Assessment of CSF Shunt Function Using Ultrasound Characterization of Valve Interface Pulsatility as a Proxy

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Introduction

The diagnosis of CSF shunt failure often relies on indirect clinical evidence. A direct, non-interventional method for reliably evaluating CSF function does not exist due to the difficulty of measuring in vivo flow characteristics. The objective of this study is to apply a novel method of ultrasound monitoring to characterize the oscillation observed during pulsatile CSF flow and failure states, in an in vitro and cadaveric model.

Methods

In this proof-of-concept study, in vitro and in situ testing was performed, both using a pulsatile flow generator, connected via standard silastic tubing to the inlet of a fixed medium-pressure valve, and with an outlet to an open container. In the in vitro test, the valve was secured above an acoustically opaque platform to emulate the cranium, and covered with artificial skin. In the in situ test, the valve was implanted subcutaneously under the scalp, with inflow and outflow catheters entering and exiting percutaneously. A linear array ultrasound transducer, was positioned over the valve to observe the valve cross-section in B-mode, which was used to derive time-dependent displacement waveforms of shunt states: [1] no flow, [2] proximal occlusion, [3] normal flow, [4] distal occlusion. Qualitative features of the waveforms, and peak-to-peak (PTP) and RMS amplitude analyses were used for comparison.

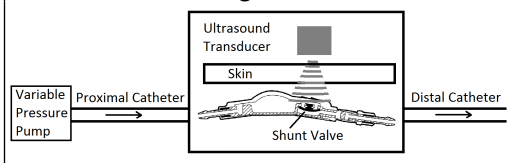
Learning Objectives

[1] To understand mechanisms of shunt failure.

[2] To understand flow mechanics with regards to CSF shunts.

[3] Discuss non-invasive methods of determining shunt function.

Figure 1

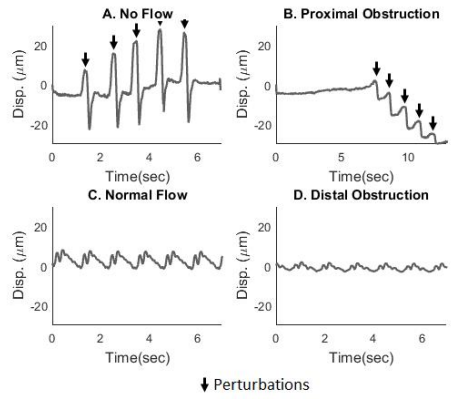


Schematic diagram of the in vitro set up which shows fluid flow through the variable pressure pump, into the valve and catheters. The artificial skin is placed over the reservoir and valve, and images are taken with the transducer clamped transversely over the valve

Results

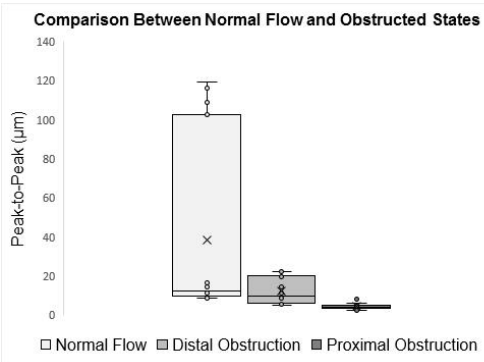
Normal pulsatile flow demonstrated a periodic waveform, with a PTP displacement of 4.4±2.4 μm, and an RMS amplitude of 1.0±0.6 μm, which were significantly reduced (P<0.0001) in proximal occlusion states (PTP=0.28±0.1 μm, RMS=0.05±0.01 μm) and distal occlusion states (PTP=2.6±1.4 μm, RMS=0.6±0.3 μm). Qualitatively, proximal occlusion tracings demonstrated absent pulsatility, whereas distal occlusion states yielded a dampened pulsatile waveform.

Figure 2



The observed patterns in the displacement profiles in situ return the same patterns found in in vitro testing.

Figure 3



A numerical comparison of the maximum displacement amplitudes of various flow conditions for 15 independent trials. Paired, 2-tailed t-Tests gave a statistically significant p-value < .05 when blockage conditions were tested against the normal condition.

Conclusions

Ultrasonic measurement of the shunt valve pulsatility can differentiate between normal, proximal and distal failure states. Further in vivo tests are required to assess the clinical utility of this method.

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