Distinct Radiographic Phenotype of Low-Grade Meningiomas

Abraham Dada, BA[1]; Aymen Kabir, BA[1]; Wesley Shoap, MD[1]; Rithvik Ramesh BS[1]; Daniel Quintana, BA[1]; Michael A. Torres-Espinosa, BS[1]; Christian Jimenez, BS[1]; Robert C. Osorio, MD[1]; Ezequiel Goldschmidt, MD, PhD[1];
[1]Department of Neurological Surgery, University of California, San Francisco

Introduction

Despite recent developments in meningioma classification systems, WHO grades remain a robust predictor of tumor recurrence. Accurate pre-operative identification of Grade 1 meningiomas is crucial for informed management decisions and effective patient counseling. This study aimed to establish clinically single-slide MR and CT, sensitive and specific markers for low-grade meningioma to develop automated image recognition software

Table 1. Cohort Characteristics

Characteristic	Grade I	High Grade	p Value
No. of patients	230	91	
Age in yrs., mean ± SD	59.3 ± 14.7	60.8 ± 16.2	0.431*
Female n (%)	170 (73.9)	47 (51.6)	<0.001‡
Location, n (%)			
Convexity	73 (31.7)	49 (53.8)	<0.001‡
Skull Base	157 (68.3)	42 (46.2)	
MRI Features			
Maximal Tumor Dimension, mean ± SD	3.43 ± 1.50	4.5 ± 1.85	<0.001*
Sinus Invasion, n (%)	41 (17.8)	27 (29.7)	0.046‡
Homogenous Enhancement, n (%)	180 (78.3)	49 (53.8)	<0.001‡
Cystic, n (%)	3 (1.3)	2 (2.2)	0.625†
T2 Signal Change, n (%)	97 (42.2)	68 (74.7)	<0.001‡
T2 Signal Change 2x Tumor Volume, n (%)	5 (2.2)	5 (5.5)	0.802†
CT Features			
Bone Involvement	46 (20.0)	18 (19.8)	1.0‡
Osteolytic, n (%)	11 (4.8)	9 (9.9)	0.150‡
Hyperostosis, n (%)	33 (14.3)	9 (9.9)	0.369‡
Hyperostosis Type, n (%)			0.442‡
Type I Hyperostosis	14 (42.4)	2 (22.2)	
Type II Hyperostosis	19 (57.6)	7 (77.8)	
Bone > Tumor, n (%)	6 (18.2)	0 (0)	0.567†

Methods and Materials

We retrospectively reviewed patients with newly diagnosed WHO 1-3 meningioma from a single center between 2021-2024. Radiographic features were manually curated from CT and MRI sequences, including location, size (maximal tumor dimension), T1 enhancement pattern, T2 signal change, bone involvement, presence of osteolysis, and hyperostosis type (none, Type 1, Type II). Type 1 hyperostosis was defined as hyperostosis with destruction of cortical architecture while Type 2 referred to the preservation of cortical structure. Univariate analyses and multivariate logistic regression analyses compared differences between low- and high-grade meningiomas. Three machine learning models—Random Forest, Support Vector Machine, and Gradient Boost Machine—were employed to assess nonparametric relationships between features. Subsequent receiver operating characteristic (ROC) analyses was subsequently used to determine thresholds of top features that optimally predicted low- vs high-grade meningiomas.

Table 2. Multivariate logistic regression analysis for TRAF7 mutation status

Feature	OR (CI)	P value
Location		
Convexity	Reference	Reference
Skull Base	7.63 (2.43-25.61)	<0.001
Maximal Tumor Dimension	0.76 (0.62-0.91)	0.004
Sinus Invasion	0.62 (0.33-1.19))	0.15
Enhancement Pattern		
Heterogenous	Reference	Reference
Homogenous	1.64 (0.85-3.13)	0.138
T2 Signal Change	0.46 (0.24-.88)	0.02

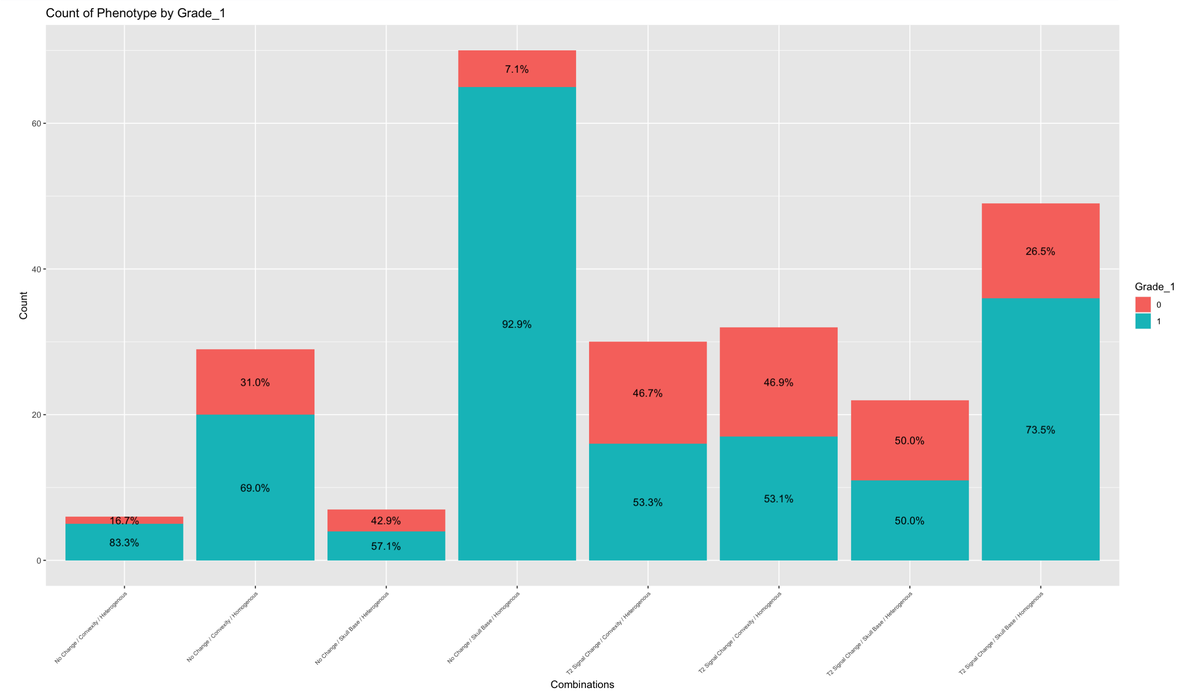
Results

230 low-grade meningioma were compared to 91 high-grade meningiomas. Compared to high-grade meningiomas, low-grade meningiomas were more likely in females (73.9% vs 51.6% p<0.001), located at the skull-base (68.3% vs 46.2% p<0.001), smaller size (3.43 ± 1.50 vs 4.5 ± 1.85 p<0.001), had no sinus invasion (17.8% vs. 29.7% p=0.046), were homogenous enhancing (78.3% vs 53.8% p<0.001), and exhibited T2-signal change (42.2% vs 74.7% p<0.001).

Multivariate logistic regression analysis showed low-grade meningiomas were significantly associated with skull base location (OR: 7.63 P<0.011), smaller size (OR 0.76 p=0.004), and absence of T2 signal change (OR:0.46, P=0.02).

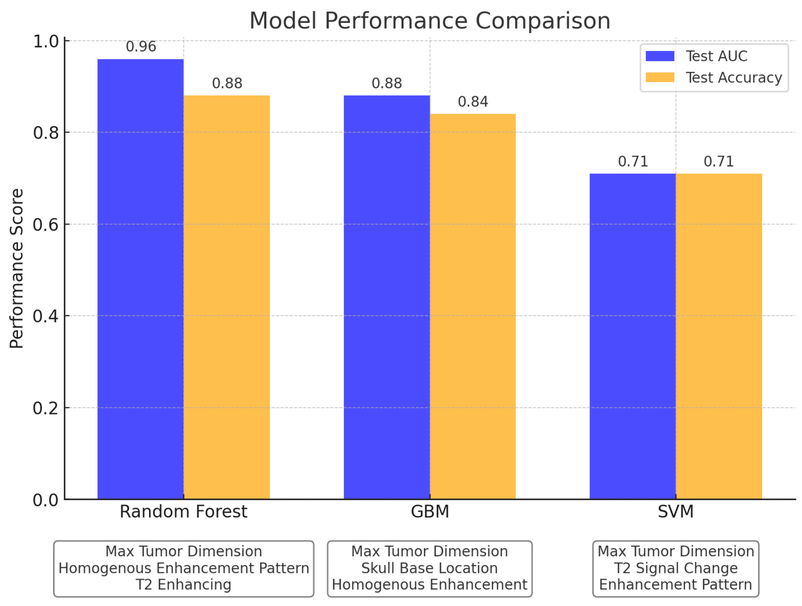
Among machine learning models, the RF model achieved the highest performance on the test set (AUC: 0.96, Accuracy: 0.88) compared to the GBM (AUC:0.88, Accuracy: 0.84) and SVM (AUC:0.71, Accuracy: 0.71). Top features of the RF model included tumor size, enhancement pattern, and T2-enhancment.

In subgroup analysis 92.9% of meningiomas with no signal change, homogenous enhancement, and located at the skull base were low-grade. This phenotype was present in 40% of grade I meningiomas. ROC analyses showed a size cut-off of 3.65 cm had a sensitivity of 0.64 and specific of 0.68.



Discussion

In addition to the known skull base location and smaller size, Grade 1 meningioma pathology is associated with the absence of T2 signal change and homogenous enhancement pattern. The presence of all these features is highly predictive of a Grade 1 meningioma and can help making decisions regarding surgical removal, counseling and follow-up.



Conclusions

Machine learning pipeline can adequately delineate Grade I Meningiomas using preoperative imaging.

Contact

Abraham Dada
University of California, San Francisco
Abraham.dada@ucsf.edu