Abstract

Aims: To investigate the effect of instruction on activation of pelvic floor muscles (PFM) in men as quantified by transperineal ultrasound imaging (US) and to validate these measures with invasive EMG recordings.

Methods: Displacement of pelvic floor landmarks on transperineal US, intra-abdominal pressure (IAP) recorded with a nasogastric transducer, and surface EMG of the abdominal muscles and anal sphincter were recorded in 15 healthy men during sub-maximal PFM contractions in response to different verbal instructions: “tighten around the anus”, “elevate the bladder”, “shorten the penis”, and “stop the flow of urine”. In three men, fine-wire EMG recordings were made from puborectalis and bulbocavernosus, and trans-urethral EMG recordings from the striated urethral sphincter (SUS). Displacement data were validated by analysis of relationship with invasive EMG. Displacement, IAP and abdominal/anal EMG were compared between instructions.

Results: Displacement of pelvic landmarks correlated with the EMG of the muscles predicted anatomically to affect their locations. Greatest dorsal displacement of the mid-urethra and SUS activity was achieved with the instruction “shorten the penis”. Instruction to “elevate the bladder” induced the greatest increase in abdominal EMG and IAP. “Tighten around the anus” induced greatest anal sphincter activity.

Conclusions: The pattern of urethral movement measured from transperineal US is influenced by the instructions used to teach activation of the pelvic floor muscles in men. Efficacy of PFM training may depend on the instructions used to train activation. Instructions that optimise activation of muscles with a potential to increase urethral pressure without increasing abdominal EMG/IAP are likely ideal.
1. Introduction

Incontinence is a common problem for men after surgical removal of a cancerous prostate. Pelvic floor muscle exercises are the cornerstone of conservative management of mild/moderate incontinence but the efficacy has been questioned. A surprising feature of clinical trials, which have mixed results (e.g. 3, 4), is the lack of consistency of the instructions used to teach men to activate the pelvic floor muscles, however “tighten around the anus” is common. This instruction targets muscles that are anatomically remote from the urethra, but may encourage activation of puborectalis (PR) which can modify urethral pressure, at least in women. There are two limitations. First, no studies have identified the optimal instructions to activate the muscles of the pelvic floor that have the potential to influence urinary continence in men. Second, there is limited evidence regarding which muscle(s) of the array of striated muscle complexes related to continence should be targeted with intervention. Although the efficacy of a pelvic floor muscle exercise program for treatment of incontinence after prostatectomy is likely to depend on if and how the muscles of urinary continence are activated, optimal methods to achieve activation have received limited attention.

Urinary continence in men is maintained by a combination of active (activation of smooth and striated muscles) and passive (e.g. elasticity of urethra, passive muscle tension, etc.) mechanisms. In addition to smooth muscle (bladder neck and urethra), multiple striated muscles influence urethral pressure. These include the levator ani (LA) group of puborectalis, iliococcygeus and pubococcygeus, the striated urethral sphincter (SUS) and the bulbocavernosus ([BC]). Unlike smooth muscle, striated muscles can be trained with voluntary activation. Training generally targets strength, endurance or timing of activation, but the instructions used in clinical trials are variable (e.g. “tighten around the anus” or “stop the flow of urine” or “elevate the penis”) or are not reported. Recent studies suggest
deficits in activation of the LA (reduced bladder elevation\textsuperscript{15}) and SUS (reduced closure pressure\textsuperscript{16}) in men with incontinence. Furthermore, it is likely that an optimal training program would be one that avoids excessive activation of abdominal muscles and elevation of intra-abdominal pressure (IAP), which would increase bladder pressure and challenge continence. An understanding of how the activation of each muscle is affected by different instructions is required.

This study investigated the effect of verbal instruction on activation of pelvic floor and abdominal muscles. This was achieved by estimation of muscle activation from urethral movement acquired with transperineal ultrasound imaging (US)\textsuperscript{17}. An additional aim was to use invasive electromyography (EMG) recordings of the PR, SUS, and BC in a subset of participants to validate the interpretation of urethral motion. We hypothesized that verbal instructions which encourage the recruitment of different muscle groups would achieve different patterns of movement of anatomical landmarks.

2. Materials and Methods

2.1 Participants

Fifteen men aged 28-44 years with no history of urological or neurological disease volunteered in response to advertisements placed around the University, electronic newsletter or within a local paper. Men were excluded if they had a history of pelvic floor dysfunction, any urological dysfunction, any major respiratory or neurological condition, or were more than 50 years of age. Six participants were physiotherapists and had knowledge of the pelvic floor. The remaining nine participants had no academic or clinical training related to pelvic floor muscles. No participant had undergone previous training for the pelvic floor muscles. An \textit{a priori} power calculation using the mean (2.83 mm) and SD (1.34 mm) of MU displacement reported in an earlier study of healthy males\textsuperscript{17} indicated that this sample size
was sufficient to detect a 25% difference in MU displacement between instructions with an
alpha of 5% and beta of 50%. Three participants volunteered for an additional data collection
session that included fine-wire EMG recordings of PR and BC, and trans-urethral surface
EMG recordings of SUS\textsuperscript{18}. This component was added to validate the measures made with
ultrasound imaging and the sample size was limited due to the invasive nature of the
methods. Participants provided informed written consent and the Institutional Medical
Research Ethics Committee approved the study.

2.2 Measurement

All data were collected by the same assessor in a research laboratory at the University
of Queensland. Urethral displacement was recorded using real-time US in video format with
a transducer placed mid-sagittal on the perineum (M7C; Logiq9, GE Healthcare, Australia) as
described in detail elsewhere\textsuperscript{17}. IAP was recorded with a naso-gastric pressure transducer
(CTG-2, Gaeltec Ltd, UK). EMG recordings were made from the right obliquus externus
(OE), internus abdominis (OI), and rectus abdominis (RA) muscles using surface electrodes
(Noraxon Inc, USA; 2cm electrode spacing) with a reference electrode (9160F, 3M Ltd,
Australia) over the iliac crest. Anal sphincter (AS) EMG was recorded from nine participants
with a rectal electrode (Neen, UK). Abdominal and AS EMG was filtered (10-1000Hz),
amplified 2000x (Neurolog, Digitimer Ltd, UK), and sampled at 2kHz using a Power1401
and Spike2 software (Cambridge Electronic Design, UK).

In three participants who volunteered for the additional experiment, fine-wire
electrodes (2 Teflon-insulated 75µm stainless steel wires [A-M Systems Inc, USA] inserted
into a 23Gx70mm hypodermic needle; 1mm of insulation removed; tips bent at 1 and 3mm to
form hooks) were inserted into PR and BC with guidance of ultrasound and palpation by a
colorectal surgeon. Recordings of SUS EMG were made with a transurethral catheter
electrode as described elsewhere\textsuperscript{18,19}. Fine-wire/catheter EMG was filtered (10-2000Hz),
amplified 2000x (Neurolog, Digitimer Ltd, UK), and sampled at 10kHz using a Power1401
and Spike2 software (Cambridge Electronic Design, UK). EMG and pressure data were
synchronised with ultrasound via a footswitch.

2.3 Experimental protocol

Participants sat upright on a plinth (backrest reclined at ~20° from vertical) with
knees extended. Prior to commencement of data collection, a brief period of familiarisation
was provided to educate participants of the anatomy of the pelvic floor muscles and how
contraction of these muscles relates to movements observed in the US image. No specific
instructions were provided regarding how to contract the muscles and participants did not use
the US for feedback of activation. Three repetitions of voluntary pelvic floor contractions
were performed with guidance of specific verbal instructions to a standardised effort of 3/10
on a modified Borg scale (“no activity” - zero, “maximal voluntary contraction” - ten).
Contractions were sustained for 3s and separated by ~10s rest. Four instructions were tested:
“tighten around the anus” – predicted to target the anal sphincter, “elevate the bladder” –
predicted to target PR; “shorten the penis” – predicted to target SUS; and “stop the flow of
urine” – predicted to target SUS and PR. Instructions were performed in random order and
separated by ~2min rest. No instruction was provided regarding the abdominal muscles.

2.4 Data analysis

Individual frame images were exported from the US video data and analysed by a
single assessor to calculate pelvic floor landmark displacements associated with activation of
SUS (motion of the midurethra [MU]), PR (motion of the urethra-vesical junction [dorsal –
dUVJ; ventral – vUVJ] and anorectal junction [ARJ]) and BC (compression of the bulb of the
penis [BP]) muscles, as described previously\textsuperscript{17,20} (Figure 1). The experimenter was blinded to
the identity of the participant and the task during analysis. Displacement of each landmark
was averaged over the three repetitions for each instruction. Averaged displacement data (for
each anatomical location) were normalised to the maximum value for each participant across all instructions to optimise comparison between tasks. The number of participants who demonstrated maximum displacement (at each location) was determined for each instruction, and expressed as a proportion of the number of participants (n=15). Root-mean-square (RMS) EMG amplitude and average IAP amplitude were calculated for 1s (500ms before and after the time of maximum landmark displacement (Figure 1)) in each task and expressed as a change from baseline (1s prior to instruction). EMG and IAP data were averaged over the three repetitions and normalised to the maximum value across all instructions.

2.5 Statistical analysis

To investigate the relationship between urethral displacement (US imaging) and pelvic floor muscle activity (EMG), we assessed the linear regression and Pearson’s coefficient of the correlations between pelvic floor EMG (SUS, BC and PR; proportion of peak EMG across the tasks) and displacement measured from US data (dorsal MU displacement, BP compression and UVJ elevation/ventral ARJ displacement; proportion of the peak motion across the tasks).

Displacement of landmarks measured from US, change in AS (n=9) and abdominal muscle EMG, and IAP amplitude were compared between instructions using repeated measures analysis of variance (ANOVA) (repeated measures; Instruction [“elevate the bladder”, “shorten the penis”, “stop the flow of urine” vs. “tighten around the anus”]). For trials in which AS EMG was recorded the “stop the flow of urine” instruction was not used and thus omitted from the ANOVA model. Post-hoc testing was performed with Duncan’s multiple range test. The fine-wire/catheter EMG recordings (n=3) were also interpreted but these data are presented individually and the pattern is considered qualitatively without statistical analysis because of the small number. Data for the main trial are presented as mean±95% confidence intervals throughout the text and figures.
3. Results

In the three participants with fine-wire/catheter EMG recordings, displacement at the five pelvic landmarks was most strongly correlated (highest mean $R^2$ coefficients) with the change in EMG activation of the appropriate muscle (SUS-MU; PR-vUVJ/dUVJ/ARJ; BC-BP)(Table 1). Figure 2 shows the relationships between US and EMG for each participant and each muscle across instructions.

Figure 3 shows the group data for US landmarks, IAP and surface EMG with each instruction. Displacement at the MU differed between instructions (Main effect: $P=0.018$). Peak MU displacement was greater during “shorten the penis” than “elevate the bladder” (Post hoc: $P=0.017$) and “tighten around the anus” (Post hoc: $P=0.007$) but not “stop the flow of urine” (Post hoc: $P=0.187$). Instruction had no differential effect on displacements at vUVJ (Main effect: $P=0.879$), dUVJ ($P=0.910$), BP ($P=0.975$) or ARJ ($P=0.815$) that was systematic for the group. Table 2 shows the proportion of participants who demonstrated their largest displacement of the US landmarks for each instruction. When these data were considered for individual participants the instruction that achieved the greatest MU displacement for most participants was “shorten the penis”, then “stop the flow of urine”. More variation was observed for movements related to activation of PR. The instruction that achieved maximum displacement for individual participants was distributed between “elevate the bladder”, “shorten the penis” and “stop the flow of urine”. Most participants achieved maximum displacement of ARJ with “tighten around the anus” and “stop the flow of urine”, and greatest movement at BP was most commonly observed for “tighten around the anus”, then “shorten the penis”. OI RMS EMG and IAP amplitudes were higher with “elevate the bladder” than “tighten around the anus” (Main effect: OI EMG – $P=0.044$; IAP - $P=0.004$; Post hoc: OI EMG - $P=0.014$; IAP – $P=0.007$), “shorten the penis” (Post hoc: OI EMG – $P=0.038$; IAP – $P=0.003$) and “stop the flow of urine” (Post hoc: OI EMG – $P=0.045$; IAP -
P=0.003) and did not differ between the latter three conditions (Post hoc all: P>0.05). No differences were observed between instructions for RA and OE RMS EMG amplitudes (Main effect all: P>0.05). AS EMG amplitude was higher during instruction to “tighten around the anus” than “elevate the bladder” (Main effect: P=0.041; Post hoc: P=0.034) and “shorten the penis” (Post hoc: P=0.029).

Fine-wire/catheter EMG data from the additional experiment are shown for the three participants in Figure 4. EMG amplitudes generally follow the observations reported above for US recordings in the larger experiment. Key observations are; SUS EMG was greatest with “shorten the penis” for 2/3 participants, greatest activation of PR with either the “shorten the penis” or “elevate the bladder” instructions; and no systematic pattern for BC. The main difference between the fine-wire/catheter EMG and US data was that SUS EMG was consistently lowest during “stop the flow” but this was commonly associated with peak US displacement.

4. Discussion

These data from healthy continent men show that verbal instructions used to encourage voluntary contraction of different pelvic floor muscles influences the pattern of urethral movement observed with US, and that these movements can determine the degree of activation of specific muscles. These observations have two key implications. First, if the aim of a pelvic floor exercise program is to optimise activation of SUS with limited increase in IAP, this is best achieved with the instruction to “shorten the penis” or “stop the flow or urine”. Second, the relationship between movement on US and EMG provides evidence for the validity of interpretation of activity of specific pelvic floor muscles from motion of pelvic landmarks. This supports the potential clinical utility of this non-invasive method.

4.1 Optimal instructions to train muscles of continence in men
Clinical trials of pelvic floor exercise for treatment of incontinence after prostatectomy use a variety of instructions to encourage patients to contract pelvic floor muscles, including “tighten around the anus”\(^4, 21\), “elevate the scrotum”\(^22\) and “stop flow of urine”\(^10, 23\). The present data suggest that outcome of instructions differs and some may be better than others for several reasons. First, instructions that emphasise dorsal movement/retraction of the penis (“shorten the penis”) or that target contraction related to urethral closure (“stop the flow of urine”) encourage activation of the SUS. Second, anal-focused instruction (“tighten around the anus”) targets activation of the anal sphincter muscle, and although there is co-concomitant activation of the muscles that can affect the urethra (PR and SUS), activation of those muscles was less than for other instructions. Third, the instruction that emphasised ‘elevation’ caused a counter-productive increase in abdominal muscle activity and IAP that was greater than the other instructions. This would increase demand on the continence mechanism.

The present results provide a basis to re-examine the recent systematic review of pelvic floor exercise for treatment of post-prostatectomy incontinence that reported inconsistency of outcomes between trials and an overall interpretation of lack of efficacy\(^2\). It is plausible that the variability in results between seemingly similar clinical trials might be influenced by the strategies used to train the muscular mechanisms for urinary continence. An extrapolation of the present findings is that trials that used the instruction “interrupt the flow of urine” have a greater probability of success (e.g. \(^10, 23\)) than trials that focus on anal-based instructions, feedback or stimulation (e.g. \(^4, 24\)). Although there are examples where this distinction is supported, that is not always the case (i.e. poor outcome with “urethral” instructions \(^25\) and good outcome with “anal-focused” instructions\(^26\)). However, a factor that prevents determination of the potential influence of specific instructions on the outcomes of pelvic floor muscle training is that treatment efficacy is also likely to be influenced by the
targeted feature of muscle function (e.g. strength, endurance, timing of activation) and potential differences in patient phenotypes. Further studies are required to determine whether better outcomes can be achieved with instructions tailored to the male continence mechanism.

4.2 Interpretation of muscle activity from displacement of landmarks in transperineal ultrasound images

To overcome the issue of invasiveness of direct EMG recordings from the pelvic floor muscles, we estimated activation from movement of landmarks on transperineal US. Interpretation of movements was based on the motion expected from muscle shortening. In this study, motion that was consistent with ‘shortening’ was observed with each instruction and the relationships between urethral displacement and EMG were strongest for the anatomically appropriate comparisons. That is, movement at MU by SUS activation, movement at ARJ/UVJ by PR activation.

Although we observed a moderate linear relationship between EMG and displacement with low effort contractions, this relation will not be straightforward and will be dependent on contraction type. Studies of other muscles show a non-linear relationship during isometric contractions, with greater shortening during low-level contractions explained by tendon stretch. During eccentric contraction, the muscle would lengthen despite activation, and interpretation of activity from US would be impossible. In the pelvic floor, interpretation will be complicated and the potential for shortening will depend on many factors including IAP. Despite these issues, under the appropriate conditions the technique provides a valid measurement of muscle activation that would otherwise require invasive techniques.

4.3 Limitations
Although participants were instructed to perform efforts of similar intensity across instructions, we cannot be certain this was achieved. This would not be possible to confirm from EMG of any individual muscle as all tasks involved a different pattern of muscle activation. The additional study involved few participants because of the highly invasive nature of the EMG recording techniques. Although normalization of EMG amplitude to maximum voluntary activation is recommended, the generally poor volitional control of pelvic floor muscles\textsuperscript{29} precludes the reliable performance of maximum contraction by verbal instruction, hence the analysis strategy used. All measurements were performed during static contraction in sitting, whereas leakage episodes often occur during dynamic upright activities such as coughing. Whether physical activity and posture affect the outcome of verbal instruction requires exploration. Despite the small sample size, consistent relationships between EMG amplitude and movement were observed.

4.4 Implications for clinical populations

These data have potential clinical utility for management of men with incontinence but interpretation is not straight-forward. It remains unclear how anatomical changes from prostatectomy affect urethral dynamics and stiffness and this may affect the relationship between urethral movement and EMG. Further, concomitant activation of abdominal muscles during pelvic floor muscle contraction may be more prevalent in men with incontinence, as shown in women\textsuperscript{30}. This would increase IAP and challenge continence. It is necessary to determine which aspect of muscle activation is most important to train in men with incontinence and whether this differs between patient phenotypes.

The optimal instructions to activate pelvic floor muscles are likely those that induce the greatest amplitude of pelvic floor muscle shortening with minimal increase in abdominal muscle activity and IAP. From the current data, the best instruction to shorten SUS is “shorten the penis” or “stop the flow of urine”. If the anal sphincter is targeted, “tighten
around the anus” would provide the most optimal activation. As instructions to “elevate the bladder” induced the largest increase in OI EMG and IAP, this may not be ideal unless the intervention aims to increase continence demand. Bladder base movement occurred with each instruction and didn’t differ between them, indicating similar activation of PR. The optimal instruction for PR may be best determined by the instruction that limits the increase in IAP. Overall, these data show that verbal instructions can elicit different amplitudes of pelvic floor displacement at specific locations, but one instruction does not achieve the same pattern of activation for all men. The search for the optimal strategy would be assisted by biofeedback from transperineal US imaging.


Figure Legends

Fig. 1(A) Representative EMG recording of striated urethral sphincter (SUS), puborectalis (PR) and bulbocavernosus (BC) during voluntary contraction with associated transperineal ultrasound images during rest (B) and contraction (C). Overlaid traces of the different pelvic floor structures from (B) and (C) are shown in (D). Arrows and associated dashed lines on the EMG traces indicate the time point of image capture. In the contracted image (C), the initial position of each point of interest is indicated by a shaded circle. EMG calibration: BC – 200 µV, PR – 50µV, SUS – 20µV.

Fig. 2 Relationship between EMG activation and displacement at the appropriate anatomical location for three participants. Different shapes are used for each participant. Each data point for a participant refers to the response for a different instruction. Lines represent the best linear fit of the data with the coefficient of determination ($R^2$) shown for each. Relationship between dorsal urethra-vesical junction and puborectalis omitted due to similarity with that shown for the ventral urethra-vesical junction. SUS – striated urethral sphincter, PR – puborectalis, BC – bulbocavernosus, MU – mid-urethra, UVJ – ventral urethra-vesical junction, ARJ – ano-rectal junction, BP – bulb of penis, and prop. peak – proportion of the peak value.

Fig. 3 Mean (SD) amplitudes of movement, EMG and IAP displayed as a proportion of the peak value across the 4 instructions. RA – rectus abdominis, OE – obliquus externus, OI – internus abdominis, IAP – intra-abdominal pressure, MU – mid-urethra, vUVJ – ventral urethra-vesical junction, dUVJ – dorsal urethra-vesical junction, ARJ – ano-rectal junction and BP – bulb of penis. Differences between instructions (P<0.05) are indicated with an asterisk.

Fig. 4 EMG amplitudes of the striated urethral sphincter (SUS), puborectalis (PR) and bulbocavernosus (BC) muscles during three different verbal instructions: “shorten the penis”, “elevate the bladder” and “stop the flow of urine”. Data are presented as a proportion of the peak EMG/displacement across tasks.