FEMALE UROLOGY
Invited Review

Imaging assessments of lower urinary tract dysfunctions: Future steps

Alt üriner sistem disfonksiyonlarının değerlendirilmesinde görüntüleme: Geleceğe yönelik adımlar

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ABSTRACT

Urodynamic tests are the standard diagnostic method for lower urinary tract dysfunctions (LUTD). However, these tests are invasive. The current review describes the noninvasive imaging techniques that have been used to monitor LUTD. The main imaging technologies that have been applied in diagnosing LUTD were 2D ultrasonography, Doppler ultrasonography, and near-infrared spectroscopy (NIRS). Ultrasonographic parameters, such as bladder wall thickness (BWT), detrusor wall thickness (DWT), and ultrasound-estimated bladder weight (UEBW), have been proposed as surrogates for bladder outlet obstruction (BOO) or detrusor overactivity (DO). Few studies have reported diagnostic cut-offs in diagnosing BOO or DO; thus, there is still a need to standardize the measurement method. NIRS can detect the hemodynamic changes related to DO and BOO in real-time, which could be advantageous in clinical practice, but the liability of NIRS to motion artefacts is a limitation. Bladder strain imaging in real-time using 2D ultrasound enables noninvasive estimation of the dynamic changes in the bladder wall during voiding. Many imaging techniques have been used to monitor the urinary bladder during the storage and voiding phases of the micturition cycle. These techniques were either static [i.e., measuring fixed parameters, such as BWT, DWT, UEBW, and intravesical prostatic protrusion (IVPP)] or dynamic (monitoring the structural and hemodynamic changes in the bladder wall in real-time). These techniques are currently being developed and standardized for potential use in diagnosing LUTD in clinical practice.

Key words: Imaging; noninvasive; spectroscopy, near-infrared; Urinary bladder, overactive; urinary bladder-neck obstruction.

ÖZET

Ürodinamik testler alt üriner sistem disfonksiyonları (AÜSD) için standart tanı yöntemleridir. Ancak bu testler invazivdir. Güncel derleme AÜSD takibinde uygulanmakta olan non-invaziv görüntüleme tekniklerini tanımlamaktadır. AÜSD tanısında uygulanmakta olan başlıca görüntüleme teknolojileri; 2B ultrasonografi, Doppler ultrasonografi ve yakın infrared (kızıl ötesi) spektroskopisi (NIRS) idi. Mesane duvar kalınlığı (BWT), detrüsör duvar kalınlığı (DWT), ultrason tahmini mesane ağırlığı (UEBW) ve intravezikal prostatik çıkıntı (IVPP) gibi ultrasonografik parametreler mesane çıkışı obstrüksiyonu (BOO) veya detrüsör aşırı aktivitesi (DO) için belirteç olarak önerilmektedir. BOO veya DO'nun tanısı için tanısal cut-off değerlerini çok az çalışma gösterebilmiştir ancak ölçüm yöntemini standardize etmeye hâlâ gereksinim vardır. NIRS, DO ve BOO ile ilişkili hemodinamik değişiklikleri gerçek-zamanlı saptayabilir ve bu, hareket artefaktlarının sorumluluğu kontrol edildiğinde klinik uygulamada büyük bir avantaj olabilir. 2B ultrason kullanılarak mesanenin gerçek-zamanlı dizi görüntülemesi işeme sırasında mesane duvarındaki dinamik değişikliklerin non-invaziv değerlendirilmesini sağlar. İşeme döngüsünün depolama fazı ve işeme fazı esnasında idrar kesesinin izlenmesinde birçok görüntüleme tekniği uygulanmaktadır. Bu teknikler ya BWT, DWT, UEBW ve IVPP gibi sabit parametrelerin statik ölçümleridir ya da mesane duvarındaki yapısal ve hemodinamik değişikliklerin gerçek-zamanlı dinamik izlenmesidir. Bu teknikler klinik pratikte AÜSD tanısında potansiyel uygulama için halen geliştirilmektedir ve standardize edilmektedir.

Anahtar kelimeler: Görüntüleme; non-invaziv; yakın kızılötesi; aşırı aktif; spektroskopi; ürodinamikler; idrar kesesi; idrar kesesi boynu obstrüksiyonu

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Introduction

Lower urinary tract symptoms are either storage phase symptoms or voiding phase symptoms. Overactive bladder (OAB) syndrome is a complex of storage symptoms in the form of urgency with or without urgency incontinence, usually with frequency and nocturia in the absence of infection or any other obvious pathology.[1] In Western nations, OAB is prevalent in approximately 13% of women and 11% of men older than 18 years of age.[2] Voiding symptoms occur in the form of hesitancy, slow or intermittent stream, straining, and terminal dribble. Urodynamic tests in the form of pressure flow study (PFS) and

filling cystometry are the standard diagnostic methods for bladder outlet obstruction (BOO) and OAB syndrome, respectively. However, these tests are invasive and are associated with potential patient morbidity.[3] Therefore, efforts have been made to develop non-invasive techniques that can replace urodynamics. The current review describes imaging diagnostic techniques that have been used to diagnose functional lower urinary tract disorders.

Ultrasonographic methods

Bladder wall thickness and detrusor wall thickness

Ultrastructural studies have shown that smooth muscle bulk is increased in bladder wall specimens obtained from patients with BOO.[4] The presumption is that voiding against the increased resistance of the bladder outlet complex in these patients leads to increased bladder wall thickness (BWT).[5] The same presumption could be true for patients with OAB who have frequent involuntary detrusor contractions against a closed urethral sphincter.[5-8]

The ultrasonographic components of the urinary bladder are defined from outside-in as bladder adventitia (hyperechoic), detrusor muscle (hypoechoic) and bladder mucosa (hyperechoic).[9,10] The measurement of BWT includes all of these layers, while detrusor wall thickness (DWT) measures only the middle layer.

The mean BWT in healthy children is 2.13±0.59 mm.[11] Khullar et al.[12] suggested a BWT of 5 mm as a diagnostic cut-off for detrusor overactivity (DO), with 84% sensitivity and 89% specificity in patients presenting with OAB symptoms. Robinson et al.[5] suggested a BWT of 6.0 mm as a diagnostic cut-off for DO. BWT was found to be 3.67±0.11 mm in a group of men older than 60 years of age who presented with LUTS.[13] BWT was measured at 150-mL bladder filling in 174 patients; the authors reported a BWT of 5 mm to have 92% specificity and 54% sensitivity for detecting BOO.[14] Kuo et al.[7] suggested a cut-off of 0.75-mm DWT for bladder capacity, with 73% sensitivity and 67% specificity in diagnosing DO in women with OAB syndrome. Oelke et al.[15] suggested 2 mm as the cut-off DWT for the diagnosis of BOO, with 95.5% PPV. Kessler et al.[16] reported a 2.9-mm cut-off for DWT for a 100% PPV, with low sensitivity (43%).

Although some of these studies have shown good diagnostic accuracy for DO and BOO, there is still a need to standardize the performance measures, particularly the type of transducer, the frequency of the ultrasonic waves and zooming power applied during the measurement.

Ultrasound estimated bladder weight

Kojima et al.[10] measured the BWT and inner and outer bladder dimensions using ultrasound in 10 bladder autopsies. Assuming the bladder to have a spherical shape, the authors subtracted the inner calculated bladder volume from the total bladder volume and multiplied the outcome by the specific gravity to obtain the ultrasonographic estimation of bladder weight (UEBW).

In a group of women with OAB, mixed urinary incontinence (MUI), and stress urinary incontinence (SUI), the mean UEBW was significantly greater in the OAB group (48 g in the OAB group, 35 g in the SUI group and 40 g in the MUI group, p<0.001).[17] UEBW has been suggested as a tool for post prostatectomy follow-up in men with BOO. UEBW significantly decreased from 52.9±22.6 g to 31.6±15.8 g (p<0.0001) in approximately 33 patients 12-weeks post-prostatectomy.[18] However, the assumption that the bladder has a spherical configuration appears to be unrealistic.

Ultrasonic estimated intra-vesical prostatic protrusion

An enlarged prostatic gland may protrude through the urinary bladder neck, leading to a sort of mechanical obstruction of the urinary outflow.[19] The intra-vesical prostatic protrusion (IVPP) can be measures by ultrasound between the tip and base of the prostate and at the bladder circumference. IVPP was measured using trans-abdominal ultrasound in a study that included 200 men with LUTS.[20] IVPP is classified into 3 grades: grade I <5 mm, grade II = 5-10 mm, and grade III >10 mm. Reis et al.[21] proposed a cut-off of 5 mm in diagnosing BOO, with 95% sensitivity and 50% specificity, respectively. IVPP appears to be an anatomical rather than a functional diagnostic tool for BOO, which means that the information about detrusor muscle contractility will be deficient.

Doppler ultrasonographic measurement of detrusor resistive index (RI)

The arterial resistive index (RI) was measured in 35 patients with high UEBW using the following formula: $RI = V_{max} - V_{min} / V_{max}$, where V_{max} and V_{min} are the maximum and minimum blood flow velocities, respectively.[22] RI showed a high diagnostic accuracy (86%) for BOO when measured at 3 different urinary bladder spots, with no significant difference in the readings obtained from empty or full urinary bladders.[23]

Ultrasound bladder strain imaging

Real-time monitoring of change in the thickness of the bladder wall during voiding (i.e., bladder strain imaging) has been recently investigated by Farag and Idzenga.[24] A group of 20 men with LUTS underwent conventional PFS. Radio frequency (RF) ultrasound data were acquired using an ultrasound system equipped with a linear array 7.5-MHz transducer. Just before the patient was granted permission to void, the transducer was placed opposite the bladder region at the onset of an increase in P_{det}. Approximately 20 seconds of RF data were acquired. The ultrasound data that corresponded to the increase in P_{det} toward the opening pressure were selected for further analysis.

During the offline analysis of data, a region of interest (ROI) was selected within the bladder wall in the first obtained frame. A specific program measured the ROI width in each subsequent frame. The strain (ε) between the sequential frames was then built-up in an accumulative manner relative to the first frame. The P_{det} change, relative to the maximum ultrasound estimated strain (ε_{max}), was determined ($\Delta P_{det}@\varepsilon_{max}$) with regard to the first acquired ultrasound frame.

The measurements were successful in 13 of 20 patients. In 5 patients with only isovolumetric contraction, the axial strain showed a significantly positive correlation with P_{det} (r=0.70-0.99, p<0.05). Eight patients voided during ultrasound strain imaging, 5 of these patients showed a significant positive correlation between the cumulative axial strain in the detrusor muscle and P_{det} (r=0.52-0.81, p<0.05), and 6 of these 8 patients demonstrated a significant positive correlation between the axial strain and urinary flow (r=0.32-0.90, p<0.05).

Near-infrared spectroscopy
Near-infrared spectroscopy (NIRS) is a function imaging technology that can detect oxygen-dependent hemodynamic changes in the bladder wall either during voiding [25,26] or during involuntary detrusor muscle contractions.[27] Light in the NIR region of the light spectrum can penetrate the skin and reaches deeply located tissues before being absorbed by certain chromophores, including oxygenated hemoglobin (O_2Hb) and deoxygenated hemoglobin (HHb), in the human body. The measurement of changes in the concentration of O_2Hb and HHb in biological tissues in response to an abrupt event relative to baseline indicates the oxygen-dependent changes that occur in these tissues.[28,29] The computed variable Hb_{sum} is the sum of O_2Hb + HHb, which represents the total hemoglobin.

Farag et al.[30] investigated the reproducibility, sensitivity, and specificity of NIRS in the diagnosis of DO in a group of patients with OAB symptoms. The patients underwent filling cystometry with simultaneous noninvasive, transcutaneous NIRS of the bladder region. The obtained graphs showed curves that indicated DO and other curves that did not. Theses graphs were then separated and coded. The separated graphs representing both tests were presented to 3 urodynamicists for rating in a blinded and randomized manner. The rating session was repeated after 3 weeks to test the inter- and intra-observer agreements. Because of the occurrence of motion artifacts, the authors excluded 28% of the graphs from the rating process. The urodynamicists were asked to mark pressure changes that were suggestive of DO in the cystometry curves and to mark definite deviations from baseline in the NIRS curves. The NIRS curve representing Hb_{sum} showed an average 92% sensitivity and 72% specificity for DO (AUC, 0.80-0.82; p<0.001). The O_2Hb curves showed 82% sensitivity and 86% specificity for DO (AUC, 0.80-0.85; p<0.001). The HHb curve showed 77% sensitivity and 80% specificity for DO (AUC, 0.73-0.84; p<0.001). In observing the NIRS curve changes caused by DO, the inter- and intra-observer agreements were substantial (kappa >0.6).[30] NIRS has been used to classify men with LUTS; in that study, the authors demonstrated that NIRS discriminated BOO with 100% sensitivity and 88% specificity.[26]

In conclusion, ultrasonographic parameters, such as BWT, DWT, UEBW, and IVPP, have been proposed as surrogates for BOO or DO in patients with LUTS. Few studies have shown diagnostic cut-offs for diagnosing BOO or DO; thus, there is still a need to standardize the measurement method.

NIRS can detect the hemodynamic changes related to DO and BOO in real-time, which could be advantageous in clinical practice by reducing the liability from motion artifacts. NIRS can also help researchers to understand the underlying potential hemodynamic pathophysiologic mechanisms of LUTS.

Using noninvasive, patient friendly ultrasound, the estimation of bladder strain can be of great value when an extended measurement time window that covers the whole act of micturition is applied. Such a screening may provide a good potential diagnostic tool for BOO in patients with LUTS and may provide insight into the basic dynamic and structural changes that occur in the bladder wall during contraction.

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