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磁共振波谱成像结合扩散加权成像在脑胶质瘤及脑转移瘤鉴别诊断中的意义*

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摘要 目的:评估磁共振波谱成像(Proton Magnetic Resonance Spectroscopy, ¹H-MRS)联合磁共振扩散加权成像(Diffusion Weighted Imaging, DWI)在鉴别脑胶质瘤及孤立的脑转移瘤中的作用。**方法:**应用 3.0T 磁共振扫描仪,对临床手术确诊及组织病理学诊断证实的 49 例脑肿瘤患者(35 例多形性胶质母细胞瘤,14 例脑转移瘤)进行常规磁共振成像、磁共振波谱成像及磁共振扩散加权成像,并对获得的数据进一步测量瘤内及瘤周区的代谢比、N-乙酰天门冬氨酸(NAA)、胆碱(Cho)、肌酸(Cr)值以及表观弥散系数(ADC 值),分析两肿瘤组之间不同参数的统计学差异。此外,我们研究了感兴趣区域(ROI)的大小对肿瘤区域的病变扩散性能潜在影响。**结果:**胶质母细胞瘤瘤周 N-乙酰天门冬氨酸(NAA)、肌酸(Cr)、胆碱(Cho)/Cr, Cho/NAA 和 rCBV 显著高于颅内转移瘤($P<0.05$);ADC 值在两肿瘤组之间无显著差异($P>0.05$)。**结论:**在瘤周区 ¹H-MRS 有助于鉴别胶质母细胞瘤与单发的脑转移瘤。在瘤内扩散性的定量特性依赖 ROI 大小的设置。

关键词:脑胶质瘤;脑转移瘤;MRI; ¹H-MRS; DWI

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Magnetic Resonance Imaging Combined with Diffusion Weighted Imaging in Tumor Differential Diagnosis of Brain Glioma and Brain Metastases*

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ABSTRACT Objective: To evaluate magnetic resonance spectroscopy (Proton Magnetic Resonance Spectroscopy, ¹H-MRS) combined with magnetic resonance diffusion weighted imaging (Diffusion Weighted, Imaging, DWI) in the aneurysm role identification of gliomas and solitary brain metastases. **Methods:** using 3.0T magnetic resonance scanner, 49 cases of patients with brain tumor confirmed by operation and clinical diagnosis of pathological diagnosis (35 cases of glioblastoma, 14 cases of brain metastases) were performed magnetic resonance imaging, magnetic resonance spectroscopic imaging and diffusion weighted magnetic resonance imaging, and the data was obtained for further measurement of intratumoral and peritumoral region of metabolic ratio, N-acetyl aspartic acid (NAA), choline (Cho), creatine (Cr) values and apparent diffusion coefficient (ADC value), analysis was performed to different parameters of the statistical difference between the two tumor group. In addition, we study the region of interest (ROI) performance potentially influence the size of the diffusion of the tumor region lesions. **Results:** Glioblastoma peritumoral N- acetyl aspartic acid (NAA), creatine (Cr), choline (Cho) /Cr, Cho / NAA and rCBV were significantly higher than that in intracranial metastases ($P<0.05$); the ADC value had no significant difference between the two tumor group ($P>0.05$). **Conclusion:** there are helpful in the differential diagnosis of glioblastoma and solitary brain metastases peritumoral region in ¹H-MRS. The quantitative characteristics of diffusion in tumor size dependent ROI settings.

Key words: Cerebral gliomas; Metastatic encephaloma; MRI; ¹H-MRS; DWI;

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前言

原发性多形性胶质母细胞瘤(GBM)和颅内转移瘤是最常见的脑肿瘤。传统的磁共振(MR)胶质母细胞瘤与单发转移性病变的成像难以区分研究也显示这两个肿瘤之间缺乏差异性,其影像学特征和对比度增强模式在很多情况下可能是类似的。而这些病变的术前鉴别诊断则有助于更好的制定治疗计划^[1,2]。成像技术的进步,如磁共振质子波谱(¹H-MRS),扩散加权成像

(DWI)等成像方式提供了脑组织代谢及生理特性的信息。磁共振成像已向功能成像和分子成像方面转变,因此希望通过 MR 成像的特异性,获得洞察脑肿瘤的基本生物学特性^[2,3],以鉴别不同的肿瘤。

1 材料与方法

1.1 临床资料

2013 年 8 月至 2014 年 7 月期间在我院接受磁共振检查

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的 46 例脑肿瘤患者,经临床手术确诊及组织病理学诊断证实,33 例多形性胶质母细胞瘤,13 例脑转移瘤,年龄为 39-75.6 岁,平均年龄为 54.8 岁,其中男 25 例,女 21 例。入组标准:成人,有孤立性脑肿瘤,不均质,对比增强有脑损伤。排除标准:儿童,多重脑损伤,有过手术和化疗或放疗病史。所有神经影像及手术在一个月内执行。手术后获得病理学的诊断结果,并与影像学结果相比较。

1.2 成像设备及成像参数

常规 MRI、¹H-MRS 及 DWI 图像采集采用 GE 3.0T (GE Healthcare, Waukesha, WI, USA) 磁共振扫描仪进行采集,信号采集应用头部线圈进行,扫描使用 4 通道圆拱结构和 8 通道阶相-矩阵同步线圈。常规 MRI 成像包括 T1 加权快速自旋回波序列(重复时间(TR)/回波时间(TE)700 ms/9.3 ms),轴位 T2 加权快速自旋回波(TR/TE 2640 ms/102 ms),冠位 T2 加权快速自旋回波序列(TR/TE 292/102 ms),和 T2 FLAIR (TR/TE 8500 ms/130 ms)。DWI 图像通过单次激发、自旋回波、平面回波序列,b 值为 0 和 1000 s/mm²。为了准确地量化 ADC 中的感兴趣区域(ROI),本研究采用高 b 值。使用质子波谱成像采用二维多体素波谱(2D-CSI)技术定量分析,为了避免造影剂的干扰,在注射前成像。数据采用点分辨波谱采集(PRESS)与相位编码梯度双向脉冲序列。在 2D-CSI 中用于测量的参数为:1000/144 MS(TR/TE),16×16 相位编码、层厚 10 毫米,FOV 根据每个病人的大脑解剖大小进行调整。

1.3 后处理与数据分析

每一个患者的波谱数据是分别从瘤内区、瘤周区及对侧的

区域获得。ROI 用横向 T2 FLAIR 和 T2 FSE,矢状 T1 FSE 和冠状 T2 FSE 图像定位。2D-CSI 波谱数据分析和体内代谢物的比率计算使用 Linux 工作站 Functool 软件。原始波谱数据后处理包括基线校正,变频移相。高斯曲线拟合 NAA、Cr、Cho,用于测定脂质和乳酸峰的峰面积。最后,NAA/Cr 代谢比,Cho/Cr,Cho/NAA 和(Lip+LAC)/Cr 计算各代谢物的峰下面积,根据 ¹H-MRS 波峰显示各种代谢物峰值的变化,分析代谢物的相对浓度。根据各向同性的 DWI 获取 ADC 图,并进一步测量 ADC 值,对侧正常区作为对照,所有的测量都是使用 Linux 工作站 Functool 软件。

1.4 统计学方法

相关数据进行统计学分析以均数±标准差,采用 SPSS 13.0 软件进行统计。不同研究组之间的均数比较根据方差齐性,采用 t 检验(t-test)或秩和检验(rank-sum test),以 P 小于 0.05 为具有显著性差异。

2 结果

(1) 在胶质母细胞瘤瘤内 NAA/Cr、Cho/Cr、Cho/NAA 和 Lip+Lac/Cr 的代谢率值分别为 1.18±0.47、3.12±1.24、3.05±1.84 及 3.32±3.71。而转移瘤的代谢率值则分别为 1.62±0.83、4.52±2.34、2.76±2.52 及 7.12±11.04。

在胶质母细胞瘤瘤周区 NAA/Cr、Cho/Cr、Cho/NAA/Cr 和 Lip+Lac/Cr 的代谢率值为 1.43±0.50、1.67±0.56、1.28±0.66 及 0.64±0.47。转移瘤瘤周的代谢率值为 1.94±0.34、1.29±0.27、0.67±0.16 及 0.62±0.31,见表 1。

表 1 肿瘤内、瘤周和对侧正常区域代谢率平均值的比较结果

Table 1 Parameter mean values with their corresponding standard deviation, and comparison results in the intratumoral, peritumoral and contralateral normal area

Metrics	Intratumoral			Peritumoral			Contralateral normal area	
	GBM	Metastasis	P	GBM	Metastasis	P	GBM	Metastasis
NAA/Cr	1.18 ± 0.47*	1.62 ± 0.83	0.17	1.43 ± 0.50*	1.94 ± 0.34	0.01**	1.79 ± 0.44	1.97 ± 0.38
Cho/Cr	3.12 ± 1.24*	4.52 ± 2.34*	0.17	1.67 ± 0.56*	1.29 ± 0.27	0.05**	1.30 ± 0.36	1.09 ± 0.23
Cho/NAA	3.05 ± 1.84*	2.76 ± 2.52*	0.21	1.28 ± 0.66*	0.67 ± 0.16	<0.01**	0.81 ± 0.51	0.57 ± 0.13
Lip+Lac	3.32 ± 3.71*	7.12 ± 11.04*	0.12	0.64 ± 0.47*	0.62 ± 0.31	0.973	0.47 ± 0.27	0.49 ± 0.14
ADC	1.279 ± 0.463*	1.176 ± 0.524*	0.185	1.054 ± 0.220*	1.105 ± 0.148*	0.232	0.973 ± 0.225	0.858 ± 0.109

(注:* 差异具有统计学意义)。

(2) 在胶质母细胞瘤的肿瘤区域,小 ROI 平均 ADC 值为 ADC(GBM)=1.279±0.463 mm²/s,而在转移性肿瘤的平均 ADC 值为 ADC(Meta)=1.176±0.524 mm²/s。比较胶质瘤及转移瘤内不同 ROI 获得 ADC 值,差异无统计学意义(P>0.05),见表。

表 2 比较,胶质母细胞瘤和转移瘤的瘤内区域大、小 ROI 对 ADC 值的影响

Table 2 Comparison of ADC and FA values between the large and small ROIs in the intratumoral region of glioblastomas and metastatic tumors

ADC of Intratumoral region		
	GBM	Metastasis
Large ROI	1.272 ± 0.452	1.189 ± 0.530
Small ROI	1.279 ± 0.463	1.176 ± 0.524
P value	0.882	0.931

(3) 在鉴别不同肿瘤的敏感性和特异性的临界值如表 3 所示,这四个比率在不同的两个肿瘤组有显著的统计学意义。瘤

周的 rCBV 比值的特异性证明是优于 NAA/Cr、Cho/Cr 及 NAA/Cho 比率,而 Cho/Cr 敏感性最高。

表 3 NAA/Cr、Cho/Cr、Cho/NAA 和 rCBV 比值在鉴别颅内转移瘤敏感性和特异性

Table 3 Measures of sensitivity and specificity by using NAA/Cr, Cho/Cr, Cho/NAA and rCBV ratios in the peritumoral ROI in discrimination of GBM from intracranial metastase

Metabolite ratios	Cut-off value	Sensitivity (%)	Specificity (%)	AUC
NAA/Cr	1.50	78	82	0.778
Cho/Cr	1.40	89	62	0.705
Cho/NAA	1.10	78	93	0.870
rCBV ratio	1.70	80	94	0.850

(4) 采用 ¹H-MRS 联合 DWI 鉴别高级胶质瘤的敏感度、特异度、阳性预测值、阴性预测值均大于单独采用 MRI 的各项指标(表 4)。

表 4 不同磁共振成像方法区分高低级别胶质瘤的比较
Table 4 The comparison of different MRI methods in distinguishing high and low-grade gliomas

Indicators \ method	MRI	MRS +DWI
Sensitivity	84.3%	91.4%
Specificity	73.5%	76.1%
PPV	87.2%	91.3%
NPV	66.7%	81.2%

3 讨论

在体 ^1H -MRS 提供脑肿瘤的代谢状态,测量特定的氨基酸如 N-乙酰天门冬氨酸(NAA),胆碱(Cho),肌酸(Cr),脂类(Lip),和乳酸(Lac),和他们的相对比例,能了解脑肿瘤的生理学特征。在大多数脑肿瘤,非特异性病理谱包括:Cho/Cr 增加和 NAA/Cr 下降,表明神经元完整性的丧失^[4]。乳酸和脂质峰的存在通常与恶性肿瘤相一致,反映增加无氧代谢和细胞坏死^[5,6]。扩散加权成像对脑内不同部位的水分子扩散特性的信息,表现弥散系数(ADC)是一个指数,给出了在一定区域内的水扩散的一个粗略估计,考虑扩散的各向同性的过程。然而,研究表明,ADC 是旋转依赖性;指出水的扩散是限制或促进向一定方向进行的^[7,8]。

我们研究的胶质母细胞瘤病例中有 30%患者,其瘤旁波谱分析结果略微接近正常水平。按照 Chernov 等^[9]人的研究,怀疑可能是从胶质母细胞瘤高度坏死中心散布出的脂质和乳酸,对瘤周脑组织神经元功能的丧失有重要作用,另外,产生脂质的肿瘤可能同时分泌其他代谢物对周围脑组织神经元有抑制作用。一些研究已经报道,胶质母细胞瘤和转移瘤中脂质的存在是由于有坏死区域。然而,Opstad 等^[10]推测尽管有同样的血脂,在胶质母细胞瘤和转移瘤中,脂质信号来源却不同,如纯肿瘤坏死用于浸润的肿瘤细胞,结合在脂质膜结构上较少的坏死用于转移的肿瘤细胞,这可能是胶质母细胞瘤瘤周 NAA/Cr 较低的一个原因。

在我们的研究中,瘤周 NAA/Cr,Cho/Cr 和 Cho/NAA 比值分别有 78%,89%和 78%的敏感性,而 NAA/Cr 和 Cho/NAA 分别达到了 82%和 93%的高特异性,以鉴别胶质母细胞瘤和转移瘤。瘤周 NAA/Cr 和 Cho/NAA 的高特异性意味着,假阳性率低和真阴性率相当高。换句话说,大部分的胶质母细胞瘤病例可用这两个比率参数进行准确的分类。此外,由肿瘤周围 NAA/Cr 和 Cho/NAA 可以鉴别胶质母细胞瘤和转移瘤^[11-13]。另一方面,Cho/Cr 的特异性非常低(62%),其可以解释为,一些胶质母细胞瘤在瘤周区域可能不表现出肿瘤模式(高 Cho 级别)^[14-16],在我们的病例中 30%是这种情况。

本研究中我们已经提到,我们采用波谱测量以便同时取样整个肿瘤组织、瘤周和对照区,增加描述肿瘤最活跃区域的可能性。然而,由于 2D-CSI 中的信号是在空间上是由有限数的编码相位编码的,信号的空间起源通常并不与波谱格中矩形的三位像素相一致。由于傅立叶变换的应用而建立的数据重建,信号体元的转换可能受到其他体元信号的污染。这种现象被称为体元“渗出”,也应该被认为是这种技术的局限,这是因为从位于肿瘤边缘的体元中得到的信号强度之间可能会相互影响,肿瘤边缘区域的相关信号的价值可能被来自肿瘤的强共振态扭曲^[17,18]。

另外,瘤内的 ADC 价值来自大的 ROI 和较小的 ROI,因

为恶性胶质瘤和转移性肿瘤都显现不出统计学的差异。从两者参数来看较小的 ROI 的均值与较大的 ROI 均值相似,这表明水的扩散和病变实质区内部的各向异性可能独立于 ROI 的放置大小。因此,似乎放置单一的 ROI 在肿瘤区域内部可以充分的描绘这一区域的扩散性能^[19-21]。

在当前的研究中,在两个肿瘤群组中肿瘤内部的 ADC 值测量与在 cNA 中的大大的不同;然而,在统计方式上这两种病变类型之间没有显著差异。对这种现象的一种解释是:因为 GBM 跟转移病灶一样在坏死和囊变区域表现肿瘤多样性,水分子的扩散被促进,比在正常区域的扩散表现更多各向同性^[22-24]。所以,依照之前的研究,在这两种不同肿瘤类型的变异中,瘤内区域的 ADC 值不能起到预测指数的作用。总之,在所述肿瘤周区域,扩散各向异性的低差异表明,由含水量和肿瘤细胞共同诱导的胶质瘤相关性 ADC 值的变化可能仅仅由水含量增加诱导的代谢相关性变化。

综合上述, ^1H -MRS 结合 DWI,鉴别脑胶质瘤及颅内转移瘤,通过分析瘤体区、瘤周区及健侧对照区的各种代谢物的变化,能够有效提高胶质瘤诊断的准确性,在临床评估脑胶质瘤的分级、确定范围和鉴别诊断都具有重要的指导作用。

参考文献(References)

- [1] Server A, Orheim TE, Graff BA, et al. Diagnostic examination performance by using microvascular leakage, cerebral blood volume, and blood flow derived from 3-T dynamic susceptibility-weighted contrast-enhanced perfusion MR imaging in the differentiation of glioblastoma multiforme and brain metastasis [J]. *Neuroradiology*, 2011, 53: 319-330
- [2] Server A, Josefsen R, Kulle B, et al. Proton magnetic resonance spectroscopy in the distinction of high-grade cerebral gliomas from single metastatic brain tumors[J]. *Acta Radiol*, 2010, 51: 316-325
- [3] Ricci R, Bacci A, Tugnoli V, et al. Metabolic findings on 3T ^1H -MR spectroscopy in peritumoral brain edema[J]. *AJNR Am J Neuroradiol*, 2007, 28: 1287-1291
- [4] Chen AP, Cunningham CH, Ozturk-Isik E, et al. High-speed 3T MR spectroscopic imaging of prostate with flyback echo-planar encoding [J]. *J Magn Reson Imaging*, 2007, 25: 1288-1292
- [5] De Edelenyi FS, Rubin C, Esteve F, et al. A new approach for analyzing proton magnetic resonance spectroscopic images of brain tumors: nosologic images[J]. *Nat Med*, 2000, 6: 1287-1289
- [6] Wang S, Kim S, Chawla S, et al. Differentiation between glioblastomas and solitary brain metastases using diffusion tensor imaging[J]. *Neuroimage*, 2009, 44: 653-660
- [7] Pels P, Ozturk-Isik E, Swanson MG, et al. Quantification of prostate MRSI data by model-based time domain fitting and frequency domain analysis[J]. *NMR Biomed*, 2006, 19: 188-197
- [8] Zhu W, Zhong W, Qi J, et al. Proton magnetic resonance spectroscopy in neonates with hypoxic-ischemic injury and its prognostic value[J]. *Transl Res*, 2008, 152: 225-232
- [9] Chernov MF, Kubo O, Hayashi M, et al. Proton MRS of the peritumoral brain[J]. *J Neurol Sci*, 2005, 228: 137-142
- [10] Opstad KS, Murphy MM, Wilkins PR, et al. Differentiation of metastases from high-grade gliomas using short echo time ^1H spectroscopy[J]. *J Magn Reson Imaging*, 2004, 20: 187-192
- [11] Preul MC, Caramanos Z, Collins DL, et al. Accurate, noninvasive diagnosis of human brain tumors by using proton magnetic resonance

- disease-A clinician's perspective [J]. Indian Heart J, 2014, 66 (6): 663-671
- [3] Hallen J, Atar D, Serebruany V. Effects of FX06 in vitro on platelet, coagulation, and fibrinolytic biomarkers in volunteers and patients with documented coronary artery disease[J]. Am J Ther, 2014, 21(2): 91-98
- [4] Guallar-Castillon P, Rodriguez-Artalejo F, Tormo MJ, et al. Major dietary patterns and risk of coronary heart disease in middle-aged persons from a Mediterranean country: the EPIC-Spain cohort study [J]. Nutr Metab Cardiovasc Dis, 2012, 22(3): 192-199
- [5] Vaina S, Milkas A, Crysohoou C, et al. Coronary artery disease in women: From the yentl syndrome to contemporary treatment [J]. World J Cardiol, 2015, 7(1): 10-18
- [6] Damjanovic M, Salinger-Martinovic S, Djordjevic-Radojkovic D, et al. A successful retrieval of stripped outer coating of J-tip diagnostic guidewire from the left popliteal artery during elective coronary angiography[J]. Vojnosanit Pregl, 2014, 71(10): 969-971
- [7] Deer RR, Heaps CL. Exercise training enhances multiple mechanisms of relaxation in coronary arteries from ischemic hearts [J]. Am J Physiol Heart Circ Physiol, 2013, 305(9): H1321-H1331
- [8] Gong P, Luo S H, Li XL, et al. Relation of ABO blood groups to the severity of coronary atherosclerosis: an Gensini score assessment[J]. Atherosclerosis, 2014, 237(2): 748-753
- [9] Bekler A, Barutcu A, Tenekecioglu E, et al. The relationship between fragmented QRS complexes and SYNTAX and Gensini scores in patients with acute coronary syndrome[J]. Kardiolog Pol, 2014
- [10] 何翠芳. 康复护理干预对冠心病冠状动脉介入治疗患者生活质量的影响[J]. 辽宁医学院学报, 2013, 34(1): 91-93
He Cui-fang. Effect of Rehabilitation on the Quality of Life for Patients with CHD after PCI [J]. Journal of Liaoning Medical University, 2013, 34(1): 91-93
- [11] Han L, Fu K L, Zhao J, et al. Visceral adiposity index score indicated the severity of coronary heart disease in Chinese adults [J]. Diabetol Metab Syndr, 2014, 6(1): 143
- [12] Hirata Y, Yamamoto E, Tokitsu T, et al. Reactive Oxygen Metabolites are Closely Associated With the Diagnosis and Prognosis of Coronary Artery Disease[J]. J Am Heart Assoc, 2015, 4(2)
- [13] Tuomikoski P, Lyytinen H, Korhonen P, et al. Coronary heart disease mortality and hormone therapy before and after the Women's Health Initiative[J]. Duodecim, 2014, 130(21): 2209
- [14] Agha G, Loucks EB, Tinker LF, et al. Healthy lifestyle and decreasing risk of heart failure in women: the Women's Health Initiative observational study [J]. J Am Coll Cardiol, 2014, 64(17): 1777-1785
- [15] Poliakov RS, Saakian I, Mardanian GV, et al. Twelve months results of percutaneous coronary interventions in patients with ischemic heart disease combined with diabetes mellitus using sirolimus and everolimus covered stents[J]. Kardiologija, 2014, 54(8): 4-9
- [16] Verdoia M, Schaffer A, Barbieri L, et al. Impact of age on mean platelet volume and its relationship with coronary artery disease: A single-centre cohort study[J]. Exp Gerontol, 2015, 62C: 32-36
- [17] Koju R, Humagain S, Khanal K. Association of cardiovascular risk factors and coronary artery lesion among coronary artery disease patients[J]. Kathmandu Univ Med J (KUMJ), 2014, 12(46): 137-140
- [18] Jurczak I, Jurczak K. Chronic obstructive pulmonary disease as a risk factor for coronary heart disease [J]. Pol Merkuri Lekarski, 2015, 38 (223): 39-41
- [19] Kern DM, Balu S, Tunceli O, et al. Statin treatment patterns and clinical profile of patients with risk factors for coronary heart disease defined by National Cholesterol Education Program Adult Treatment Panel III[J]. Curr Med Res Opin, 2014, 30(12): 2443-2451
- [20] Al-Shehri AM. Prevalence and pattern of lipid disorders in Saudi patients with angiographically documented coronary artery disease[J]. J Family Community Med, 2014, 21(3): 166-169

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- spectroscopy[J]. Nat Med, 1996, 2: 323-325
- [12] Dowling C, Bollen AW, Noworolski SM, et al. Preoperative proton MR spectroscopic imaging of brain tumors: correlation with histopathologic analysis of resection specimens [J]. AJNR Am J Neuroradiol, 2001, 22: 604-612
- [13] Weber MA, Zoubaa S, Schlieter M, et al. Diagnostic performance of spectroscopic and perfusion MRI for distinction of brain tumors[J]. Neurology, 2006, 66: 1899-1906
- [14] Sinha S, Bastin ME, Whittle IR, et al. Diffusion tensor MR imaging of high-grade cerebral gliomas[J]. AJNR Am J Neuroradiol, 2002, 23: 520-527
- [15] Beppu T, Inoue T, Shibata Y, et al. Measurement of fractional anisotropy using diffusion tensor MRI in supratentorial astrocytic tumors[J]. J Neurooncol, 2003, 63: 109-116
- [16] Kono K, Inoue Y, Nakayama K, et al. The role of diffusion-weighted imaging in patients with brain tumors [J]. AJNR Am J Neuroradiol, 2001, 22: 1081-1088
- [17] Castillo M, Smith JK, Kwock L, et al. Apparent diffusion coefficients in the evaluation of high-grade cerebral gliomas [J]. AJNR Am J Neuroradiol, 2001, 22: 60-64
- [18] Altman DA, Atkinson DS, Jr, Brat DJ. Best cases from the AFIP: glioblastoma multiforme[J]. Radiographics, 2007, 27: 883-888
- [19] Kinoshita M, Hashimoto N, Goto T, et al. Fractional anisotropy and tumor cell density of the tumor core show positive correlation in diffusion tensor magnetic resonance imaging of malignant brain tumors[J]. Neuroimage, 2008, 43: 29-35
- [20] Beppu T, Inoue T, Shibata Y, et al. Fractional anisotropy value by diffusion tensor magnetic resonance imaging as a predictor of cell density and proliferation activity of glioblastomas [J]. Surg Neurol, 2005, 63: 56-61
- [21] Boddaert N, Romano S, Funalot B, et al. ¹H MRS spectroscopy evidence of cerebellar high lactate in mitochondrial respiratory chain deficiency[J]. Mol Genet Metab, 2008, 93: 85-88
- [22] Miller SP, McQuillen PS, Hamrick S, et al. Abnormal brain development in newborns with congenital heart disease [J]. N Engl J Med, 2007, 357: 1928-1938
- [23] Li Y, Chen AP, Crane JC, et al. Three-dimensional J-resolved H-1 magnetic resonance spectroscopic imaging of volunteers and patients with brain tumors at 3T[J]. Magn Reson Med, 2007, 58: 886-892