A comparative study of skull stripping methods in relapsing-remitting multiple sclerosis: Emergence of a new automatic segmentation algorithm

Jean-Christophe Souplet, Sophia Antipolis France, Christine Lebrun, Nice France, Pierre Clavelou, Clermont-Ferrand France, William Camu, Montpellier France, Jean Pelletier, Marseille France. Stéphane Chanalet, Nice France, Nicholas Ayache, Sophia Antipolis France and Grégoire Malandain, Sophia Antipolis France.

Objective: To obtain an automatic and robust brain segmentation method on a multi-site prospective database of homogenous population of relapsing-remitting (RR) multiple sclerosis (MS) patients.

Background: Skull-stripping is usually a required step before morphometric measurements on brain MRI. Manual delineation is a fastidious task and is subject to inter and intra-expert variability. Different automatic methods are available but there is no gold standard. Most methods have not been evaluated on MS patients MRI or require the lesions delineation.

Design/Methods: 25 MS patients from different sites underwent MR examination at baseline and follow up. Five skull-stripping methods BET (Smith 2002), HWA (Segonne 2004), AnaT1toBrainMask (Brainvisa), EM-BrainMask (Dugas 2004) and 3dIntracranial (Ward 1999) were run on 30 sets of MRI sequences (T1, T2 FSE, PD). From these five segmentations, the Staple algorithm (Warfield 2004) was used to give a probabilistic reference segmentation for each set. This segmentation was validated visually by an expert and compared with manual delineation when possible.

The Staple framework allowed to assess any segmentation method, by its sensitivity and its specificity. All methods and method combinations have been tested. A method combination binary segmentation was obtained by an automatic optimized thresholding of the corresponding Staple probabilistic segmentation.

Results: The (sensitivity-specificity) measurement ranges from (0.838-0.763) to (0.985-0.993) for all methods and combination of methods. Considering additional information (average execution time, software installation facility, robustness…), the best segmentation is a combination of three methods (BET, EM-BrainMask, 3dIntracranial) with (0.980-0.951). This new method has been tested and validated by an expert on all database sets.

Conclusions/Relevance: Using the Staple probabilistic framework different skull-stripping methods have been compared. An original reproducible automatic skull-stripping method has been obtained. This preliminary step is essential for atrophy and lesion load measurements.

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J.C. Souplet[1], C. Lebrun[2], P. Clavelou[3], W. Camu[4], S. Chanalet[2], N. Ayache[1], G. Malandain[1]

1. INRIA (Sophia-Antipolis, F) 2. Pasteur Hospital (Nice, F) 3. Gabriel Montpied Hospital (Clermont-Ferrand, F) 4. Gui de Chauliac Hospital (Montpellier, F)

Introduction and Purpose

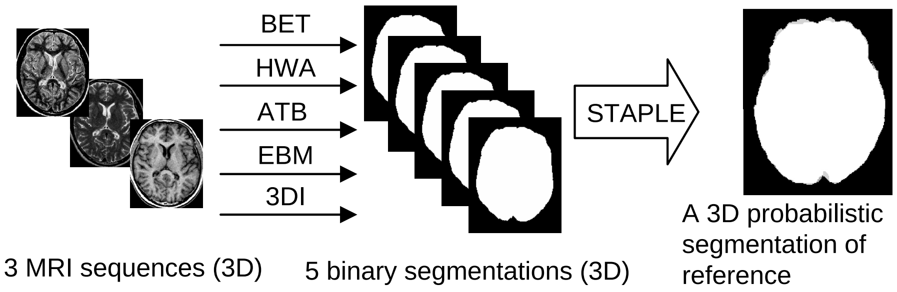
- **Observation:** Skull-stripping is usually a required step before morphometric measurements on brain MRI.
- **Problem in MS:** Most available methods have not been evaluated on MS patients MRI or require the lesion delineation.
- **Objective:** To obtain an automatic and robust brain segmentation method on a multi-site database of relapsing-remitting multiple sclerosis patients brain MRI. To compare available methods or method combinations.

Material

- **30 sets of 3D MRI sequences:** T1, T2 FSE, PD
- **5 available skull-stripping methods ("basic"):**
  1. BET [Smith 2002]
  2. HWA (mri_watershed) [Segonne 2004]
  3. AnaT1toBrainMask (ATB) [Brainvisa]
  4. EM-BrainMask (EBM) [Dugas 2004]
  5. 3dIntracranial (3DI) [Ward 1999]
- **The Staple framework** [Warfield 2004] **:**
  - Gives a probabilistic reference segmentation from the "basic" segmentations,
  - Gives for each "basic" segmentation the (sensitivity-specificity) measurements.

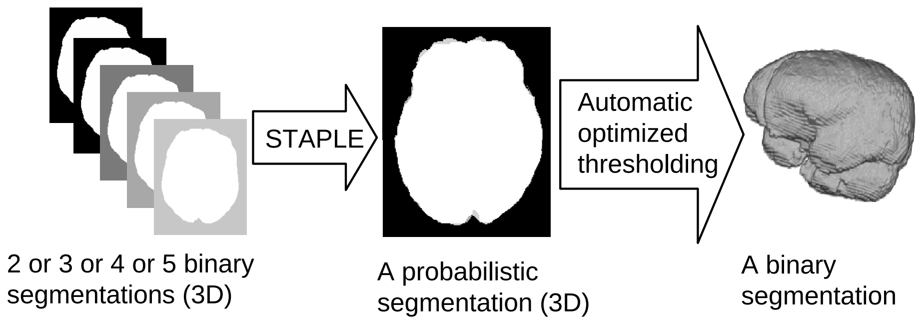
Method

- **To get the probabilistic segmentation of reference:**



- **Validation of the segmentation of reference by an expert**

- **Method Combinations:**



Results

5 basic methods + 26 Method Combinations ➔ 31 binary segmentations compared to a probabilistic segmentation of reference

Methods	Sensitivity Average	Specificity Average	√((1-Sen)²+(1-Spe)²) Average	Rank
EBM-BET-3DI-HWA-ATB	0,985	0,993	0,018	1
EBM-BET-3DI-ATB	0,971	0,997	0,030	2
EBM-3DI-HWA-ATB	0,970	0,986	0,035	3
BET-3DI-HWA-ATB	0,982	0,971	0,039	4
BET-3DI-ATB	0,982	0,969	0,042	5
EBM-3DI-ATB	0,963	0,986	0,043	6
EBM-BET-3DI	0,980	0,951	0,060	7
EBM-3DI	0,954	0,974	0,064	8
BET-3DI	0,989	0,938	0,067	9
EBM-BET-HWA-ATB	0,987	0,920	0,082	10
EBM-BET-3DI-HWA	0,991	0,914	0,087	11
EBM-BET-ATB	0,982	0,919	0,088	12
EBM-BET	0,958	0,926	0,090	13
3DI-HWA-ATB	0,952	0,940	0,100	14
3DI	0,943	0,930	0,122	15
3DI-HWA	0,904	0,948	0,129	16
3DI-ATB	0,938	0,926	0,131	17
EBM-3DI-HWA	0,966	0,873	0,138	18
EBM-HWA-ATB	0,966	0,864	0,143	19
ATB	0,867	0,961	0,149	20
EBM-HWA	0,920	0,873	0,154	21
EBM-BET-HWA	0,976	0,849	0,156	22
EBM	0,961	0,848	0,161	23
EBM-ATB	0,854	0,982	0,161	23
BET-HWA	0,949	0,841	0,172	25
BET-3DI-HWA	0,975	0,842	0,176	26
BET-HWA-ATB	0,995	0,823	0,178	27
BET	0,995	0,814	0,186	28
BET-ATB	0,979	0,824	0,194	29
HWA-ATB	0,838	0,763	0,389	30
HWA	0,948	0,368	0,636	31

Conclusions and future work

- 31 skull-stripping methods have been compared using the Staple framework
- Considering different criteria (average execution time, robustness, …), the best segmentation is the combination (BET, EBM, 3DI).
- Future work will divide this mask into three regions (cortex, cerebellum, brainstem).
- These algorithms should be included shortly in SepINRIA (software to analyse MS patient brain MRI, **http://www-sop.inria.fr/asclepios/software/SepINRIA**)

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