

Vector-quantized self-supervised MRI representation learning as robust imaging biomarkers of Alzheimer's disease

Qin, Shihua; Risacher, Shannon L; Rudolph, Marc D; Rundle, Melissa M; Alphin, Kathryn H; Craft, Suzanne; Gurcan, Metin N; Ma, Da



WAKE FOREST
UNIVERSITY

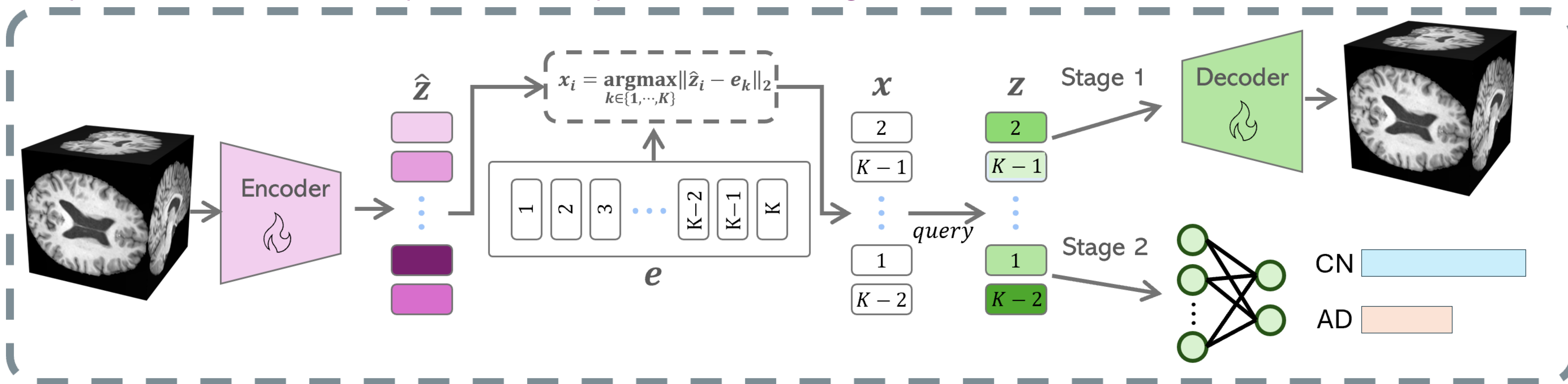
INTRODUCTION

- **T1-weighted structural MRI** is a core imaging modality for Alzheimer's disease and related dementias, capturing neurodegenerative patterns relevant to diagnosis and disease monitoring.
- **Self-supervised representation learning** enables models to learn low-dimensional latent representations from large-scale unlabeled MRI data.
- Conventional **autoencoder-based SSL frameworks** rely on continuous, weakly constrained latent spaces that may be sensitive to noise and encode disease-irrelevant variability, limiting cross-cohort generalization and sensitivity to AD-specific neurodegeneration.

METHODS

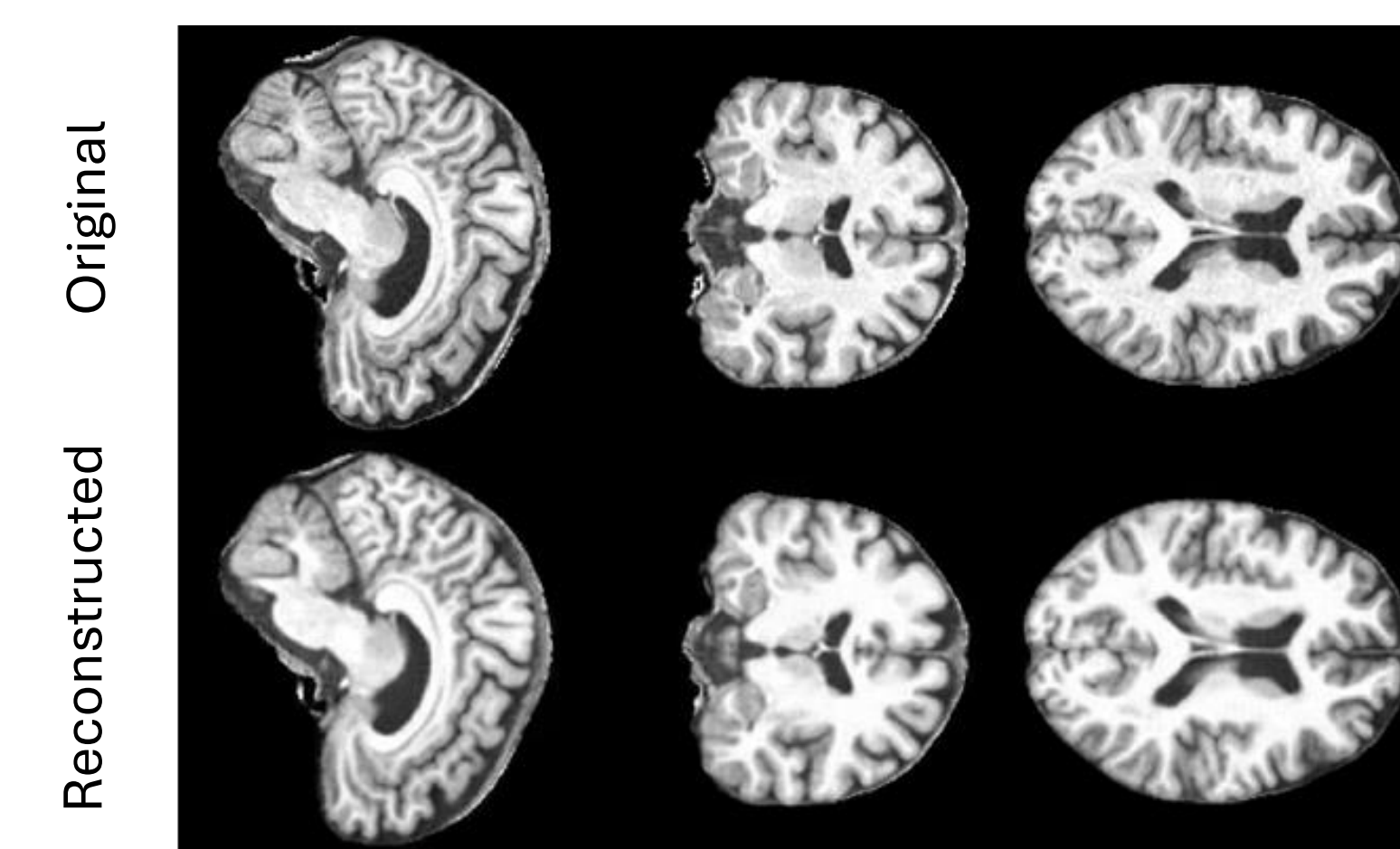
- We investigated **vector quantization (VQ)** as a latent regularization strategy for self-supervised MRI representation learning in Alzheimer's disease classification.
- A **VQ-adversarial framework** was pretrained on UK Biobank T1-weighted MRIs ($n = 36,116$) to learn discrete anatomical representations through a learnable codebook.
- The pretrained encoder was frozen, and a lightweight classifier was trained on ADNI to distinguish AD from CN individuals. Model performance was evaluated on the ADNI test set and externally validated using the WFADRC cohort.
- The proposed VQ-based model was compared with a conventional autoencoder using the same encoder-decoder architecture.

A. Pipeline for VQ-based self-supervised MRI representation learning and downstream classification.

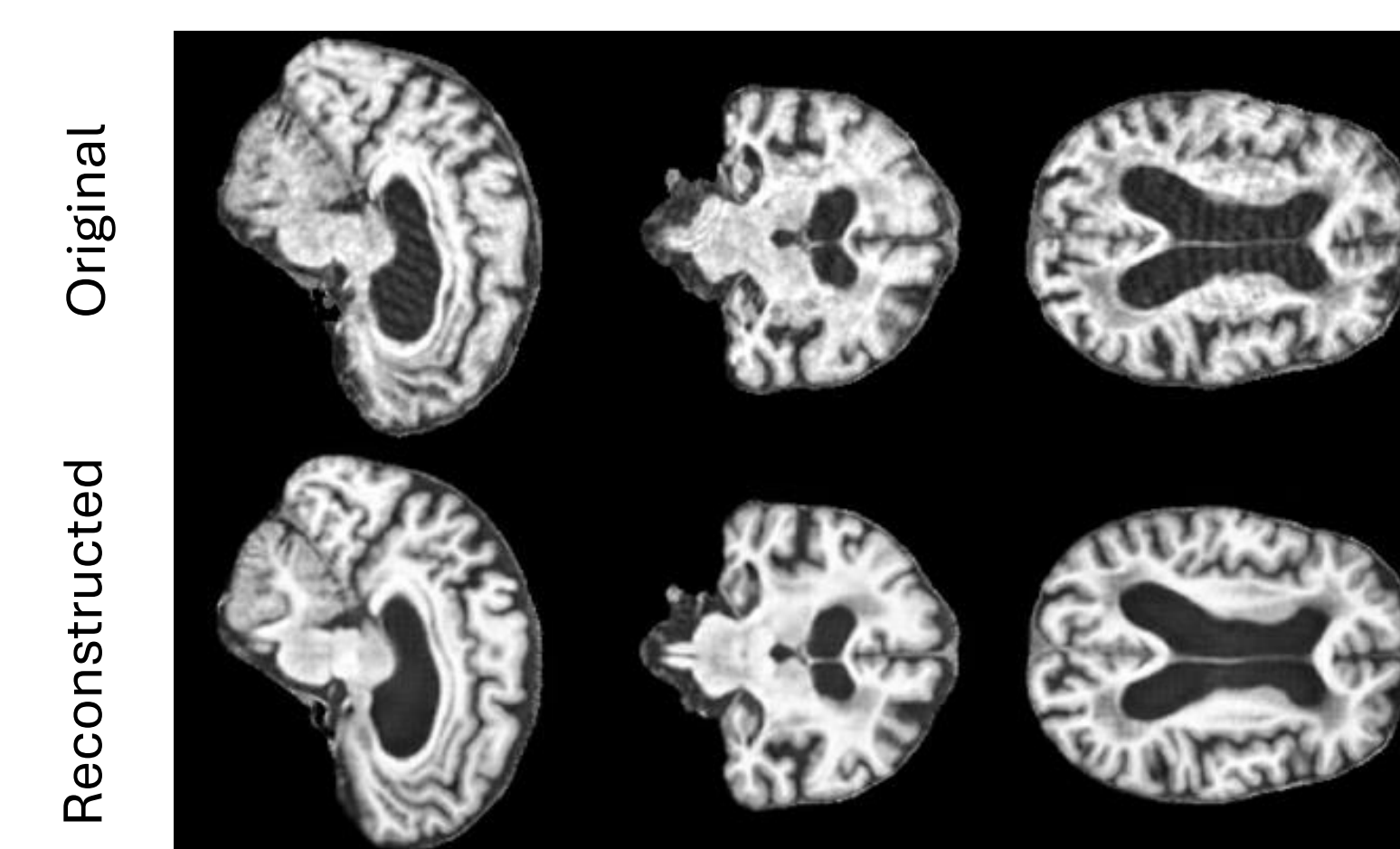


RESULTS

B. CN subject



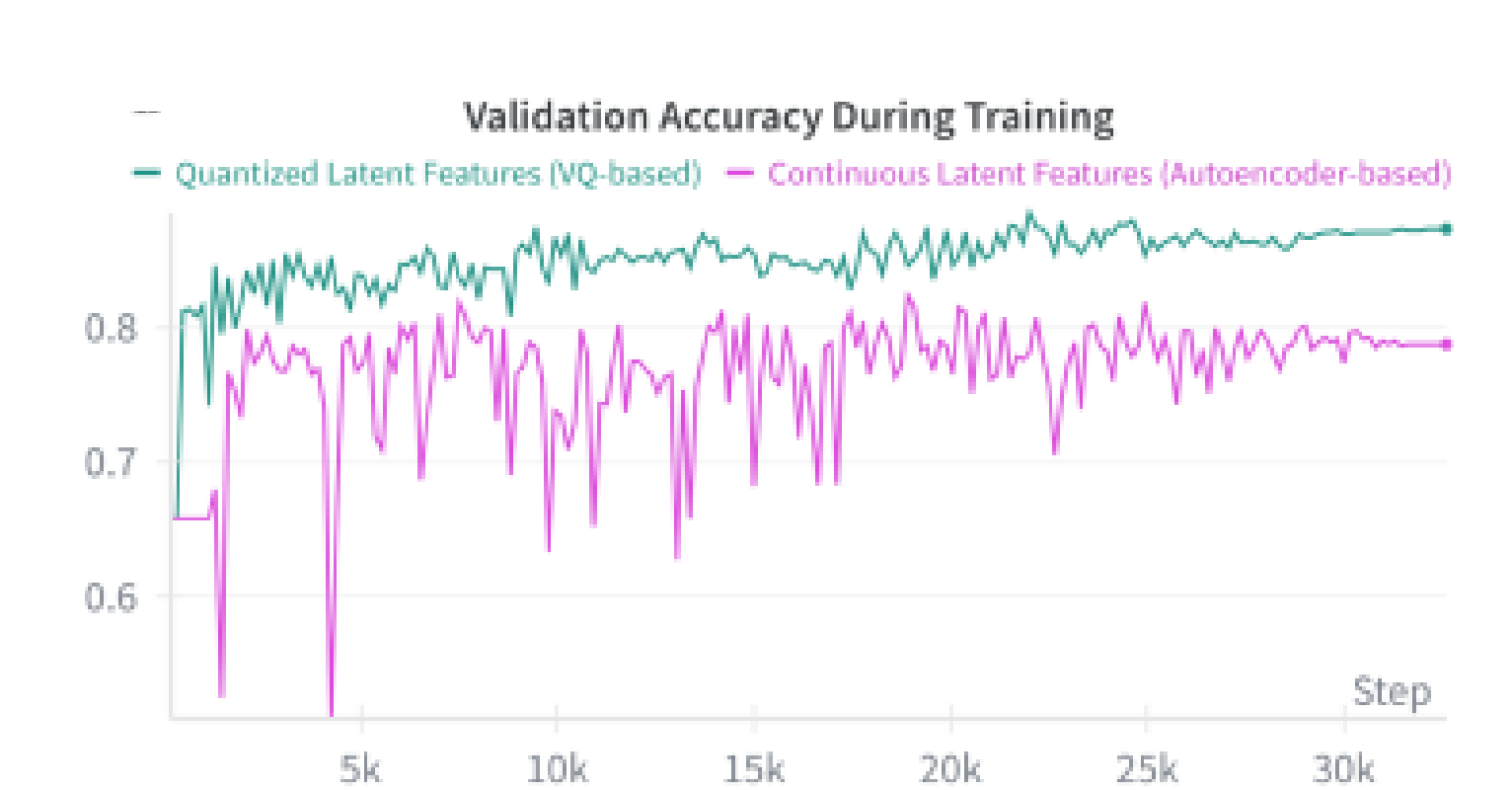
C. AD subject



D. Classification loss during training.



E. Validation accuracy during training.



F. AD/CN classification performance across datasets.

Dataset	Representation	Accuracy	Precision	Recall	AUC
ADNI	VQ-based	0.86	0.85	0.84	0.91
	AE-based	0.82	0.79	0.80	0.87
WFADRC	VQ-based	0.90	0.84	0.84	0.90
	AE-based	0.86	0.77	0.78	0.87

- **Accurate anatomical reconstruction:** The VQ-based SSL framework preserved clear anatomical structures in reconstructed MRI images (Fig. B & C).
- **More stable representation learning:** VQ regularization promoted more semantically structured feature learning, leading to faster convergence and more stable training behavior (Fig. D & E).

- **Stronger external generalization:** In the independent WFADRC cohort, the VQ-based model maintained superior performance, achieving higher accuracy 0.90 vs. 0.86 and AUC 0.90 vs. 0.87 compared with the AE baseline (Table F).
- **Improved ADNI classification performance:** On the ADNI test set (Table F), VQ-based latent representations outperformed AE-based features in accuracy 0.86 vs. 0.82 and AUC 0.91 vs. 0.87, with consistent gains in precision and recall.

CONCLUSION

Vector quantization improves self-supervised MRI representation learning by producing structured, transferable latent embeddings that capture AD-related neurodegenerative patterns and enhance cross-cohort robustness.

CONTACT



Shihua Qin, PhD Candidate
Department of Biomedical Engineering
Virginia Tech – Wake Forest University SBES
Wake Forest University School of Medicine
E: shihua.qin@wfsu.edu

WakeSHARE.org

ALZHEIMER'S ASSOCIATION | AAIC 26