European Journal of Radiology 95 (2017) 286–292

Contents lists available at ScienceDirect

European Journal of Radiology

journal homepage: www.elsevier.com/locate/ejrad

Research paper

MR diffusion kurtosis imaging predicts malignant potential and the histological type of meningioma

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ARTICLE INFO

Keywords:
Meningioma
Diffusion kurtosis imaging
Mean kurtosis
Cellular proliferation
Ki-67

ABSTRACT

Purpose: To explore the value of Diffusion kurtosis imaging (DKI) metrics in the differential diagnosis of meningioma.

Methods: For this study, we retrospectively enrolled 35 patients of cerebral meningioma with DKI which included axial diffusion coefficient (AD), radial diffusion coefficient (RD), mean diffusion coefficient (MD), fractional anisotropy (FA), axial kurtosis (AK), radial kurtosis (RK) and mean kurtosis (MK). All of these metrics were normalized according to contralateral normal-appearing white matter (NAWMc). Patients were divided into two groups (benign and malignant meningioma) and were further analyzed using the independent sample *t*-test and receiver operating characteristic (ROC) curve. A one-way ANOVA analysis was used to analyze four groups divided according to pathological subtypes.

Results: The metrics of AD, normalized AD, normalized MD, MK and normalized MK showed a significant difference between benign and malignant group, and MK showed relatively higher diagnostic ability with its cut-off value, area under the curve (AUC), sensitivity and specificity of 0.875, 0.780, 70% and 89%, respectively. The metrics of normalized MD, RD and normalized RD, FA and normalized FA, AK and normalized AK, and RK showed significant difference among four subtypes. MK and RK in meningioma were found to correlate positively with the Ki-67 labeling index (Ki-67 LI).

Conclusions: DKI metrics may be used to differentiate benign from malignant meningioma, and also to distinguish some histological subtypes of meningioma. Moreover, DKI metrics may potentially reflect cellular proliferation.

1. Introduction

Meningioma is one of the most common tumors of the central nervous system [1,2], and recent data for years 2006–2010 available in United States showed that meningioma accounted for about 35.8% of the primary intracranial tumors [3]. Pathologically, meningioma is usually classified as benign (grade I, > 90%), atypical (grade II, about 5%) and malignant meningioma (grade III, about 3–5%) [1]. The treatment of different grades of tumor may differ. Grade I tumor usually only requires surgical resection, while for grade II and III tumors, follow-up treatment with radiotherapy or chemotherapy may be prescribed after surgery [4,5]. Tumor recurrence is the most common complication of meningioma (up to 21.5%), which is mainly related to tumor grade, pathological subtype, growth site, and tumor resection area [6]. Therefore, accurate assessment of the biological characteristics of meningioma before surgery plays a key role in the choice of surgical approach and follow-up management of patients. At present, the imaging of meningioma is mainly performed using CT and conventional MRI.

Diffusion weighted imaging (DWI) and diffusion tensor imaging (DTI) are now widely used for clinical neuroimaging as they can effectively assess anisotropy of nerve fiber tracts and the microscopic characteristics of cerebral white matter. Jensen et al. [7] demonstrated that diffusion kurtosis imaging (DKI) was a feasible extension of DTI in the clinic. Standard DWI and DTI techniques assume that diffusion of water molecules can occur in a free and unrestricted environment, and the diffusion displacement follows a Gaussian distribution model. However, the presence of various structures in the tissue microenvironment (such as cells, organelles and the proton exchange between these structures, etc.) can result in deviations from random Brownian motion. At high b values, it is hypothesized that the diffusion of water molecules would deviate from a strictly Gaussian distribution model and follow a non-Gaussian distribution [8]. In probability theory and statistics, kurtosis is known as the alteration of a normative pattern

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http://dx.doi.org/10.1016/j.ejrad.2017.08.019
Received 29 March 2017; Received in revised form 17 August 2017; Accepted 20 August 2017

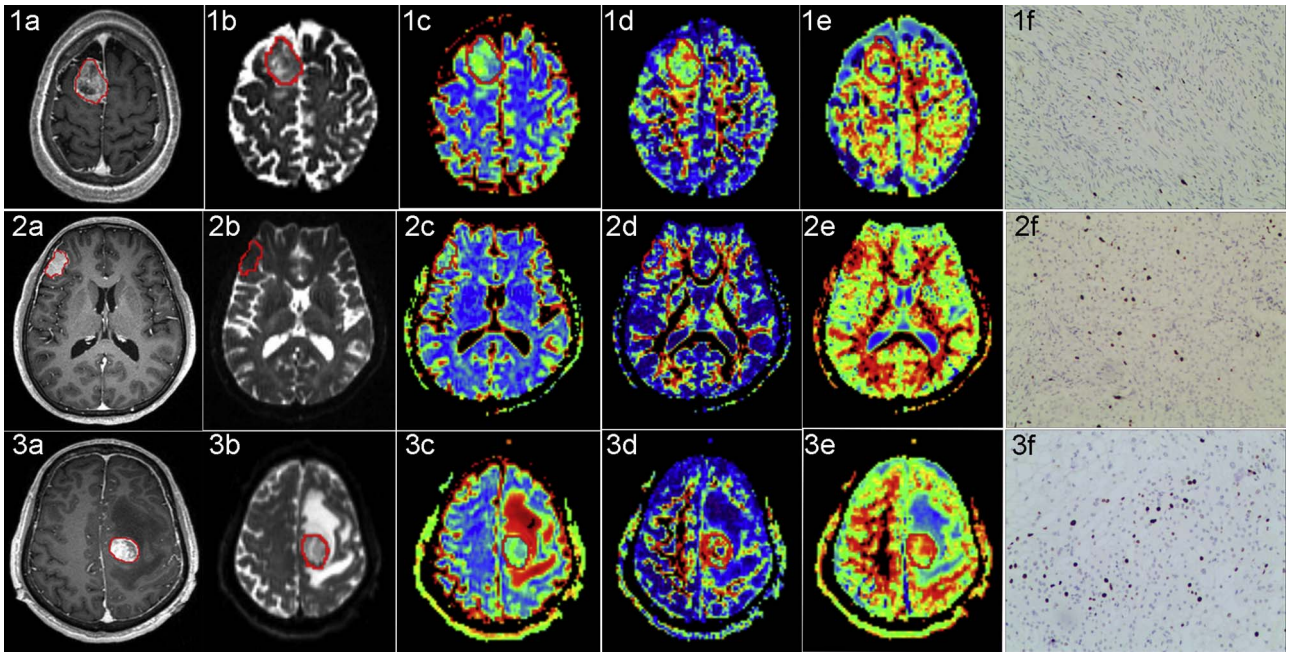

Fig. 1. Correlation of diffusion kurtosis imaging with tumor grade and Ki-67. Rows 1–3 correspond to three patients of meningioma with grade I (psammomatous) in the right frontal lobe, grade II (clear cell) in the right frontal lobe and grade III (fibrous) in the left parietal lobe, respectively. Columns a-f are T1-weighted three-dimensional contrast-enhanced MRI, b0, MD, FA, MK and Ki-67 images (100×), respectively. The Ki-67 LI value of three patients were 2%, 5% and 10%, respectively.
MD: mean diffusivity; FA: fractional anisotropy; MK: mean kurtosis; Ki-67 LI: Ki-67 labeling index

of distribution [9]. DKI is an attempt to account for this variation to provide a more accurate model of diffusion and to study non-Gaussian water diffusion in the biological tissue [10,11]. The Gaussian and non-Gaussian characteristics of water movement can be quantified by DT and DK tensor, respectively. Quantitative metrics that can be derived from DKI not only contain conventional DTI metrics which include the fractional anisotropy (FA), axial diffusion coefficient (AD), radial diffusion coefficient (RD) and mean diffusion coefficient (MD), but also contain the axial kurtosis (AK), radial kurtosis (RK) and mean kurtosis (MK).

In recent years, DKI has been applied in the clinical diagnosis of brain diseases, including cerebral white matter lesions [12], stroke [13,14] and Parkinson's disease [15,16]. It has been reported that DKI technique can be used to identify different grades of glioma [8,17], and to distinguish high-grade glioma from primary central nervous system lymphoma [8], or single brain metastases [11]. However, the application of DKI on meningioma has been rarely reported. The purpose of this study is to explore the value of Diffusion kurtosis imaging (DKI) metrics in the differential diagnosis of meningioma.

2. Materials and methods

The local Ethics Committee approved this study and the informed consent wasn't obtained from all patients because it was a retrospective study.

2.1. Patients

A total of 42 patients were retrospectively collected from May 2015 to July 2016 according to the following criteria: (1) they all had a DKI and T1-weighted three-dimensional contrast-enhanced MRI examinations; (2) they underwent surgical resection within one week and were confirmed by histopathology analysis to the World Health Organization (WHO) criteria; (3) they had not received radiotherapy or chemotherapy at the time of DKI MRI. Total seven patients were excluded from the study: two patients had lesions less than 1 cm in diameter; another five patients for the poor image quality. The rest 35 patients were included into the study (7 men and 28 women). The mean age of the patients was 54.2 years (range 39–78 years). All the patients' histopathological results were jointly determined by two neuropathologists with more than five years of relevant work. The patients were classified (based on the 2007 version of WHO [18]) into 25 cases of grade I, 7 cases of grade II and 3 cases of grade III. And the final pathological subtypes were 5 case of meningothelial, 10 cases of fibrous, 9 cases of transitional (mixed), 6 cases of psammomatous, 2 cases of angiomatous, 2 cases of microcystic and 1 case of clear cell. Besides, only 31 patients had made immunohistochemistry, which could provide the Ki-67 labeling index (Ki-67 LI).

2.2. MRI protocol

All the patients underwent imaging with a 3.0T MR scanner (Magneto Trio, Siemens Erlangen, Germany) with an eight-channel head coil. DKI was performed using a spin-echo echo-planar imaging (SE-EPI) diffusion sequence (TR, 4000 ms; TE, 99 ms; NEX, 1; matrix, 102 × 128; number of slice, 25; slice thickness, 5 mm; spacing, 0 mm; and FOV, 240 mm) with 30 diffusion-encoding directions uniformly distributed at b-values = 0, 1000 and 2000 s/mm^2. The acquisition time for DKI was 4 min 20 s.

Additionally, a T1-weighted three-dimensional contrast-enhanced MRI was served as anatomic reference for DKI. It was a fast spoiled gradient echo sequence (TR, 1900 ms; TE, 2.52 ms; NEX, 1; matrix, 102 × 128; number of slice, 25; slice thickness, 1 mm; spacing, 0 mm; and FOV, 240 mm) performed after the administration of intravenous contrast material (0.2 mmol/kg, Gadodiamide, GE Healthcare) at a speed of 2.5 ml/s.

2.3. Image post-processing

Analysis of DKI data was performed using our in-house software program and SPM (Statistical Parametric Mapping, University College London, London) including a three dimensional motion correction and registration. Regions-of-interest (ROIs) were manually identified by three readers (neuroradiologist with more than 5 years of working