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FRACTAL ANALYSIS OF THE CEREBRAL CORTEX AND WHITE MATTER FOR QUANTITATIVE ASSESSMENT OF AGE-RELATED BRAIN ATROPHY IN MEN AND WOMEN

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Abstract

The development of new and the refinement of existing algorithms for morphometric assessment of age-related atrophic changes in brain structures remains a relevant scientific endeavor in modern neuromorphology. Across an individual's lifespan, the presence of atrophic modifications can be detected in diverse brain structures, offering insights into the intricacies of the aging process. Among the relatively recent morphometric techniques, fractal analysis emerges as a noteworthy approach, enabling the assessment of spatial configuration attributes within examined structures, as well as gauging their level of structural and spatial intricacy. Consequently, fractal analysis serves as a robust and effective tool for identifying atrophic changes within brain structures.

The aim of this study was to determine the fractal dimension (FD) values in both the cerebral cortex and white matter and discern the features associated with FD changes throughout the lifespan in men and women.

For the investigation, magnetic resonance (MR) brain scans from 100 apparently healthy individuals aged 18 to 86 were employed (comprising 44 males and 56 females). For each brain, four coronal tomographic sections were selected (located at the levels of the most anterior points of the temporal lobes, mammillary bodies, quadrigeminal plate, and splenium of corpus callosum), along with one axial section (located at the level of the thalamus). MR images were segmented, resulting in creation of binary images of the cortex and white matter. Fractal analysis was conducted using the ImageJ software, employing the box-counting method. Mean FD values were calculated for all five tomographic sections (FD-5) and for the four coronal sections (FD-4).

As a result of morphometric analysis, it was determined that the average FD-5 value of the cerebral cortex was 1.694±0.003 (ranging from 1.663 to 1.736) in males and 1.694±0.003 (ranging from 1.659 to 1.747) in females. The average FD-4 value of the cerebral cortex was 1.693±0.003 (ranging from 1.659 to 1.738) in males and 1.694±0.003 (ranging from 1.660 to 1.739) in females. The difference in FD-5 and FD-4 values of the cerebral cortex between males and females was not statistically significant ($P > 0.8$ for both FD values). Both FD values of the cortex exhibited strong negative statistically significant correlations with age: FD-5: $r = -0.726$, $p < 0.001$ (males) and $r = -0.687$, $p < 0.001$ (females); FD-4: $r = -0.753$, $p < 0.001$ (males) and $r = -0.734$, $p < 0.001$ (females).

The average FD-5 value of the cerebral white matter was 1.732±0.003 (ranging from 1.654 to 1.774) in males and 1.731±0.003 (ranging from 1.674 to 1.772) in females. The average FD-4 value of the cerebral white matter was 1.715±0.004 (ranging from 1.635 to 1.766) in males and 1.714±0.003 (ranging from 1.660 to 1.765) in females. The difference in FD-5 and FD-4 values of the white matter between males and females was not statistically significant ($P > 0.9$ for both FD values). In contrast to cortical FD, white matter FD displayed weak negative correlations with age that were not statistically significant: FD-5: $r = -0.247$, $p > 0.05$ (males) and $r = -0.047$, $p > 0.05$ (females); FD-4: $r = -0.154$, $p > 0.05$ (males) and $r = 0.033$, $p > 0.05$ (females).

In the investigation of the relationships between cortical and white matter FD values, it was observed that these FD values exhibited negative correlations of weak to moderate strength: FD-5: $r = -0.154$, $p > 0.05$ (males) and $r = -0.423$, $p < 0.001$ (females); FD-4: $r = -0.230$, $p > 0.05$ (males) and $r = -0.497$, $p < 0.001$ (females).

In this study, it was found that cortical FD values had stronger correlations with age compared to white matter FD values. There were no statistically significant differences in cortical and white matter FD values between males and females, but age-related changes in white matter were more pronounced in males, while in females, these changes were negligible. Thus, fractal analysis can be used for the

detection and quantitative characterization of age-related atrophic changes in brain structures, and the results of this study may serve as normative criteria for differentiating normal and pathological brain aging.

Keywords: aging, cerebral cortex, cerebral white matter, fractal analysis, fractal dimension, magnetic resonance imaging.