiation exposure in the low-dose biopsy group compared with the regular-dose group, we predict that a DLP might be lowered even further by reducing tube voltage (mAs) and/or current (kVp), increasing the pitch and decreasing the scan range in the z-axis.<sup>20,26-29</sup> Intermitent axial scanning mode rather than helical mode and the use of a stationary CT table may further contribute to radiation dose reduction.<sup>24,30</sup>

A substantial proportion of radiation exposure comes from pre- and postbiopsy scans because they are designed to optimize soft tissue visualization for needle guidance and to exclude post-

biopsy traumatic sequelae. In fact, 1 study showed that up to 90% of the total patient dose during biopsies was administered during the helical planning stage.<sup>29</sup> Therefore, prebiopsy diagnostic imaging should be carefully reviewed beforehand to determine whether repeat conventional dose scanning may be avoided during the procedure.<sup>31</sup> If a prebiopsy scan is necessary, a grid can be placed over the spinal level of interest before the first series of scans based on known anatomic landmarks.<sup>31</sup> Chintapalli et al<sup>31</sup> suggest that in low-risk CT-guided interventions, which may include some spine biopsies, regular-dose postbiopsy scans can be eliminated at the discretion of the radiologist. A low-dose protocol, as well as techniques to further reduce dose, should be familiar to the radiologist performing the procedures and technologist acquiring the images.<sup>31</sup>

Newer techniques have recently emerged to address image quality when reducing CT dose. These include iterative reconstruction models such as adaptive statistical iterative reconstruction and model-based iterative reconstruction.<sup>9-14,32-40</sup> Although these imaging algorithms provide an additional method for dose reduction in CT-guided procedures, their availability is currently limited to newer CT scanners for routine diagnostic CT imaging. The greater availability of the iterative reconstruction software over time may allow for increased operator comfort when evaluating low-dose images during CT-guided procedures, potentially further reducing the radiation dose.

This retrospective study did have some limitations. It was not randomized, and a single operator performed most of the CT-guided spine biopsies. Therefore, the reproducibility of the results using the low-dose protocol cannot be fully assessed in this study. In addition, it would be difficult to determine whether increasing comfort with the procedure may have contributed to a slightly greater efficiency of the procedure using a low-dose protocol. The retrospective nature of this study also limits assessment of factors related to operator scanning protocol adjustments in challenging biopsy cases.

## CONCLUSIONS

Radiation exposure to patients undergoing CT-guided spinal biopsies can be optimized to reduce the overall dose during the examination. Low-dose CT-guided spine biopsies have a significantly lower total cumulative radiation exposure compared with regular-dose CT biopsies without significantly affecting procedural time or diagnostic tissue yield. A simple dose-reduction protocol can use reduction in mAs and kVp during the procedure. A number of additional modifications to image acquisitions can be made to reduce the dose. Our data show that a low-dose protocol should be considered as an alternative to regular-dose protocol when performing CT-guided spinal biopsies, allowing the operator to reduce ionizing radiation dose while maintaining overall quality and efficiency of the procedure.

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## REFERENCES

- Brugieres P, Revel MP, Dumas JL, et al. **CT-guided vertebral biopsy. A report of 89 cases.** *J Neuroradiol* 1991;18:351–59
- Lis E, Bilsky MH, Pisinski L, et al. **Percutaneous CT-guided biopsy of osseous lesion of the spine in patients with known or suspected malignancy.** *AJNR Am J Neuroradiol* 2004;25:1583–88
- Kornblum MB, Wesolowski DP, Fischgrund JS, et al. **Computed tomography-guided biopsy of the spine. A review of 103 patients.** *Spine (Phila Pa 1976)* 1998;23:81–85
- Rimondi E, Staals EL, Errani C, et al. **Percutaneous CT-guided biopsy of the spine: results of 430 biopsies.** *Eur Spine J* 2008;17:975–81
- Coursey C, Frush D. **CT and radiation: what radiologists should know.** *Appl Radiol* 2008;37:22–29
- Brenner DJ, Hall EJ. **Computed tomography—an increasing source of radiation exposure.** *N Engl J Med* 2007;357:2277–84
- Huda W, Mettler FA. **Volume CT dose index and dose-length product displayed during CT: what good are they?** *Radiology* 2011;258:236–42
- Smith JC, Jin DH, Watkins GE, et al. **Ultra-low-dose protocol for CT-guided lung biopsies.** *J Vasc Interv Radiol* 2011;22:431–36
- Corcuera-Solano I, Doshi AH, Noor A, et al. **Repeated head CT in the neurosurgical intensive care unit: feasibility of sinogram-affirmed iterative reconstruction-based ultra-low-dose CT for surveillance.** *AJNR Am J Neuroradiol* 2014;35:1281–87
- Mathieu KB, Ali H, Fox PS, et al. **Radiation dose reduction for CT lung cancer screening using ASIR and MBIR: a phantom study.** *J Appl Clin Med Phys* 2014;15:4515
- Flicek KT, Hara AK, Silva AC, et al. **Reducing the radiation dose for CT colonography using adaptive statistical iterative reconstruction: a pilot study.** *AJR Am J Roentgenol* 2010;195:126–31
- Kambadakone AR, Chaudhary NA, Desai GS, et al. **Low-dose MDCT and CT enterography of patients with Crohn disease: feasibility of adaptive statistical iterative reconstruction.** *AJR Am J Roentgenol* 2011;196:W743–52
- Shuman WP, Green DE, Busey JM, et al. **Model-based iterative reconstruction versus adaptive statistical iterative reconstruction and filtered back projection in liver 64-MDCT: focal lesion detection, lesion conspicuity, and image noise.** *AJR Am J Roentgenol* 2013;200:1071–76
- Becce F, Ben Salah Y, Verdun FR, et al. **Computed tomography of the cervical spine: comparison of image quality between a standard-dose and a low-dose protocol using filtered back-projection and iterative reconstruction.** *Skeletal Radiol* 2013;42:937–45
- Meng XX, Kuai XP, Dong WH, et al. **Comparison of lung lesion biopsies between low-dose CT-guided and conventional CT-guided techniques.** *Acta Radiol* 2013;54:909–15
- Patel AS, Soares B, Courtier J, et al. **Radiation dose reduction in pediatric CT-guided musculoskeletal procedures.** *Pediatr Radiol* 2013;43:1303–08
- Shepherd TM, Hess CP, Chin CT, et al. **Reducing patient radiation dose during CT-guided procedures: demonstration in spinal injections for pain.** *AJNR Am J Neuroradiol* 2011;32:1776–82
- Artner J, Cakir B, Reichel H, et al. **Radiation dose reduction in CT-guided sacroiliac joint injections to levels of pulsed fluoroscopy: a comparative study with technical considerations.** *J Pain Res* 2012;5:265–69
- Kröpil P, Lanzman RS, Walther C, et al. **Dose reduction and image quality in MDCT of the upper abdomen: potential of an adaptive post-processing filter [in German].** *Rofo* 2010;182:248–53
- Kloeckner R, dos Santos DP, Schneider J, et al. **Radiation exposure in CT-guided interventions.** *Eur J Radiol* 2013;82:2253–57
- Monfardini L, Preda L, Aurilio G, et al. **CT-guided bone biopsy in cancer patients with suspected bone metastases: retrospective review of 308 procedures.** *Radiol Med* 2014;119:852–60
- Gogna A, Peh WC, Munk PL. **Image-guided musculoskeletal biopsy.** *Radiol Clin North Am* 2008;46:455–73, v
- Hau A, Kim I, Kattapuram S, et al. **Accuracy of CT-guided biopsies in 359 patients with musculoskeletal lesions.** *Skeletal Radiol* 2002;31:349–53
- Leng S, Christner JA, Carlson SK, et al. **Radiation dose levels for interventional CT procedures.** *AJR Am J Roentgenol* 2011;197:W97–103
- Lucey BC, Varghese JC, Hochberg A, et al. **CT-guided intervention with low radiation dose: feasibility and experience.** *AJR Am J Roentgenol* 2007;188:1187–94
- Kalra MK, Maher MM, Toth TL, et al. **Strategies for CT radiation dose optimization.** *Radiology* 2004;230:619–28
- Tsalafoutas IA, Tsapaki V, Triantopoulou C, et al. **CT-guided interventional procedures without CT fluoroscopy assistance: patient effective dose and absorbed dose considerations.** *AJR Am J Roentgenol* 2007;188:1479–84
- Smith AB, Dillon WP, Lau BC, et al. **Radiation dose reduction strategy for CT protocols: successful implementation in neuroradiology section.** *Radiology* 2008;247:499–506
- Sarti M, Brehmer WP, Gay SB. **Low-dose techniques in CT-guided interventions.** *Radiographics* 2012;32:1109–19; discussion 1119–20
- Chang AL, Schoenfeld AH, Brook AL, et al. **Radiation dose for 345 CT-guided interlaminar lumbar epidural steroid injections.** *AJNR Am J Neuroradiol* 2013;34:1882–86
- Chintapalli KN, Montgomery RS, Hatab M, et al. **Radiation dose management: part I, minimizing radiation dose in CT-guided procedures.** *AJR Am J Roentgenol* 2012;198:W347–51
- McKnight CD, Watcharotone K, Ibrahim M, et al. **Adaptive statistical iterative reconstruction: reducing dose while preserving image quality in the pediatric head CT examination.** *Pediatr Radiol* 2014;44:997–1003
- Hara AK, Paden RG, Silva AC, et al. **Iterative reconstruction technique for reducing body radiation dose at CT: feasibility study.** *AJR Am J Roentgenol* 2009;193:764–71
- Silva AC, Lawder HJ, Hara A, et al. **Innovations in CT dose reduction strategy: application of the adaptive statistical iterative reconstruction algorithm.** *AJR Am J Roentgenol* 2010;194:191–99
- Yanagawa M, Gyobu T, Leung AN, et al. **Ultra-low-dose CT of the lung: effect of iterative reconstruction techniques on image quality.** *Acad Radiol* 2014;21:695–703
- Deák Z, Grimm JM, Treitl M, et al. **Filtered back projection, adaptive statistical iterative reconstruction, and a model-based iterative reconstruction in abdominal CT: an experimental clinical study.** *Radiology* 2013;266:197–206
- Pickhardt PJ, Lubner MG, Kim DH, et al. **Abdominal CT with model-based iterative reconstruction (MBIR): initial results of a prospective trial comparing ultralow-dose with standard-dose imaging.** *AJR Am J Roentgenol* 2012;199:1266–74
- Sagara Y, Hara AK, Pavlicek W, et al. **Abdominal CT: comparison of low-dose CT with adaptive statistical iterative reconstruction and routine-dose CT with filtered back projection in 53 patients.** *AJR Am J Roentgenol* 2010;195:713–19
- Prakash P, Kalra MK, Kambadakone AK, et al. **Reducing abdominal CT radiation dose with adaptive statistical iterative reconstruction technique.** *Invest Radiol* 2010;45:202–10
- Mitsumori LM, Shuman WP, Busey JM, et al. **Adaptive statistical iterative reconstruction versus filtered back projection in the same patient: 64 channel liver CT image quality and patient radiation dose.** *Eur Radiol* 2012;22:138–43