

VesselGPT: Autoregressive Modeling of Vascular Geometry

Background & Motivation. Realistic 3D models of blood vessels are essential for medical applications such as diagnosis, prognosis, surgical planning, and fluid dynamics simulations. Yet, reconstructing high-fidelity vascular structures from patient scans is difficult, requiring expert knowledge and often missing fine details. To overcome these challenges, generative methods have been developed to synthesize vascular geometries.

Objective. This work introduces a novel autoregressive framework for synthesizing realistic vascular tree geometries by embedding structural components into a learned discrete vocabulary and modeling their generation using transformer-based sequence modeling techniques.

Approach. First, vascular tree structures are encoded into discrete tokens through a vector-quantized variational autoencoder (VQ-VAE), capturing local structure and cross-sectional morphology. Next, a GPT-style autoregressive model is trained to generate token sequences that represent vascular tree geometry. Finally, decoded tokens are reassembled into continuous geometric structures using B-spline representations, preserving critical anatomical fidelity.

Results. Generated vascular trees exhibit realistic branching patterns and continuity comparable to real anatomical data. The learned discrete vocabulary enables concise modeling with reduced memory footprint and efficient sampling.

Impact & Applications. This autoregressive modeling framework enables controllable and scalable synthesis of vascular geometries, useful for data augmentation, computational simulation, and pre-surgical planning. The discrete tokenization and sequence modeling approach may generalize to other anatomical tree structures (e.g., bronchial or neuronal trees).

Conclusion. Our method demonstrates a promising direction for anatomically realistic and computationally efficient vascular tree synthesis using modern sequence modeling techniques.

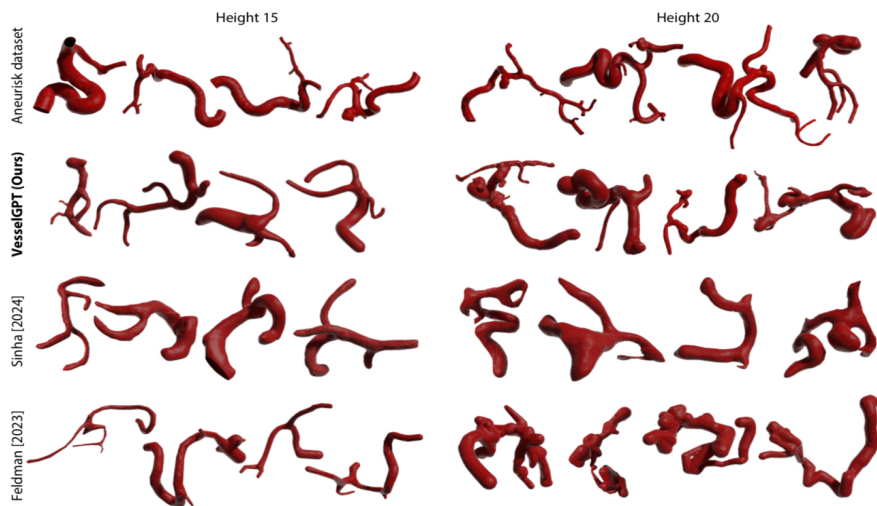


Figure 1: Qualitative comparison of vascular tree synthesis across methods. VesselGPT demonstrates anatomically realistic branching patterns comparable to ground truth. Baselines include VesselVAE and TrIND.

Feldman, P., Fainstein, M., & Siless, V. (2023). VesselVAE: Recursive Variational Autoencoders for 3D Blood Vessel Synthesis. In *International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI)*. Springer, LNCS 14221, pp. 3–13.

Sinha, A., & Hamarneh, G. (2024). TrIND: Representing Anatomical Trees by Denoising Diffusion of Implicit Neural Fields. In *International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI)*, LNCS 15012.