Quantitative Hemodynamic Assessment of Venous Stenosis: A Novel Single-Transducer Methodology

Karthikeyan Arcot   Chander Sadasivan   Julia Lin   Sophia Derosa

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Abstract Venous stenosis presents diagnostic and therapeutic challenges, especially in quantifying hemodynamic severity and confirming intervention efficacy. We introduce a cost-effective method using a single pressure transducer integrated with a Philips Xper system to capture high-fidelity venous waveforms. A custom Rust analysis pipeline removes non-physiological artifacts and computes high-frequency power (HFP) as a surrogate for turbulent flow and venous wall flutter. Across a cohort, HFP reliably discriminates stenotic from stented veins, showing improvement factors from 2.5× to 14× post-intervention. This approach offers objective, real-time feedback without specialized dual-sensor wires.

1. Introduction

Venous outflow obstruction contributes to intracranial hypertension, pulsatile tinnitus, and other pathologies. Conventional assessment relies on imaging (venography, IVUS) and mean pressure gradients, which may miss complex fluid dynamics such as turbulence and aeroelastic wall flutter ("fremitus"). A functional hemodynamic metric directly reflecting these instabilities is needed.

2. Methods

2.1. Patient Selection & Protocol

Consecutive patients undergoing diagnostic venography and manometry for suspected venous stenosis were enrolled. Measurements were taken in supine position both before and after stent deployment.

2.2. Data Acquisition System

- **Hardware**: Single fluid-filled pressure transducer.
- **Integration**: Connected to the analog input of a Philips Xper hemodynamic recording system.
- **Sampling**: 500 Hz (Nyquist = 250 Hz), providing sufficient bandwidth for turbulent frequencies.

2.3. Computational Analysis

A. Artifact Removal

The pipeline monitors the first derivative (dP/dt) and flags instantaneous jumps > 1.5 mmHg per sample (≈ 750 mmHg/s) as artifacts, then linearly interpolates to preserve cardiac phase continuity. ### B. Signal Processing (FFT) Cleaned waveforms are transformed via FFT. High-frequency power (HFP) is calculated as the integral of the power spectrum above 10 Hz, isolating turbulence-related energy.

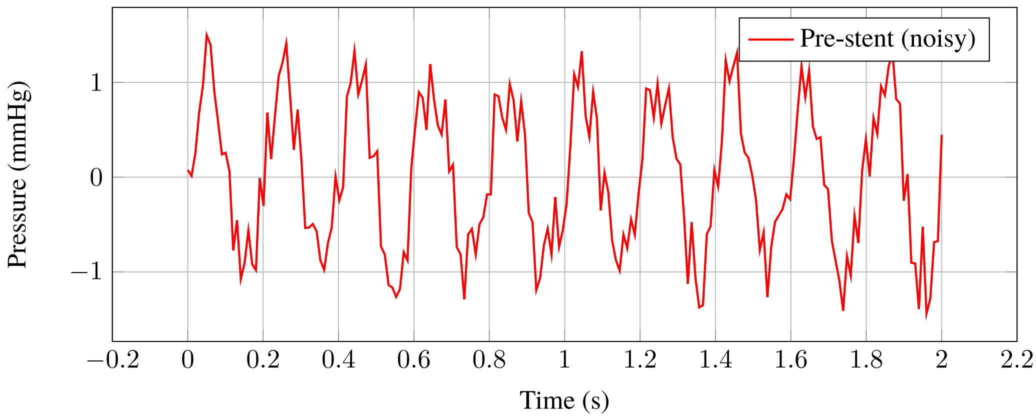

Figure 1: Pre-stent noisy waveform.

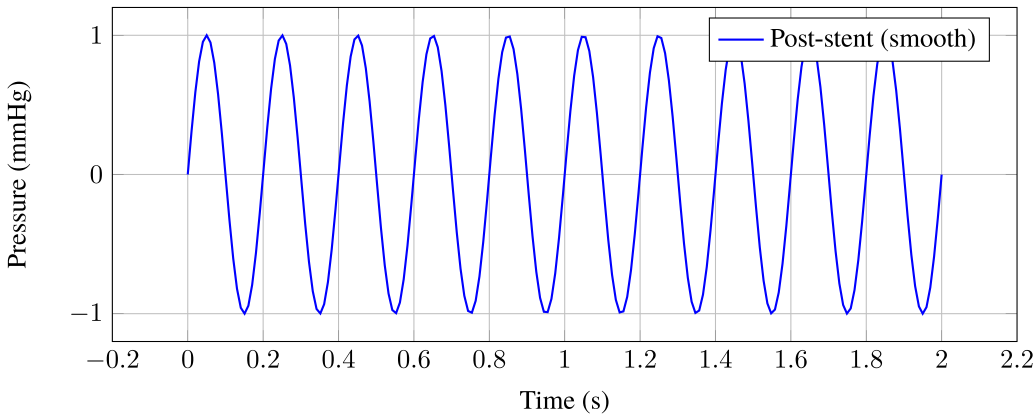

Figure 2: Post-stent smooth waveform.

3. Results

3.1. Artifact Cleaning Efficacy

The algorithm successfully removed catheter-whip artifacts, preventing false HFP elevations. ## 3.2. Hemodynamic Improvements Across the cohort, HFP decreased markedly after stenting: * **Patient 1 (Right Jugular)**: ~14× reduction (3.0 M → 0.2 M). * **Patient 2 (Left Jugular)**: 11.8× reduction (0.53 M → 0.04 M). * **Patient 3 (Right Jugular)**: 9× reduction. * **Patient 4 (Left Jugular)**: 4.5× reduction. Mean pressure and cardiac amplitude also normalized, indicating restored laminar flow.

4. Discussion

The HFP reduction confirms that critical stenosis generates turbulent energy and wall flutter, which are eliminated by stenting. Compared to mean pressure gradients, HFP provides a more sensitive functional endpoint. The single-wire approach simplifies clinical workflow while delivering quantitative hemodynamic insight.

5. Conclusion

High-frequency power analysis offers an objective, functional metric for venous stenting outcomes. Implemented with standard equipment and automated artifact removal, the method is robust, cost-effective, and ready for clinical deployment.