Literature Review: Deep Learning-Based Intracranial Aneurysm Detection and Segmentation

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Abstract

This literature review synthesizes recent advances (2018–2025) in deep learning-based detection and segmentation of intracranial aneurysms (IAs) across CTA and MRA modalities. It compares architectures (U-Net variants, attention modules, multi-task models), training strategies (multi-institutional datasets, external validation), and clinical translation outcomes (radiologist-assist improvements, workflow integration). Key findings: state-of-the-art systems achieve >90% sensitivity for ≥5 mm aneurysms with <2 false positives per case, while performance on tiny aneurysms (<3 mm) remains challenging. Methodological rigor (external validation, cross-modality testing) and integration into clinical workflows are essential for reliable deployment.

1. Introduction

Intracranial aneurysms are dilations of cerebral arteries with a global prevalence of ~3%. Rupture leads to subarachnoid hemorrhage with high morbidity and mortality, emphasizing the need for early detection. Manual reading is time-consuming and variable, particularly for small aneurysms. Deep learning offers automated, sensitive tools to augment radiologists.

2. Imaging Modalities and Data

- DSA (gold standard), 3DRA (high-resolution), CTA (fast, non-invasive), TOF-MRA (non-contrast). Public and multi-center datasets are increasingly available to promote generalization.

3. Methods Landscape (2018–2025)

- Early CNNs and U-Net baselines for segmentation.
- GLIA-Net: global localization + local 3D U-Net segmentation on large CTA cohorts.
- Attention-enhanced U-Nets (CBAM, dual attention) to handle scale variation and edges.
- Geometric learning and modality-agnostic pipelines combining vessel segmentation with point-cloud classification.
- External clinical validations on TOF-MRA show high accuracy and subgroup sensitivity by size.

4. Performance and Validation

- Sensitivity typically 80–95% (≥5 mm), Dice 0.6–0.75 for segmentation; FP/case targeted <2 for clinical usability.
- External validation and cross-scanner robustness are critical; scanner shifts can degrade performance.

5. Clinical Translation

- AI assistance improves sensitivity and reduces reading time; strongest gains for junior readers.
- Real-world deployments highlight FP management, consistency monitoring, and QA loops.

6. Challenges

- Tiny aneurysm detection (<3 mm) and generalization across modalities/sites.
- Label noise, domain shift, and data governance for multi-site collaboration.

7. Future Directions

- Vision transformers and self-supervised pretraining for data efficiency.
- Federated learning for privacy-preserving multi-center training.
- Explainable AI, uncertainty quantification, and standardized benchmarks (e.g., RSNA challenges).

8. Conclusion

Deep learning has matured for IA detection and segmentation, with demonstrated clinical benefits when properly validated and integrated. Continued focus on tiny lesions, domain robustness, and workflow integration will unlock broader clinical adoption.

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