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Novel insight into the dynamics of male pelvic floor contractions through transperineal ultrasound imaging

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Abstract

Purpose—Transperineal ultrasound imaging (US) enables minimally invasive assessment of pelvic floor muscle function. Although commonly used in females, the approach has not been reported in males. This approach has advantages because the mid-sagittal view visualises a bony landmark and the entire urethral length. This allows investigation of displacement of multiple points along the urethra and the unique mechanical actions of multiple muscles that could influence continence. We used a new transperineal US technique to compare relative displacement of urethra-vesical junction, ano-rectal junction, and distal urethra during voluntary pelvic floor muscle contractions in continent men.

Materials and Methods—Measurement and comparison of urethral displacement at specific urethral regions in ten continent males (28–41 years). Measures made on 2D mid-sagittal plane ultrasound images included the displacements of specific points along the urethra. Anatomic considerations suggest that these are caused by contraction of the levator ani, striated urethral sphincter and bulbocavernosus muscles. Pearson's correlation coefficient was used to investigate the relationship between displacements of pairs of points.

Results—Data show individual variation in displacement of the distal urethra (striated urethral sphincter contraction) and urethra-vesical junction (levator ani contraction). A strong inverse linear relationship (0.723) between displacements of these points indicates two alternative strategies of urethral movement.

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Conclusions—Transperineal US imaging allows simultaneous investigation of multiple pelvic floor muscles by measurement of urethral displacement. Data provide evidence of different but coordinated strategies of urethral displacement in males.

Keywords

perineal; ultrasound imaging; male continence; striated urethral sphincter; urinary incontinence

Introduction

Urinary continence in males and females is maintained by smooth muscle of the bladder neck and urethra¹, mucosal factors and vascularity², and striated muscles³ including the closely approximated rhabdosphincter or striated urethral sphincter (SUS) and more distant levator ani (LA) muscles. Although research has mainly focussed on females^{4, 5-8}, interest in males is increasing⁹. In females, LA contributes ~10-20% to increased urethral closure pressure as well as providing support for the bladder neck for continence^{5, 6} and the pelvic organs^{7, 8}. LA contraction is often targeted in exercise for female stress urinary incontinence (SUI) treatment¹⁰ and quantified from bladder neck displacement on dynamic magnetic resonance imaging or, more inexpensively, ultrasound (US) imaging. Although urethral pressure measures have quantified closure pressures generated by SUS, attention to its contribution to continence in women is limited, perhaps because of difficulty in making electromyographic (EMG) recordings. In contrast, research in males has prioritised investigation of SUS for urinary continence using muscle histology⁹ and EMG activity¹¹. Although SUS has been targeted in biofeedback training for SUI management after prostatectomy¹², feedback is provided by perineal surface EMG electrodes or anal pressure/EMG measures, neither of which provide information regarding SUS status. Although a role for LA muscles (puboperinalis) has been described in male imaging studies¹³, their contribution is largely ignored. Other muscles that compress the urethra, such as bulbocavernosus (BC), may also contribute, particularly if conventional mechanisms of continence are disrupted by disease or surgery. It remains unclear how LA, SUS and BC interact to maintain urinary continence and their relative contributions may vary between individuals.

Investigation of striated pelvic floor muscles in men has been limited because of poor access for measurements. Development of non-invasive measurement techniques would facilitate investigation. Real-time US imaging provides a potential solution. US is minimally-invasive and has well-documented validity for assessment of LA function and feedback for treatment of pelvic floor muscle dysfunction in females¹⁴. Transabdominal¹⁵⁻¹⁷, transrectal¹⁸⁻²⁰, transvaginal^{21, 22} and transperineal^{23, 24} approaches image bladder and anorectal junction (ARJ) movements from LA contraction. In men, SUS anatomy and activation has been imaged with transrectal²⁵ and transurethral²⁶ approaches. Transperineal imaging is advantageous for both genders because the image includes a bony landmark to reference measures of motion (unlike the transabdominal approach). It also images all three striated muscles simultaneously (unlike the transrectal and transvaginal approaches) and minimally distorts motion (unlike intrarectal and intravaginal transducers¹⁴).

Measurement of displacement of pelvic structures by pelvic floor muscle contraction provides valid measures of contraction in females^{23, 24}. However, only LA activation has been analysed in this manner from ARJ, urethra and urethra-vesical junction (UVJ) movements using transperineal US in women^{23, 24}. In men, quantification of UVJ motion with transabdominal²⁷ and transperineal^{28, 29} US, and SUS motion with transurethral²⁶ and transrectal US²⁵ has been investigated. However, these studies only evaluated single structures, generally involved limited quantification of movements, and did not consider the relative contributions of the multiple striated muscles with potential to influence continence.

Simultaneous visualisation and measurement of motion generated by the three key muscles with the potential to maintain urinary continence using a transperineal US imaging approach is likely to improve understanding of the coordination of these muscles in men. We hypothesized that, given multiple mechanisms with potential to influence urethral closure (Fig. 1A), men may use variable patterns of motion during voluntary contractions. Although complete understanding of male urinary continence would require measurement of EMG and urethral, bladder and intra-abdominal pressures, quantification of movement from striated muscle contraction, which has been interpreted for LA activation in women, represents an important first step towards this goal.

This study aimed to test the above hypothesis using transperineal US to compare the relative displacement of UVJ and ARJ (movements that could be attributed to the LA), and distal urethra (related to SUS and BC activation) during voluntary pelvic floor muscle contractions in young continent men.

Material and Methods

Participants

Ten healthy men (28-41 years) with no history of urological or neurological disorders volunteered. The institutional Medical Research Ethics Committee approved the study and participants provided informed written consent.

Ultrasound Imaging

A curved linear array ultrasound transducer (frequency: 7.0 MHz [M7C]; Logiq9 ultrasound, GE Healthcare, Australia) was used to image pelvic structures. The transducer was enclosed in a rubber sheath with ultrasound gel used as the transmission medium. Image collection and analysis was performed by a single experienced investigator.

Procedure

To standardise bladder volume and optimise imaging, participants voided their bladder and consumed 450 ml water 1 hr before testing and refrained from voiding until after testing. Images were captured with participants reclined on a plinth in a semi-seated position (back rest at ~70° to the horizontal) with a towel around their waist, undergarments removed, and the legs extended (Fig. 1B). The sagittally-aligned transducer was placed with moderate pressure on the perineum and held in position by the participant. Participant privacy was maintained without exposure of the perineum. The image was optimised such that the pubic

symphysis (PS), urethra, UVJ, BU and ARJ were visible simultaneously. Participants were instructed to make small adjustments to transducer placement for image optimisation.

Participants relaxed the pelvic floor muscles and then contracted maximally using an instruction that made reference to attempting to stop the flow of urine during micturition. Contraction intensity increased gradually to maximum, was held for 3 s, and repeated three times with 1-min rests. US images were recorded as a cine-loop of the contraction sequence (from relaxation to maximum) and exported in video format (.MPG, frame rate 30 Hz). Optimal frames for evaluation of the relaxed and contracted state were identified and captured as .JPG images (640 × 480 pixels) for analysis.

Image Analysis

A graphical user interface (GUI) for analysis of 2D ultrasound images was developed using Matlab software (r2010b, The Mathworks, USA) to measure displacement of pelvic floor structures. Detailed description of analysis is provided elsewhere (Stafford et al, submitted). In brief, standardised points (P1-P5, Fig. 2D) were identified in relaxed and contracted states for each repetition and their displacement was calculated to quantify the movement of pelvic floor structures as defined in Table 1. The embedded image scale was used to calibrate motion.

Statistical Analyses

Descriptive data of the mean and standard deviation of the displacement of each structure are presented. A linear regression was fitted to the data to study the relationship between displacements of the different structures. Pearson's r-squared correlation coefficient was calculated with $P < 0.05$ being considered significant.

Results

When pelvic floor muscles were contracted voluntarily with maximum effort, movement of the points of interest (UVJ, ARJ, BU and SUS) was clearly observed in transperineal ultrasound images. Although the direction of movement of each structure followed the pattern proposed in Fig. 1 for all participants, the amplitude of movement of each structure varied between participants.

Motion of points of interest

The UVJ moved 4.6 to 20.6 mm along a superior/ventral vector for the ventral aspect and 3.2 to 27.4 mm for the posterior aspect. The superior/ventral displacement of ARJ was 4.9 to 21.5 mm. The bulb of the penis was compressed ventrally by 0.2 to 16.5 mm. Dorsal displacement of the ventral urethral border in the region of the SUS muscle ranged from 1.0 to 5.2 mm. Table 2 shows data for each point of interest for each participant.

Relationship between movements of different points of interest

ARJ displacement was strongly positively correlated with anterior/posterior UVJ displacement (Fig. 3). Although urethra displacement in the region of the SUS was strongly linearly related with UVJ (anterior) displacement, the relationship was negative (Fig. 3); i.e.

greater SUS displacement was associated with smaller UVJ displacement. SUS and ARJ displacements were also negatively correlated. BU compression was only weakly related in an inverse manner with urethral displacement at SUS.

Discussion

This study is the first to use transperineal US in men to compare relative displacements of pelvic structures related to striated muscle contraction during voluntary activation, and the first to validate movements of UVJ, ARJ, SUS and BU from a single US image. Data provide new insight into coordinated function of the SUS, LA and BC muscles and represent an important step towards improved understanding of the male urinary continence mechanism. Consistent with our hypothesis, kinematic data show variation between men in terms of displacement of the urethra in regions that can be affected uniquely by the SUS (inferior to the prostate) and LA (at the UVJ) muscle, providing evidence of potential variation in strategies to maintain urinary continence.

Using the transperineal US approach in **young** men, the PS and five points of interest (UVJ [dorsal and ventral], ARJ, BU and urethra at level of SUS) were clearly observed in single, sagittal plane images. Movement of the points of interest with maximal pelvic floor muscle contraction agreed with that depicted in Fig. 1A, confirming our predictions of urethral movement based on striated muscle morphology. Visibility of the points of interest and PS remained sufficient for measurement of change between images at rest and during contraction. The graphical user interface could select the points regardless of change in PS position over multiple repetitions. High ICC values provided evidence that the method was reliable between days in **young continent men** (Stafford et al, submitted). Although this new method reliably depicts displacement of pelvic structures, it is acknowledged that displacement is not linearly related muscle activity³⁰. These measures provide a significant advance over the limited quantification of UVJ displacement (e.g. motion greater than or less than 1.5 cm displacement²⁸) and restriction of measures in previous studies to motions most likely caused by contraction of puborectalis (elevation of UVJ²⁷ and changes in anorectal and levator plate angle²⁹).

In **young** continent men, mean (SD) displacements of the inner margin of SUS to the dorsal aspect of urethra of 1.7(0.4) mm (transurethral)²⁶ and 1.4(0.2) mm (transrectal)²⁵ have been measured during voluntary contractions, whereas similar measures in men with incontinence show motion <1 mm. Although capable of measuring SUS displacement, these approaches assume the direction of SUS contraction is in a similar plane to the US beam (transverse plane), and intraurethral/rectal placement of the stiff probe is likely to mechanically affect the contraction. Transperineal US circumvents these issues through sagittal plane imaging (which enables observation of all points of interest through caudocranial motion) and external transducer placement. The present data of SUS displacement in continent men show greater motion and variability between participants compared to previous reports (range: 0.7 to 5.2 mm). Transabdominal US is often used to investigate LA contraction/bladder base movement^{16, 17}, perhaps due to the importance of LA for female continence^{5, 6} and pelvic organ support^{7, 8}. Although the technique is used in men to measure bladder base movement for pelvic floor muscle assessment²⁷, failure to consider SUS may limit interpretation from

that technique given the well-documented importance of SUS for urinary continence in men. Likewise, predictions of male continence status based on SUS displacement alone^{25, 26} may be flawed.

The strong inverse relationship between displacements of UVJ and urethra at the level of SUS provide evidence of two pelvic floor muscle contraction strategies which involve variable yet coordinated activity of SUS and LA: one that appears to rely predominantly on LA, and one that relies more on SUS. These data are the first to show a possible functional interrelationship between two discrete muscles of the pelvic floor (LA and SUS) and support the hypothesis that urinary continence mechanisms may vary among healthy males.

The value of transperineal US to assess pelvic floor muscle function/dysfunction is well documented in women¹⁴, but has yet to be described in men. Although the transabdominal approach can measure bladder base elevation in men²⁷, the relationship between displacement of UVJ and SUS demonstrated in our data implies measurement of a single component may provide limited insight into urinary continence function in men. Transperineal US measurement of pelvic floor displacement in men has benefits given its ability to investigate UVJ, SUS, ARJ and BC in a single image. The linear relationship between SUS and UVJ movements may have value in predicting the necessary displacement of one muscle/mechanism to meet continence demands when the other is known, but this requires further validation. A limitation of perineal US is potential variation in the force used to hold the probe against the perineum which may affect kinematic measurements. This is less likely with experienced operators. Although participants consumed equal volumes of water prior to the investigation we acknowledge their actual bladder volumes may have been different and could have affected the motion related to contraction of the pelvic floor muscles. Further, as we did not concurrently record EMG activity of the striated muscles with electromyography we cannot be certain that participants completely relaxed the muscles between contractions. Although the return to a similar position for each repetition suggests relaxation was likely, if the muscle did remain active our analysis will have underestimated the amount of motion with contraction. The use of a single experienced operator and a small sample size in this study mean that one must await further studies by others to know whether these results can be generalized to other males.

Conclusions

Transperineal US and the graphical user interface reliably measure displacements of UVJ, SUS, ARJ and BU between relaxed and contracted-states. The inverse linear relationship between displacement at UVJ and SUS provides evidence of different but coordinated strategies of urethral displacement in males. Investigation of a single component may provide limited insight into urinary continence function. Future studies should measure EMG and pressure (urethral, bladder and intra-abdominal) in addition to perineal US imaging to gain a more complete understanding of the male urinary continence mechanism.

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Key of definitions for abbreviations

ARJ	Anorectal junction
BC	Bulbocavernosus
BU	Bulb of the penis
EMG	Electromyography
ICC	Intra-class correlation
LA	Levator ani
PS	Pubic Symphysis
SUI	Stress urinary incontinence
SUS	Striated urethral sphincter
US	Ultrasound
UVJ	Urethra-vesical junction

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Fig. 1. (A) Male pelvic floor and associated structures viewed in the midsagittal plane. Bold arrows indicate hypothesized direction of movement during voluntary muscle contraction, based on anatomical description. (B) Participant position and experimental setup.

Fig. 2. Representative transperineal ultrasound images made in the (A, B) relaxed and (C) contracted states. (B,C) Borders and points of interest superimposed on the US images. (D) Overlaid borders of the two images; dark circles indicate the points of interest in the relaxed state and light circles from the contracted state.

Fig. 3. Group data showing the linear relationship between displacements of each possible pair of points of interest derived from pelvic structures. Absolute displacement values are shown with corresponding R^2 values.

Table 1

Parameters used to define location and movement of pelvic floor structures

Point	Location definition	Movement definition	Structure
P1	Inflection point of ventral aspect of UVJ	Vector displacement	Ventral UVJ
P2	Inflection point of dorsal aspect of UVJ	Vector displacement	Dorsal UVJ
P3	Dorsal-most point of SUS in contracted state	Vector displacement	SUS
P4	Ventral-most point of ARJ	x displacement	ARJ
P5	Dorsal-most point of BU	x displacement	BU

UVJ - urethra-vesical junction, ARJ - ano-rectal junction, BU - bulb of the penis, SUS - striated urethral sphincter

Table 2

Mean displacement (standard deviation) of pelvic floor structures with maximal voluntary contraction

Subject	UVJ (ventral)	UVJ (dorsal)	ARJ	BU	SUS
1	20.6(0.1)	27.4(0.7)	21.5(2.9)	13.9(0.2)	1.5(0.4)
2	12.9(0.7)	11.2(2.4)	12.3(0.9)	7.4(0.7)	1.8(0.3)
3	11.6(0.2)	13.2(0.5)	13.5(1.1)	3.5(0.3)	2.5(0.2)
4	11.2(2.1)	11.8(2.6)	12.3(3.1)	5.7(0.4)	3.6(0.2)
5	5.8(1.7)	5.9(1.6)	8.7(1.7)	3.3(0.6)	5.2(0.2)
6	4.6(0.4)	3.2(1.0)	4.9(1.1)	4.1(0.3)	4.5(0.2)
7	12.0(0.4)	10.7(1.2)	10.1(0.6)	0.2(0.3)	1.4(0.1)
8	10.8(5.8)	10.5(2.2)	11.2(4.7)	4.9(1.1)	3.3(0.1)
9	8.2(0.6)	8.0(0.9)	8.9(1.0)	2.2(0.8)	3.1(0.1)
10	17.1(0.5)	18.7(0.1)	18.1(0.4)	16.5(0.7)	1.0(0.1)

UVJ - urethra-vesical junction, ARJ - ano-rectal junction, BU - bulb of the penis, SUS - striated urethral sphincter