Non-Invasive Detection of Rapid and Reversible Intracranial Pressure Changes From Retinal Fundus Images

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Introduction

Intracranial pressure (ICP) is a key physiological variable in neurocritical care, as sustained elevation can impair cerebral perfusion, precipitate secondary brain injury, and lead to life-threatening brain herniation. Currently, ICP assessment relies on invasive monitoring techniques that require neurosurgical intervention and carry procedural risks. As an extension of the central nervous system, the retina offers a non-invasive window into intracranial dynamics. While retinal vascular changes have been linked to chronically elevated ICP [1][2], it remains unclear whether retinal imaging is sensitive to rapid, reversible ICP changes occurring over short, clinically relevant timescales.

Materials and Methods

A controlled physiological experiment was conducted in 25 healthy adult volunteers, in whom systematic body-position changes and a standardized Valsalva maneuver were used to induce transient ICP elevations. Retinal fundus images were acquired across all pressure conditions using a handheld non-mydriatic camera and analysed using complementary biomarker-based and image-based modelling approaches under patient-independent evaluation.

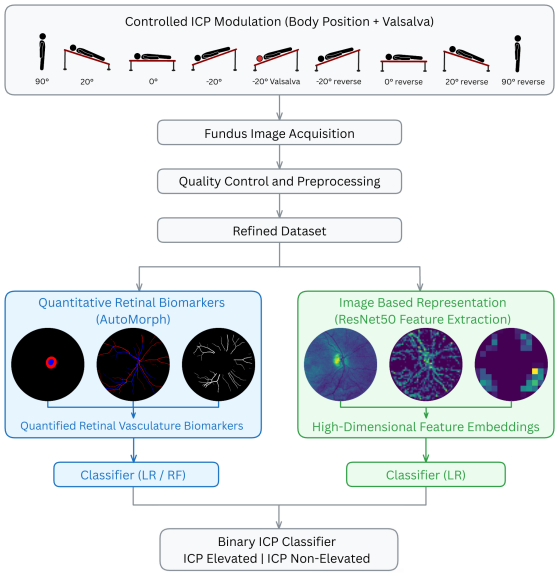

Fig. 1 High-level overview of the experimental workflow.

Results

Quantitative retinal vascular biomarkers showed consistent modulation across physiologically defined states, responding systematically to rapid ICP elevation. Deep-learning models trained on fundus images achieved high discrimination between elevated and non-elevated ICP states. While unconstrained full-field models partly relied on acquisition-related cues, fine-tuning with circular masking maintained high performance (ROC–AUC ≈ 0.84), shifting attention to the optic disc and peripapillary vasculature (Fig. 2).

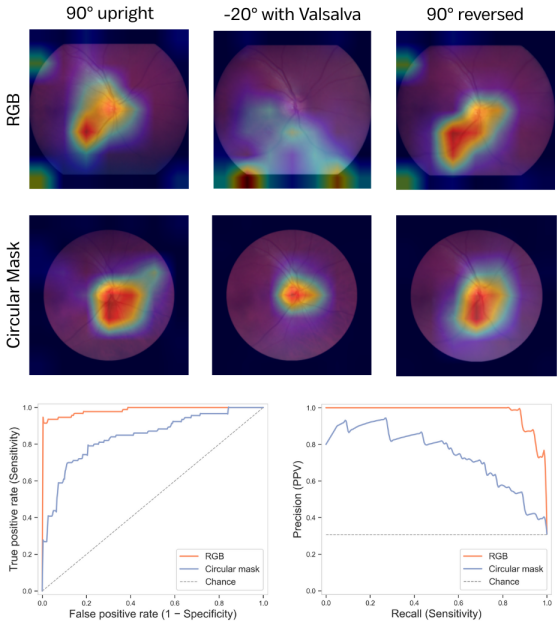

Fig. 2 Top: Grad-CAM visualisations for fine-tuned ResNet50 models with and without circular masking. Bottom: Corresponding ROC and precision-recall curves.

Discussion

These results suggest that retinal fundus images encode information related to rapid intracranial pressure dynamics beyond predefined vascular biomarkers. The convergence of venous biomarker responses and image-based findings supports the physiological relevance of the extracted signals, highlighting retinal imaging as a non-invasive approach for assessing dynamic ICP changes.

References

[1] Andersen et al. Assessing intracranial pressure using non-invasive fundus images. Sci. Rep. 10, 13062 (2020).
[2] Moss, H. E. Retinal vein changes as a biomarker of elevated intracranial pressure. Front. Neurol. 12, 751370 (2021).

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