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From Image to Insight

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Clinical Applications of Deep Learning-Based Automated Pituitary Gland Segmentation in MRI

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Deep learning is transforming MRI-based neuroendocrine imaging by enabling precise and reproducible measurement of small anatomical structures. The pituitary gland is a vital endocrine organ, and its volume, shape, and regional morphology provide critical diagnostic and prognostic indicators for conditions such as pituitary adenomas, hypopituitarism, central precocious puberty, and growth hormone deficiencies. However, manual segmentation of the pituitary gland remains highly challenging because it is a small, variable target surrounded by complex sellar structures with subtle boundaries on routine MRI. Furthermore, manual delineation is labor-intensive and highly prone to inter- and intra-observer variability, which significantly limits its utility in longitudinal patient tracking and large-scale clinical trials.

To address these limitations, we developed a fully automated, two-stage deep learning framework for pituitary gland segmentation on T1-weighted brain MRI. The first stage employs a 3D heatmap-regression model to precisely localize the pituitary center. The second stage extracts a local patch and performs high-precision fine segmentation optimized for small and delicate anatomical targets. To identify the optimal model for this constrained sellar target under limited training resources, thirteen diverse candidate architectures—spanning conventional CNNs, residual networks, attention mechanisms, transformers, and state-space models—are comprehensively benchmarked under a rigorous cross-validation protocol.

The clinical value of this automated framework extends far beyond simple binary masking; it establishes a standardized, objective foundation for advanced morphometric analysis. By providing highly reproducible extractions of pituitary volume and midsagittal area, this technology enables the sensitive detection of subtle, micro-level physiological changes and pathological deviations. In clinical practice, this supports the objective tracking of longitudinal tumor progression or shrinkage, facilitates early intervention in pediatric endocrine disorders, and significantly reduces the diagnostic workload of radiologists.

Keywords: *Pituitary gland, Deep learning, Magnetic resonance imaging, Automated segmentation, Neuroendocrine imaging*