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On the construction of a 3D-printed brain phantom as gold standard for the validation of brain segmentations

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Background: In Multiple Sclerosis, quantification of the volume of brain structures in images acquired by magnetic resonance imaging (MRI) is a basic method involved in the assessment of structural abnormalities or in monitoring disease progression. However, tissue segmentation algorithms in MRI lack a ground truth for efficient and reliable validation. Aim: The aim of this study is to develop a realistic 3D-printed brain phantom to facilitate the development and validation of brain segmentation algorithms. Methods: The phantom was built in three stages. First, white matter (WM) and grey matter (GM) T1 intensities were derived from T1 relaxation maps of a healthy subject acquired in a 3T MRI scanner using an inversion recovery spin echo sequence. For mimicking WM and GM intensities, 0.6% agar gel samples with different concentrations of the contrast medium manganese chloride (MnCl2) were prepared. Moreover, 10 mg/mL 1% paraben was added as antimicrobial agent. At a second stage, to resemble the complex 3D geometry of the brain, WM and GM surface meshes were automatically extracted from an isotropic MPRAGE scan of the same subject. Extracted surfaces were then 3D-printed using polylactic acid thermoplastic and covered by a brushable silicone rubber to obtain flexible molds. At the last stage, the different parts of the phantom were assembled: the WM gel was injected into the WM surface mold; once the gel set, the mold was removed, a hydrophobic varnish layer was applied, and the GM mold was positioned on top; finally the GM gel was injected and the corresponding mold was pulled off when the gel became solid. Results: All the steps described were completed and the brain phantom was successfully constructed. T1 values calculated in the healthy subject (WM: 748.7 ś 13.0ms; GM: 1306.9 ś 76.5ms) were achieved using 0.12mM (WM gel: 842.0 ś 32.9ms) and 0.04 mM (GM gel: 1250.9 ś 65.3ms) of MnCl2, respectively. By means of the silicone molds, the folding patterns typical of WM and GM were reproduced, showing a high similarity with the real counterpart. Moreover, the thin layer of varnish added between tissues reduced the diffusion of the gels without creating a distinguishable interface. Discussion and conclusions: The described procedure enabled us to construct the first anthropomorphic brain phantom that can in the future be used for efficiently evaluating the performance of different MRI brain segmentation algorithms.

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