Radiography 27 (2021) 768–772

Contents lists available at ScienceDirect

Radiography

journal homepage: www.elsevier.com/locate/radi

Adaptive statistical iterative reconstruction for computed tomography of the spine

M. Tsuda [a,*], H. Yunaga [b], A. Murakami [b], S. Yata [b]

[a] Department of Radiological Technology, Tottori University Hospital, 36-1, Nishi-cho, Yonago-shi, Tottori-ken, 683-8504, Japan
[b] Department of Radiology Tottori University Hospital, 36-1, Nishi-cho, Yonago-shi, Tottori-ken, 683-8504, Japan

A R T I C L E I N F O

Article history:
Received 8 June 2020
Received in revised form
21 August 2020
Accepted 10 December 2020
Available online 28 December 2020

Keywords:
Computed tomography (CT)
Adaptive statistical iterative reconstruction (ASiR)
z-axis spatial resolution
Noise power spectrum (NPS)
Spine
Sagittal view

A B S T R A C T

Introduction: The utility of evaluating a sagittal view of CT of the spine is well-known. In many clinical cases, the sagittal view includes noise generated from surrounding objects and may degrade the image quality. Iterative reconstruction (IR) techniques are useful for noise reduction; however, they can reduce spatial resolution. The aim of this study was to evaluate the effectiveness of the adaptive statistical iterative reconstruction (ASiR) for generating sagittal CT images of the spine when compared to filtered back projection (FBP).
Methods: The image quality of clinical images from 25 patients were subjectively assessed. Three radiologists rated spatial resolution, image noise, and overall image quality using a five-point scale. For objective assessment, z-direction modulation transfer function (z-MTF) was measured using a custom-made phantom. Additionally, z-axis noise power spectrum (z-NPS) was measured using a water phantom. An improved adaptive statistical iterative reconstruction algorithm called ASiR-V was used in this study. Blending levels were 50%, and 100% (ASiR-V50, ASiR-V100, respectively).
Results: For subjective assessments, images using ASiR-V100 were determined to have the best overall image quality, despite having received the worst score in the assessment of spatial resolution. For objective assessments, the image using ASiR-V50 and ASiR-V100 curves were slightly degraded in terms of low contrast z-MTF when compared to FBP.
Conclusion: ASiR-V was effective to improve the image quality when compared with FBP when reviewing sagittal reformats of the spine.
Implications for practice: This study suggests that high resolution is not the only thing that is key when reviewing sagittal CT spinal reformats. Such images should be provided as part of routine CT spine protocols, where available.

Introduction

Computed tomography (CT) scanning using a bone kernel is useful for evaluating bone pathology, including fractures, tumours and malalignment and is an essential part of medical care.[1,2]

Using a high-resolution reconstruction kernel, i.e. a bone kernel, the image noise typically stands out because there is a trade-off between image noise and spatial resolution.[3] Image using a high-resolution kernel can contain significant levels of noise due to the higher spatial resolution. On the other hand, images using a soft or standard kernel generally contain lower spatial resolution but also less noise.

Multiplanar reformations (MPR) of CT data is useful for aiding image interpretation[4] and is especially important for CT examinations of the spine. The evaluation of sagittal CT reformats of the spine can be useful when evaluating spinal diseases and injuries.[2,5,6] Streak artefacts may be apparent when observing sagittal views of the spine, such artefacts are generated from surrounding high attenuation objects such as the shoulder joints, abdominal organs, and fat and they may degrade the image quality.[7] Steak artefacts are a type of image noise, as such noise reduction technique will potentially be useful when reconstructing the image. Iterative reconstruction (IR) is one of the possible noise reduction techniques.[8–10] As described previously, there is a trade-off between noise and spatial resolution; therefore, even when reducing

* Corresponding author.
E-mail addresses: joey.no.1@hotmail.co.jp (M. Tsuda), yunagahiroto@gmail.com (H. Yunaga), welldone.gm@gmail.com (A. Murakami), yata-s@med.tottori-u.ac.j (S. Yata).

https://doi.org/10.1016/j.radi.2020.12.002

noise through IR, some papers have reported subsequent image blurring.[11,12] The effect of using IR for reducing noise on sagittal CT reformats is not well reported. Thus, the aim of this study was to explore the effect and utility of using adaptive statistical iterative reconstruction (ASiR) (GE Healthcare, Milwaukee, WI, USA) for generating sagittal CT reformats of the spine.

Methods

This study was approved by the Ethics Committee of Tottori University Hospital. The requirement to obtain informed consent from each patient was waived due to the retrospective nature of data collection.

All the images in this study were acquired using a GE Revolution 256-slice CT scanner (GE Healthcare, Milwaukee, WI, USA). Sagittal CT reformats for all evaluated images were generated with a 2.0 mm slice thickness and a 2.0 mm increment (no overlap). Reformats were obtained from 0.625 mm thick axial images acquired with a bone plus kernel and were reconstructed initially using FBP. Additional datasets with generated using ASiR-V with 50% and 100% blending levels (ASiR-V50, ASiR-V100, respectively). A field of view of 20 cm was set for the axial acquisitions.

The scan parameters to obtain the clinical images for subjective assessment were held constant and used a helical scanning mode: 120 kVp, 0.5 s rotation time, 0.992:1 pitch and a 256 × 0.625 mm detector configuration. Scanning used the automatic exposure control (AEC) and a 10.0 noise index was set.

Image quality assessments

For objective assessments, all the scan parameters were same as the subjective assessment except the tube current. This was set at 70 mA which adjusted the clinical image noise setting using AEC. Beforehand, the standard deviation (SD) was measured on several images using a water phantom, this aided determining the tube current that would produce the same image noise levels for the subjective assessments.

For subjective assessments, the image quality of 25 clinical images from 25 patients (13 men and 12 women mean ± SD age, 68.5 ± 11.5 years, mean ± SD body mass index 21.0 ± 3.3) were assessed. Clinical images were acquired using a consecutive neck to pelvis CT technique and were graded by three radiologists (H.Y., A.M., and S.Y., with 9, 6, and 20 year of experience, respectively) for spatial resolution, image noise, and overall image quality using a five-point scale. Images were randomly displayed one at a time on a liquid crystal display monitor, and the radiologists scored them independently. The observers were not informed of the image reconstruction technique or the patients' clinical data. Window level and width were set at 200 and 2000. A five-point scale was used to grade the images as follows: sharpness: 1 = blurry image, 2 = below average spatial resolution, 3 = average spatial resolution, 4 = above average spatial resolution, and 5 = high spatial resolution; image noise was ranked: 1 = unacceptable image noise, 2 = above average noise, 3 = average image noise, 4 = less than average noise, and 5 = minimal image noise; and overall image quality: 1 = poor, 2 = fair, 3 = average, 4 = good, and 5 = excellent image quality. The higher the score, the better the image quality. A Wilcoxon signed-rank test with Bonferroni's correction was used to assess the differences for these subjective assessments.

Objective assessments

Measuring z-MTF

z-direction modulation transfer function (z-MTF) was measured to estimate craniocaudal axis resolution using a custom-made phantom which had three contrast objects that were set in a cylindrical water phantom (Fig. 1). These objects were resin plates made from polycarbonate (PC), polyethylene terephthalate (PET), and polyvinyl chloride (PVC) and produced three different Hounsfield Unit (HU) images (PC: 88 HU (low contrast), PET: 147 HU (medium contrast), and PVC: 790 HU (high contrast) respectively). From the resultant images, three types of MTF curves were plotted to disclose spatial resolution of the different (low, medium, and high) contrast images. Objects were placed obliquely to the z-axis in the water phantom and were each scanned five times. Scanned images were reformatted to 2.0 mm sagittal images (2.0 mm increments) which were used for measuring z-MTF using the slant-edge method.[14] The calculation software used was CTmeasure (Japanese Society of CT Technology) and first a region of interest (ROI) was set on the sagittal image (boundary between the water and the plastic plate). Next an edge profile was plotted and was used to obtaina line spread function (LSF). Finally, the measured value was calculated using a Fourier-transform to plot the MTF curve (Fig. 1).

Measuring z-NPS

We also measured z-axis noise power spectrum (z-NPS) to investigate z-axis image noise. To do this, we scanned a cylindrical water phantom to acquire axial images and then reformatted them 2.0 mm thick (2.0 mm increment). We used 11 sagittal images to plot z-NPS curves using radial frequency method on the CTmeasure software.

Results

Subjective assessments

The mean ± SD scores for the spatial resolution assessment were 3.4 ± 0.6 (FBP), 3.4 ± 0.6 (ASiR-V50), and 3.1 ± 0.7 (ASiR-V100) (Table 1). There were statistical significances between ASiR-V50 vs. ASiR-V100 ($P < 0.05$), and FBP vs. ASiR-V100 ($P < 0.001$); however, there were no significant differences between FBP vs. ASiR-V50. In terms of the assessment of image noise, the average ± SD scores were 2.1 ± 0.4 (FBP), 2.7 ± 0.6 (ASiR-V50), and 3.5 ± 0.6 (ASiR-V100) (Table 1). Statistically significant differences were observed between all comparisons ($P < 0.001$, respectively). Regarding overall image quality, the average ± SD scores were 2.7 ± 0.8 (FBP), 3.1 ± 0.8 (ASiR-V50), and 3.4 ± 0.7 (ASiR-V100) (Table 1). Again, statistically significant differences were observed between all comparisons (FBP vs. ASiR-V50 ($P < 0.05$). ASiR-V50 vs. ASiR-V100 ($P < 0.05$), and FBP vs. ASiR-V100 ($P < 0.001$).

Objective assessments

Concerning z-MTF: ASiR-V50 and ASiR-V100 curves were slightly degraded in terms of low contrast z-MTF when compared with FBP. However, these two curves did not differ much when compared to the FBP curve for medium and high contrast z-MTF (Fig. 2). The z-NPS curve showed that as ASiR-V blending levels were increased, the lower the image noise (Fig. 3) matching the results of the subjective assessment.

Discussion

For the subjective assessments, ASiR-V100 received the highest score in the evaluation of overall image quality despite it having received the worst scores for spatial resolution. One possible reason could be that the radiologists might not require high resolution

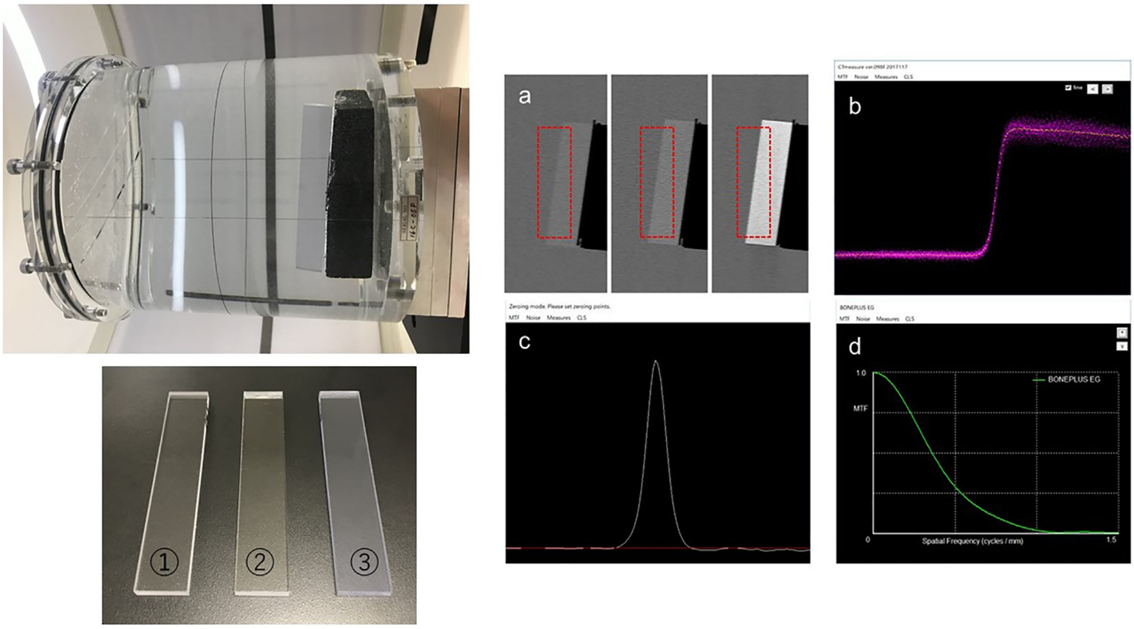

Figure 1. 【Upper left】 The appearance of a custom-made phantom. 【lower left】 The objects made by PET (①), PC (②), and PVC (③) to obtain the three types of contrast slanted edge images. These were put into a water phantom. 【right】 The process of drowing z-MTF curve using "CT measure". (a) ROI was set on the sagittal slanted edge image (low contrast image using PET [left], medium contrast image using PC [center], and high contrast image using PVC [right]). (b) The edge profile was plotted. (c) Transformed curve of LSF. (d) Plotted z-MTF curve.

Table 1
The average scores in subjective assessment.

	Rater 1	Rater 2	Rater 3	Average
Spatial Resolution				
FBP	3.0	3.7	3.6	3.4
ASiR-V50	3.0	3.5	3.7	3.4
ASiR-V100	2.9	2.6	3.6	3.0
Images Noise				
FBP	2.0	2.2	2.2	2.1
ASiR-V50	2.6	2.4	3.0	2.7
ASiR-V100	3.1	3.4	4.0	3.5
Overall Image Quality				
FBP	2.1	3.0	3.0	2.7
ASiR-V50	2.6	3.1	3.6	3.1
ASiR-V100	3.1	3.2	3.9	3.4

levels for sagittal CT views of the spine. Using axial CT images, visualisation of bone trabecula and microfractures are important, in these instances high-resolution must be prioritized even at the detriment of increased image noise.[15] However high-resolution images may not always be necessary for sagittal reformats of the spine, such tasks may include spinal alignment,[6] detecting bone metastasis and observing vertebral or spinous fractures.[16] Mahnken and colleagues reported on their study using CT spine for evaluating multiple myeloma.[17] Their study included lesions with a size of 5–10 mm and illustrates one example of sagittal CT reformats not only for observing extremely small substances or structures. Furthermore, they recommended using a high tube current when acquiring the clinical images. References to image noise and

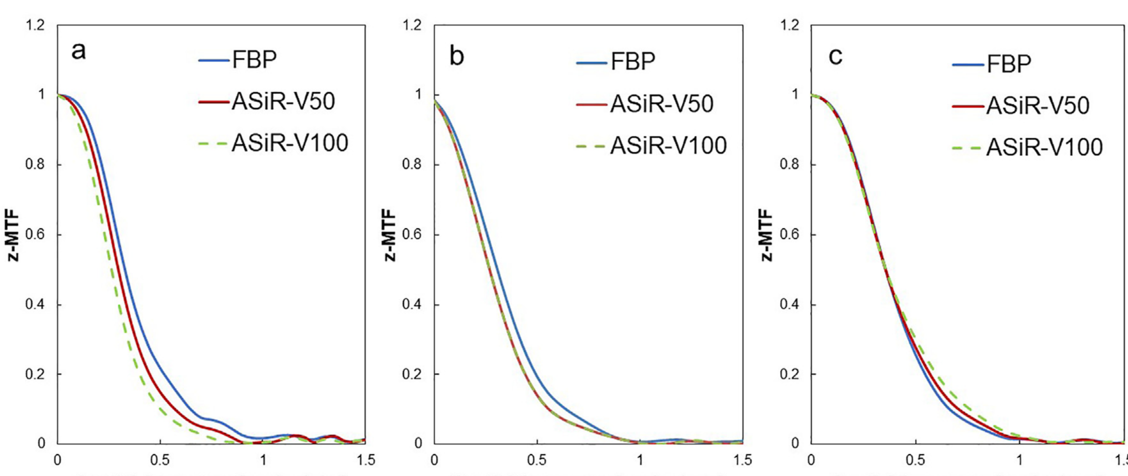

Figure 2. z-MTF curves of low (a), medium (b), and high (c) contrast images.

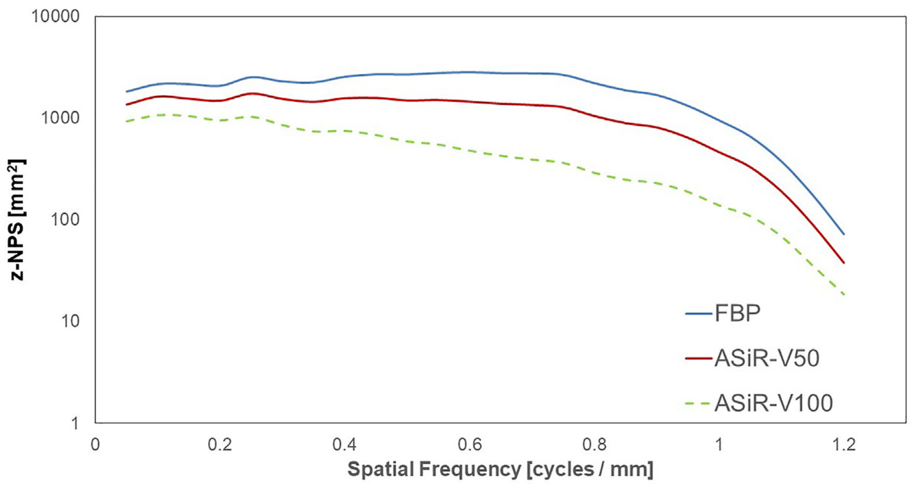

Figure 3. z-NPS curves.

increased tube potential, we interpret, as suggesting that noise could become a problem when evaluating lesions. To maintain spatial resolution is important for image reconstruction, however for sagittal CT views of the spine, a careful balance between noise and spatial resolution is required. Marius and colleagues[16] documented that a mid-resolution kernel is more suitable than a high-spatial frequency kernel for noisy images. This again explains the importance of balancing noise and resolution.

In our study, ASiR-V images improved the z-MTF for high contrast details. Figures of z-MTF (Fig. 2) indicate that as the image contrast becomes higher, the spatial resolution is improved. Bone and soft tissue have large differences in CT value boundaries which results in high-contrast images.

We measured the CT value on the images from a 71-year-old man (four points) using a workstation (Ziostation 2, Ziosoft) with an arbitrary ROI. The average CT value of the whole vertebral body was 172.6, the front of the vertebral body was 352.0, lower vertebral body was 277.8, and the adjacent soft tissue was 39.9. The CT value of the whole vertebral body was a little low, the marginal region of vertebral body was mostly high. Differences in CT values, between the marginal region of the vertebral body and soft tissue, was about 200 or more. These difference in CT value would be categorized as medium to high contrast, the spatial resolution does not seem to deteriorate seriously in these contrast images (Fig. 2). Richard and colleagues.[13]reported that enhanced MTF can be seen in high contrast images when using IR method. This trend corresponds with the result of our study. Besides, the noise was dramatically reduced in parts of the cervical and lumber spine (Fig. 4). Such a noise reduction effect is well known[18]and can be understood from our z-NPS curve (Fig. 3). We think that is the reason why the ASiR-V images received the higher scores.

Our study has limitations. First: this study assessed only three contrasts of z-MTF, hence measured z-MTF was not a strictly task-based.[13] However, it showed the tendency of the z-MTF. Lifeng and colleagues also reported that the IR technique shows the higher the contrast image, the better the spatial resolution,[19] as mentioned above, Richard et al.[13] also referred it. Second: only a bone plus kernel was evaluated. There is room to consider additional reconstruction algorithms. Results of subjective assessment in this study suggests that high resolution is not the only thing that is most important. The balance between spatial resolution and image noise is important when reviewing sagittal views of the spine. Therefore, other kernels such as standard kernel should be investigated to decide the most appropriate method of image reconstruction.

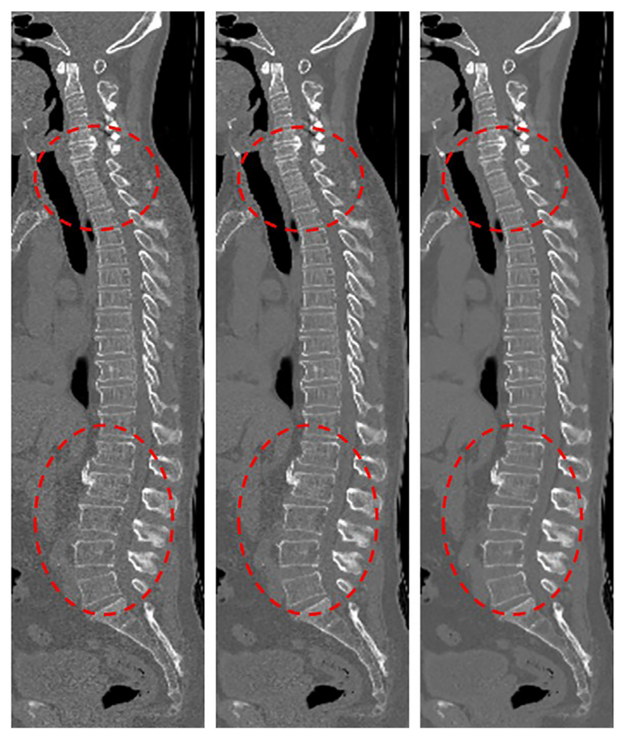

Figure 4. The noise reduction of the part of the cervical and lumber spine on FBP (left), ASiR-V50 (center), and ASiR-V100 (right) image.

Conclusions

Improving image quality is one of the most beneficial ways to use clinical images obtained from patients. We believe it is extremely important to pursue this. Radiographers and radiologists have a responsibility to use the scan data obtained from the patients effectively. This study was able to suggest a method for improving the quality of sagittal CT reformats of the spine. We additionally demonstrated z-MTF and z-NPS as evaluation methods for assessing z-axis CT image quality.

In conclusion, ASiR-V worked effectively on sagittal view of the CT of the spine, and the image quality was significantly improved compared to FBP images.

Conflict of interest statementt

We declare that we have no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.radi.2020.12.002.

References

1. Dreizin D, Nam NJ, Diaconu SC, Bernstein M, Bodanapally U, Munera F. Multidetector CT of midfacial fracture: classification systems, principles of reduction, and common complications. *RG* 2018;**38**:248–74. https://doi.org/10.1148/rg.2018170074.
2. Bensch FV, Kiuru MJ, Koivikko MP, Koskinen SK. Spine fractures in falling accidents: analysis of multidetector CT findings. *Eur Radiol* 2004;**14**:618–24. https://doi.org/10.1007/s00330-003-2090-6.
3. F Edward B, Dominik F. CT artifacts: causes and reduction techniques. *Imag Med* 2012;**4**(2):229–40.
4. Chang H, Roland B, Uwe JS, Kyongtae TB, Maximilian FR. Multiplanar reformat display technique in abdominal multidetector row CT imaging. *J Clin Imag* 2003;**27**(2):119–23. https://doi.org/10.1016/S0899-7071(02)00490-4.
5. Herzog C, Ahle H, Mack MG, Maier B, Schwarz W, Zangos S, et al. Traumatic injuries of the pelvis and thoracic and lumbar spine: does thin-slice multidetector-row CT increase diagnostic accuracy? *Eur Radiol* 2004;**14**:1751–60. https://doi.org/10.1007/s00330-004-2424-z.
6. Matthew PA, William SB, Paul AA. Spine thoracolumbar sagittal spine alignment: comparing computerized tomography and plain radiographs. *Spine* 2012;**37**(4):340–5.
7. Lee SM, Choo HJ, Lee SJ, Kim SK, Lee IS, Kim DW, et al. Cervical spine CT using spectral shaping: can it be a solution to overcome artifacts in the lower cervical spinal region? *Korean J Radiol* 2019;**20**(3):469–78. https://doi.org/10.3348/kjr.2018.0517.
8. Singh S, Kalra MK, Gilman MD, Hsieh J, Pien HH, Digumarthy SR, et al. Adaptive statistical iterative reconstruction technique for radiation dose reduction in chest CT: a pilot study. *Radiology* 2011;**259**:565–73. https://doi.org/10.1148/radiol.11101450.
9. Nakamoto A, Kim T, Hori M, Onishi H, Tsuboyama T, Sakane M, et al. Clinical evaluation of image quality and radiation dose reduction in upper abdominal computed tomography using model-based iterative reconstruction; comparison with filtered back projection and adaptive statistical iterative reconstruction. *Eur J Radiol* 2015;**84**:1715–23. https://doi.org/10.1016/j.ejrad.2015.05.027.
10. Leipsic J, Labounty TM, Heilbron B, Min JK, Mancini GBJ, Lin FY, et al. Adaptive statistical iterative reconstruction: assessment of image noise and image quality in coronary CT angiography. *AJR Am J Roentgenol* 2010;**195**:649–54. https://doi.org/10.2214/AJR.10.4285.
11. Hussain FA, Mail N, Shamy AM, Suliman A, Saoudi A. A qualitative and quantitative analysis of radiation dose and image quality of computed tomography images using adaptive statistical iterative reconstruction. *J Appl Clin Med Phys* 2016;**17**:419–32. https://doi.org/10.1120/jacmp.v17i3.5903.
12. Greffier J, Frandon J, Larbi A, Beregi JP, Pereira F. CT iterative reconstruction algorithms: a task-based image quality assessment. *Eur Radiol* 2020;**30**:487–500. https://doi.org/10.1007/s00330-019-06359-6.
13. Richard S, Husarik DB, Yadava G, Murphy SN, Samei E. Towards task-based assessment of CT performance: system and object MTF across different reconstruction algorithms. *Med Phys* 2012;**39**(7). https://doi.org/10.1118/1.4725171. 4415-4122.
14. Williams D, Burns PD. Low-frequency MTF estimation for digital imaging devices using slanted edge analysis. *SPIE* 2004;**5294**:93–101. https://doi.org/10.1117/12.532405.
15. Strohm PC, Kubosch D, Bley TA, Sprecher CM, Südkamp NP, Milz S. Detection of bone graft failure in lumbar spondylodesis: spatial resolution with high-resolution peripheral quantitative CT. *AJR* 2008;**190**:1255–9. https://doi.org/10.2214/AJR.07.2701.
16. Horger M, Classen CD, Bross-Bach U, Vonthein R, Trabold T, Heuschmid M, et al. Whole-body low-dose multidetector row-CT in the diagnosis of multiple myeloma: an alternative to conventional radiography. *Eur J Radiol* 2004;**54**(2):289–97. https://doi.org/10.1016/j.ejrad.2004.04.015.
17. Mahnken AH, Wildberger JE, Gehbauer G, Schmitz-Rode T, Blaum M, Fabry U, et al. Multidetector CT of the spine in multiple myeloma: comparison with MR imaging and radiography. *AJR* 2002;**178**(6):1429–36. https://doi.org/10.2214/ajr.178.6.1781429.
18. Paolo DM, Daniela O. New adaptive statistical iterative reconstruction ASiR-V: assessment of noise performance in comparison to ASiR. *J Appl Clin Med Phys* 2018;**19**(2):275–86. https://doi.org/10.1002/acm2.12253.
19. Yu L, Vrieze TJ, Leng S, Fletcher JG, McCollough CH. Technical note: measuring contrast- and noise-dependent spatial resolution of an iterative reconstruction method in CT using ensemble averaging. *Med Phys* 2015;**42**(5):2261–7. https://doi.org/10.1118/1.4916802.