SIIM CAIMI25
Conference on Artificial Intelligence in Medical Imaging
OCT 20-21 | UNIVERSITY OF CALIFORNIA, IRVINE

Active Learning Pipeline for Accelerated Segmentation of 11,000+ Longitudinal Brain Metastasis MRI Studies-Initial Work

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Introduction/Background

Accurate segmentation of brain metastases, the most common intracranial tumor in adults, and surrounding edema is essential for treatment planning and prognosis. However, manual segmentation is time-consuming, and automated AI methods often fall short compared to neuroradiologists, partly due to the small datasets used for training. One of largest publicly available brain metastases dataset of 11,892 studies (Yale-Brain-Mets-Longitudinal) is available and provides a need for segmentation. In this initial work, we introduce a segmentation pipeline designed to streamline the annotation process utilizing active learning.

Methods/Intervention

The dataset includes T1-weighted pre-contrast, T1-weighted post-contrast, T2-weighted, and FLAIR sequences for all studies in NIfTI format. To generate accurate lesion segmentations at scale, we developed an iterative, batch-wise segmentation pipeline that uses active learning to efficiently annotate brain metastasis studies. We start by using an internally developed 3D U-Net model selecting approximately 150 high-resolution MR studies. The model performs the initial segmentations on the studies. The model uses patch-based inputs (96×96×96×1) from post-contrast T1-weighted sequences and employs a cascaded strategy: a high-sensitivity region proposal network followed by a high-specificity false positive reduction network. The studies segmented by the model are refined by approximately fifteen medical trainees, followed by confirmation from four board-certified neuroradiologists using a custom web-based annotation platform. The revised segmentations are used to retrain the model. The improved model is applied to the next 150 studies, and this iterative cycle is repeated multiple times until the performance exceeds the predefined threshold. Afterward, the final model is applied to the remaining studies. The remaining studies are randomly sampled for validation. The segmentation accuracy is measured using the Dice coefficient.

Results/Outcome

The model has been trained on the BRATS-METS dataset and fine-tuned on 400 MRIs from UC Irvine (100 positive, 300 negative), achieving a mean Dice score of 0.72 ± 0.17 and a per-lesion sensitivity of 0.98 in its high-sensitivity configuration.

Conclusion

Our pipeline combines active learning with human oversight, aiming to improve the annotation efficiency of brain metastasis.

Statement of Impact

This work presents a scalable pipeline for AI-driven lesion segmentation in longitudinal MRIs with confirmed brain metastasis, enabling efficient dataset curation, disease progression tracking, and treatment response evaluation.

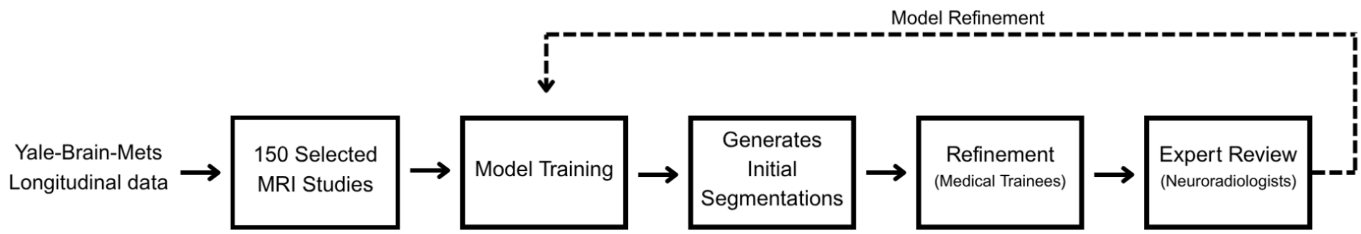

Figure 1: Active Learning Based Lesion Segmentation Pipeline

Active Learning Based Lesion Segmentation Pipeline

Keywords
Brain Metastases; MRI; Deep Learning; Active Learning; Segmentation; Neuroradiology