International Journal of Medical Science and Clinical Invention 10(5): 6760-6763, 2023
DOI:10.18535/ijmsci/v10i5.09
https://valleyinternational.net/index.php/ijmsci

Research Article,

A Mathematical Simulation of the Influence a CMG Catheter's Frequency Response on Urodynamic Diagnosis

A M Mackay[1,2,3] ,N M Harris[4]

[1]Flex Clin Sci Ltd, UK
[2]Biology, Medicine, and Health, University of Manchester, UK
[3]Gastro-Intestinal Physiology, Leeds Teaching Hospitals NHS Trust, UK
[4]Urology, Leeds Teaching Hospitals NHS Trust, UK
Email Address: **alisonmackay@live.co.uk**

Introduction:

Urodynamics comprises urine flow testing, ultrasound estimation of post-void residual, and Cystometry with filling and voiding phases [1]. Cystometry is the concurrent pressure measurement from the bladder and an abdominal control site, with parallel urine flow measurement. Using conventional water filled catheters; pressures are referenced to atmospheric pressure and the physical height of the external pressure transducer. Cystometry facilitates assessment of detrusor strength, and weakness or obstruction in the tract below.

Video Urodynamics (VUDS) adds fluoroscopy to these physiological measurements, and allows differential diagnosis of pathology in Stress Urinary Incontinence (SUI) as well as surveillance of upper tract integrity [2]. A cysto-urethrogram is a non-invasive alternative to VUDS, allowing the whole urinary tract to be visualised during micturition. [3] It sacrifices pressure data, but can include a measurement of flow rate [4]

Historically, cystometry with internal placement of water-perfused catheters (WPCs) to assess detrusor and abdominal pressure (Pdet and Pabd) have provided the gold standard in assessing Bladder Outlet Obstruction (BOO) [5]. A CMG is also the only way to differentiate between sensitive bladder (SB), Detrusor Over activity (DO) and SUI as causes of incontinence. However, WPCs are subject to test-retest variation related to their placement, errors related to changes in the patient's position, and poor alignment between symphysis pubis and pressure transducer. Additionally, air-bubbles in the transducer and handling of the catheter will create positive pressure artefacts, while blockage of the catheter's lumen by stones, debris, faeces, or the organ wall will reduce pressure erroneously.

Air charged catheters (ACCS) avoid most of these artefacts as they measure pressure locally and don't have lumen. Like micro-tip solid-state lines, this tends to create a systematic Measurement difference with respect to WPCs [6], and so conversion could be possible for clinical comparisons.

ACCs are also reported as being easy to use, and comfortable across cohorts [7,8] however in a clinical situation the total number of technical issues for each catheter was found to be the same [9]. The one negating factor is the low-pass filtering effect of ACCs presented by Cooper and co-authors [10] , and this presented the need for the present study. The aim here is to characterise, simulate, and apply this filtering effect of ACCs to local clinical data recorded using WPCs. Any resulting (theoretical) changes to Urodynamic parameters and diagnoses will then be identified.

Methods:

A Chi-squared test of independence was performed to confirm the equivalence of recording quality for the catheters using the data of Abrams et al [11]. Next, the frequency response published by Cooper et al. [10] was enlarged allowing resolution to be added to both frequency and pressure axes. The exact frequency (Hz) at which the response was reduced to 50% of its peak amplitude (the 3dB point) could then be identified. A range of digital filters with this cut-off [12,13] were programmed into individual excel spreadsheets, and each used to process a series of test sinusoids creating its transfer function (TF). The filter with the most similar TF to the ACC was chosen.

The filter equation was embedded in a MATLAB program which also opened and closed clinical measurement files exported in .csv format. The final step of the code was to produced a graph of the results which remained on screen for identification of key parameters. Pre- and post-filter Urodynamic diagnoses were compared qualitatively, while Pdet.max and DO amplitude were evaluated with 95% confidence intervals of the change following filtering.

Results:

There was no statistically significant difference in the number of QA issues for each type of catheter (Pves: 100/321 vs. 96/321, p=0.79; Pabd 109/321 vs. 109/321, χ^2 =1.79, P=0.62). Close inspection of the published frequency response revealed that ACCs create a high- frequency cut-off of 2.5Hz with a fairly shallow roll-off, and this was replicated most effectively by a two-pole Chebyshev recursive digital filter with 0.5% pass band ripple.

Preliminary analysis of the first 19 clinical traces allowed for a power calculation which suggested 119 cases would need to be processed to prove any change. Applying this filter to 119 prospectively collected clinical traces using the MATLAB program showed that there were no changes in urodynamic diagnosis or the maximum voluntary (Pdet.max) and involuntary (DO) detrusor contractions.

Discussion:

In this unique prospective study, we have shown that urodynamic diagnoses and key features are unchanged by the low-pass filtering effect of ACCs. The theoretical nature of the study means the 'level of evidence' is lower than for a Clinical trial or meta-analyses of trials [14]. However, it's format allowed a lot of data has been processed quickly by a single Clinical Scientist, and presents an inexpensive initial evaluation method that could be applied across medical disciplines.

The International Continence Society (ICS) have published performance guidelines for Urodynamic equipment advising pressure recording between 0Hz and 3Hz or greater [15]. The low-pass filter was set to 3Hz during the clinical recordings entered into this study by a more senior colleague for clinical reasons, regardless of any research also underway. This explains why we didn't reproduce the differences seen in some other studies, but mostly it highlights that the use of the narrowest filter settings allows WPCs and ACCS to be used interchangeably enabling comparison between centres.

The Damaser group presented a range of features following their experimental comparisons of WPCs and Air charged Catheters ACCs [10]. However, we focussed on the frequency response here. The resonance they describe at 15 Hz could be removed by using the narrowest permitted filter settings during clinical application.

The clinical study of a female cohort by Digesu et al found systematically higher pressure measurements for ACCS than WPCs given the use a wider bandwidth for pressure measurement[16]. Keeping the filter open undoubtedly also explains earlier reports of systematic differences between the two techniques [6]. Another exclusively female study found good overall correlation between WPCs and ACCs but, somewhat surprisingly, greater variability when bladder volume was less than 50ml [17]. A recent clinical study of a mixed cohort found that ACC pressure was generally larger, but its relationship with WPCs was inconsistent [18]; again, this could reflect a wide bandwidth during pressure recording.

Finally, a range of pathologies call for the addition of Fluoroscopy (Video Urodynamics) and this is heading towards standardisation [2]. Contrast media is a viscous and sticky substance that absorbs x-rays. The long-term effect of these phenomena on the reusable portion of air-charged catheters may have to be tested in the lab before they can be considered for VUDS.

Conclusion:

There is no difference between ACCS and WPC's when used with the equipment specifications typical of a clinical urodynamics service and within the technical recommendations of the International Continence Society.

References:

[1] Drake MJ, Doumouchtsis SK, Hashim H, Gammie A. Fundamentals of urodynamic practice, based on International Continence Society good urodynamic practices recommendations. *Neurourol Urodyn*. 2018;37(S6):S50-S60. doi:10.1002/nau.23773

[2] Anding, R., Rosier, P., Smith, P., Gammie, A., Giarenis, I., Rantell, A., Thiruchelvam, N., Arlandis, S. and Cardozo, L. (2016), When should video be addedto conventional urodynamics in adults and is it justified by the evidence? ICI-RS 2014. Neurourol. Urodynam., 35: 324-329. doi.org/10.1002/nau.22865

[3] Shetty A, Niknejad M, Morgan M, et al. Voiding cystourethrography. Reference article, Radiopaedia.org (Accessed on 10 Jan 2023) doi.org/10.53347/rID-27057

[4] Mackay AM, Harris NM. Measurement and Analysis Changes for Cystometry in Immobile Men. Continence. *In Review*.

[5] Nitti VW. Pressure flow urodynamic studies: the gold standard for diagnosing bladder outlet obstruction. *Rev Urol*. 2005;7 Suppl 6(Suppl 6):S14-S21.

[6] Zhao H, Liao L, Deng H, Wang Y. Differences between water-filled and air-charged urodynamic catheters for determining the urethral pressure profile in neurogenic lower urinary tract dysfunction patients. Neurourology and Urodynamics. 2019;38: 1760, 1766. doi.org/10.1002/nau.24071.

[7] Kern NG, Gray M, Corbett S, Leroy S, Wildasin A, Al-Omar O. Usability, and safety of the new 5 French air-charged catheter for performing urodynamic studies on pediatric patients. *Neurourol Urodyn*. 2020;39(8):2425-2432. doi:10.1002/nau.24506

[8] Sheng, W. Comparison of air-charged and water-filled catheters for use in cystometric assessment. 2018. PhD Thesis. Aus Hunan. China.

[9] Mackay A.M., Munbauhal G, Harris NM. Does the choice of Cystometry Catheter affect Urodynamic Diagnosis? ICS 2017, Abstract 695.

[10] Cooper MA, Fletter PC, Zaszczurynski PJ, Damaser MS. Comparison of air-charged and water-filled urodynamic pressure measurement catheters [published correction appears in Neurourol Urodyn. 2011 Jun;30(5):786]. *Neurourol Urodyn*. 2011;30(3):329-334. doi:10.1002/nau.20991

[11] Abrams P, Damaser MS, Niblett P, et al. Air filled, including "air-charged," catheters in urodynamic studies: does the evidence justify their use? *Neurourol Urodyn*. 2017;36(5):1234-1242. doi:10.1002/nau.23108

[12] Thyagarajan KS, Brisenot AE, Valencia AA. Design of Butterworth and Chebyshev Filters. Int. J. Elect. Enging Educ. 1983; 20: 59-70.

[13] Smith S. The Scientist and Engineers Guide to Digital Signal Processing. 1997. ISBN 0-9660176-3-3.

[14] The Levels of Evidence and their role in Evidence-Based Medicine. P.B. Burns, R. J. Rohrich, K.C. Chung. Plastic Reconstr Surg (2011) 128 (1);305-310.

[15] Gammie, A., Clarkson, B., Constantinou, C., Damaser, M., Drinnan, M., Geleijnse, G., Griffiths, D., Rosier, P., Schäfer, W., Van Mastrigt, R. (2014). International continence society guidelines on urodynamic equipment performance. Neurourol. Urodynam., 33: 370-379. doi.org/10.1002/nau.22546

[16] Digesu GA, Derpapas A, Robshaw P, Vijaya G, Hendricken C, Khullar V. Are the measurements of water-filled and air-charged catheters the same in urodynamics? *Int Urogynecol J*. 2014;25(1):123-130. doi:10.1007/s00192-013-2182-z

[17] McKinney TB, Babin EA, Ciolfi V, McKinney CR, Shah N. Comparison of water and air charged transducer catheter pressures in the evaluation of cystometrogram and voiding pressure studies. *Neurourol Urodyn*. 2018;37(4):1434-1440. doi:10.1002/nau.23466

[18] Rosier PFWM. Head-to-head comparison of pressures during full cystometry, with clinical as well as in-depth signal-analysis, of air-filled catheters versus the ICS - standard water-filled catheters. *Neurourol Urodyn*. 2021;40(8):1434-1440.

doi:10.1002/nau.24762

Acknowledgements:

The authors did not receive any funding for this work.

Patients were asked if they minded their clinical measurements being used for research, as a courtesy, and so thank you to the vast majority who didn't mind.

Also thank you to the department of Urology at Leeds Teaching Hospitals for buying a year's licence for MATLAB allowing the programming and analysis to take place. Also thanks for registration costs for ICS Florence in 2017 where some of the findings were presented.

Finally, thank you to my parents Alistair and Margaret Mackay for also supporting my trip to ICS Florence, and to Tim McKinney for a single stimulating discussion with Neil and I that spawned the idea.