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Functional Studies to Assess Bladder Contractility

M. Sullivan, S. V. Yalla

Die Blasenkontraktilität betrifft die intrinsische Eigenschaft der Blasenglattmuskulatur, auf eine bestimmte Länge zu kontrahieren. Intuitiv steht sie nicht nur für die Stärke der Detrusorkontraktion, sondern auch für die Fähigkeit, eine Kontraktion adäquat aufrecht zu erhalten. Geeignete Methoden zum Messen der Blasenkontraktilität und Methoden zur Quantifizierung dieser Messungen sind unabdingbar für eine genaue Beschreibung von Entleerungsdysfunktionen. Zahlreiche Techniken zur funktionalen Bewertung der Blasenkontraktilität auf Basis anerkannter biomechanischer Prinzipien wurden beschrieben. Dementsprechend ist die Wahl des methodologischen Ansatzes von den Zielen der Evaluation abhängig zu machen.

Bladder contractility refers to the intrinsic property of bladder smooth muscle to contract at a given length and intuitively represents not only the strength of the detrusor contraction, but the ability to adequately sustain a contraction. Suitable methods of measuring bladder contractility and approaches to quantifying these measurements are essential to accurately characterize voiding dysfunctions. Numerous techniques for functionally assessing bladder contractility, based on established biomechanical principles, have been described and thus the choice of methodological approach should be determined by the goals of the evaluation. ***J Urol Urogynäkol 2007; 14 (1): 7–10.***

Introduction

Contractility is a broad physiologic term used to describe muscle performance and generally refers to the intrinsic property of smooth muscle to contract at a given length. In relation to the bladder, the concept of contractility intuitively represents the strength of the detrusor contraction, as well as the ability to adequately sustain a contraction. Numerous physiologic and pathophysiologic alterations modulate bladder contractility, including neurologic, biochemical, biomechanical, behavioral and hormonal factors. Thus evaluation of ensuing voiding abnormalities requires suitable methods of measuring bladder contractility and approaches to quantifying these measurements in order to accurately characterize voiding dysfunctions prior to initiation of appropriate management strategies.

Bladder Contractility Assessed During Voiding

During urination, contraction of the bladder generates both detrusor pressure and urinary flow. Accordingly, the strength of the bladder contraction is a function of the complex interplay between pressure and flow. Several clinical methods of analyses that are based on Hill's force-velocity relationship are used to assess the ability of the detrusor to contract during a pressure-flow (PQ) study. The Hill equation describes the biomechanical hyperbolic relationship between the active force of muscle contraction and the velocity of shortening, such that any muscle contraction can be described by two fundamental parameters – the maximum velocity of shortening and isometric force. For the bladder, an analogous relationship between the circumferential shortening velocity and the pressure within the bladder lumen has been defined [1]. Watts Factor (WF = $[(p_{det} + a)(v_{det}+b) – ab]/2\pi$, where a = 25 cm H_2O and b = 6 mm/s, fixed values derived from clinical and experimental data, and v_{det} is calculated from bladder volume and urinary flowrate) introduced by Griffiths is obtained from PQ studies and is interpreted as the mechanical power generated per unit area of the detrusor surface [2]. As the product of detrusor pressure and shortening velocity, WF approximates the isovolumetric detrusor pressure when flow is zero. During flow, WF equals the detrusor pressure plus a contribution dependant upon the shortening velocity to similarly approach the isovolumetric detrusor pressure. WF represents contractility as a single parameter, typically at its maximum value or the value at maximum flowrate. This parameter has been shown to be only weakly volume dependent [2] and to be independent of the degree of acute outlet obstruction [3]. Thus WF is considered a useful clinical research tool. However, this calculation requires computer analysis and does not easily describe the sustainability of detrusor contraction or the quality of detrusor activation.

Many other contractility parameters derived from pressure-flow studies have been described. Schafer introduced a simplified approach to classify contractile strength using linearized bladder output relations on pressure-flow nomograms in which the peak of the passive urethral resistance relation indicates detrusor contraction strength [4]. The Schafer nomogram can also be used to approximate the maximum isovolumetric pressure by projecting the point defined by p_{det} and Q_{max} towards the y-axis at an angle parallel with the linearized bladder output relation. Using the slope of this line (established to be 5 cm H_2O/ml/s), this projected isovolumetric pressure (PIP) can be calculated as $p_{det.Qmax} + 5Q_{max}$ in men. However, this slope may need to be adjusted for different populations, since a slope of 1 cm H_2O/ml/s appears to better approximate isovolumetric bladder pressure in older women [5], and in men can vary considerably depending on the type of dysfunction [unpublished observations].

Bladder Contractility Assessed by Isometric Techniques

The above types of analyses require PQ studies which sometimes cannot be easily obtained, especially in the non-ambulatory frail and elderly population. Special table and equipment are required to acquire accurate PQ data in such disabled patients. Other simpler methods advocated involve isometric testing techniques in the mid-voiding phase, with interruption of flow by either voluntary contraction of the external sphincter or by sudden occlusion of the bladder neck with a balloon. Also, the velocity of detrusor contraction before voiding has been used to determine the detrusor performance. These non P/Q methods have not been adequately standardized or extensively validated and are known to have certain drawbacks. The isometric detrusor contractions generated from voluntary interruption are not entirely isometric since reflex detrusor inhibition induced by voluntary contraction of the striated sphincter can result from these maneuvers. Further, this technique may be unsuccessful in certain demented patients who are unable to effectively interrupt urinary flow or cannot comprehend the commands of the

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investigator and in those with myeloneuropathies who are unable to voluntarily contract their striated sphincter. While mechanical occlusion of the bladder neck during voiding may avoid the problem of sphincter induced reflex detrusor inhibition, other disadvantages are evident. For example, the timing of the occlusion of the outlet during bladder contraction has not been optimized and the potential effects of sudden discomfort to the patient that may cause contraction of periurethral musculature resulting in reflex detrusor inhibition have not been addressed. Furthermore, neither of these isometric methods provides information regarding the duration of detrusor activation.

Efficient urination requires a detrusor contraction of appropriate strength that can be rapidly attained and adequately sustained. Thus, any assessment of detrusor contractility must ideally include a characterization of each of these contraction phases. A modified method of inducing an isovolumetric contraction has been introduced that involves occluding the outlet with a balloon catheter positioned at the bladder neck prior to the initiation of a voiding contraction and challenging the detrusor throughout the period of its activation [6] (fig. 1). This continuous occlusion test is applicable to the evaluation of many types of voiding dysfunction in both males and females. The maximum isovolumetric pressure (P_{isv}) obtained from this method has been shown to increase with bladder outlet obstruction in men (fig. 2) and with detrusor overactivity in both men and women [6–8] and to decrease with impaired voiding efficiency [9].

This method of bladder contractility assessment allows consideration of the duration of detrusor activation, an important parameter that complements isovolumetric pressure in the evaluation of detrusor contractile performance. Adequate activation of the detrusor, reflected by the duration of bladder contraction, is essential for efficient emptying of the bladder. Thus, elevated post-void residual volumes are associated with unsustained isometric bladder contractions, despite the generation of high maximum isovolumetric pressures. Previous studies have demonstrated that the duration of isometric contraction, though well correlated with voiding efficiency, is poorly correlated with maximum P_{isv} [6], indicating that these two parameters characterize independent aspects of detrusor contractile performance.

Although in vitro and in vivo experimental studies in animals indicate that P_{isv} decreases with increased bladder volume [10, 11], detrusor contractions are better maintained at higher bladder volumes, suggesting that bladder efficiency improves at larger volumes (approaching capacity) by generating sustained contractions of lower magnitude. In humans however, the dependence of isovolumetric detrusor pressure on bladder volume is relatively minor over a limited range of bladder volumes encompassing bladder capacity [1, 6, 12].

Relationship between P_{isv} and WF

Assessment of bladder contractility based on pressure-flow studies have been compared with those derived from isometric testing. P_{isv} has been shown to be highly correlated with maximum WF [6] and is approximately equal to 10 x WF [2]. Moreover, the behavior of these parameters with various types of voiding dysfunction has been compared. Like P_{isv}, WF is positively correlated with bladder outlet obstruction [13]. However the relationship between voiding efficiency and WF is less clear than with

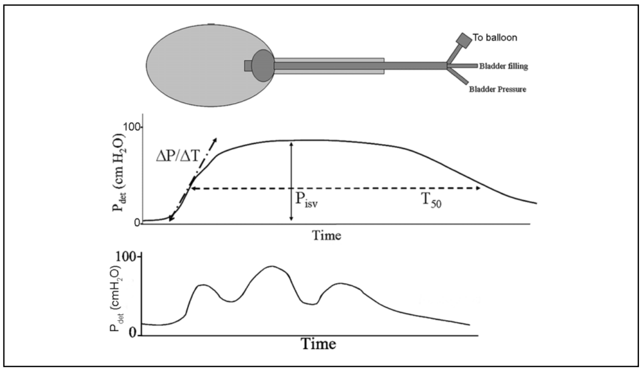

Figure 1. Schematic diagram of isometric pressure generated during the continuous occlusion test. Foley catheter is inserted into the bladder for simultaneous bladder filling and measurement of bladder pressure. From the detrusor contraction that is generated, the maximum isovolumetric pressure (P_{isv}), the slope of the contraction (ΔP/ΔT) and the duration that the isometric contraction remains above 50 % of its maximum (T_{50}) can be determined. Top tracing demonstrates strong bladder contractility while bottom tracing reflects contraction that attains a similar maximum isovolumetric pressure but is phasic and poorly sustained.

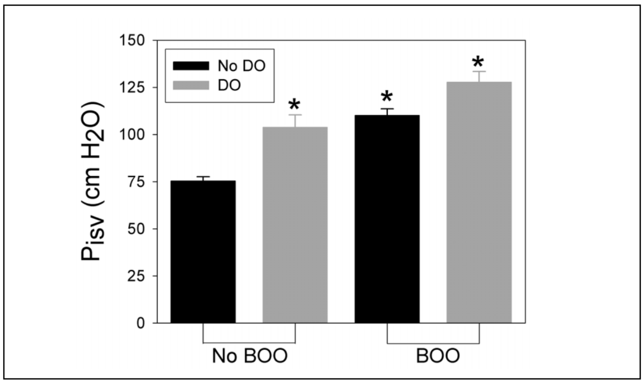

Figure 2. Maximum isovolumetric pressure (P_{isv}) in patients with voiding dysfunction. P_{isv} is significantly higher in patients with detrusor overactivity (DO) and/or bladder outlet obstruction (BOO).

the duration of isometric contraction. WF was not shown to be correlated with post-void residual (PVR) volumes in men with bladder outlet obstruction, but WF was negatively correlated with PVR in diabetic patients [14]. In men with bladder outlet obstruction, PIP and WF were increased in those with detrusor overactivity [15], and WF in women with overactive bladder is greater than in those with normal bladder, similar to the results reported with P_{isv}. The diagnostic correspondence in these approaches to contractility assessment points towards the accuracy and suitability of each technique; thus the choice of approach can be determined by patient needs and the urodynamic environment.

Non-invasive Measurement of Bladder Contractility

To develop appropriate methods of non-invasively evaluating men with voiding dysfunction, several techniques for estimating P_{isv} without urethral catheterization have been devised. This can be achieved either by placing a flexible cuff around the penis which is automatically inflated to interrupt flow [16, 17], or by using the condom catheter method in which a modified incontinence condom is fitted to the penis and attached to variable outlet resistances controlled by a pneumatic valve [18]. The concept underlying these techniques is that the pressure transmitted to the measurement site during occlusion of urinary flow reflects the isovolumetric bladder pressure generated against a closed outlet. To measure this pressure, the bladder neck and proximal urethra must remain open with fluid in continuity from the bladder to the site of pressure measurement and the external sphincter should be in a relaxed state. Under these conditions, both of these methods have been shown to produce quantitative measures of bladder contractility that closely approximate maximum isovolumetric detrusor pressures measured invasively and represent promising approaches to the practical assessment of bladder contractile function.

Bladder Contractility Assessed Experimentally by Force and Velocity

Bladder contractility is assessed in the clinical setting using mechanical variables that are accessible and easily measured: pressure, flow, and volume. Bladder contractility has also been experimentally defined by the relationship between bladder wall force and velocity. In vitro force-velocity measurements have confirmed that bladder smooth muscle can generally be approximated by hyperbolic Hill equation derived from striated muscle. Examination of this relationship under various conditions demonstrates that increasing the stretched muscle length up to an optimum length increases maximum isometric force and alters the curvature of the hyperbolic force-velocity relationship, whereas the degree of activation of bladder smooth muscle affects the maximum isometric force, maximum shortening velocity as well as the shape of the hyperbolic curve [19].

Assuming that the bladder has a spherical shape, is incompressible and stretches equally in all directions throughout all regions, force (tension) can be related to bladder pressure using the law of Laplace, $T = (p_{det} \times r)/2$, where "T" is wall tension and "r" is the radius of the bladder volume. Bladder wall stress then is the ratio bladder wall tension and wall thickness. In contrast to the inverse relationship between isovolumetric pressure and bladder volume, the length (circumference)-tension relationship is relatively constant for the whole bladder, with a slight increase in tension in the mid-volume range [11]. The in vitro length-tension relationship of detrusor muscle from several species however increases to a maximum response at an optimum length [20] (250 % or more of resting length), with greater muscle lengths resulting in less tension development. The vesical wall stress increases directly with increasing bladder circumference, reflecting the striking decrease in bladder wall thickness with increased bladder volume. Interestingly, active bladder wall stress varies by region such that the posterior wall exhibits greater stress than the anterior wall [21].

In summary, many techniques are available and well characterized for functionally assessing bladder contractility. These methods, generally derived from the biomechanical properties of muscle, vary considerably in their complexity, applicability and diagnostic value. While measurement of bladder contractile performance is essential for an accurate appreciation of lower urinary tract dysfunction, the specific technique or methodological approach employed is determined by the goals of the evaluation.

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