Validation of a Metal Artifact Reduction Algorithm Using 1D Linear Interpolation for Cone Beam CT after Endovascular Coiling Therapy for Cerebral Aneurysms

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SUMMARY – *This study aimed to evaluate the effect of a metal artifact reduction (MAR) algorithm using 1D linear interpolation on cone-beam CT (CBCT). We performed phantom and clinical qualitative studies with and without MAR application using 1D linear interpolation. In the phantom study, the standard deviation (SD) was estimated from the images obtained from the water phantom in which a metal coil was placed at the center, and observed the changes in the SDs before and after MAR application. In the clinical qualitative study, the clinical images after endovascular treatment (EVT) for cerebral aneurysms were visually evaluated before and after MAR application. In the phantom study, the SDs after MAR application decreased by 56 to 35% compared with that before MAR application. In the clinical qualitative study, the artifacts from the metal coil decreased or increased depending on locations, and the contrasts of gray matter and white matter were attenuated when MAR was applied. In conclusion, the metal artifact decreases when MAR using 1D linear interpolation is applied to cerebral CBCT. However, another artifacts increase or soft tissue contrast is changed in some cases. MAR largely contributes to the reduction of streaking artifacts, whereas it may induce cerebral parenchyma at distant metal body or quality deterioration of the image not including the metal body. This should be taken into account in the diagnosis of secondary hemorrhage or infarction.*

Introduction

In endovascular treatment (EVT) for cerebral aneurysm, a catheter is carried forward to the cerebral aneurysm, and a metal coil is inserted into the aneurysm from the head of catheter under X-ray fluorography to produce aneurysmal thrombolysis.

Compared with surgical treatment, EVT is noninvasive, and has the advantage for a patient to be able to leave the hospital at an ear-

lier date. The number of EVT procedures has increased recently worldwide. However, there are complications such as cerebral complications due to cerebral bleeding from an aneurysm damaged by a catheter or coil¹. Countermeasures against such complications should be considered. There is a concept of risk management in the preliminary prevention of severe complications and in preliminary planning of the countermeasures against onset of complications, though it is not limited to the medi-

Figure 1 Phantom structure. A metal coil for packing of a cerebral aneurysm is enclosed in the tip of a cylinder. The cylinder is fixed to the phantom. The phantom is filled with 5000 mL water.

Figure 2 ROI set on the phantom image. Eight ROIs were set at 8 segments around the metal coil on the image that was cross-sectioned at the center of metal coil, and SDs were estimated.

cal area alone. For a concrete example of risk management in EVT, postsurgical cerebral X-ray computed tomography (X-ray CT) is used to diagnose the existence/absence of cerebral bleeding promptly, and the countermeasure is promptly taken against cerebral bleeding if it is found. However, in postsurgical cerebral X-ray CT, a metal artifact is largely affected by the metal coil inserted into aneurysm, and it may become difficult to diagnose the existence/absence of intracerebral bleeding.

Cone-Beam CT (CBCT) equipped with the recently released flat-panel-detector digital angiography system has the function to reduce metal artifacts (metal artifact reduction: MAR) in the system. MAR reconstructs the CT data taken as usual and reduces metal artifacts without taking new CT scans. Useful clinical applications of MAR have been reported in the head and intrapelvic regions²⁻⁵. In MAR installed in CBCT used in daily clinical practice, the image is reconstructed by 1D linear interpolation

Figure 3 Definition of proximal portion and distal portion in visual evaluation. The length from the metal coil to the inner surface of the skull was divided into two parts. The areas proximal and distal to metal coil were defined as proximal portion and distal portion, respectively.

Figure 4 Phantom images without and with MAR application. A) Before metal artifact reduction (MAR) application, remarkable streaking artifact induced by metal coil was demonstrated. B) After MAR application, the streaking artifact from the metal coil was eliminated almost entirely by MAR, and a reinserted hyperdense object was depicted at the position of the metal coil.

to save data processing time, and the incidence of secondary artifacts has been reported in this 1D linear interpolation⁵. However, these findings resulted from studies observed on the metallic coil-included cross-sectional surface, and the effect on the metal-excluded cross-sectional surface was not observed. Therefore, investigations are needed on how MAR impacts on the degree of the reduction effect and clinical images. We performed physical and clinical evaluations of MAR-applied CBCT images both including and excluding metal-containing cross-sectional surfaces after surgical operation of cerebral aneurysms.

Materials and Methods

Physical and Visual Evaluation for Phantom CT Images

For physical evaluation in the phantom, an endovascular embolization coil (GDC™-18, a thickness of 0.015 inch, total length of 300 mm, helical shape of 10 mm, Boston Scientific, MA, USA) was inserted in a cylinder of 0.15 mL in volume and approx. 4 mm in diameter, and placed and fixed at the center of a cubic acrylic case (170 mm×170 mm×170 mm). The case was filled with 5000 mL water (Figure 1). The above

phantoms were set at the position so that the axis of a coil-enclosed cylinder was located at the center of image rotation. CT images were obtained using CBCT (FD2020, Philips Medical Systems, Netherlands). The images obtained before and after MAR application were reconstructed respectively for comparative evaluation. Imaging was repeated ten times. The reconstruction range was FOV 250 mm. In the reconstruction function, a soft tissue algorithm was used with a reconstructed slice thickness of 0.982 mm. The evaluated cross-sectional image was obtained on the surface containing the center of the metal coil. The scan parameters of CBCT included an exposure angle of 210°, 122 frames collected, and a scanning time of 20 seconds. The values of tube voltage and tube current were those for full-automatic operation.

In evaluation, the region of interest (ROI) was set at eight segments around the center of the metal coil on the cross-sectional image before and after MAR application, and SDs were estimated for comparison. The ROI was a quadrangle 50 mm × 45 mm (Figure 2). The images obtained from ten repeated scans were used for measurement, and the statistical significance at each region was analyzed by Wilcoxon signed-rank test at each measuring point before and after MAR application. A risk rate less than 5% was designated as statistically

Table 1 The clinical case visually evaluated for cerebral aneurysm packed by a metal coil.

<i>Case</i>	<i>Sex</i>	<i>Age</i>	<i>Lesions of brain aneurysm</i>	<i>Diameter of cerebral aneurysm (mm)</i>
1	f	77	Rt. MCA	37 × 31
2	m	67	Rt. ACA	8 × 8
3	f	76	Lt. ICA	11 × 11
4	f	52	Lt. ICA	14 × 13
5	f	65	Lt. ICA	14 × 13
6	m	75	Rt. ICA	5 × 5
7	f	75	Rt. MCA	8 × 8
8	f	86	Tip of VA	7 × 7
9	m	46	Lt. MCA	13 × 12
10	f	43	Rt. MCA	13 × 10
11	f	41	Lt. VA	10 × 8
12	f	71	Lt. ACA	7 × 6
13	m	73	Tip of VA	11 × 8
14	f	73	Lt. ACA	8 × 7
15	f	46	Tip of VA	13 × 11
16	f	81	Lt. MCA	10 × 10

ACA, anterior cerebral artery; ICA, internal cerebral artery; MCA, middle cerebral artery; VA, vertebral artery.

significant. All regions and sizes of ROI were the same. A workstation (Advantage Workstation 4.2, GE Healthcare, Milwaukee, WI, USA) was used for measurement. We also estimated SDs on the images containing no metal body as described above. The region containing no metal body in the same phantom was used for measurement, and positioning of ROI was selected to become the same.

Qualitative Evaluation for Clinical CT images

The images before and after MAR application were visually evaluated in 16 patients (four males and 12 females; mean age, 65.4 years; range, 41-86 years) who received coil embolization for cerebral aneurysm during the period April to August, 2013 (Table 1). Visual evaluation was performed by 11 radiological technologists who were routinely engaged in interventional radiology and two clinically experienced neuroradiologists. The scan parameter for cerebral CBCT includes; exposure angle, 210°; number of acquisition frame, 122; and imaging time, 20 s. The values of X-ray tube voltage and tube currents were the same as those under full-automatic operation. Range of reconstructed slice was FOV 250 mm, reconstruction function was soft tissue algorithm, and reconstructed slice thickness was 0.982 mm.

The labels of patient data and scan parameters were erased from all evaluated images. In image observation, the images set at 200 Hounsfield units (HU) for window width and 40 HU for window center were displayed with a digital PACS system (SYNAPSE, Fujifilm Medical System, Tokyo, Japan). The images with MAR applied and not applied were displayed on the same computer screen at right and left sides, respectively and observed under the same room conditions. Use of patient data for this study was previously approved by the Institutional Review Board of Showa University Fujigaoka Hospital. Written informed consent was obtained from all patients or their families prior to participation in this study.

Images were evaluated on five parameters; A) strength of the artifact at the proximal portion to metal coil, B) strength of the artifact at the distal portion to metal coil, C) differentiation of cerebrospinal fluid (CSF) and cerebral parenchyma (CP) at the portion proximal to the metal coil, D) differentiation of CSF and CP at the distal portion to the metal coil, and E) differentiation of gray matter (GM) and white matter (WM) in the image containing no metal coil. In assessment of E, plural cross-sectional images containing no metal were observed while scrolling them, and they were evaluated overall. In the definition of proximal and dis-

Table 2 SD values estimated before and after metal artifact reduction (MAR) application (sectional image containing metal coil).

<i>Position of ROI</i>	<i>MAR</i>	<i>SD^a</i>	<i>SD</i>	<i>p</i>
1	—	20.57	0.24	p<0.01
	+	10.70	0.27	
2	—	13.86	0.49	p<0.01
	+	6.11	0.19	
3	—	22.51	0.27	p<0.01
	+	12.59	0.19	
4	—	12.68	0.17	p<0.01
	+	7.65	0.20	
5	—	12.50	0.19	p<0.01
	+	7.47	0.15	
6	—	23.76	0.35	p<0.01
	+	13.60	0.25	
7	—	12.53	0.27	p<0.01
	+	8.25	0.16	
8	—	18.49	0.14	p<0.01
	+	12.18	0.07	

^aThe SD values at each of 8 ROIs are the mean of 10 repeated measurements.

tal portions, the length from the metal coil to the inner surface of the skull was divided into two parts, the areas proximal and distal to the metal coil were defined as proximal portion and distal portion, respectively (Figure 3).

In evaluation criteria, a pair of the images before and after application of MAR was compared on a five-point scale. The scale includes; -2: the contrast of the image before MAR application is stronger, -1: the contrast of the image before MAR application is slightly stronger, 0: the contrast of the image after MAR application is the same as that before MAR application, 1: the contrast of the image after MAR application is slightly stronger, and 2: the contrast of the image after MAR application is stronger. Data obtained were analyzed by Wilcoxon signed rank test, and a risk rate less than 5% was designated as statistically significant.

Results

Physical Evaluation of Phantom CT Images

ROI was set at eight segments on the cross-sectional image containing the metal coil, and digital SD was estimated. As a result, SD in the image obtained after MAR application decreased much more than that in the image before MAR application on all regions of interest. The degree of decrease was 56% maximum and 36% minimum. In analysis by Wilcoxon signed rank test, statistically significant differences were observed between both SDs on all regions of interest. The variation of the changes in SDs was in the range from 0.07 to 0.49, and was stable (Table 2).

ROI was set at eight segments on the cross-section surface containing no metal coil, and digital SD was estimated. As a result, there

Table 3 SD values estimated before and after metal artifact reduction (MAR) application (sectional image containing no metal coil).

<i>Position of ROI</i>	<i>MAR</i>	<i>SD^a</i>	<i>SD</i>	<i>p</i>
1	—	9.35	0.17	0.12
	+	9.41	0.06	
2	—	7.25	0.07	0.46
	+	7.26	0.10	
3	—	9.61	0.12	0.39
	+	9.60	0.12	
4	—	7.39	0.14	0.47
	+	7.38	0.10	
5	—	7.52	0.19	0.17
	+	7.46	0.14	
6	—	10.97	0.09	0.09
	+	10.93	0.10	
7	—	8.72	0.12	0.11
	+	8.59	0.08	
8	—	8.62	0.08	0.09
	+	8.70	0.11	

^aThe SD values at each of 8 ROIs are the mean of 10 repeated measurements.

Figure 5 Clinical cases in which evaluation occurred after application of MAR. A,B) An 86-year-old woman (case 8) with subarachnoid hemorrhage from a ruptured aneurysm at the tip of the vertebral artery. A) The detail around the metal coil is not observed at all due to a streaking artifact introduced by the metal coil. B) The artifact was reduced by application of metal artifact reduction (MAR), and the bleeding at the proximal portion of metal coil was differentiated. C,D) A 71-year-old woman (case 12) with an unruptured aneurysm at the right anterior cerebral artery. C) Hypodense area distal from the metal coil was demonstrated, but this finding could not be diagnosed as a lesion or artifact before MAR application. D) The streaking artifact from the metal coil in the anterior cerebral artery disappeared almost entirely after MAR application. The ringing artifact not observed clearly before MAR application was observed in the image after MAR was applied (arrow).

Figure 6 Clinical cases in which a secondary artifact increased after MAR application. A,B) A 75-year-old man (case 6) with subarachnoid hemorrhage from a ruptured aneurysm at the right internal cerebral artery. C,D) A 41-year-old woman (case 11) with subarachnoid hemorrhage from a ruptured dissecting aneurysm at the left vertebral artery. A,C) In both cases, radial linear artifacts centering on metal coils were demonstrated before metal MAR application. B,D) Both linear artifacts from metal coils changed to the band-like artifacts after MAR was applied, and the results of visual evaluation became poor in both cases.

were no changes in the SDs in the images before and after MAR application. The results of Wilcoxon signed rank test showed $p < 0.05$ and were statistically insignificant. The variation of the results was in the range of 0.07 to 0.19, and was stable (Table 3). Actual phantom images are presented (Figure 4).

Qualitative Evaluation for Clinical CT images

The visual evaluation data were the sum of the clinical image data obtained from 16 patients and evaluated by 13 observers. These evaluation data were analyzed by Bonferroni method to inspect any differences in the visual evaluation ability among observers. No significant interobserver variability was found for visual evaluation ability.

In strength of artifacts at the proximal portion of the metal coil, 150 answers were that strength of the artifacts was stronger and 38 answers were that it was slightly stronger in the cases when MAR was not applied, and seven answers were that it was slightly stronger in the cases with MAR added, suggesting that artifacts are significantly reduced at the proximal region of the metal coil by application of MAR. A typical clinical image showing that metal-induced artifacts were reduced by MAR is presented in Figure 5. On the other hand, there were seven answers that artifacts became slightly stronger by application of MAR. Two of these seven cases are presented in Figure 6. In strength of artifacts at the distal portion of the metal coil, 74 answers were that strength of the artifacts was stronger and 71 answers were that it was slightly stronger in the cases when MAR was not applied, 22 answers were that it was not different between the cases with MAR applied and not applied, and 28 and 13 answers were

that it was stronger and it was slightly stronger in the cases with MAR applied, respectively. A metal artifact reduction effect by applying MAR was not observed so much at the distal portion compared with that at the proximal portion. A typical image showing that artifacts became strengthened by MAR application is presented in Figure 7. In differentiation of CSF and CP at the proximal portion of the metal coil, 81 and 28 answers were that their differentiation was stronger and more stronger in the images after MAR application, respectively, accounting for 50% of the total. No changes in differentiation before and after MAR application were found in 76 answers. In differentiation at the distal portion, results tended to be same as those observed at the proximal portion. In identification of GM and WM in the images containing no metal coil, no changes in the images obtained before and after MAR application were found in 111 answers, accounting for half of the total. Moreover, 63 answers were that GM and WM were differentiated more clearly in the images before MAR application, and 33 answers were that they were more clearly in the images after MAR application. Differentiation ability tended to decrease by applying MAR. The results of visual evaluation obtained from the clinical images before and after MAR application were analyzed by Wilcoxon signed rank test, and statistically significant differences were observed at $p < 0.01$ in all parameters evaluated (Table 4).

Discussion

The report of risk management in the endovascular treatment of cerebrovascular diseases states that the failure rate of treatment decreases with highly experienced technics and

Table 4 Results of visual evaluation of clinical images of patients.

Aspects	Scoring ^a					p^b
	-2	-1	0	1	2	
Artifacts with a metal coil (proximal)	150	38	13	7	0	<0.01
Artifacts with a metal coil (distal)	74	71	22	28	13	<0.01
Cerebrospinal fluid / brain parenchyma differentiation (proximal)	0	23	76	81	28	<0.01
Cerebrospinal fluid / brain parenchyma differentiation (distal)	3	21	88	73	23	<0.01
White matter / gray matter differentiation (Part not metal)	0	63	111	33	1	<0.01

^aScoring criterion; -2: the contrast of the image before metal artifact reduction (MAR) application is stronger, -1: the contrast of the image before MAR application is slightly stronger, 0: the contrast of the image after MAR application is same with that before MAR application, 1: the contrast of the image after MAR application is slightly stronger, and 2: the contrast of the image after MAR application is stronger.

^bThe results of visual evaluation were analyzed by Wilcoxon signed rank test.

Figure 7 Clinical cases in which visual evaluation became poor after MAR application. A,B) A 52-year-old woman (case 4) with an unruptured aneurysm at the left internal cerebral artery. C,D) An 81-year-old woman (case 16) with an unruptured aneurysm at the left middle cerebral artery. A,C) As in Figure 6, radial linear artifacts centering on metal coils were demonstrated before MAR application in both cases. B,D) The linear artifacts from the metal coils changed to band-like artifacts, and showed the shadow that disturbs image evaluation at the distal portion. A dark linear artifact also is observed at the border of band-like artifact (arrow in D).

advancement of equipment⁶. Therefore, it is important to introduce the new software function of equipment to clinical practice. On the other hand, data collection is needed to verify if the original function is affected by the new software function. Our study investigated if cerebral CT images after surgical cerebral aneurysm clipping are affected by MAR installed in CBCT. In evaluation of the phantom, SDs before and after MAR application were compared after ROI was set at eight segments in the image of CBCT containing the metal body. The SDs in all ROIs decreased to approximately one half. This may be related to a decreased variation of digital signal values in the image because streaking artifacts from the metal coil were reduced by MAR application.

Similarly, ROI was set in the image containing no metal body, and the SDs were compared before and after application of MAR. Statistically significant changes were not observed. This may be related to the result that a faint signal near 0 HU observed in water was not affected because a threshold of 4000 HU was selected and the signal having a very high CT number was isolated⁵ and mapped on the original image using a projection algorithm in MAR application^{2,7}. Moreover, the threshold of approximately 1000 HU was the highest among the thresholds of HU observed in the human body⁸. The signals from the materials other than the metal body may not be affected by of MAR application in clinical practice.

In visual evaluation of clinical images, a significant artifact reduction effect was observed by applying MAR at the proximal portion of the metal coil. This may be related to the mechanism that, as mentioned before, a high CT value from the metal body and CT number from the human body are isolated, the data of the metal body are differentiated from the data of the human body, and the anatomical information of the human body alone is reconstructed. In particular, in the cases in which spreading cerebral hemorrhage was not clearly differentiated due to the artifacts generated from a metal coil in the vertebrobasilar artery, artifacts were reduced by applying MAR and bleeding spread in the ambient cistern was clearly observed in some cases. In other cases the structure in the cerebral parenchyma was not observed at all due to the artifacts generated by the metal coil, the structure was clearly observed after MAR was applied (Figure 5). These cases suggest the usefulness of the reduction effect of artifacts at the proximal portion of the metal body.

The reduction effect of artifacts tended to decrease at the distal portion of the metal coil more than that at the proximal portion. In many of the cases in which artifacts were more enhanced by MAR application, artifacts were thin streaky artifacts before MAR application, but they became white band-like artifacts after MAR application, and visibility of the differentiation between CS and CE at the distal portion decreased (Figure 7). Artifacts may be induced by multiple factors:

First, the exponential edge gradient effect-related artifacts that occurred before MAR application were observed more clearly because metal artifacts were reduced by MAR. The onset of artifacts due to the exponential edge gradient effect is caused by averaging the measured intensity over a finite beam width (and finite focal spot width), while the mathematics used for the reconstruction assumed zero width⁹. These artifacts are border-unclear bright band-like artifacts unclear around the edges that generate at very high peripheral contrast as seen in a metal body.

Second, the aliasing artifacts observed after MAR application might have appeared as white band-like artifacts¹⁰. These aliasing artifacts were generated by subtracting metal-containing data from the original image before MAR application during the process of 1D reconstruction.

Third, the artifacts may be derived from the filtered back projection (FBP) used in the MAR in this study. In the presence of high-density objects such as metals, however, the effects of beam hardening and scattered radiation are known to cause the FBP algorithm to produce reconstructions characterized by streaking and star-shaped artifacts¹¹. These artifacts are similar to those observed in our study. Moreover, 1D linear interpolation was used in our MAR algorithm. 1D linear interpolation routine is used to replace underexposed data in the raw projections, and artifacts are secondarily generated⁵. Further study will be required in the future by comparison with the 3D linear interpolation that did not tend to induce artifacts.

Visual evaluation was conducted for differentiations of GM and WM in the image containing no metal coil. The differentiation ability in the image with MAR applied clearly decreased compared with the image before MAR application. The causative factors affecting the low contrasts include tube voltage, tube current, slice thickness, filter function, and image processing¹²⁻¹⁴.

In MAR that reduces metal artifacts by image-processing, any filter function or image

processing may affect the contrasts of GM and WM, which will be made clear by future investigation.

The main limitation of this study is the small number of our cases used for clinical visual evaluation and results differed case by case. They include streaking artifacts from a metal body reduced significantly by MAR, band-like artifacts newly generated, and changes in the contrast of GM and WM. A variety of environmental factors including shape of the metal body, size, density, position, and surrounding tissue composition are involved in clinical case study. From the 16 cases evaluated in this study, we could not demonstrate a more exact tendency in the reason different results of visual evaluation were observed. Further study will be required with many more cases in the future.

Conclusion

A quite effective reduction effect of artifacts was observed at the proximal portion of the metal coil embolized in cerebral aneurysms af-

ter application of MAR using 1D linear interpolation installed in the CBCT of a flat-panel-detector digital angiography system. However, at the distal portion of a metal coil, specific secondary artifacts are generated, and diagnosis may become difficult. Moreover, in images containing no metal body, low contrast may be affected as observed in gray matter and white matter. Therefore, when the existence of secondary cerebral bleeding or infarction is evaluated, both images before and after application of MAR should be used. In addition, CT or MRI are required for diagnosis of the cerebral infarction of cerebral hemorrhage or an acute period using both sides of the picture with and without MAR.

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References

- 1 Johnston SC, Higashida RT, Barrow DL, et al. Recommendations for the endovascular treatment of intracranial aneurysms: a statement for healthcare professionals from the Committee on Cerebrovascular Imaging of the American Heart Association Council on Cardiovascular Radiology. *Stroke*. 2002; 33 (10): 2536-2344. doi: 10.1161/01.STR.0000034708.66191.7D.
- 2 Prell D, Kyriakou Y, Struffert T, et al. Metal artifact reduction for clipping and coiling in interventional C-arm CT. *Am J Neuroradiol*. 2010; 31 (4): 634-639. doi: 10.3174/ajnr.A1883.
- 3 Morsbach F, Bickelhaupt S, Wanner GA, et al. Reduction of metal artifacts from hip prostheses on CT images of the pelvis: value of iterative reconstructions. *Radiology*. 2013; 268 (1): 237-244. doi: 10.1148/radiol.13122089.
- 4 Rinkel J, Dillon WP, Funk T, et al. Computed tomographic metal artifact reduction for the detection and quantitation of small features near large metal implants: a comparison of published methods. *J Comput Assist Tomogr*. 2008; 32 (4): 621-629. doi: 10.1097/RCT.0b013e318149e215.
- 5 van der Bom IM, Hou SY, Puri AS, et al. Reduction of coil mass artifacts in high-resolution flat detector conebeam CT of cerebral stent-assisted coiling. *Am J Neuroradiol*. 2013; 34 (11): 2163-2170. doi: 10.3174/ajnr.A3561.
- 6 Pouratian N, Oskouian RJ Jr, Jensen ME, et al. Endovascular management of unruptured intracranial aneurysms. *J Neurol Neurosurg Psychiatry*. 2006; 77 (5): 572-578. doi: 10.1136/jnnp.2005.078469.
- 7 Ruijters D, ter Haar Romeny BM, Suetens P. GPU-accelerated digitally reconstructed radiographs. *BioMED'08: Proceedings of the Sixth IASTED International Conference on Biomedical Engineering*. Anaheim, California: ACTA Press. 2008; 431-435. Available from: <http://www.mate.tue.nl/mate/pdfs/10285.pdf>.
- 8 Perron AD. *Emergency Medicine*. Philadelphia: Saunders Elsevier; 2008. p. 753-763.
- 9 Schulze R, Heil U, Gross D, et al. Artifacts in CBCT: a review. *Dentomaxillofac Radiol*. 2011; 40 (5): 265-273. doi: 10.1259/dmfr/30642039.
- 10 Kak AC, Slaney M, editors. *Principles of Computerized Tomographic Imaging*. In: IEEE Press. Philadelphia: Society of Industrial and Applied Mathematics; 1988. p. 177-201.
- 11 Mouton A, Megherbi N, Van Slambrouck K, et al. An experimental survey of metal artefact reduction in computed tomography. *J Xray Sci Technol*. 2013; 21 (2): 193-226.
- 12 Goodenough DJ, Weaver KE. Factors related to low contrast resolution in CT scanners. *Comput Radiol*. 1984; 8 (5): 297-308. doi: 10.1016/0730-4862(84)90042-8.
- 13 Funama Y, Awai K, Nakayama Y, et al. Radiation dose reduction without degradation of low-contrast detectability at abdominal multisecton CT with a low-tube voltage technique: phantom study. *Radiology*. 2005; 237 (3): 905-910. doi: 10.1148/radiol.2373041643.
- 14 Liu JX, Chen DG. Study of helical CT low-contrast resolution and its influencing factors. *Zhongguo Yi Liao Qi Xie Za Zhi*. 2000; 24 (3): 165-167.

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