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Efficacy of Subtraction Computed Tomography Arteriography During Preoperative Embolization in Spinal Tumors

Jun Makishima,* Shuichi Yamamoto,* Shinsaku Yata,* Shohei Takasugi,* Yuji Kamata*, Shinji Tanishima† and Shinya Fujii*

**Division of Radiology, Department of Multidisciplinary Internal Medicine, Faculty of Medicine, Tottori University, Yonago 683-8504, Japan, and †Division of Orthopedic Surgery, Department of Sensory and Motor Organs, Faculty of Medicine, Tottori University, Yonago 683-8504, Japan*

ABSTRACT

Background This study aimed to evaluate the efficacy of subtraction computed tomography arteriography (s-CTA) during preoperative embolization in spinal tumors.

Methods The study analyzed 17 vertebrae in 13 patients who underwent preoperative embolization before spinal fixation surgery for malignant spinal tumors to decrease blood loss at our hospital from 2019 to 2021. Their ages ranged from 56 to 88 years (average, 73.5 years). Metastatic bone tumors were most common, including five cases originating as lung carcinomas and three as renal cancers. After digital subtraction angiography of selected tumor-feeding arteries and non-subtraction CTA (ns-CTA) were performed, s-CTA was conducted using data obtained from both procedures. A clarity score of the boundary between the normal bone and tumor was derived for each patient, which was then classified into four grades (good, 3 points; fair, 2 points; faint, 1 point; poor, 0 points) by two experienced radiologists, followed by a comparison between the s-CTA and ns-CTA groups using the Wilcoxon signed-rank test.

Results Clarity scores were significantly higher in the s-CTA group than in the ns-CTA group ($P < 0.001$). The agreement of Cohen's coefficients between the two radiologists was $\kappa = 0.724$ in s-CTA scoring and $\kappa = 0.622$ in ns-CTA scoring, which were moderately matched. Seven arteries were not embolized due to insufficient tumor contrast enhancement and their poor relation to the surgical invasion zone. No complications were observed during or after embolization.

Conclusion S-CTA successfully distinguished between tumor and normal bone and may help avoid unnecessary embolization.

Key words computed tomography; embolization; metastasis; spine; subtraction Technique

Spinal metastasis can cause serious problems, including paralysis, pain, and fractures in patients with cancer. It is often managed through decompression and immobilization surgeries. Preoperative transcatheter arterial embolization (preoperative embolization) has emerged as an effective procedure for reducing intraoperative blood loss.[1–6] Furthermore, several meta-analyses have indicated that preoperative embolization of hypervascular metastatic tumors, such as renal cell carcinomas and thyroid cancers, can reduce intraoperative blood loss.[7–9] Additionally, there are several reports on the efficacy of cone-beam computed tomography arteriography (CTA) in preoperative embolization, which produced an excellent three-dimensional configuration of tumor-feeding blood vessels and required relatively few digital subtraction angiography (DSA) runs.[10, 11] Chatani et al. reported that CTA could identify the radiculomedullary artery (RMA), which supplies the spinal cord in the preoperative embolization of spinal tumors[12]; further, subtraction CTA (s-CTA) has been used to visualize intracranial vessels during neurointervention procedures.[13] There have been studies on the utility of non-subtraction CTA (ns-CTA) for preoperative embolization; however, the usefulness of s-CTA for spinal tumors remains unclear. Ns-CTA may not distinguish among tumor enhancement, sclerotic metastasis, and osteoarthritis since they all present high density on CT scans. Contrastingly, s-CTA may differentiate among these conditions and reduce the influence of osteoarthritis on the evaluation of tumor enhancement. Therefore, this study aimed to evaluate the usefulness of s-CTA during preoperative embolization of spinal tumors.

MATERIALS AND METHODS

Patient background

This retrospective study was approved by the

Corresponding author: Jun Makishima, MD
max@tottori-u.ac.jp
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Abbreviations: DSA, digital subtraction angiography; Ns-CTA, non-subtraction computed tomography arteriography; RMA, radiculomedullary artery; S-CTA, subtraction computed tomography arteriography

Table 1. Clinical characteristics of the patients

Variables			Total (n = 13)
Average age in years (range)			73.5 (56–88)
Sex	Male		5 (38%)
	Female		8 (62%)
Tumor location	Cervical spine		1 (8%)
	Thoracic spine		12 (92%)
Tumor subtype	Metastasis	Lung cancer	5 (38%)
		Renal cell carcinoma	3 (23%)
		Hepatocellular carcinoma	1 (8%)
		Breast cancer	1 (8%)
		Rectal cancer	1 (8%)
	Primary tumor	Multiple myeloma	2 (15%)

institutional review board of our hospital (approval number 21A143). A total of 17 vertebrae were examined from 13 consecutive patients who requested embolization prior to spinal surgery, performed by orthopedic surgeons at our hospital between July 2019 and October 2021. The indications for embolization included potentially hypervascular tumors (e.g., renal cancer and thyroid cancer),[14] and cases with spinal cord compression.

Among the 13 patients, there were 5 (38%) male and 8 (62%) female patients, with a mean age of 73.5 (56–88) years. One tumor was located in the cervical spine (8%), while the remaining tumors were observed in the thoracic spine (12 [92%]). Eleven tumors were classified as metastatic (85%) and two as multiple myelomas (15%). The primary sites of metastases included five lung cancers (38%), three renal cell carcinomas (23%), one hepatocellular carcinoma (8%), one breast cancer (8%), and one rectal cancer (8%). Patient backgrounds details are shown in Table 1.

Imaging method

Prior to the procedure, contrast-enhanced CT and magnetic resonance imaging were performed to determine the vertebrae to be embolized. During the procedure, the 4-F sheath introducer (Super Sheath Medikit, Tokyo, Japan), 4-F Mikaelson catheter (Seiya, Medikit, Tokyo, Japan), and 1.9-F microcatheter (ASAHI Tellus, Asahi Intecc, Aichi, Japan; or Carnelian SI, Tokai Medical Products, Aichi Japan) were used to select the spinal segmental arteries. Spinal segmental angiography was performed before the embolization using the hybrid CT/angiography system (Infinix Aquilion PRIME 80-detector row, Toshiba Medical Systems, Japan). The DSA and CTA images of the upper and lower spinal segmental arteries as well as spinal segmental tumor-feeding arteries were obtained. Subsequently, the unenhanced CT images were treated with 4–10 mL of iopamidol (iopamirone 300 mg/mL, Bayer Healthcare, Osaka, Japan) using an automatic power injector at a rate of 0.4–0.8 mL/s under CT scanning (tube voltage, 120 kV; slice thickness, 0.5 mm; rotation time, 0.5 s) with a 5–10 s delay from the initiation of contrast injection in each session. S-CTA was created from the data of unenhanced CT and ns-CTA in a workstation (Ziostation 2 ver 2.1, Ziosoft, Tokyo, Japan) for further evaluation of the tumor staining and other feeders of the spinal cord (Fig. 1). The spinal cord blood supply was determined based on the depiction of RMAs connecting the anterior and posterior spinal arteries. All diagnostic angiography and embolization procedures were conducted within 24 h before surgery.

Embolization method

Following DSA and s-CTA, the observed enhanced areas were evaluated to determine the necessity for embolization. Embolization was not performed under the following conditions: the RMA was clearly visualized, only a small area of the tumor was enhanced, or only normal bone and soft tissue were enhanced. If embolization was considered necessary, normal branches distal to the feeding artery were first embolized by microcoils. Next, embolization was performed using hand-cut gelatin sponge particles (Spongel, LTL Pharma, Tokyo, Japan) and/or microspheres (Embosphere, φ300–500 μm, MERIT Medical Japan, Tokyo, Japan) from the spinal segmental artery proximal to the feeding arteries. The tumor-feeding arteries were embolized only if it was necessary to resect part of the tumor for spinal cord decompression or a massive hemorrhage was expected. We focused our embolization zone on tumor parts that

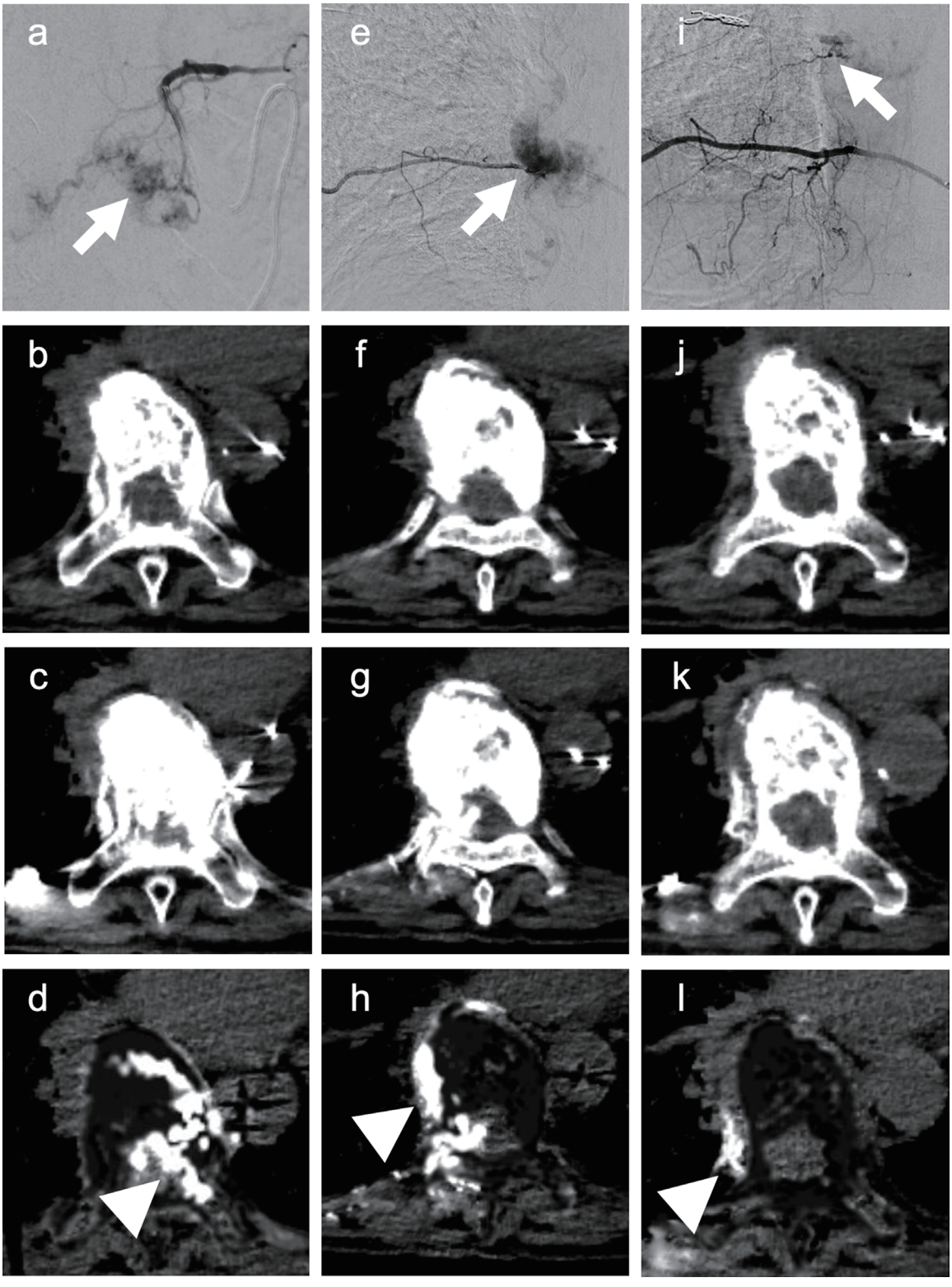

Fig. 1. Renal cell carcinoma in a 70-year-old woman. Spinal metastasis was found in the eighth thoracic vertebra. Images of DSA (**a**, **e**, **i**), unenhanced CT (**b**, **f**, **j**), ns-CTA (**c**, **g**, **k**), and s-CTA (**d**, **h**, **l**) after selection of intercostal arteries (**a–d**: left 7th, **e–h**: right 8th, **i–l**: right 9th) are shown. Tumor enhancement is identified in DSA (arrows in **a**, **e**, and **i**). Enhancement of a part of the surgical invasion zone in the tumor is more clearly identified by s-CTA (arrowheads in **d** and **h**) than by ns-CTA (**c** and **g**) prior to embolization. Contrastingly, it is more clearly identified by s-CTA (arrowhead in **l**) when enhancement does not include the surgical invasion zone than by ns-CTA (**k**). Therefore, embolization was not adopted. CT, computed tomography; DSA, digital subtraction angiography; ns-CTA, non-subtraction computed tomography arteriography; s-CTA, subtraction computed tomography arteriography.

compressed the spinal cord rather than the entire tumor. Further, the orthopedic surgeons considered the embolization zone when performing the tumor resection. This selective embolization area was defined as the surgical invasion zone. Angiography and embolization were repeated until the contrast agent stagnated.

Surgical procedures

Orthopedic surgeons calculated the spinal instability neoplastic score (SINS) as well as the new Katagiri score and/or revised Tokuhashi score before the surgery. The indications for metastatic spine surgery at our hospital are as follows: patients with metastatic spinal tumors without metastasis to other organs (in this case, total en bloc spondylectomy is indicated and embolization is not performed [not included in this study]); patients with metastatic spinal tumors that have invaded the spinal canal, leading to spinal cord disorders; and patients with metastatic spinal tumors with extensive bone destruction that require spinal stabilization.

All patients underwent palliative decompression and posterior stabilization. First, pedicle screws were placed across two or three levels above and below the affected areas. Second, laminectomy was performed one segment above and one segment below the vertebra with the tumor, with the tumor compressing the spinal cord being extensively resected. Subsequently, stabilization was performed using pedicle screws and rods across two or three levels above and below the affected areas. Estimated intraoperative blood loss and the transfusion volume were obtained from operation records for all patients.

Evaluation method

Images and medical records were evaluated by two experienced radiologists (with 15 and 7 years of radiological diagnostic experience), who assessed and scored the clarity of the boundary between the normal bone and tumor depicted by s-CTA or ns-CTA. The clarity score, which was based on a scoring system for arterial invasion of pancreatic body and tail cancer,[15] was divided into four grades: good (all boundaries between normal bone and tumor could be traced, 3 points), fair (more than half of the boundaries between normal bone and tumor could be traced, 2 points), faint (less than half of the boundaries between normal bone and tumor could be traced, 1 point), and poor (none of the boundaries between normal bone and tumor could be traced, 0 points) (Fig. 2).

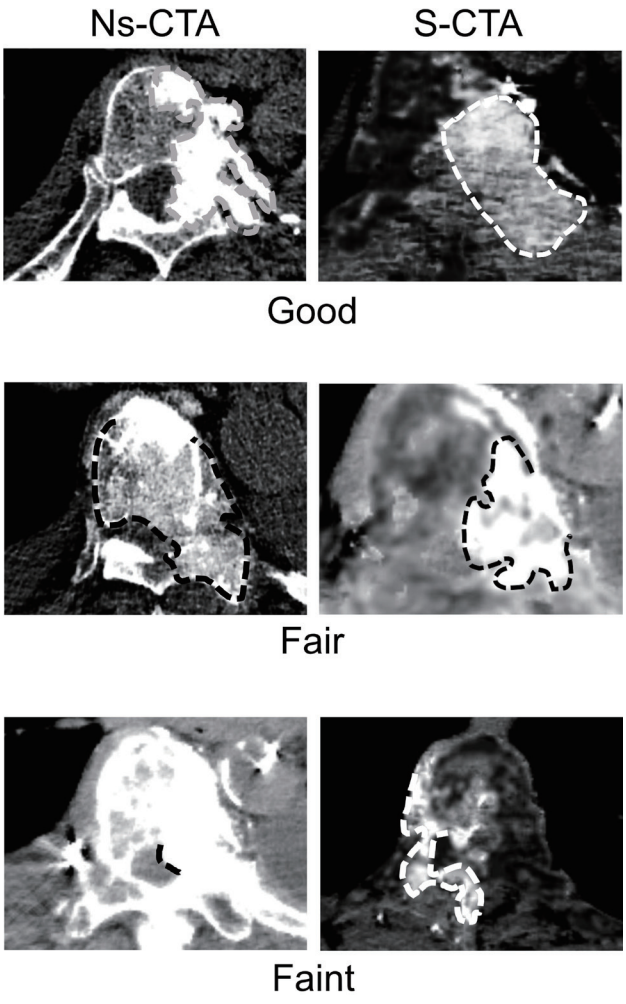

Fig. 2. Examples of clarity scores. Left, non-subtraction computed tomography arteriography; right, subtraction computed tomography arteriography. Good, fair, and faint boundaries are located in the upper, middle, and bottom rows, respectively.

Statistical analysis

Between-group comparisons of the clarity scores of s-CTA and ns-CTA were performed using the Wilcoxon signed-rank test. The difference in the clarity score between the two radiologists was compared using Cohen's coefficient of agreement ($\kappa < 0.20$, poor; $\kappa = 0.21$–0.40, fair; $\kappa = 0.41$–0.60, moderate; $\kappa = 0.61$–0.80, good; $\kappa = 0.81$–0.90, very good; $\kappa > 0.90$, excellent agreement). Further, neurological complications during and after embolization as well as postoperative complications were assessed. Statistical analyses were performed using the statistical software EZR version 1.54 (Division of Hematology, Saitama Medical Center, Jichi Medical University, Japan).[16] A probability (P) value of < 0.05 was considered statistically significant.

Table 2. Comparison of tumor subtype, intraoperative blood loss, transfusion volume for each patient, and clarity scores (description of tumor enhancement) between s-CTA and ns-CTA by two radiologists as well as Cohen's coefficient of agreements for s-CTA and ns-CTA

Patient	Level of the spine	Clarity score (Index: good, 3 points; fair, 2 points; faint, 1 point; poor, 0 points)		Tumor subtype	Intraoperative blood loss (mL)	Transfusion volume (U)
		Radiologist A (s-CTA/ns-CTA)	Radiologist B (s-CTA/ns-CTA)			
Patient 1	Th2	Faint/Faint	Faint/Faint	Renal cell carcinoma	185	0
	Th3	Good/Fair	Good/Faint			
Patient 2	Th8	Good/Faint	Good/Faint	Renal cell carcinoma	1420	3
Patient 3	Th9	Good/Fair	Good/Fair	Multiple myeloma	200	1
Patient 4	Th9	Fair/Faint	Good/Faint	Rectal cancer	50	1
Patient 5	Th10	Good/Good	Good/Good	Lung cancer	565	3
Patient 6	Th3	Fair/Faint	Fair/Fair	Lung cancer	440	0
Patient 7	Th8	Fair/Faint	Good/Faint	Lung cancer	700	1
	Th9	Good/Faint	Good/Faint			
Patient 8	C7	Good/Fair	Good/Fair	Breast cancer	230	0
Patient 9	Th11	Good/Fair	Good/Faint	Lung cancer	315	0
Patient 10	Th3	Good/Fair	Good/Fair	Lung cancer	935	0
	Th4	Good/Fair	Good/Fair			
Patient 11	Th9	Good/Good	Good/Good	Multiple myeloma	235	0
Patient 12	Th7	Good/Fair	Good/Faint	Hepatocellular carcinoma	360	0
	Th8	Fair/Faint	Good/Fair			
Patient 13	Th8	Good/Fair	Good/Faint	Renal cell carcinoma	125	0
		***$P < 0.001$	***$P < 0.001$	mean	443	0.69

Cohen's coefficient of agreement in s-CTA: $\kappa = 0.724$
Cohen's coefficient of agreement in ns-CTA: $\kappa = 0.622$

Ns-CTA, non-subtraction computed tomography arteriography; S-CTA, subtraction computed tomography arteriography.

RESULTS

Clarity score

The clarity scores were significantly higher in the s-CTA group than in the ns-CTA group ($P < 0.001$, Table 2). Identical results were obtained by both radiologists, with Cohen's coefficient of agreement of $\kappa = 0.724$ for s-CTA scoring and $\kappa = 0.622$ for ns-CTA scoring.

Preoperative embolization

A total of 52 spinal segmental arteries were selected in all patients and tumor staining was visualized by DSA. Forty-two of these arteries were embolized with particles and microcoils after s-CTA confirmed sufficient supply to the tumor. Embolized spinal segmental arteries comprised 38 intercostal arteries, three deep cervical arteries, and one bronchial artery. Three arteries were not embolized due to detection of a connection to the RMA or Adamkiewicz artery on DSA, while seven arteries were judged to be poorly related to the surgical invasion zone in the s-CTA. No neurological complications were documented during or after embolization.

Surgical procedures

The mean estimated intraoperative blood loss was 443.0 mL (range: 125–1420 mL). Transfusion was performed in five patients (one with renal cell carcinoma, two with lung cancer, one with rectal cancer, and one with multiple myeloma), and the mean transfusion volume was 0.69 U (range: 0–3 U) (Table 2). No severe surgery-related complications were recorded.

DISCUSSION

Our results indicate that s-CTA is superior to ns-CTA for clarifying spinal tumor enhancement. A primary explanation for this result lies in the better identification of tumor enhancement without the influence of sclerotic metastasis and osteosclerosis in the spines, which is present in ns-CTA. Accordingly, s-CTA appears more practical in the evaluation of preoperative embolization

of spinal metastasis. Moreover, s-CTA could facilitate identification of the tumor area, simplifying the judgment and discussion of whether embolization is required. This could eliminate unnecessary embolization of arteries that only perfused normal tissues and were not manipulated during surgery, thus potentially decreasing neurological complications. Although spinal embolization is considered relatively safe, several studies have reported complications.[7, 17–24] Griessenauer et al. reported that the overall complication rate was 3.1% in preoperative embolization of spinal tumors, which included spinal ischemia and infarction.[2]

Several studies have demonstrated the beneficial effects of preoperative embolization in reducing intraoperative blood loss in patients with hypervascular metastatic spinal tumors.[7, 8, 23, 25] Since arteries run through the vertebrae from above and below forming a network, the embolization of the upper and lower segmental arteries can further reduce the blood flow to the spinal tumor.[20, 26] Wilson et al. found that embolization with additional segments resulted in less bleeding, especially for renal cell carcinomas; however, the difference was not significant.[7] Our mean intraoperative blood loss was 443.0 mL, which was less than those reported in previous studies describing preoperative embolization (618–2,350 mL).[7–9, 27, 28] This could be partly attributed to the inclusion of non-hypervascular tumors, including lung and breast cancer, but also be that s-CTA facilitates the identification of the tumor boundary. This resulted in successful embolization involving essential vessels only and reduced blood loss. Thus, the accurate description of the tumor boundary using s-CTA strongly aided the operation process with reduced intraoperative blood loss, compared to those reported in previous studies.

The boundaries between normal bone and tumor in some patients were judged as faint or fair by both radiologists. This could be attributed to several reasons, including the lack of contrast enhancement despite the metastasis of the hypervascular tumor (e.g. renal cell carcinoma and lung cancer), failure of s-CTA creation due to body movements during the procedure, and difficulty in viewing CT images due to artifacts caused by metal or other factors.

S-CTA may be beneficial not only for preoperative spinal embolization but also for other applications. For example, Dae et al. reported the usefulness of cone-beam contrast-enhanced CT in preoperative embolization of hypervascular tumors in the pelvic bone.[11] In their study, vessel visibility was improved by digitally subtracting nearby bones and organs from three-dimensionally reconstructed arteries. Alternatively, our study successfully adopted the subtraction technique to distinguish between contrasted metastasis, non-contrasted osseous metastasis, and degeneration. Therefore, such subtraction techniques may be useful in distinguishing areas for embolization in metastasis of the pelvic bone as well as other bones.

There are some limitations to this study. First, the sample size was not large enough to draw several conclusions. For instance, fewer cases of hepatocellular and renal cell carcinoma were examined compared with other studies, which might have contributed to a reduction in the observed blood loss. Second, our κ value was not very high. This may be due to fluctuations resulting from one radiologist setting the boundary more strictly or leniently. Accordingly, there is a need to establish a systematic method of diagnosis, including the use of artificial intelligence. Finally, we did not consider the effects of the increased radiation dose due to the non-contrast CT performed before the contrast CT.

In conclusion, s-CTA successfully captured the distinction between tumor staining and normal bone, which reduced unnecessary embolization. These findings can reduce surgical complications and lead to safer preoperative embolization of spinal tumors; however, larger studies are warranted to further evaluate the efficacy of s-CTA.

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REFERENCES

1 Wahood W, Alexander AY, Yolcu YU, Brinjikji W, Kallmes DF, Lanzino G, et al. Trends in utilization of preoperative embolization for spinal metastases: A study of the National Inpatient Sample 2005-2017. Neurointervention. 2021;16:52-8. DOI: 10.5469/neuroint.2020.00381, PMID: 33657312

2 Griessenauer CJ, Salem M, Hendrix P, Foreman PM, Ogilvy CS, Thomas AJ. Preoperative embolization of spinal tumors: A systematic review and meta-analysis. World Neurosurg. 2016;87:362-71. DOI: 10.1016/j.wneu.2015.11.064, PMID: 26704206

3 Facchini G, Parmeggiani A, Peta G, Martella C, Gasbarrini A, Evangelisti G, et al. The role of percutaneous transarterial embolization in the management of spinal bone tumors: a literature review. Eur Spine J. 2021;30:2839-51. DOI: 10.1007/s00586-021-06963-5, PMID: 34415449

4 Chiras J, Gaston A, Gaveau T, Sellier N, Marsault C, Bories J. [Preoperative embolization in spinal pathology. Apropos of 21 cases]. J Radiol. 1983;64:397-403. PMID: 6620224

5 Roscoe MW, McBroom RJ, Louis S, Grossman H, Perrin R. Preoperative embolization in the treatment of osseous metastases from renal cell carcinoma. Clin Orthop Relat Res. 1989;238:302-7. DOI: 10.1097/00003086-198901000-00042, PMID: 2910614

6 Gellad FE, Sadato N, Numaguchi Y, Levine AM. Vascular metastatic lesions of the spine: preoperative embolization. Radiology. 1990;176:683-6. DOI: 10.1148/radiology.176.3.2389026, PMID: 2389026

7 Wilson MA, Cooke DL, Ghodke B, Mirza SK. Retrospective analysis of preoperative embolization of spinal tumors. Am J Neuroradiol. 2010;31:656-60. DOI: 10.3174/ajnr.A1899, PMID: 19942697

8 Clausen C, Dahl B, Frevert SC, Hansen LV, Nielsen MB, Lönn L. Preoperative embolization in surgical treatment of spinal metastases: single-blind, randomized controlled clinical trial of efficacy in decreasing intraoperative blood loss. J Vasc Interv Radiol. 2015;26:402-412.e1. DOI: 10.1016/j.jvir.2014.11.014, PMID: 25636672

9 Nair S, Gobin YP, Leng LZ, Marcus JD, Bilsky M, Laufer I, et al. Preoperative embolization of hypervascular thoracic, lumbar, and sacral spinal column tumors: technique and outcomes from a single center. Interv Neuroradiol. 2013;19:377-85. DOI: 10.1177/159101991301900317, PMID: 24070089

10 Bai J, Bakula A, Fellows DW, Ollenschleger MD, Kureshi IU, Spiegel GR. Novel application of 3-dimensional rotational C-arm conebeam computed tomography angiography for metastatic hypervascular tumor mass in the spine. Spine. 2014;39:E300-3. DOI: 10.1097/BRS.0000000000000128, PMID: 24253797

11 Park DY, Kim H-C, Chung JW, Hur S, Kim M, Lee M, et al. Correction: cone-beam computed tomography with automated bone subtraction in preoperative embolization for pelvic bone tumors. PLoS One. 2017;12:e0181645. DOI: 10.1371/journal.pone.0181645

12 Chatani S, Haimoto S, Sato Y, Hasegawa T, Murata S, Yamaura H, et al. Preoperative Embolization of Spinal Metastatic Tumor: The Use of Selective Computed Tomography Angiography for the Detection of Radiculomedullary Arteries. Spine Surg Relat Res. 2021;5:284-91. DOI: 10.22603/ssrr.2020-0202, PMID: 34435153

13 Gözer H, Heimberger K, Schindler E. Spiral CT angiography with digital subtraction of extra- and intracranial vessels. J Comput Assist Tomogr. 1994;18:839-41. DOI: 10.1097/00004728-199409000-00031, PMID: 8089342

14 Tan BWL, Zaw AS, Rajendran PC, Ruiz JN, Kumar N, Anil G. Preoperative embolization in spinal tumour surgery: enhancing its effectiveness. J Clin Neurosci. 2017;43:108-14. DOI: 10.1016/j.jocn.2017.05.021, PMID: 28629680

15 Watanabe S, Kobayashi N, Kubota K, Sato T, Kato S, Hosono K, et al. A novel scoring system for arterial invasion of pancreatic body and tail cancer based on multidetector row computed tomography and biomarkers. Pancreatology. 2013;13:161-9. DOI: 10.1016/j.pan.2012.12.364, PMID: 23561974

16 Kanda Y. Investigation of the freely available easy-to-use software 'EZR' for medical statistics. Bone Marrow Transplant. 2013;48:452-8. DOI: 10.1038/bmt.2012.244, PMID: 23208313

17 Jackson RJ, Gokaslan ZL, Arvinloh S-C. Metastatic renal cell carcinoma of the spine: surgical treatment and results. J Neurosurg Spine. 2001;94(suppl):18-24. DOI: 10.3171/spi.2001.94.1.0018, PMID: 11147860

18 Houten JK, Swiggett SJ, Hadid B, Choueka DM, Kinon MD, Buciuc R, et al. Neurologic complications of preoperative embolization of spinal metastasis: A systemic review of the literature identifying distinct mechanisms of injury. World Neurosurg. 2020;143:374-88. DOI: 10.1016/j.wneu.2020.08.006, PMID: 32805465

19 Finstein JL, Chin KR, Alvandi F, Lackman RD. Postembolization paralysis in a man with a thoracolumbar giant cell tumor. Clin Orthop Relat Res. 2006;453:335-40. DOI: 10.1097/01.blo.0000229304.59771.a3, PMID: 16936586

20 Berkefeld J, Scale D, Kirchner J, Heinrich T, Kollath J. Hypervascular spinal tumors: influence of the embolization technique on perioperative hemorrhage. AJNR Am J Neuroradiol. 1999;20:757-63. PMID: 10369341

21 Fernandez-Torron R, Palma J-A, Riverol M, Irimia P, Martinez-Vila E. Brown-sequard syndrome after endovascular embolization of vertebral hemangioma. Spinal Cord. 2012;50:636-7. DOI: 10.1038/sc.2012.3, PMID: 22310318

22 Voelker A, Osterhoff G, Einhorn S, Ebel S, Heyde CE, Pieroh P. Does the anatomical region predict blood loss or neurological deficits in embolized renal cancer spine metastases? A single-center experience with 31 patients. World J Surg Oncol. 2022;20:208. DOI: 10.1186/s12957-022-02676-1, PMID: 35710422

23 Tang B, Ji T, Guo W, Tang X, Jin L, Dong S, et al. Which is the better timing between embolization and surgery for hypervascular spinal tumors, the same day or the next day? Medicine (Baltimore). 2018;97:e10912. DOI: 10.1097/MD.0000000000010912, PMID: 29879030

24 Gong Y, Wang C, Liu H, Liu X, Jiang L. Only tumors angiographically identified as hypervascular exhibit lower intraoperative blood loss upon selective preoperative embolization of spinal metastases: systematic review and meta-analysis. Front Oncol. 2021;10:597476. DOI: 10.3389/fonc.2020.597476, PMID: 33585214

25 Nambu K, Kawahara N, Kobayashi T, Murakami H, Ueda Y, Tomita K. Interruption of the bilateral segmental arteries at several levels: influence on vertebral blood flow. Spine. 2004;29:1530-4. DOI: 10.1097/01.BRS.0000131420.32770.06, PMID: 15247574

26 Komiyama M. [Functional vascular anatomy of the spine and spinal cord]. No Shinkei Geka. 2013;41:481-92. PMID: 23732759

27 Hong CG, Cho JH, Suh DC, Hwang CJ, Lee DH, Lee CS. Preoperative embolization in patients with metastatic spinal cord compression: mandatory or optional? World J Surg Oncol. 2017;15:45. DOI: 10.1186/s12957-017-1118-3, PMID: 28193282

28 Kato S, Hozumi T, Takaki Y, Yamakawa K, Goto T, Kondo T. Optimal schedule of preoperative embolization for spinal metastasis surgery. Spine. 2013;38:1964-9. DOI: 10.1097/BRS.0b013e3182a46576, PMID: 23917645