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Deep Learning and Automated MRI Analysis in Idiopathic Normal Pressure Hydrocephalus

Methodological developments for outcome prediction and quantitative DESH assessment

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Academic dissertation

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Abstract

Idiopathic normal pressure hydrocephalus (INPH) is a neurological disorder characterized by impaired gait and balance, cognitive decline and incontinence, in combination with enlarged lateral ventricles. Although symptoms can often be alleviated through surgical insertion of a cerebrospinal fluid (CSF) shunt, a substantial proportion of patients do not improve after surgery. There is therefore a need for new analytical methods that can extract more informative features from MRI to improve diagnostic and prognostic accuracy.

This thesis consists of the work from four papers with the overall aim to develop and assess artificial intelligence (AI)-based and fully automated MRI-based methods, to improve objective assessment and shunt decision support in INPH.

Several well-known convolutional neural networks (CNNs) were applied to 3D brain magnetic resonance imaging (MRI) data to distinguish between participants with an INPH-typical gait pattern and controls. An ensemble model search was developed to find the optimal ensemble for the task at hand, by optimizing combinations of diverse models. A fusion search strategy was also developed, to determine the optimal fusion points for information fusion between different MRI sequences. Shunt outcome prediction was evaluated with both deep learning approaches, using the two search algorithms, as well as with radiomics-based machine learning models. Finally, a fully automated pipeline was developed for assessment of disproportionally enlarged subarachnoid space hydrocephalus (DESH), utilising image segmentation and image analysis techniques to determine a quantitative DESH metric (qDESH). The work was conducted on brain MRI from one population-based cohort (Paper I), two open access datasets (Paper II), a clinical cohort of shunted INPH patients (Paper III) and a retrospective cohort of INPH patients and controls (Paper IV).

All CNNs distinguished between gait-impaired and controls, in terms of a chi-square test of independence. The optimized ensemble model achieved the highest classification performance, exceeding that of the individual networks and conventional radiological measures. The results support the presence of detectable structural differences in brain MRI between the groups. The sequential search of multimodal fusion points improved classification performance compared with unimodal and conventional fusion strategies, while reducing computational cost. However, when applying these methodologies to predict shunt outcome, no model achieved clinically sufficient performance. These findings indicate that structural MRI alone is not yet reliable for shunt prediction in INPH. The fully automated qDESH pipeline demonstrated high agreement with the established semi-automatic qDESH method, although the agreement was lower than between two raters of the semi-automatic method. The automated measure of qDESH aligned well with visual assessment of DESH.

In conclusion, this thesis advances methodologies for AI-based and automated brain MRI analysis, particularly for INPH. Introducing and evaluating an optimized ensemble strategy, a systematic multimodal fusion approach, and a fully automated quantitative imaging pipeline, the work demonstrates both the potential and the current limitations of advanced and automated MRI analysis in INPH. The fully automated qDESH pipeline showed good agreement with both the semi-automatic method and visual DESH ratings, although further refinement is required before it can be applied in clinical practice. While CNNs can capture differences in brain MRI beyond conventional linear measures, they cannot yet predict shunt response in a clinically useful way. Structural MRI data alone might be insufficient, and additional non-imaging data might be required. The findings highlight the importance of diversity across models and imaging sequences to improve data-driven image assessment. The need for large clinical datasets is a limiting factor, making collaboration among multiple centres necessary to enable further methodological developments. The methodological approaches and insights presented here may also be transferable to other neurological disorders in which MRI plays a central diagnostic role, thereby contributing more broadly to the neuroimaging field.

Keywords: Idiopathic normal pressure hydrocephalus, Deep learning, Ensemble search, Medical imaging, MRI, Automated image analysis, Multimodal ensembles, Outcome prediction

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