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Machine Learning Applied to Neuroimaging for Diagnosis of Adult Classic Chiari malformation: Role of the Basion as a Key Indicator

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Purpose

The current diagnostic criterion for Chiari malformation Type I (CM-I), based on tonsillar herniation (TH), includes a diversity of patients with amygdalar descent that may be caused by a variety of factors. In contrast, patients presenting with an overcrowded posterior cranial fossa, a key characteristic of the disease, may remain misdiagnosed if they have little or no TH. The objective of the present study was to use machine-learning classification methods to identify morphometric measures that help discern patients with classic CM-I to improve diagnosis and treatment and provide insight into the etiology of the disease.

Methods

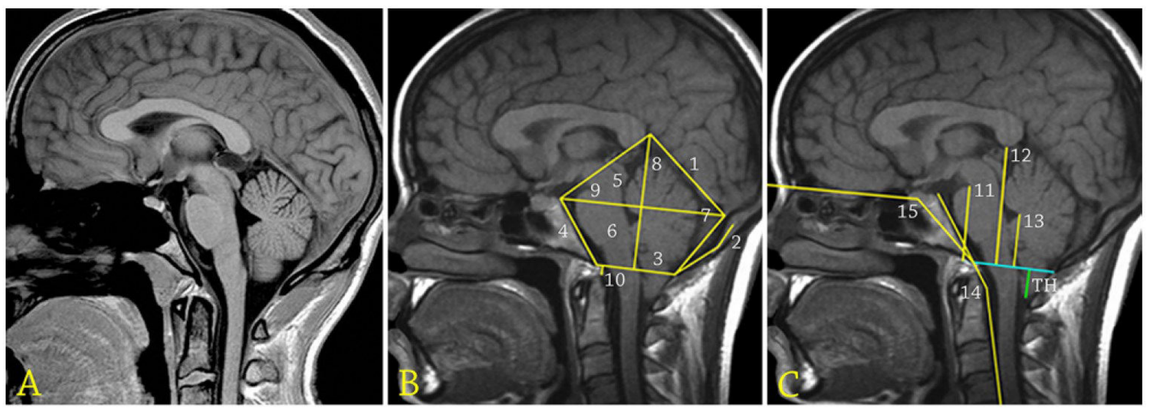
Fifteen morphometric measurements of the posterior cranial fossa were performed on midsagittal T1-weighted MR images obtained in 195 adult patients diagnosed with CM. Seven different machine learning classification methods were applied to images from 117 patients with classic CM-I and 50 controls matched by age and sex to identify the best classifiers discriminating the 2 cohorts with the minimum number of parameters. These classifiers were then tested using independent CM cohorts representing different entities of the disease.

Results

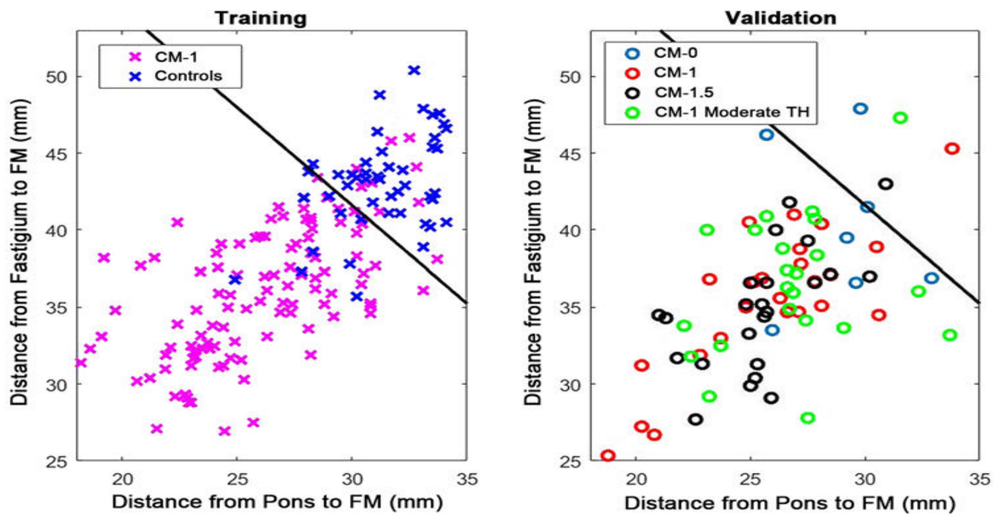
Machine learning identified combinations of 2 and 3 morphometric measurements that were able to discern not only classic CM-I (with more than 5 mm TH) but also other entities such as classic CM-I with moderate TH and CM Type 1.5 (CM-1.5), with high accuracy (> 87%) and independent of the TH criterion. The distances from the lower aspect of the corpus callosum, pons, and fastigium to the foramen magnum and the basal and Wackenheim angles were identified as the most relevant morphometric traits to differentiate these patients. The stronger significance ($p < 0.01$) of the correlations with the clivus length, compared with the supraoccipital length, suggests that these 5 relevant traits would be affected more by the relative position of the basion than the opisthion.

Conclusions

Tonsillar herniation as a unique criterion is insufficient for radiographic diagnosis of CM-I, which can be improved by considering the basion position. The position of the basion was altered in different entities of CM, including classic CM-I, classic CM-I with moderate TH, and CM-1.5. This suggests a predictive model based on 3 parameters, all related to the basion location, to discern classic CM-I with 90% accuracy and suggest considering the anterior alterations in the evaluation of surgical procedures and outcomes.



Ordination plots depicting the distribution of data points used for training (left) and validation (right). The classification line generated by the support vector machine using only 2 features is also shown.



Accuracies of the 7 supervised classification methods using different numbers of features applied to independent cohorts of patients with CM-I, CM-I patients with moderate TH, CM-1.5, and CM-0.

Cohort & No. of Features	Linear Discriminant Analysis	Quadratic Discriminant Analysis	Naïve Bayes	Decision Tree	Logistic Regression	k-Nearest Neighbors	Support Vector Machine
CM-I pts (n = 24; all F)							
2	96%	93%	96%	93%	96%	98%	96%
3	97%	100%	96%	92%	96%	83%	96%
4	96%	97%	93%	88%	96%	85%	88%
5	94%	96%	93%	92%	96%	91%	96%
6	96%	92%	96%	92%	96%	94%	96%
7	96%	96%	96%	92%	96%	96%	96%
CM-I pts w/ mod TH (n = 23; 6 M, 17 F)							
2	96%	92%	96%	86%	96%	76%	96%
3	91%	91%	96%	86%	91%	86%	96%
4	93%	90%	96%	90%	91%	90%	87%
5	95%	90%	83%	92%	96%	91%	95%
6	96%	91%	90%	92%	96%	91%	95%
7	93%	91%	96%	92%	95%	85%	96%
CM-1.5 pts (n = 24; 2 M, 22 F)							
2	96%	96%	96%	93%	96%	93%	96%
3	96%	96%	96%	93%	96%	86%	96%
4	96%	96%	95%	96%	96%	89%	92%
5	94%	96%	93%	92%	96%	91%	96%
6	96%	92%	96%	92%	96%	94%	96%
7	96%	96%	96%	92%	96%	86%	96%
CM-0 pts (n = 7; 3 M, 4 F)							
2	68%	57%	71%	61%	57%	50%	68%
3	71%	68%	71%	54%	71%	57%	64%
4	68%	71%	50%	68%	71%	57%	68%
5	68%	100%	54%	68%	57%	57%	57%
6	64%	82%	71%	68%	57%	57%	64%
7	64%	82%	71%	68%	57%	57%	64%