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Case report

Ultrasound for the assessment of distal shunt malfunction in adults with internal ventricular shunts

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ABSTRACT

Shunts that are used for the treatment of hydrocephalus have a propensity towards malfunction, however, diagnosing a shunt malfunction can sometimes be a challenge. The purpose of this study was to investigate whether ultrasound technology can be safely and effectively used to assess for distal shunt malfunction. This was a prospective cohort study at a single institution. Eighteen adult patients that received a radionuclide shunt patency study also underwent an ultrasound shunt patency study. Ultrasound with Doppler technology was used to visualize flow through the shunt tubing following manual compression of the shunt reservoir. A peak flow speed was recorded and the results were compared to the results of the radionuclide shunt patency study. A Receiver Operating Characteristic (ROC) curve comparing the ultrasound to the radionuclide shunt patency study was generated, revealing an Area Under the Curve (AUC) of 0.95 (95% CI: 0.84–1.00). The ultrasound test performed maximally with a cutoff speed of $\leq$10 cm/s as the criteria for malfunction, with a sensitivity of 100.00%, specificity of 90.91%, accuracy of 94.44%, positive likelihood ratio of 11.000 and negative likelihood ratio of 0.000 using the radionuclide study results as criteria for comparison. Overall, ultrasound has the potential to be a safe, quick, available and cost-effective screening test for patients with suspected distal shunt malfunction. The high sensitivity of the test makes it an attractive option for use as a screening method that could potentially reduce the number of cases requiring radionuclide shunt patency study.

1. Introduction

Cerebrospinal fluid (CSF) shunting is an effective treatment for patients with hydrocephalus or pseudotumor cerebrii [1–5]. Ventriculoperitoneal (VP) and Ventriculoatrial (VA) shunts are two common ways for achieving CSF diversion, however, they have a high propensity to malfunction [6,7]. Therefore, it is important that we have a means to diagnose shunt malfunction to help make a decision about whether to perform a shunt revision or not. Imaging modalities, such as MRI and CT, can visualize ventricular morphology and indirectly (and usually inadequately) assess for shunt malfunction [8,9]. The radionuclide shunt patency study is commonly used to directly assess for shunt malfunction, however, it has several limitations; it is costly, time-consuming, and invasive [10–13].

The use of ultrasound is an example of a diagnostic test that has been studied to evaluate for shunt malfunction, which would have several advantages over the radionuclide study. There have been several studies that have been able to demonstrate the visualization of CSF flow in shunt tubing with the use of ultrasound, potentially due to the generation of microbubbles as a result of compressing the shunt reservoir [14,15]. Injecting microbubbles into the shunt reservoir also enables flow to be observed with ultrasound [16]. The use of ultrasound for determining shunt patency has been investigated in pediatric patients, which found ultrasound to have a diagnostic accuracy of 87–90% [17,18]. However, the diagnostic accuracy of ultrasound in adult patients has not been validated.

The goals of the present study were to develop a protocol for the use of ultrasound to assess for shunt patency in adults and to compare the results of this test to the radionuclide shunt patency study.

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2. Methods

2.1. Experimental model

An experimental model was developed and tested in the laboratory using ultrasound to assess for shunt occlusion in an ex vivo shunt. Water was flushed through shunt catheter tubing that was connected to a valve and reservoir. An ultrasound probe with Doppler was placed over the distal end of the shunt tubing. The reservoir was manually pumped with the tubing open and the Doppler flow data was recorded. Next, a kink was placed in the tubing and the Doppler flow data was again recorded after reservoir compression. This experimental model served as a proof of concept for the use of this method to assess for distal shunt malfunction in patients.

2.2. Patient enrollment

After obtaining Institutional Review Board approval we conducted a prospective cohort study at a single academic institution. After signing the research consent form, twenty patients suspected of having shunt malfunction that were scheduled to have a radionuclide shunt patency study were recruited to participate. Programmable valve settings were first adjusted to rule-out underdraining or overdraining before patients were included in the study. Patients were recruited between April 2014 and June 2015, forming a convenience series based upon our ability to perform the ultrasound study. Data was collected on patient age, sex, diagnosis and on the type of shunt and valve that they had. Two patients declined to be in the study, and eighteen agreed to participate. The ultrasound was obtained immediately before the radionuclide study. The assistant, the ultrasonographer, and the patient were all blinded to the results of the radionuclide study, but were not blinded to clinical information on the patient. The readers of the radionuclide imaging study were blinded to patient clinical information and the results of the ultrasound study.

2.3. Part 1 – Ultrasound study

Ultrasound (an unlabeled device for the diagnosis of shunt obstruction) was used to visualize the shunt tubing at the level of the neck. Two different ultrasound machines were used during the course of the study: a Siemens S300 manufactured in Issaquah, Washington with an 18L5 transducer and a Philips IU22 manufactured in Bothell, Washington with a L12-5 transducer. Fig. 1 shows the ultrasound viewing window that was used to find the shunt tubing. To locate the shunt, an ultrasonographer scanned the neck with the transducer in a transverse plane, and once the tubing was found, the probe was turned longitudinal to the tubing. The reservoir of the shunt on the scalp was located by palpation or by reviewing a prior radiograph of the skull. With the patient laying in a supine position, the reservoir was given a firm, fast press by an assistant and Doppler technology was used to record the speed of flow through the shunt tubing. Care was taken to choose a location that had minimal interference from nearby blood vessels before pumping the reservoir, and also to make sure that the patient was still. This technique was repeated two additional times and the average speed of the three trials was calculated. Results from trials where there was excessive movement by the patient, or where there was not enough force applied to the shunt reservoir, were discarded.

2.4. Part 2 – Radionuclide study

The patients participating in the study underwent a subsequent radionuclide study. The details of how this procedure is performed are described in previous reports [13]. A 1-variable algorithm, using $T_{1/2}$ (half-time), was used to assess for shunt malfunction. It was pre-determined that if the $T_{1/2}$ was not reached after 30 min, then the shunt was deemed to be malfunctioning. The flow speed measurements from the ultrasound study were compared to the results of the radionuclide shunt patency study. In addition, the results of the ultrasound and radionuclide study were compared to the intra-operative findings if a patient underwent a revision surgery. Results from the radionuclide study was used as the reference because of the availability of this test in our institution and because it has been well studied as a method to assess shunt patency.

2.5. Sample size calculation

Sample size was calculated to estimate the number of patients required to demonstrate a statistical difference between patients that had a patent shunt and those that did not. We used data from our study to calculate means and standard deviations of the ultrasound flow speeds in patients that had a patent vs. non-patent shunt. Alpha was set at 0.05 and beta at 0.8.

2.6. Statistical analysis

STATA IC version 12 (StataCorp, College Station, Texas, USA) was used to perform the statistical analysis, and statistical significance was defined as $p < 0.05$. Simple linear regression was used to assess the association between flow speed and $T_{1/2}$. A receiver-

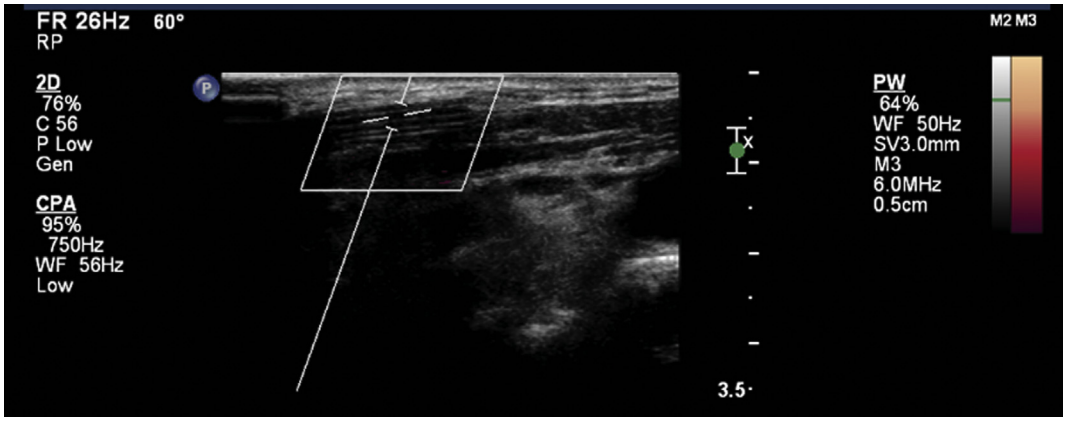

Fig. 1. Shunt catheter in neck visualized with ultrasound.

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