Original Article
Multi-modal magnetic resonance imaging in efficacy assessment of combined therapy for glioma

Weiqing Wang[1], Longxian Gai[2], Weihua Liu[1], Xuejian Liu[2], Juan Xiang[3], Xia Wu[2]

Departments of [1]Radiology, [2]Oncology, The Third People's Hospital of Linyi, Linyi, Shandong Province, China; [3]Department of Medicine, Linyi City Dermatology Hospital, Linyi, Shandong Province, China

Abstract: Objective: To study the application of multi-modal magnetic resonance imaging (MRI) in efficacy assessment of therapy for glioma. Methods: We enrolled 108 patients with glioma confirmed by biopsy in this retrospective study. They were randomized into the observation group (n = 54) and the control group (n = 54). Multi-modal MRI was used in the observation group and CT scan was used in the control group to detect the normal and cancer tissues in brain for apparent diffusion coefficient (ADC), early-phase enhancement rate, and the type of dynamic contrast enhanced time intensity curve (TIC) shape. The detections were performed again after surgical resection of glioma and chemoradiotherapy. The rate of complete resection after the first surgery and the differences in the ADC before and after chemoradiotherapy were compared between the two groups. The early-phase enhancement rate and the type of TIC shape of the cancer tissue before and after chemoradiotherapy were compared with those of the normal tissue. The association between patients' survival rates and the results of multi-modal MRI were also analyzed. Results: The difference in the ADC before and after chemoradiotherapy was statistically significant in both groups (both P < 0.05). The rate of complete resection after the first surgery was significantly lower in the observation group than in the control group (P < 0.05). There were statistical differences betwen the early-phase enhancement rates of the normal tissues and those of the cancer tissues before and after chemoradiotherapy (all P < 0.001). The type of TIC shape of the normal tissue was persistent enhancement, while that of the tumor tissue was mostly high enhancement with plateau before chemoradiotherapy and was persistent enhancement in 79.63% of cases after chemoradiotherapy. The difference in the type of TIC shape was statistically significant (P < 0.001). In the observation group, the one-year survival rate was 90.74%, the three-year survival rate was 79.63%, and the five-year survival rate was 66.67%, all significantly higher than those of the control group (all P < 0.001). Conclusion: Multi-modal MRI provides accurate information about the ADC and early-phase enhancement rate of the tissues, the rate of complete resection of cancer tissues, and semi-quantitative analysis by TIC. Moreover, it compares the tissues before and after chemoradiotherapy to determine the effectiveness of the treatment, and then provides reference for planning of subsequent treatment.

Keywords: Multi-modal MRI, glioma, CT scan, chemoradiotherapy, efficacy assessment

Introduction

Glioma is the most common type of primary brain tumor with a high incidence, accounting for about 60% of intracranial tumors, and considered as one of the refractory brain tumors in neurosurgical treatment [1]. Due to the aggressive tumor growth, the overall efficacy of treatment is poor. High-grade glioma is characterized by anaplasia, thereby resulting in a high recurrence rate and poor prognosis, thus rendering it a serious threat to human health [2]. At present, surgical resection combined with chemoradiotherapy is a major therapy for glio-

ma. However, the effects of the treatment vary due to the complex structure of the brain featuring small and numerous functional units, and different sensitivity of each patient to chemoradiotherapy. Therefore, efficacy assessment is the key to the subsequent planning for glioma treatment [3].

Studies have shown that multi-modal magnetic resonance imaging (MRI) has high accuracy in distinguishing between tumors and normal tissues, thanks to its sensitivity for delineating soft tissues [4]. Multi-modal MRI is a system for imageological examination with various func-

tions, including dynamic susceptibility contrast material-enhanced (DSC) MRI, diffusion-weighted imaging (DWI), and susceptibility-weighted imaging (SWI) [5]. Different from other conventional imaging devices, multi-modal MRI can monitor tumor location in real time and has higher sensitivity for soft tissues, as it can effectively identify tumor and normal tissues, and explicitly reveal the differentiation of cancer tissues and tumor grades [6]. The integration of multiple functions enables multi-modal MRI to be more accurate for diagnosis and evaluation of tumor diseases, which is conducive to the efficacy evaluation of treatment. This advantage, in turn, will help plan and carry out subsequent treatment [7]. Therefore, this study focused on the role of multi-modal MRI in the efficacy assessment of the surgery and chemoradiotherapy for glioma. It was designed to provide evidence for the clinical efficacy assessment of chemoradiotherapy and the improvement in the efficacy of glioma treatment.

Materials and methods

General information

A total of 108 patients diagnosed with glioma by biopsy were recruited in this study after approval from the Ethics Committee of The Third People's Hospital of Linyi. Inclusion criteria: Patients who met the diagnostic criteria for glioma defined by *The 2016 World Health Organization Classification of Tumors of the Central Nervous System* and by conventional molecular diagnosis; patients with glioma confirmed by biopsy; patients who received surgery from the same group of doctors; patients who never received chemoradiotherapy; patients who volunteered to participate in the study and signed informed consent [8]. Exclusion criteria: Patients with behavioral or mental disorders; patients who were pregnant or lactating women; patients who underwent cardiac surgery or implanted with pacemaker or prosthetic valve; patients who underwent aneurysm surgery or had aneurysm clips; patients who had metallic implants in the body or in the eyes; patients who were accompanied by other diseases that would affect the results of this study.

Methods

We enrolled 108 patients with glioma confirmed by biopsy to this retrospective study.

They were randomized into the observation group (n = 54) and the control group (n = 54). Multi-modal MRI was used in the observation group, and CT scan was applied in the control group to detect the normal and cancer tissues in brain for apparent diffusion coefficient (ADC), early-phase enhancement rate, and the type of dynamic contrast enhanced time intensity curve (TIC) shape. The control group received examination using Siemens Scope 16-Slice CT scanner (Siemens, Germany). With Signa HDxt 3.0 T magnetic resonance scanner (GE Healthcare, China), the observation group received routine MRI including transverse T1-weighted imaging (T1WI), T2-weighted imaging, fluid-attenuated inversion recovery, and DWI, sagittal T1WI, and contrast-enhanced transverse, coronal and sagittal T1WI [9]. Functional MRI was performed using a Philips Ingenia 3.0T Magnetic Resonance System (Royal Philips Electronics, the Netherlands) [10]. The values of the parameters of pulsed-continuous arterial spin labeling were set as: repetition time (TR), 400 ms; echo time (TE), 16 ms; matrix size, 128 * 128; field of view (FOV), 240 mm * 240 mm. Diffusion tensor imaging (DTI) was performed using spin-echo echo-planar imaging sequence with 36 directions of diffusion. The values of the parameters of DTI were set as: b, 0 s/mm^2 and 800 s/mm^2; TR, 1,677 ms; TE, 83 ms; matrix size, 144 * 144; FOV, 220 mm * 220 mm. The values of the parameters of SWI were set as: TR, 31 ms; TE, minimum; matrix size, 768 * 768; FOV, 230 mm * 230 mm. Point-resolved spectroscopy sequence was applied for ^{1}H-Magnetic Resonance Spectroscopy, with the values of the parameters set as: TR, 1,000 ms; TE, 144 ms. Tumors were located using axial and sagittal T2-weighted images. After the first surgical resection, the rate of complete resection was measured in both groups, and chemoradiotherapy was tailored to the specific conditions of each patient. In 1997, the World Health Organization classified gliomas into four grades according to their degree of malignancy, of which grade I-II were referred to as low-grade and grade III-IV as high-grade. Patients with low-grade gliomas have good prognosis, but those with high-grade gliomas have poor prognosis with markedly shortened survival period and substantially elevated recurrence rates after surgery [11].

Table 1. Comparison of baseline characteristics

	The control group (n = 54)	The observation group (n = 54)	t/χ^2/H	P
Gender			0.162	0.693
Male	32	34		
Female	22	20		
Mean age (year)	32.28 ± 3.23	32.32 ± 3.26	0.064	0.949
Mean tumor volume/mm³	27.96 ± 2.14	28.01 ± 2.17	0.122	0.901
Tumor grade/cases (n/%)			0.232	0.891
I	0 (0.00)	0 (0.00)		
II	25 (46.30)	26 (48.15)		
III	17 (31.48)	18 (33.33)		
IV	12 (22.22)	10 (18.52)		
Tumor site/cases (n/%)			0.214	0.972
Temporal lobe	21 (38.89)	22 (40.74)		
Frontal lobe	13 (24.07)	14 (25.93)		
Parietal lobe	15 (27.78)	14 (25.93)		
Occipital lobe	5 (9.26)	4 (7.40)		
BMI (kg/m²)	25.84 ± 4.70	25.41 ± 4.27	0.498	0.620

Note: BMI: body mass index.

Measurements

The rate of complete resection after the first surgery and ADC before and after chemoradiotherapy were compared between the two groups. ADC was calculated as ln(S2-S1)/(b1-b2). Early-phase enhancement rate and the type of TIC shape were compared among normal tissues and cancer tissues before and after chemoradiotherapy. Early-phase enhancement rate was calculated as (SIc-SI)/SI * 100% (SIc: signal intensity on contrast-enhanced image; SI: signal intensity on image before contrast enhancement). One-, three-, and five-year survival rates were compared between the two groups.

Statistical analysis

All statistical data were processed using SPSS 21.0 software package. Measurement data are expressed as mean ± standard deviation ($\bar{x}$ ± sd). Comparisons between two groups were based on independent t-tests. The Wilcoxon rank-sum test was used for ranked variables, denoted by H. All the enumeration data are expressed as cases/percentage (n/%), and were compared based on chi-squared tests and F-tests. P < 0.05 was considered to be statistically significant.

Results

Baseline characteristics

There were no statistical differences between the two groups in baseline characteristics including gender, age, body mass index, etc. (all P > 0.05). See **Table 1**.

Comparison of rates of complete resection after the first surgery and the ADC values before and after chemoradiotherapy

The rate of complete resection after the first surgery in the observation group was significantly lower than that of the control group (53.70% vs. 75.93%, P < 0.05, χ^2 = 5.850). There were significant differences in the ADC value between the two groups before and after chemoradiotherapy (P = 0.002, P < 0.001). See **Table 2**, **Figures 1** and **2**.

Comparison of early-phase enhancement rates and types of TIC shape

The early-phase enhancement rate of normal tissues was 3.70%, which was significantly different from that of cancer tissue before and after chemoradiotherapy (55.56% and 10.19%, respectively). The differences in the early-phase enhancement rates of cancer tissue before and after chemoradiotherapy were also statistically significant (P < 0.001, χ^2 = 96.910). The type of TIC shape of normal tissue was persistent enhancement, while that of tumor tissue was mostly high enhancement with plateau before chemoradiotherapy (86.11%), and was persistent enhancement after chemotherapy in most cases (79.63%). The differences in the types of TIC shape before and after chemoradiotherapy were statistically significant (P < 0.001, χ^2 = 191.01). See **Table 3**, **Figures 3** and **4**.

Comparison of survival rates

The one-, three-, five-year survival rates of the observation group were all significantly higher

Table 2. Comparison of ADC values (($\bar{x}$ ± sd) * 10^3 mm^2/s) and rates of complete resection (n (%))

	Rate of complete resection after the first surgery	ADC of cancer tissue before chemoradiotherapy	ADC of cancer tissue after chemoradiotherapy
The observation group (n = 54)	29 (53.70)	1.07 ± 0.24	1.37 ± 0.11
The control group (n = 54)	41 (75.93)	1.21 ± 0.22	1.45 ± 0.12
P	0.015	0.002	0.000
t/χ^2	5.850	3.160	3.611

Note: ADC: apparent diffusion coefficient.

Figure 1. Comparison of rates of complete resection after the first surgery.

Figure 2. Comparison of ADC values between two groups before and after chemoradiotherapy. Compared with the control group, *P < 0.05. ADC: apparent diffusion coefficient.

than those of the control group (90.74% vs. 70.37%, 79.63% vs. 50.00%, and 66.67% vs. 38.89% respectively; all P < 0.001). See **Figure 5**.

Discussion

Glioma is the most common type of primary malignant brain tumor and is regarded as a neurosurgical disease with high incidence, reoccurrence and mortality rates [12]. It has been reported that the development of glioma is the result of both exogenous pathogenic factors and genetic susceptibility that cause carcinogenic mutations in glial cells at the cellular genetic and epigenetic levels [13]. But the integrity of the theory has not been proved, and it is difficult to carry out the clinical treatment to cure glioma. Therefore, as an indirect approach to improve the prognosis, the early evaluation of treatment efficacy provides reference for the subsequent planning of chemoradiotherapy. The expansion of the size of glioma can cause mass effect, causing such clinical symptoms as headache, nausea, vomiting and blurred vision, and reducing patients' quality of life due to
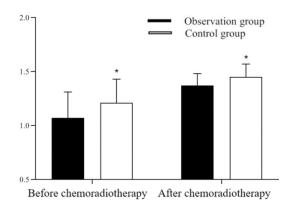
obstruction of blood circulation, an increase in venous blood pressure and accumulation of fluid in the interstitial space [14]. Studies have shown that surgical resection combined with chemoradiotherapy is currently a preferred treatment for patients with glioma, but the same dosage and course of treatment of chemoradiotherapy may result in different therapeutic effects due to individual differences in the sensitivity to chemoradiotherapy [15]. Therefore, the treatment efficacy needs to be evaluated to screen patients with poor sensitivity, so that chemoradiotherapy can be tailored to the patient's condition to improve treatment efficiency and survival [16].

Rohde et al. found that multi-modal MRI had a unique advantage of producing images with different modalities, allowing it to distinguish the differences between tissues and identify the location and volume of cancer tissues, all in a way clearer and accurate than CT-scan and X-ray [17]. In multi-modal MRI, DSC can track foreign markers, locate tumors in real time, and observe the effectiveness of chemotherapy drugs in tumors [18]; magnetic resonance spectroscopy can perform quantitative analy-

Table 3. Comparison of early-phase enhancement rates and types of TIC shape (n (%))

Groups	Normal tissue (n = 108)	Cancer tissue before chemoradiotherapy (n = 108)	Cancer tissue after chemoradiotherapy (n = 108)	P	χ^2
Early-phase enhancement rate	4 (3.70)	60 (55.56)	11 (10.19)	0.000	96.910
TIC (persistent enhancement)	108 (100.00)	15 (13.89)	86 (79.63)	0.000	191.071

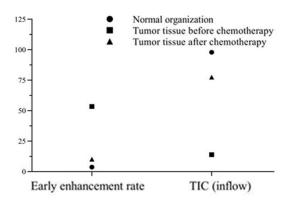Note: TIC: dynamic contrast-enhanced time-intensity curve.

Figure 3. Comparison of early-phase enhancement rates and types of TIC shape between normal tissues and tumor tissues before and after chemoradiotherapy.

sis of human tissues based on magnetic resonance imaging, and effectively distinguish tumors from normal tissues [19]; DWI can reflect the degree of malignancy of the tumor with ADC, a quantitative parameter; lower ADC values indicate more malignant tumors [20]; SWI can effectively identify tumor grade by the degree of intratumoral susceptibility signals; the greater the degree, the higher the tumor grade is [21]. Therefore, multi-modal MRI can be effective in distinguishing normal soft tissues and cancer tissues, and in identifying the degree of malignancy of the tumor. It can be applied to evaluation of the efficacy of chemoradiotherapy after surgery of glioma resection and the analysis of changes in parameters before and after chemoradiotherapy, so as to assess the effect of chemoradiotherapy on tumor cells [22].

A previous study showed that multi-modal MRI is more accurate than CT scans and other detection equipment in detecting the volume and location of tumors. Higher accuracy in detection is conducive to improvement in the detection rates of residual tumor after resection, thereby allowing the individualized treatment plan to be consistent with the patient's

condition and improving patient's treatment effect and prognosis [23]. The results of this study showed that the difference in the ADC before and after chemoradiotherapy was statistically significant in both groups. The rate of complete resection after the first surgery in the control group was significantly higher than that in the observation group, indicating that CT scan has higher detection rates of complete resection than MRI. Therefore, the control group had smaller dosage and shorter course of treatment than the observation group during chemoradiotherapy following surgery due to a lower rate of complete resection measured by MRI. The early-phase enhancement rate of normal tissues was significantly different from that of cancer tissues before and after chemoradiotherapy, and there was also significant difference in the early-phase enhancement rate of cancer tissues before and after chemoradiotherapy. The type of TIC shape of normal tissue was persistent enhancement, while that of tumor tissue was high enhancement with plateau in most cases before chemoradiotherapy and persistent enhancement after chemoradiotherapy. There were significant differences in the types of TIC shape before and after chemoradiotherapy, indicating that there were differences in the early-phase enhancement rates and the types of TIC shape not only between normal tissues and cancer tissues before and after chemoradiotherapy, but also between cancer tissues before and after chemoradiotherapy. After chemoradiotherapy, cancer tissues were higher in ADC value, but significantly lower in the early-phase enhancement rate, and the type of TIC shape changed from high enhancement with plateau to persistent enhancement in most cases. The findings showed that the type of TIC shape of cancer tissues after chemoradiotherapy was the same as that of normal tissues in the observation group, suggesting that patients' conditions were improved. The findings of MRI were multidimensional, revealing changes of the glioma
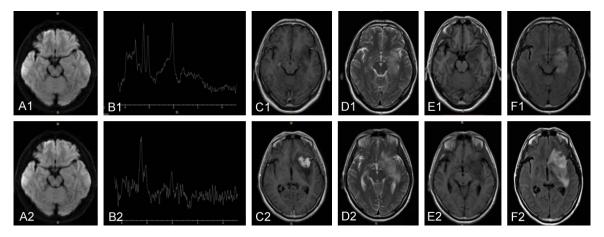
Figure 4. Multi-modal MRI images. Graph group 1: Images of left brain occupying patients in the observation group before chemoradiotherapy. Graph group 2: Images of patients after four cycles of chemoradiotherapy. A. Diffusion-weighted imaging; B. Magnetic resonance spectroscopy; C. Contrast-enhanced T1-weighted imaging; D. T2-weighted imaging; E. T1-weighted imaging; F. Contrast-enhanced T2 fluid-attenuated inversion recovery imaging.
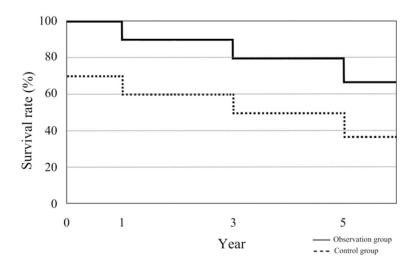

Figure 5. Survival curves of two groups of patients.

through multiple images and different exposures, indicating that multi-modal MRI can show changes in soft tissue from multiple parameters, and can objectively reflect the treatment effects of chemoradiotherapy on tumors [24]. In this study, chemoradiotherapy reduced the malignancy of glioma and effectively improved patient's condition. The one-, three-, and five-year survival rates of the observation group were significantly higher than those of the control group, which were not consistent with the difference in the rate of complete resection measured before chemoradiotherapy. After surgical resection, each patient underwent chemoradiotherapy according to the results of the corresponding detection technique, indicating that the differences in survival rates were caused by different accuracy between CT scan and multi-modal MRI, which led to the difference in calculating the rate of complete resection after the first surgery and affected subsequent planning of chemoradiotherapy. The survival period of patients in the observation group was significantly longer than that in the control group, indicating that the multi-modal MRI evaluated the rate of complete resection more accurately than CT scans; higher accuracy enabled the dosage and course of treatment of chemoradiotherapy to be more consistent with the patient's own condition. The results showed that the sensitivity of multi-modal MRI to cancer tissue is higher than that of CT scan. Greater sensitivity increases the efficiency of chemoradiotherapy and improves patient's condition. The results of this study were consistent with previous studies, demonstrating the credibility of the study. However, the limited sample size of this study cannot fully demonstrate the miss rate of multi-modal MRI. This technique still requires further research.

In conclusion, multi-modal MRI provides accurate information about the ADC and early-phase enhancement rates of the tissue, and semi-quantitative analysis by TIC. Moreover, it com-

pares the tissues before and after chemoradiotherapy to determine effectiveness of the treatment, and then provide reference for subsequent treatment. If the results of multi-modal MRI show insufficient efficacy, the treatment plan can be changed promptly to prevent unsatisfactory treatment effect due to mistakes or defects in the plan.

Disclosure of conflict of interest

None.

Address correspondence to: Xia Wu, Department of Oncology, The Third People's Hospital of Linyi, No.117 Huaxia Road, Economic and Technological Development Zone, Linyi 276023, Shandong Province, China. Tel: +86-0539-8769202; E-mail: wuxia48@163.com

References

[1] Khain E, Sander LM and Stein AM. A model for glioma growth. Complexity 2017; 11: 53-57.

[2] Qin L, Li A, Qu J, Reinshagen K, Li X, Cheng SC, Bryant A and Young GS. Normalization of ADC does not improve correlation with overall survival in patients with high-grade glioma (HGG). J Neurooncol 2018; 137: 313-319.

[3] Corradini S, Hadi I, Hankel V, Ertl L, Ganswindt U, Belka C and Niyazi M. Radiotherapy of spinal cord gliomas: a retrospective mono-institutional analysis. Strahlenther Onkol 2016; 192: 139-145.

[4] Price SJ, Young AM, Scotton WJ, Ching J, Mohsen LA, Boonzaier NR, Lupson VC, Griffiths JR, McLean MA and Larkin TJ. Multimodal MRI can identify perfusion and metabolic changes in the invasive margin of glioblastomas. J Magn Reson Imaging 2016; 43: 487-494.

[5] Eskildsen SF, Gyldensted L, Nagenthiraja K, Nielsen RB, Hansen MB, Dalby RB, Frandsen J, Rodell A, Gyldensted C, Jespersen SN, Lund TE, Mouridsen K, Brændgaard H and Østergaard L. Increased cortical capillary transit time heterogeneity in Alzheimer's disease: a DSC-MRI perfusion study. Neurobiol Aging 2017; 50: 107-118.

[6] Zeestraten EA, Lawrence AJ, Lambert C, Benjamin P, Brookes RL, Mackinnon AD, Morris RG, Barrick TR and Markus HS. Change in multi-modal MRI markers predicts dementia risk in cerebral small vessel disease. Neurology 2017; 89: 1869-1876.

[7] Koob M, Girard N, Ghattas B, Fellah S, Confort-Gouny S, Figarella-Branger D and Scavarda D. The diagnostic accuracy of multiparametric MRI to determine pediatric brain tumor grades and types. J Neurooncol 2016; 127: 345-353.

[8] van den Bent MJ, Weller M, Wen PY, Kros JM, Aldape K and Chang S. A clinical perspective on the 2016 WHO brain tumor classification and routine molecular diagnostics. Neuro Oncol 2017; 19: 614-624.

[9] Miyata K, Hasegawa M, Abe Y, Tabuchi T, Namiki T and Ishigami T. Radiofrequency heating and magnetically induced displacement of dental magnetic attachments during 3.0 T MRI. Dentomaxillofac Radiol 2012; 41: 668-674.

[10] Lenting K, Verhaak R, Laan MT, Wesseling P and Leenders W. Glioma: experimental models and reality. Acta Neuropathol 2017; 133: 263-282.

[11] Harrabi SB, Bougatf N, Mohr A, Haberer T, Herfarth K, Combs SE, Debus J and Adeberg S. Dosimetric advantages of proton therapy over conventional radiotherapy with photons in young patients and adults with low-grade glioma. Strahlenther Onkol 2016; 192: 759-769.

[12] Yang P, Qiu Z, Jiang Y, Dong L, Yang W, Gu C, Li G and Zhu Y. Silencing of cZNF292 circular RNA suppresses human glioma tube formation via the Wnt/β-catenin signaling pathway. Oncotarget 2016; 7: 63449-63455.

[13] Duran CL, Lee DW, Jung JU, Ravi S, Pogue CB, Toussaint LG, Bayless KJ and Sitcheran R. NIK regulates MT1-MMP activity and promotes glioma cell invasion independently of the canonical NF-κB pathway. Oncogenesis 2016; 5: e231.

[14] Lockhart AC, Rothenberg ML, Dupont J, Cooper W, Chevalier P, Sternas L, Buzenet G, Koehler E, Sosman JA, Schwartz LH, Gultekin DH, Koutcher JA, Donnelly EF, Andal R, Dancy I, Spriggs DR and Tew WP. Phase I study of intravenous vascular endothelial growth factor trap, aflibercept, in patients with advanced solid tumors. J Clin Oncol 2010; 28: 207-214.

[15] Pessina F, Navarria P, Cozzi L, Ascolese AM, Simonelli M, Santoro A, Tomatis S, Riva M, Fava E and Scorsetti M. Value of surgical resection in patients with newly diagnosed grade III glioma treated in a multimodal approach: surgery, chemotherapy and radiotherapy. Ann Surg Oncol 2016; 23: 1-7.

[16] Chai CY, Zhang Y, Song J, Lin SC, Sun S and Chang I. VNN1 overexpression is associated with poor response to preoperative chemoradiotherapy and adverse prognosis in patients with rectal cancers. Am J Transl Res 2016; 8: 4455.

[17] Rohde M, Nielsen AL, Johansen J, Sørensen JA, Nguyen N, Diaz A, Nielsen MK, Asmussen JT, Christiansen JM, Gerke O, Thomassen A, Alavi A, Høilund-Carlsen PF and Godballe C. Head-to-head comparison of chest X-Ray/head and neck MRI, chest CT/head and neck MRI, and 18F-FDG PET/CT for detection of distant me-

tastases and synchronous cancer in oral, pha-
ryngeal, and laryngeal cancer. J Nucl Med
2017; 58: 1919-1924.

[18] Zhu J, Zhang F, Yun L, Peng C, Fei L, He W and
Wang D. Can dynamic contrast-enhanced MRI
(DCE-MRI) and diffusion-weighted MRI (DW-
MRI) evaluate inflammation disease: a prelimi-
nary study of crohn's disease. Medicine (Abing-
don) 2016; 95: e3239.

[19] Zhang X, Chen YL, Lim R, Huang C, Chebib IA
and El FG. Synergistic role of simultaneous
PET/MRI-MRS in soft tissue sarcoma metabo-
lism imaging. Magn Reson Imaging 2016; 34:
276-279.

[20] Choi MH, Oh SN, Rha SE, Choi JI, Lee SH, Jang
HS, Kim JG, Grimm R and Son Y. Diffusion-
weighted imaging: apparent diffusion coeffi-
cient histogram analysis for detecting patho-
logic complete response to chemoradiotherapy
in locally advanced rectal cancer. J Magn Re-
son Imaging 2016; 44: 212-220.

[21] Hu J, Yu Y, Juhasz C, Kou Z, Xuan Y, Latif Z,
Kudo K, Chugani HT and Haacke EM. MR sus-
ceptibility weighted imaging (SWI) comple-
ments conventional contrast enhanced T1
weighted MRI in characterizing brain abnor-
malities of sturge-weber syndrome. J Magn Re-
son Imaging 2008; 28: 300-307.

[22] Piper RJ, Mikhael S, Wardlaw JM, Laidlaw DH,
Whittle IR and Bastin ME. Imaging signatures
of meningioma and low-grade glioma: a diffu-
sion tensor, magnetization transfer and quanti-
tative longitudinal relaxation time MRI study.
Magn Reson Imaging 2016; 34: 596-602.

[23] Price SJ, Boonzaier NR, Yan J and Mclean MA.
P07.12 Multimodal imaging of the invasive mi-
croenvironment predicts survival in glioblasto-
mas. Neuro Oncol 2016; 18: iv36-36iv36.

[24] Sengeh DM, Moerman KM, Petron A and Herr
H. Multi-material 3-D viscoelastic model of a
transtibial residuum from in-vivo indentation
and MRI data. J Mech Behav Biomed Mater
2016; 59: 379-392.