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PERFORMANCE OF DISPOSABLE PRESSURE-SENSING CATHETERS DURING SIMULATED URODYNAMIC EVENTS

<ins>Hypothesis / aims of study</ins>
Water filled catheters (WFCs) use a weighted medium (water) to transmit pressure signals and have traditionally been used for urodynamic pressure measurements. However, they are highly responsive to water line movement and position changes, creating artifacts in pressure data [1]. In addition, they must be cleared of air bubbles which degrade the pressure measurement. In contrast, air charged catheters (ACCs) use a non-weighted medium (air) to transmit pressure signals and are not responsive to movement or position changes [1]. Although they are a newer technology, they have rapidly become popular for use in urodynamic systems and are used in 70% of U.S. facilities. We have previously demonstrated that these two systems respond differently to rapidly changing pressures [1]. However, the clinical relevance of these different frequency responses to pressure measurement during urodynamic testing is not known.
Coughs contain the fastest changing pressure signal in urodynamic testing. Therefore, the objective of this study was to compare the responses of WFC and ACC catheters when exposed to bladder pressures during simulated variations of a cough. Specifically, our goal was to assess any clinically relevant differences between the two catheters.
<ins>Study design, materials and methods</ins>

A published urodynamic trace during a cough [2] was digitized using Matlab (Mathworks, Natick MA). The digitized values were then modified to create eight simulated coughs with peaks ranging from 50 to 175 cm H_2O by maintaining the same cough duration as in the original data, while manipulating the peak pressure. A blood pressure transducer calibrator controlled by an arbitrary waveform generator was used to generate the simulated pressures in a test pressure chamber via an oscillating diaphragm. A WFC and ACC were inserted into the test chamber through watertight ports. A water-filled transducer attached to the side of the chamber simultaneously recorded ambient chamber pressure as a reference. The system was flooded with water and flushed of air bubbles. Following transducer calibration, the water-filled system was zeroed to the height of the center of the chamber. Simultaneous signals from all three pressure transducers were amplified, digitized, and recorded. Simultaneous peak pressures recorded by each system were compared using a one way ANOVA with $p<0.05$ indicating a significant difference.
Fast Fourier transform (FFT) analysis (Matlab) was used to analyze the resultant pressure signals in the frequency domain. Each of the eight coughs' FFTs was normalized to the FFT of the simultaneous reference pressure and was then averaged over five repeated trials. Mean ± standard error of the normalized FFTs of all eight coughs were used for comparison. Normalized powers of the WFC and ACC were compared at each frequency component using a t-test with $p<0.05$ indicating a significant difference.
Using a pressure signal obtained from ACC, we amplified the power of frequency components between 0 and 5 Hz to the reference power values in the frequency domain to explore the significance of low frequencies. An inverse FFT (Matlab) was used to return the signal to the time domain. A fifth order Butterworth filter with a 5 Hz cutoff frequency (Matlab), as used by Kim et al. [3], was applied to digitally low-pass filter a pressure signal obtained from WFC to explore the significance of high frequencies.

<ins>Results</ins>
Pressures recorded by the WFC overestimated the power of frequency components, which produced ringing in the pressure signal (Fig 1A). In contrast, pressures recorded by the ACC underestimated the power of frequency components, which produced a damped signal with a delayed pressure peak (Fig 1A). Normalized power recorded by the ACC was significantly less than normalized power recorded by the WFC at all frequencies. Peak pressures were also significantly different between reference, WFC, and ACC (Fig 1B). However, both catheters showed consistency in peak differences as pressure amplitudes changed. WFC produced a peak 2 ± 0.2 % higher than the peak reference pressure and ACC produced a peak 13 ± 0.9% lower than the peak reference pressure (Fig 1B).
The ACC pressure signal, whose power between 0 and 5 Hz was amplified, displayed a pressure peak increase from 107 cm H_2O to 122 cm H_2O and greatly reduced the offset of pressures in time (Fig 2A & B). The Butterworth filter delayed the WFC pressure peak, but maintained the original peak pressure and reduced the ringing (Fig 2C & D).

<ins>Interpretation of results</ins>
The WFC overestimated the peak chamber pressure, whereas it was underestimated and delayed when measured with the ACC. After amplifying the power of low frequencies in the ACC signal, it resembled the peak pressure and timing of the reference. Reducing the power of frequency components greater than 5 Hz in the WFC signal reduced ringing while maintaining the same peak pressure. Our investigations have demonstrated that frequencies below 5 Hz contain the general shape of the signal as well as its peak.

<ins>Concluding message</ins>
These two catheter systems produce significantly different cough peak pressures. The differences may not be clinically significant since there is high clinical variability due in part to measurement artifact from motion or position change, particularly with a WFC system. However, the important aspects of bladder pressure during a cough are contained in frequencies below 5 Hz, suggesting that we can derive similar peak pressures with either system and translate between them in a predictable manner. Therefore, either catheter is suitable for urodynamic testing but knowledge of the biomechanical characteristics of the pressure-sensing system will facilitate a better interpretation of the results and a method of translating results between different measurement systems.

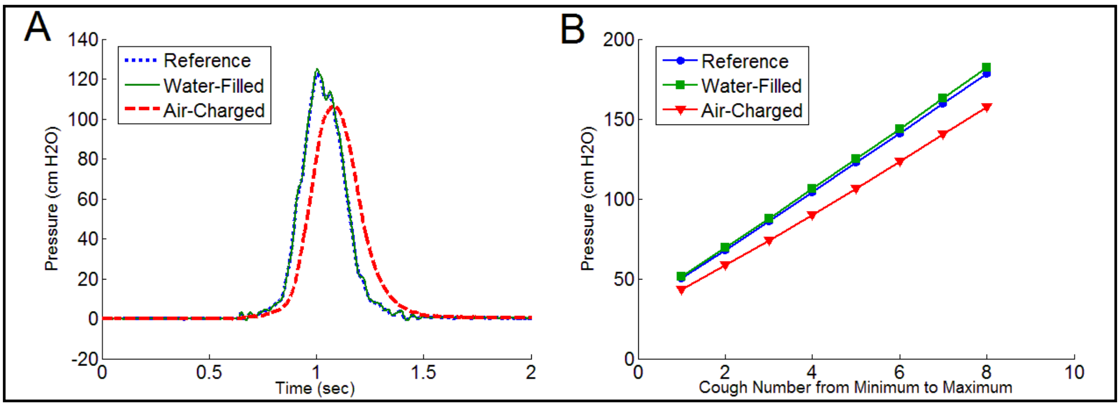

Figure 1. Characteristics and behaviour of water filled (WFC) and air charged (ACC) catheters as compared to the reference. **A** Bladder pressure during a cough as recorded by the reference, WFC, and ACC. WFC shows overestimation of peak pressure and a ringing response; whereas ACC shows underestimation of peak pressure with no ringing. **B** Peak pressures of a ramped series of simulated coughs. Results are reported as mean ± SD of five repeated trials. Error bars are smaller than symbols and therefore are not displayed.

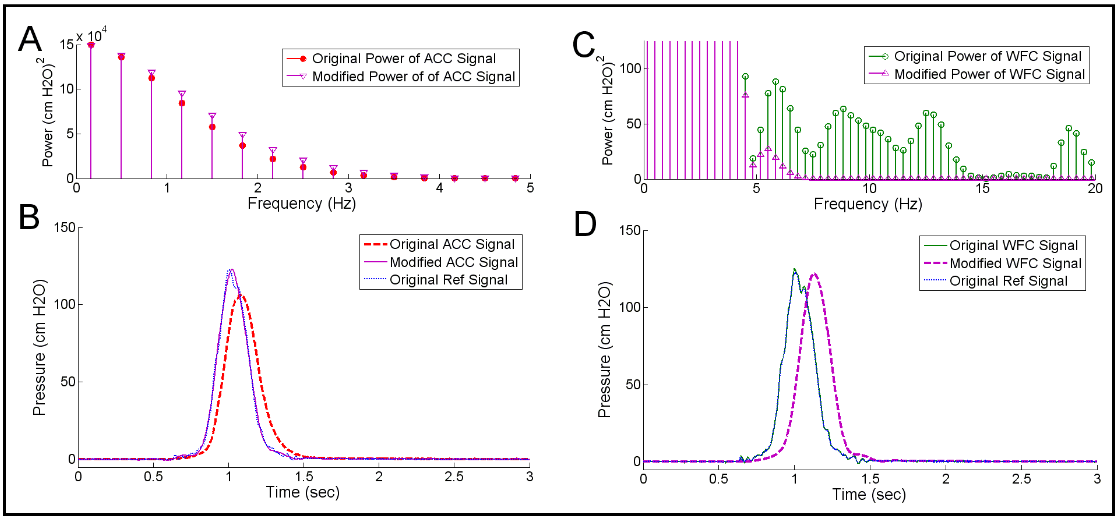

Figure 2. Power Modification of air-charged (ACC) and water-filled (WFC) pressure signals and comparison to the reference. **A** Power of frequencies between 0 & 5 Hz from ACC signal amplified to the reference power values. **B** Original ACC signal, modified ACC signal, and reference signal in time domain. **C** WFC signal low-pass filtered with 5 Hz cutoff frequency. **D** Original WFC signal, modified WFC signal, and reference signal in time domain.

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