Intratumoral Flow Void Diameter on Magnetic Resonance Imaging Predicts Hypervascularity in Metastatic Spinal Tumors

Yuji Ishino, Satoshi Kato, Noriaki Yokogawa, Takaki Shimizu, Kazuhiro Nanpo, Megumu Kawai, Narimichi Takino, Yuji Ishino

INTRODUCTION:

Massive intraoperative blood loss remains a significant challenge in metastatic spinal tumor surgery (MSTS). Digital subtraction angiography (DSA) is the gold standard for evaluating tumor vascularity, but its invasive nature, high cost, and reliance on specialized expertise limit routine use. While primary tumor type is often used as a surrogate vascularity marker, its reliability is compromised by intratumoral heterogeneity. Even within the same tumor type, vascularity can vary significantly, leading to inaccurate assessment and missed embolization opportunities. A noninvasive, reproducible imaging biomarker is needed. Intratumoral flow void (IFV), seen as serpiginous, tubular signal voids on non-contrast MRI, represent intratumoral vessels and may serve as such a marker. However, the diagnostic significance of IFV morphology—especially diameter—has not been systematically analyzed. To evaluate whether maximum IFV diameter (IFVd) on standard MRI more accurately identifies hypervascular metastatic spinal tumors than primary tumor classification, using DSA as the reference. Secondary aims were to determine an optimal IFVd threshold, assess interobserver reliability, and examine implications for preoperative embolization.

METHODS:

This retrospective study included 134 patients who underwent en-bloc spondylectomy and preoperative DSA with embolization between 2010 and 2023. MRI was performed within 14 days prior to surgery using standard T1-, T2-, and STIR sequences (3.0-T, 3-mm slices, non-contrast). Two spine surgeons independently measured the largest tubular IFVd per lesion; absent IFVs were recorded as 0 mm. The mean value was used for analysis. Interobserver reliability was assessed using intraclass correlation coefficient (ICC). DSA within 3 days preoperatively graded tumors from 0 to 4, with grades 3 and 4 considered hypervascular. Flow voids were identified as serpiginous low-signal structures within the tumor, as illustrated in Figure 1, which shows both representative MR imaging and schematic depiction of IFVs. Correlations between IFVd, DSA grade, and primary tumor type were analyzed using Spearman's ρ. Receiver operating characteristic (ROC) analysis determined the optimal IFVd threshold for detecting hypervascularity, and diagnostic performance (sensitivity, specificity, accuracy, PPV, NPV) was compared between IFVd and primary tumor classification.

RESULTS: Intratumoral flow void were observed in 131 of 134 tumors (97.8 percent). The mean IFVd was 2.0 ± 0.8 mm (ICC = 0.82; 95 percent CI, 0.78–0.86), increasing progressively with DSA grade: 0.83, 1.54, 1.84, 2.65, and 3.90 mm for grades 0 to 4, respectively. Demographic and oncologic characteristics stratified by hypervascular status are presented in Table 1, which shows that tumors with DSA grades 3 or 4 had significantly larger IFVd than non-hypervascular tumors (2.7 mm vs 1.7 mm, $p < 0.01$). IFVd strongly correlated with DSA grade ($\rho = 0.73$, $p < 0.001$), while primary tumor type showed only modest correlation ($\rho = 0.39$, $p < 0.001$). ROC analysis identified an optimal IFVd cutoff of 2.5 mm (AUC = 0.91), yielding sensitivity 77.1 percent, specificity 97.6 percent, PPV 94.7 percent, NPV 87.0 percent, and accuracy 88.8 percent. Diagnostic performance metrics for IFVd and primary tumor classification are summarized in Table 2. Compared to IFVd, classification by tumor histology had lower accuracy (64.2 percent) and markedly lower specificity (60.7 percent).

DISCUSSION AND CONCLUSION:

This is the first study to validate IFVd on non-contrast MRI as a quantitative and reproducible marker of tumor vascularity in metastatic spinal tumors. An IFVd ≥ 2.5 mm was highly predictive of DSA-determined hypervascularity and outperformed primary tumor type classification. The physiological basis is supported by Poiseuille's law, in which flow increases exponentially with vessel diameter. Since IFVs reflect high-velocity blood flow in enlarged intratumoral vessels, IFVd represents an anatomically and hemodynamically meaningful indicator of bleeding risk. Compared with advanced perfusion-based modalities such as DCE-MRI or CT-DSA, IFVd measurement requires no contrast, radiation, or specialized processing, and can be integrated into routine MRI protocols. In conclusion, IFV diameter ≥ 2.5 mm on standard MRI is a reliable, noninvasive marker of hypervascularity in metastatic spinal tumors, demonstrating superior diagnostic performance over primary tumor classification. Incorporating this measure into preoperative workflows can improve embolization planning and reduce intraoperative hemorrhage, especially in settings where advanced angiography is not feasible.

Figure1

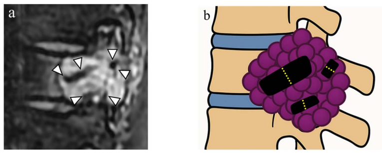

TABLE 1

Demographic, Oncological and Radiological Characteristics of Patients with Hypervascular or Non-hypervascular Tumors on DSA

Characteristics	Total (n=134)	Hypervascular (n=50)	Non-hypervascular (n=84)	P-value
Age, mean (SD)	57.2 (11.3)	56.1 (11.4)	59.0 (11.2)	0.19
Gender, n (%)				0.82
Male	78 (58.2)	30 (38.4)	48 (61.5)	
Female	56 (41.8)	20 (35.7)	36 (64.3)	
BMI, mean (SD)	22.5 (3.2)	22.1 (3.0)	22.8 (3.2)	0.23
Primary tumor n (%)				NA
Renal cell carcinoma	51 (38.1)	25 (49.0)	26 (51.0)	
Breast carcinoma	19 (14.2)	6 (31.6)	13 (68.4)	
Thyroid carcinoma	15 (11.2)	9 (60.0)	6 (40.0)	
Lung carcinoma	13 (9.7)	3 (23.1)	10 (76.9)	
Colorectal carcinoma	6 (4.5)	2 (33.3)	4 (66.7)	
Leiomyosarcoma	5 (3.7)	2 (40.0)	3 (60.0)	
Bladder carcinoma	3 (3.2)	0 (0.0)	3 (100)	
Hepatocellular carcinoma	2 (2.2)	1 (50.0)	1 (50.0)	
Parotid carcinoma	2 (2.2)	1 (50.0)	1 (50.0)	
Gastrointestinal tumor	2 (2.2)	0 (0.0)	2 (100)	
Esophageal carcinoma	2 (2.2)	0 (0.0)	2 (100)	
Others	14 (10.4)	1 (7.1)	13 (92.9)	
Tumor location n (%)				0.84
Thoracic	98 (72.3)	36 (36.7)	62 (63.2)	
Lumbar	36 (27.6)	14 (38.9)	22 (61.1)	
Presence of IFV	131 (97.8)	50 (100)	81 (96.4)	0.25
IFV diameter, mean (SD)	2.0 (0.8)	2.7 (0.65)	1.7 (0.53)	**<0.01***

Abbreviations: DSA, digital subtraction angiography; IFV, intratumoral flow void; NA, not applicable.

Others include malignant melanoma, pharyngeal cancer, maxillary cancer, submandibular gland cancer, thymic carcinoma, gastric cancer, adrenocortical carcinoma, endometrial cancer, ureteral cancer, testicular cancer, prostate cancer, liposarcoma, angiosarcoma, and epithelioid sarcoma.

Data are expressed as mean ± SD or number (%). For continuous variables, Welch's t-test was used if normality was assumed and variances were unequal; for categorical variables, the chi-square test or Fisher's exact test was used if the expected count in any cell was <5. *Statistical significance was defined as $p < 0.05$

TABLE 2

Diagnostic Performance of IFV Diameter and Primary Tumor Type in Predicting Angiographic Hypervascular Tumors

Diagnostic variable	Cutoff/ Method	Sensitivity (95%CI)	Specificity (95%CI)	PPV (95%CI)	NPV (95%CI)	Accuracy (95%CI)	AUC (95%CI)	P-value
IFV diameter, mean (SD)	2.5mm	77.6 (64.1-87.0)	97.6 (91.8-99.4)	95.0 (83.5-98.6)	95.0 (83.5-98.6)	88.3 (80.2-93.3)	0.91 (0.85-0.96)	**<0.001***
Primary tumor type	Binary Classification	70.0 (57.3-82.7)	60.7 (50.3-71.1)	51.5 (39.6-63.4)	77.3 (67.2-87.4)	64.2 (56.1-72.3)	0.66 (0.56-0.72)	**<0.001***

Abbreviations: DSA, digital subtraction angiography; IFV, intratumoral flow void; PPV, positive predictive value; NPV, negative predictive value; AUC, area under the curve

Method: Binary classification based on primary tumor type (Hypervascular = renal cell carcinoma, hepatocellular carcinoma, and thyroid carcinoma; Non-hypervascular = other tumor types)

*Statistical significance defined as $p < 0.05$