Preoperative Grading and Subtyping of Meningiomas using Diffusion Tensor Imaging

S. Wang[1], S. Kim[2], Y. Zhang[1], L. Wang[1], E. B. Lee[3], P. Syre[4], J. Y. Lee[4], H. Poptani[1], and E. R. Melhem[1]
[1]Radiology, University of Pennsylvania, Philadelphia, PA, United States, [2]Radiology, New York University School of Medicine, New York, NY, United States, [3]Pathology and Laboratory Medicine, University of Pennsylvania, Philadelphia, PA, United States, [4]Neurosurgery, University of Pennsylvania, Philadelphia, PA, United States

Introduction
Preoperative information about the histological grades and subtypes of meningiomas is very important as it aids the surgeon in planning the resection. Hard consistency, such as encountered in fibroblastic subtypes, makes the removal of the tumor difficult, especially located at the skull base. Conventional MRI is limited in the differentiation between grades and subtypes. Earlier studies have demonstrated the group differences in DTI metrics such as MD, FA, CL, CP and CS between atypical and typical[1-2], fibroblastic and other benign subtype meningiomas[2-3]. However there is no report regarding the sensitivity and specificity of these methods. Skewness (SK) is the third moment of eigenvalues, which acts as a combination of CL and CP[4]. Lattice index (LI) is a measure of orientation coherence of diffusion tensor in neighboring voxel[5]. In our previous study[6], FA has been shown to be a complimentary measure of CS. SK, LI and FA might assist in better classification of meningiomas. Use of histogram for studying distributions of various DTI metrics may further elucidate tissue characterization. The purpose of this study is to determine whether DTI metrics along with histogram analysis can help in grading and subtyping of meningiomas.

Materials and Methods
Forty-five meningiomas from forty-four patients with histopathologic diagnosis of atypical (n=9, Grade II, 6M/3F, age 47-80), anaplastic (n=3, Grade III, 3F, age 41-76) and typical (n=33, Grade I, 8M/25F, age 27-86) meningiomas were included in this study. Subtypes of typical meningiomas include 8 fibroblastic, 12 transitional, 12 meningothelial, 2 angiomatous, 1 secretary. Atypical and anaplastic meningiomas were grouped together as atypical meningiomas. Of the typical meningiomas, transitional, meningothelial, angiomatous and secretary subtypes were put together as others. All patients underwent MR studies before surgery on a 3T Siemens Tim Trio scanner with a 12-channel phased-array head coil. DTI data was acquired using a single shot spin echo EPI sequence with parallel imaging using GRAPPA (acceleration factor = 2). Sequence parameters were as follows: TR/TE = 5000/86, NEX = 3, FOV = 22 x 22 cm^2, b = 1000 s/mm^2, number of diffusion weighting directions = 30, slice thickness 3 mm. Contrast-enhanced T1 weighted images, FLAIR, FA, MD, CL, CP, CS, LI and SK maps were co-registered and DTI metrics were measured from the enhancing region. Mean, variance, skewness and kurtosis of each DTI metrics were computed using IDL routines. A pair-wise comparison was performed for each parameter using a Mann-Whitney U test. A two level decision tree was designed to discriminate different types of tumors. At the first level, atypical meningiomas were differentiated from typical meningiomas. At the second level, typical meningiomas were further sub-divided into fibroblastic and other subtypes. At both levels, two DTI parameter sets (first set with MD, CL, CP, and CS, and second set with MD, FA, LI, and SK) were fed into a multivariate logistic regression analysis respectively to determine the best model for classification.

Results
For atypical vs typical meningiomas, the best logistic regression model (LRM) consisted of mean of SK, kurtosis of FA, skewness of SK and kurtosis of SK, resulting in an AUC of 0.952. Skewness of SK was the single best predictor with an AUC of 0.828. For typical fibroblastic vs other subtypes, the best LRM comprised of mean of CL, CP, CS and skewness of CP with an AUC of 0.938 (Fig.1). LI was the single best classifier with an AUC of 0.852. Boxplots of the imaging parameters selected by LRM from the three types of meningiomas are shown in Fig. 2. Significantly increased mean FA, CP, LI and decreased CS were observed in fibroblastic subtypes compared with both atypical and other subtype meningiomas.

Discussion
Previous study demonstrated that MD was able to differentiate atypical from typical meningiomas due to the high cellularity of atypical meningiomas[1]. Our study showed that histogram analysis of eigenvalue skewness further improves the classification with an AUC of 0.952. This is may be due to the heterogenous nature of atypical meningiomas. Prior studies also reported increased FA and CP in fibroblastic meningiomas[2-3,7], which is consistent with our study. The high degree of anisotropy within fibroblastic meningiomas is probably due to their high content of intercellular collagen and reticulin, which is believed to be responsible for the hard consistency of these tumors. Histogram measures of CL, CP and CS can help distinguish fibroblastic meningiomas from other subtypes. These results suggest that histogram analysis of DTI metrics can help in grading and subtyping of meningiomas.

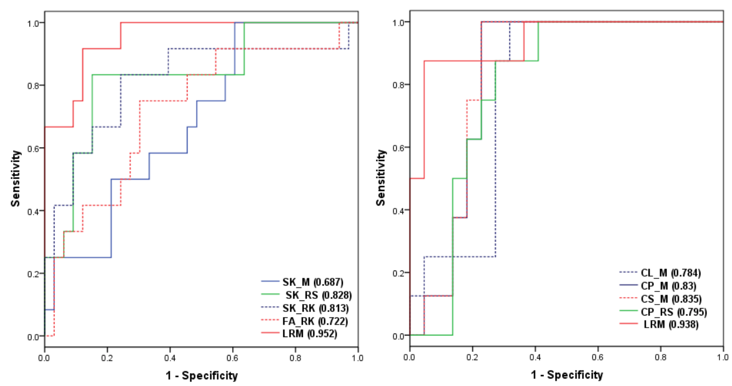

Fig 1. ROC curves from the enhancing region of the meningiomas. Logistic regression model (LRM) including mean skewness (SK_M), kurtosis of FA (FA_RK), skewness of skewness (SK_RS) and kurtosis of skewness (SK_RK) was the best predictor for differentiation of atypical from typical meningiomas (Left), whereas mean CL (CL_M), mean CP (CP_M), mean CS (CS_M) and skewness of CP (CP_RS) was the best model for distinguishing fibroblastic from other subtypes (Right). The numbers in the parentheses are AUC values.

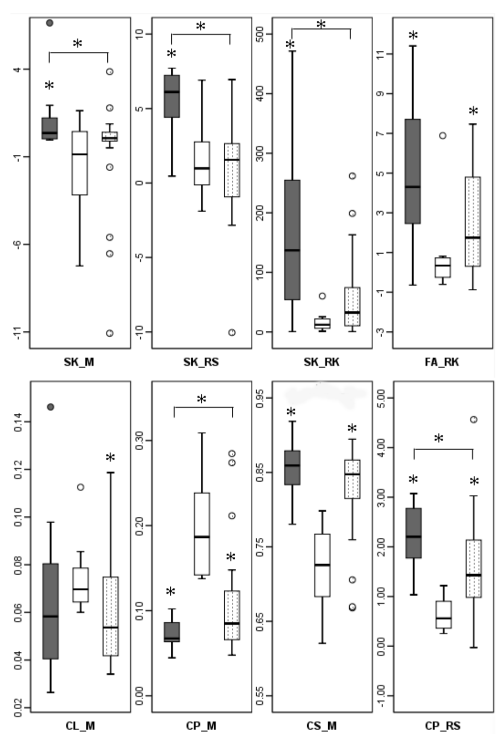

Fig.2. Box plot of DTI parameters selected by LRM in atypical (grey); fibroblastic (white); and other subtype (dotted) meningiomas. The outliers are represented by circles. * indicates significant difference ($p<0.05$) for fibroblastic *vs* atypical, fibroblastic *vs* others

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