

Are the measurements of water-filled and air-charged catheters the same in urodynamics?

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Abstract

Introduction and hypothesis The aim of our study was to compare air-charged and water-filled catheters simultaneously in the measurement of the intravesical, abdominal and detrusor pressure during urodynamic investigations.

Methods Consecutive women with lower urinary tract symptoms, referred for urodynamics were prospectively studied. Readings of intravesical pressure (p_{ves}), abdominal pressure (p_{abd}) and detrusor pressure (p_{det}), recorded by both the air-charged and water-filled catheters, were displayed simultaneously and compared at the end of filling, on standing, on sitting prior to voiding and at the maximum involuntary detrusor contraction. The signals (pressures) recorded by both types of catheter were compared using the Bland–Altman plot and paired samples *t* test.

Results Twenty women with a mean age of 49 (range 36–72) were recruited. One patient with normal urodynamics was excluded in view of the poor quality trace. At each of the four comparison points, the air-charged catheters consistently produced higher mean pressures than the water-filled catheters. There were wide variations in the difference between the readings produced by the two types of catheter.

Conclusions Pressures measured using air-charged catheters are not comparable with water-filled catheters and are therefore not interchangeable. Caution must be used when comparing urodynamic parameters using air-charged and water-filled catheters.

Keywords Air-charged · Water-filled · T-doc® · Urodynamics · Catheters · Pressures

Introduction

Urodynamic studies are valuable adjuncts in the investigation of patients with lower urinary tract symptoms [1, 2]. Catheter-based manometer systems are used to measure both intravesical and abdominal pressures. Three such systems are currently used in clinical practice: water-filled catheters, air-charged catheters, and catheter mounted (microtip) transducers.

Water-filled catheters allow the transmission of intravesical and abdominal pressures from the patient to the external pressure transducers, which are attached to the urodynamic system [3–5]. The main disadvantage when using water-filled catheters is that the quality of the signals measured can be impaired by the presence of air bubbles and movement artefacts. In addition, as the transducers are mounted externally, their level during urodynamic investigations should be changed according to the patient position in order to keep them at the level of the superior edge of the symphysis pubis. Catheter-mounted pressure transducers, so-called micro-tip catheters, have the pressure transducer mounted at the tip of the catheter. Although they have become popular, their high cost, the need for sterilisation, being non-disposable and the variable “directional” character of the measurement represents the main limitations of those catheters [5–8]. More recently, air-charged catheters have been proposed as ideal alternatives to water-filled catheters as they eliminate both the risk of air bubble interference and movement artefacts. This catheter uses a miniature, air-filled balloon placed circumferentially around a polyethylene catheter. External forces on the balloon are transmitted to the air-filled catheter lumen and communicated to an external transducer. The theoretical advantage of this technology is that the circumferential measurements of

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pressure lead to more accurate readings [9]. In contrast to the water filled-catheters, the air-charged catheters do not have an external reference level and therefore the values vary according to the position of the tip, producing variability, which is a disadvantage.

To date, only a few studies have looked at comparing different catheters during urodynamic studies, mainly for the evaluation of maximal urethral closure pressure (MUCP) and Valsalva leak point pressure (VLPP) [10–12]. To the best of our knowledge, the simultaneous comparison of pressure measurements during cystometry between air-charged and water-filled catheters has never been evaluated to date.

Therefore, the aim of our study was to evaluate the agreement of air-charged catheters with a water-filled system, which are the most common catheters used during urodynamics, simultaneously in the measurement of intravesical, abdominal and detrusor pressures.

Materials and methods

Consecutive women with lower urinary tract symptoms referred for urodynamics were prospectively studied. A 7-Fr double lumen, air-charged catheter (T-doc[®]) and a 3.3-Fr single lumen, water-filled catheter were inserted through the urethra to fill the bladder and simultaneously measure the intravesical pressure. Similarly, a 7-Fr air-charged catheter was inserted rectally beyond the anal sphincter (up to the 10- to 12-cm mark). A 4.5-Fr single lumen water-filled balloon catheter was also inserted into the rectum to measure the abdominal pressure. In order to avoid overinflating the balloon, which could cause artificially elevated abdominal pressure (p_{abd}), no more than 2.5 ml of sterile water (50 % of the nominal capacity) was used to fill the balloon, as recommended [13]. The balloon was also punctured to prevent this possibility. However, its accuracy was monitored throughout the study, by ensuring that transient pressure excursions due to coughing were recorded equally in vesical pressure (p_{ves}) and p_{abd} .

All four catheters were connected to a Laborie TRITON[™] urodynamic system (Laborie Medical Tech. S.A., Williston, VT, USA). All tests were carried out by the same experienced clinician.

Standard quality control procedures, as recommended by the International Urogynaecology Association (IUGA)/International Continence Society (ICS), were undertaken prior to commencing urodynamics [14]. The water-filled catheters were flushed with sterile water, zeroed to atmospheric pressure and the external transducers placed at the superior edge of the symphysis pubis. The air-charged catheters were used according to the manufacturer's guidelines. They were zeroed externally, inserted in the open position and the connector then switched to the "charge" position. Air filled the balloon and the sensing mechanism was then ready

to detect pressure changes. Subtracted detrusor pressures were checked by asking patients to cough before the start of filling and every minute throughout the test (Fig. 1). Filling cystometry commenced only once adequate subtraction was confirmed and the resting pressure measurements of intravesical, abdominal and detrusor pressures for both the air-charged and water-filled catheters were within the normal ranges, as described by the ICS [14]. Urodynamic studies were carried out using a standardised protocol with the women supine and normal saline at room temperature [15].

Readings of intravesical, abdominal and detrusor pressures, recorded once by both the air-charged and water-filled catheters, were displayed on the computer screen simultaneously. Pressure readings were compared at the start of filling (when the infusion pump started), end of filling (when the infusion pump stopped), on standing, on sitting prior to voiding and at the maximum involuntary detrusor contraction (if any). The above pressure readings were measured regardless of the presence of abnormal detrusor contractions. The mean pressures of the whole sample, recorded by both types of transducers were compared using the Bland–Altman plot. The analysis of the 95 % confidence interval (CI) of the mean difference air-water against the mean pressures was also performed. The Bland and Altman plot is a statistical method that allows two measurement techniques to be compared. In this graphical method the differences between the two techniques are plotted against the averages of the two techniques. Horizontal lines are drawn at the mean difference, and at the limits of agreement, which are defined as the mean difference plus and minus 1.96 times the standard deviation of the differences. This range of values defines the 95 % limits of agreement which indicates an interval within which 95 % of differences between measurements by the two methods are expected to lie. Usually, if the raters tend to agree, the mean will be near zero [16, 17]. The measurement values were compared using paired samples *t* test, and significance was considered to be $P < 0.05$. The Bland–Altman plot (difference vs mean plot) was used to show the degree of agreement between the measurements.

At the beginning and at the end of each urodynamic test both rectal and vesical air-charged catheters were calibrated by using a column of distilled water at 30, 20 and 0 cmH₂O. The level was measured from the centre of each air-charged balloon to the surface of the water which represents level 0 (0 cmH₂O). The calibration of the water-filled transducers was performed using a ruler. The end of each catheter was then placed at the level of each transducer, which represents level 0 (0 cmH₂O) and holding the end of the catheter 20 and 30 cm above the transducer, which represents a pressure of 20 and 30 cmH₂O.

Methods, definitions and units conform to the standards jointly recommended by the IUGA/ICS [18]. Written,

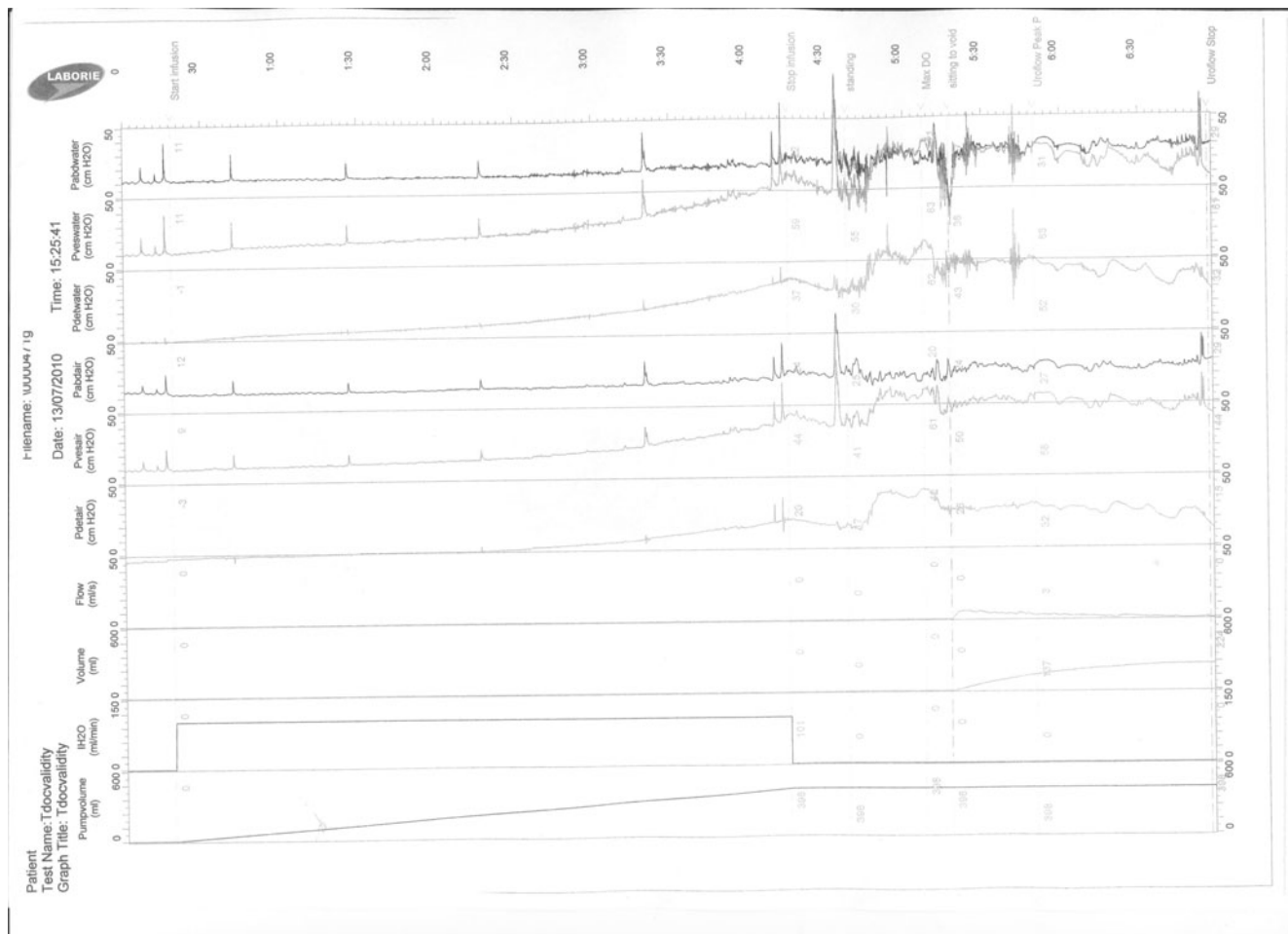


Fig. 1 Urodynamic trace showing the pressures recorded by water-filled and air-charged catheters simultaneously (p_{ves} = intra-vesical pressure; p_{abd} = abdominal pressure; p_{det} = detrusor pressure). The pressure readings at the five standard points (1. At the start of filling (start infusion—when the infusion pump started); 2. End of filling (stop infusion—when the infusion pump stopped); 3. On standing; 4. On sitting prior to voiding; 5. At the maximum involuntary detrusor

contraction [max DO]) have been marked on the trace. From the top to the bottom the traces shown represent p_{abd} ($p_{abdwater}$), p_{ves} ($p_{veswater}$) and p_{det} ($p_{detwater}$) measured by the water-filled catheters; p_{abd} (p_{abdair}), p_{ves} (p_{vesair}) and p_{det} (p_{detair}) measured by the air-charged catheters. Finally the flow, the volume voided and the volume of sterile water infused are shown

informed consent was obtained from all participants. This study is part of a research project that was approved by the Local Research Ethics Committee (reference number 10/HO722/29). A version 19.0 SPSS software program (SPSS Inc., Chicago, IL, USA) was used for statistical analysis.

Results

Twenty women with a mean age of 49 (range 36–72) were recruited to the study. Eight women (40 %) had detrusor overactivity (DO), 3 (15 %) had urodynamic stress incontinence (USI) and 5 (25 %) women had a mixed picture of both DO and USI. Urodynamics was normal in 4 women (20 %). One patient with normal urodynamics was excluded in view of the poor quality of the trace. At each of the four points, the mean pressures measured by the water-filled and air-charged

catheters were different. The air-charged catheters consistently produced higher mean pressures than water-filled catheters for p_{ves} and p_{abd} . For p_{det} , the mean pressures produced by the air-charged catheters were consistently lower. There were also wide variations in the difference between the readings produced by the two different types of catheters, as shown in Table 1. The means of the pressures measured by the water-filled and air-charged catheters and the difference in the means between the catheters are shown in Table 1. The difference between the readings produced by the two different catheters was significantly greater for the p_{abd} with the exception of sitting prior to voiding as shown in Table 1 (p value < 0.05, paired samples t test). The higher p_{abd} measured by the air-charged catheter compared with the water-filled one also explains the different p_{det} measured by the two different catheters. The Bland–Altman plots for the pressure readings, which were significantly different between water-filled and air-charged

Table 1 Simultaneous pressures measured by air-charged and water-filled catheters during urodynamics at the end of filling, on standing, on sitting and during involuntary detrusor contractions

	Water-filled (±SD)	Air-charged (±SD)	Difference in means (±SD)	Paired samples <i>t</i> test
Start of filling (<i>n</i> =19)				
<i>p</i> _{ves}	9.2 (7.3)	16.8 (8.2)	7.6 (8.2)	0.06
<i>p</i> _{abd}	8.3 (7.8)	20.2 (10.3)	11.9 (9.5)	0.04
<i>p</i> _{det}	-0.9 (2.6)	-3.4 (4.6)	-2.5 (0.9)	0.05
End of filling (<i>n</i> =19)				
<i>p</i> _{ves}	25.7 (23.5)	29.7 (12.5)	4.0 (22.8)	0.45
<i>p</i> _{abd}	10.9 (16.3)	26.6 (12.2)	15.7 (15.1)	0.002
<i>p</i> _{det}	14.8 (31.8)	3.3 (13.7)	-11.5 (30.9)	0.271
Standing (<i>n</i> =19)				
<i>p</i> _{ves}	33.8 (12.8)	41.7 (17.6)	7.9 (16.9)	0.055
<i>p</i> _{abd}	28.8 (16.4)	38.3 (18.4)	9.5 (16.5)	0.021
<i>p</i> _{det}	5.1 (8.4)	2.5 (16.7)	-2.6 (13.7)	0.424
Sitting (<i>n</i> =19)				
<i>p</i> _{ves}	28.3 (13)	30.7 (13.2)	2.4 (14.1)	0.455
<i>p</i> _{abd}	20.6 (17.2)	29.0 (15.8)	8.4 (22.9)	0.129
<i>p</i> _{det}	7.7 (10.4)	1.8 (14.8)	-5.9 (18.5)	0.182
At maximum involuntary detrusor contraction (<i>n</i> =13)				
<i>p</i> _{ves}	34.9 (21.8)	39.4 (15.4)	4.5 (14.9)	0.400
<i>p</i> _{abd}	18.5 (16.2)	30.7 (13.3)	12.2 (14.9)	0.006
<i>p</i> _{det}	16.4 (15.6)	9.7 (18.9)	-6.7 (12.6)	0.021

Values are expressed as the mean in cmH₂O. The standard deviation (SD) for the mean pressures and for the difference in means is shown in brackets

*p*_{ves} intra-vesical pressure; *p*_{abd} abdominal pressure; *p*_{det} detrusor pressure

catheters, are shown in Figs. 2, 3, 4, 5 and 6. However, the urodynamic diagnoses were same when the signals were measured using the air-charged or the water-filled catheters.

Discussion

Water-filled, microtip and air-charged catheters are all presently in clinical use for making urodynamic measurements. However, they are not identical in their signal transduction methods [11] and this may underlie some of the differences between them that have been observed. The ICS Good Urodynamic Practice Guidelines recommends using water-based catheters as well as external transducers for the measurement of intravesical and abdominal pressures, principally based on the ability to establish the IUGA/ICS reference level during testing [19]. However, it is accepted that many clinicians may use alternative transducer technology, and so the ICS guidelines further advise that clinicians minimise

deviations from this reference level and take potential variations into account when analysing test results [19].

Few studies have actually looked at comparing different urodynamic catheters in terms of their reproducibility and comparability of pressure measurements. Wang and Chen compared urethral pressure profilometry using microtip and double-lumen perfusion catheters. They concluded that both systems had good reproducibility; however, measurements obtained from the double-lumen catheter were significantly higher than those obtained from the micro-tip catheter [10]. Kuhn et al. compared the reproducibility and comparability of MUCP measurements using micro-tip and water-filled catheters and came to the same conclusion that both types of catheters have very good reproducibility [11].

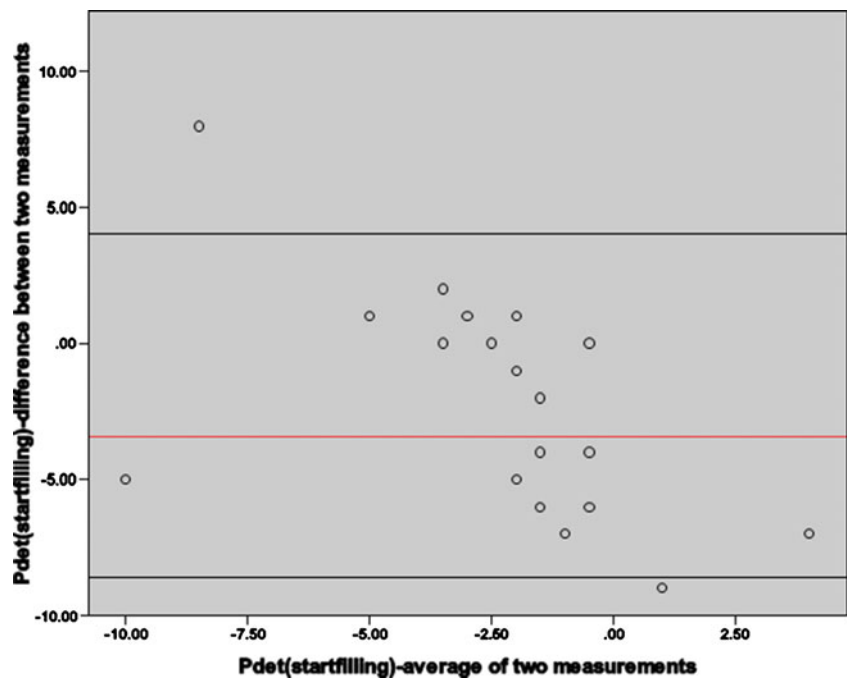
The reliability of air-charged catheters in comparison to micro-tip catheters has only been assessed for MUCP and VLPP [5, 9]. Pollak et al. reported high concordance in MUCP and VLPP with air-charged and micro-tip catheters [7]; however, agreement between the two catheters was assessed using the Lin concordance coefficient, rather than the more generally accepted Bland–Altman 95 % limits of agreement method. It has also been suggested that this statistical approach could result in potentially misleading results and therefore should be avoided [16]. The same group found differences in the measurements of functional urethral length (FUL) between the two types of catheter. Concordance was low and there was a wide variation in readings [9, 12].

Zehnder et al. also compared measurements of MUCP and FUL using air-charged and micro-tip catheters in a prospective, single-blind, randomised trial [5]. They concluded that for urethral pressure measurements, the air-charged catheter is at least as reliable as the micro-tip catheter; however, it generally gives higher readings. They also noted that owing to the wide 95 % limits of agreement for these readings, air-charged and micro-tip catheters cannot be used interchangeably for clinical purposes [5].

Until now, no studies have looked at comparing water-filled and air-charged catheters for measuring intravesical and abdominal pressures during cystometry. This was highlighted by the International Consultation on Incontinence Committee on “Dynamic testing” who recently reported that “while air-charged catheters may provide an acceptable alternative to other techniques for measuring the pressure closing the female urethra, there have been no studies to show whether these catheters provide an acceptable alternative to fluid-filled lines for measuring intravesical and abdominal pressure in urodynamics” [19].

Our study has shown that air-charged catheters measure different abdominal, intravesical and detrusor pressures than water-filled catheters, when used in urodynamic assessment. This finding is important, as this study is the first to assess

Fig. 2 Bland–Altman plot showing the p_{det} signals measured by the water-filled and air-charged catheters at the start of infusion. The direction of the differences presented is air-charged minus water-filled catheter



both catheters simultaneously, in the same patients, thus removing a large source of uncontrolled error and allowing valid reliability assessment. Until now, studies have only looked at sequential pressure measurements in the same patient in either a randomised or non-randomised way. Performing pressure readings simultaneously eliminated any potential effect of catheter order on outcomes.

The difference between the readings produced by the two different catheters highlights their lack of comparability and underlines their inability to be used interchangeably. This result supports conclusions made by other groups [5, 12].

The source of pressure discrepancies can be physiological, or technical, or just plain measurement error. Technical differences must be understood and these sources of error must be

Fig. 3 Bland–Altman plot showing the p_{abd} signals measured by the water-filled and air-charged catheters at the end of infusion. The direction of the differences presented is air-charged minus water-filled catheter

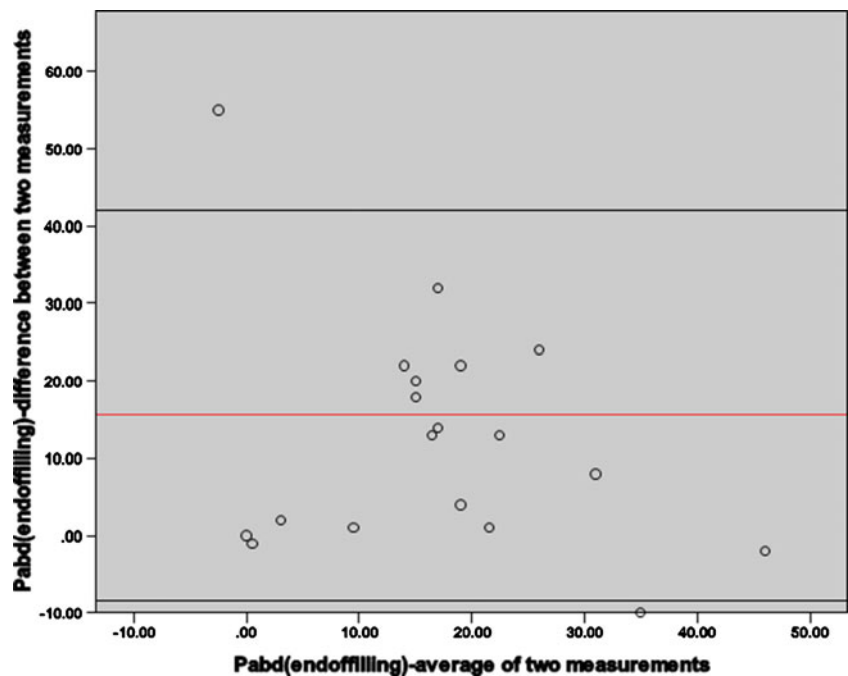
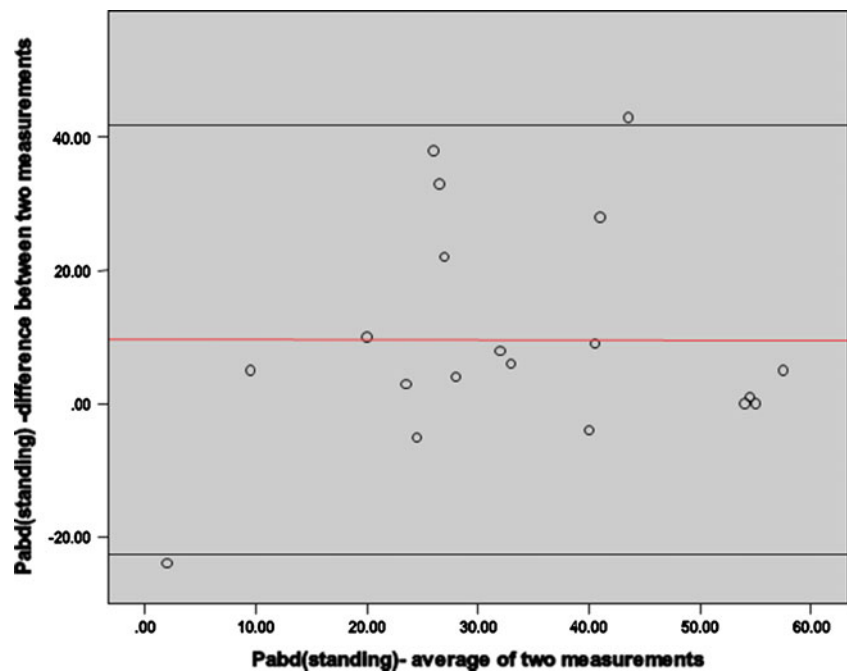


Fig. 4 Bland–Altman plot showing the p_{abd} signals measured by the water-filled and air-charged catheters on standing. The direction of the differences presented is air-charged minus water-filled catheter



corrected. Physiological sources of apparent error may be clinically important in themselves, but they are not often easy to correct. Considering that in our study a quality control check was undertaken during each test, we believe that the discrepancy between the pressures measured by air-charged and water-filled catheters was due to physiological source.

Ideally, if we put an air-charged catheter in the same pressure chamber as a water balloon, we will get the same

readings. However, physiologically, the catheters measure pressures in the rectum a little differently. For the water system, the baseline pressure depends on the height of the external transducer and we can control and monitor that by placing both transducers (vesical and abdominal) at the same height as the symphysis pubis. For the air-charged catheter, the position of the balloon tip in the rectum/bladder and how it pushes against rectal/bladder walls seem to affect the readings

Fig. 5 Bland–Altman plot showing the p_{abd} signals measured by the water-filled and air-charged catheters at the maximum involuntary detrusor contraction. The direction of the differences presented is air-charged minus water-filled catheter

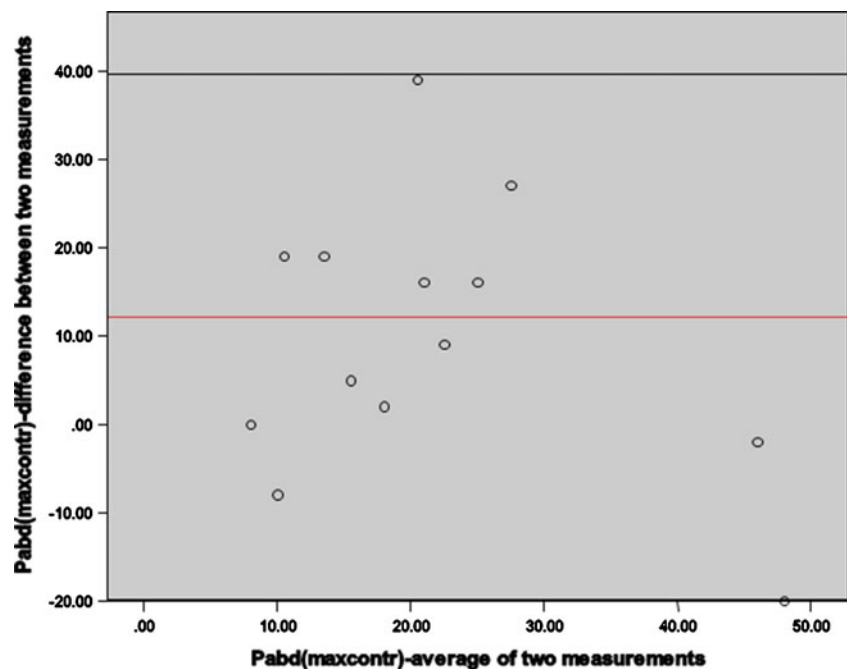
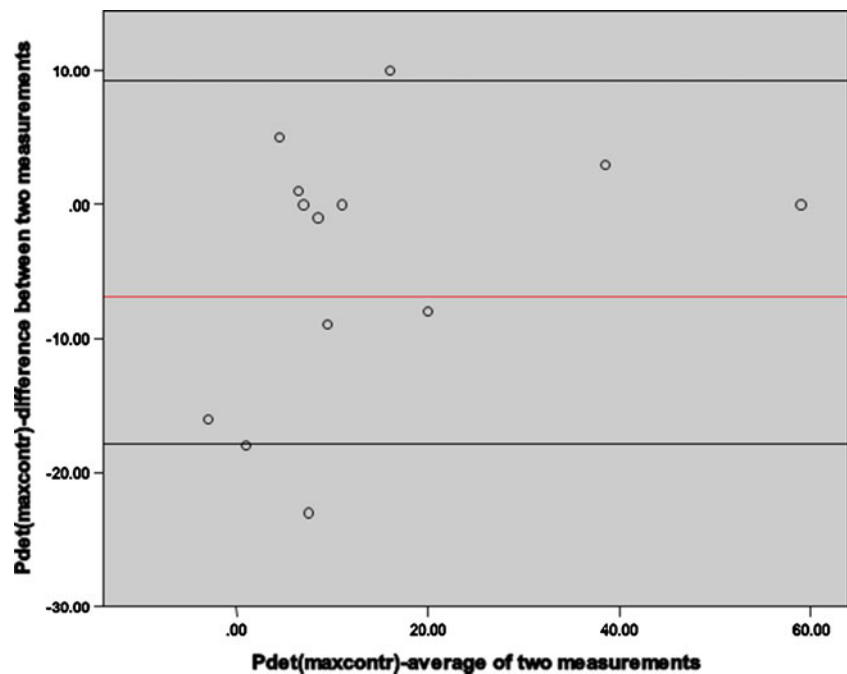


Fig. 6 Bland–Altman plot showing the p_{det} signals measured by the water-filled and air-charged catheters at the maximum involuntary detrusor contraction. The direction of the differences presented is air-charged minus water-filled catheter



more. The balloon size is also very small (technical limitation of the design) so we shall expect to see more variances compared with the larger water balloons. In addition, measuring abdominal pressure with a water-filled catheter requires attention throughout the test. Open balloon catheters may need continuous flushing, while balloon catheters may be easily overinflated. However, why air-charged catheters measure higher pressure readings compared with water needs to be further investigated. Finally, during the bladder filling and/or when the patient changes position during the test the balloon or catheter tip may move vertically relative to the symphysis. Although this will not affect water-filled measurements, the pressures measured by the air-charged system are likely to be affected. This source of error should also be considered while comparing the two catheters.

This study did not attempt to determine if the different readings obtained by the two methods were clinically significant, as this would have required a different study design. The aim of our study was only to assess if they can produce comparable pressure readings. Therefore, further studies to investigate their effect on clinical practice are needed.

Although the reproducibility and reliability of the air-charged catheter during urethral pressure profilometry has been already investigated, further studies analysing each subject population separately, as well as assessing the reliability and repeatability of the signals measured during urodynamics using different catheters such as double lumen water-filled catheters as with each subject as an individual, are mandatory. Finally, an interaction between catheters cannot be excluded and should also be considered, as it might have affected the signals measured.

In conclusion, our study demonstrated that air-charged catheters measure higher abdominal and intravesical pressures as well as lower detrusor pressures than water-filled catheters when used simultaneously in urodynamic investigation. The variation in the difference between the readings obtained by the two different types of catheter highlights their lack of comparability and that they cannot be used interchangeably. This has implications for multi-centre studies, where uniform types of air-charged or water-filled lines catheters should be used when assessing groups of patients across centres, as only then will the results have intergroup validity. The small study population represents the main limitation of our study; thus, larger studies are needed in order to confirm our data.

The small population considered may explain the reason why no differences were found between the urodynamic diagnoses. Finally, we can speculate that the different pressures may have a more significant impact on diagnosis in a male population where pressure measurement is more important. Thus, caution should be exercised when comparing urodynamic parameters using the two different types of catheter.

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