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GENERAL GYNECOLOGY

Urethral length and bladder neck behavior: can dynamic magnetic resonance imaging give the same results as introital ultrasound?

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Abstract

Purpose To compare dynamic magnetic resonance imaging (dMRI) and introital ultrasound results with regard to urethral length measurements and the evaluation of bladder neck changes.

Methods Retrospective analyses of urethral length measurements and detection of bladder neck changes (rotated/vertical bladder neck descent, urethral funneling) were conducted in women—scheduled for surgical treatment with alloplastic material—who had undergone introital ultrasound and dMRI presurgery and 3 months postsurgery. Measurement differences between both imaging modalities were evaluated by assessing the confidence interval for the difference in means between the datasets using bootstrap analysis.

Results Based on data from 40 patients (320 image series), the urethra could be clearly measured on every pre- and postsurgical dMRI dataset but not on preoperative ultrasound images in nine women during Valsalva maneuver due to a large cystocele. The estimation of the mean difference distribution based on 500,000 bootstrap resamples indicated that the urethral length was measured shorter by dMRI pre- and postsurgery at rest and postsurgery during Valsalva maneuver (median 1.6–3.1 mm) but longer by dMRI (median 0.2 mm) during Valsalva maneuver presurgery. Rotated/vertical bladder neck descent and urethral funneling diagnoses showed concordance of 67–74% in the direct comparison of patients; the estimation of the concordance indicated poorer outcomes with 50–72%.

Conclusions Metric information on urethral length from dMRI is comparable to that from introital ultrasound. dMRI is more advantageous in cases with an extended organ prolapse. At present, dMRI does not give the same diagnosis on bladder neck changes as introital ultrasound does.

Keywords Introital ultrasound · Dynamic magnetic resonance imaging · Urethral length measurement · Bladder neck descent · Urethral funneling

Introduction

Pelvic floor dysfunction (PFD) is a widespread health issue with a high socioeconomic impact and is a steadily growing concern in women of increasing age [1, 2]. Due to an increasing demand for remedying therapeutic options, surgical procedures utilizing alloplastic material to treat pelvic organ prolapse (POP) or stress urinary incontinence have been introduced in the past decade [3–6].

To provide an individually suitable therapeutic management system for each patient, a presurgical overview of the pelvic floor and the entire pelvis to visualize all disorders leading to PFD has played an increasing role. In addition to a urogynecological examination, including an introital ultrasound, dynamic magnetic resonance imaging (dMRI) serves as an objective diagnostic imaging tool to supplement the clinical data in selecting surgical candidates and in planning repairs [7–9].

Focusing on the anterior compartment, the individual length of the urethra, together with obesity and vaginal deliveries, is an important factor for the therapeutic success of treating stress urinary incontinence using urethral sling procedures [10]. The optimal sling location is reported to be in the high pressure zone between 53 and 72% of the total urethral length, varying between 19 and 45 mm [10,

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11]. Incorrect sling placement (e.g., particularly close to the bladder neck) is reported to be associated with persistent or recurrent incontinence [10, 12, 13]. Gaining a presurgical impression of the anterior compartment and the urethral behavior under the Valsalva maneuver, in addition to measuring the urethral length, therefore, seems crucial, and Pomian et al. [10] proposed the use of ultrasound. They also stated that there are no data comparing the different methods of urethral length measurement, e.g., ultrasound and MRI [10].

The aim of this study was to directly compare dMRI and introital ultrasound with each other in women at rest and during the Valsalva maneuver before and after pelvic floor surgery. The focus was on the urethral length measurement and the detection of bladder neck changes, particularly rotated or vertical bladder neck descent and urethral funneling.

Materials and methods

Between January 2008 and July 2012 women with symptomatic POP and/or stress urinary incontinence who were scheduled for surgical treatment with alloplastic material were included in a prospective longitudinal clinical single-center study database for the evaluation of PFD pre- and postsurgery with dMRI after they had given their written informed consent. The study was approved by the institutional review board (trial number: S-473/2007) with an approved amendment dated October 30th, 2012.

For the intermodal comparison of urethral length measurement and bladder neck changes, we retrospectively evaluated all women from the abovementioned database who had undergone an introital ultrasound in addition to clinical urogynecological examination and dMRI pre- and 3-months postsurgery. The time interval between ultrasound, which was performed directly after clinical examination, and dMRI was a maximum of 1 week in the preoperative setting and a maximum of several hours in the follow-up care. On the available image datasets, we focused on measurement of the total urethral length and on evaluating the urethral and bladder neck changes that were associated with the given pelvic floor disorder before and after surgery; specifically, we focused on rotated and vertical bladder neck descent and urethral funneling [14–16].

Ultrasound performance

An introital two-dimensional (2D) ultrasound was performed during the clinical urogynecological examination at rest and during the Valsalva maneuver with a moderately filled bladder, which is known to be more efficient for diagnosing bladder neck disorders, especially funneling, and this was achieved by asking the patient not to void 1 h before the examination [17]. The examination was performed by an experienced gynecologist with greater than 5 years of specialization in urogynecology using a vaginal probe (Voluson e, General Electric, USA, E8C-RS, 4.0–10.0 MHz, fixed angle), which was placed in the vaginal introitus at the level of the external urethral orifice [18]. The ultrasound image evaluation within this trial was performed at a later time by the same urogynecologist by the measurement of the total length of the urethra along its long axis from the internal urethral orifice into the bladder to the most peripheral part inside the hypoechogenic part of the urethra [19, 20], and documentation of the presence of a rotated or vertical bladder neck descent or urethral funneling on the pre- and postsurgical images (Figs. 1, 2).

MRI performance

The dMRI procedure was also performed with a moderately filled bladder by asking the patient not to void 1 h before the dMRI examination. Before the examination, the patients were instructed on how to correctly perform the Valsalva maneuver. The dMRI was performed with a 1.5 Tesla scanner (Magnetom Symphony, Siemens, Erlangen, Germany) with patients lying in supine position, knees elevated on a high pillow, following a predefined sequence protocol including T2- and T1-weighted sequences in sagittal or axial plane [8]. Vaginal opacification was not mandatory. For this study, T2-weighted high-resolution images in the sagittal

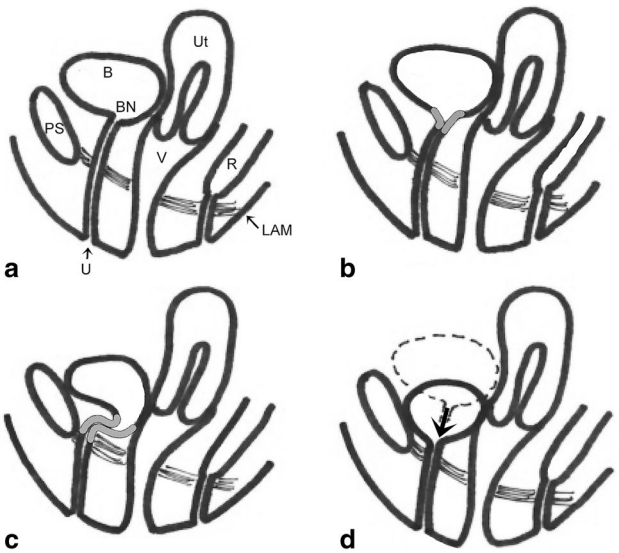

Fig. 1 Schematic drawing of the evaluated pathologies compared to a normal appearance: **a** normal anatomy; *B* bladder, *BN* bladder neck, *V* vagina, *Ut* uterus, *PS* pubic symphysis, *U* urethra, *R* rectum, *LAM* levator ani muscle complex; **b** urethral funneling; **c** rotated bladder neck descent; **d** vertical bladder neck descent

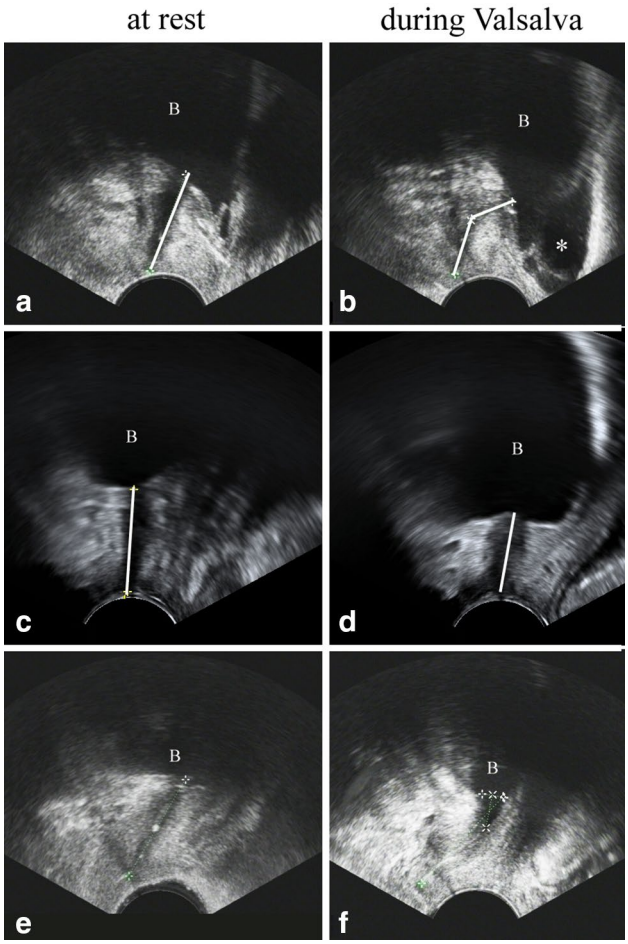

Fig. 2 Images gained from introital ultrasound in three different women. Image quality varies due to default settings the US investigator used for documentation (**a**, **b**) presentation of RBD and a cystocele (*). (**c**, **d**) Presentation of VBD. (**e**, **f**) Presentation of urethral funneling. *B* bladder

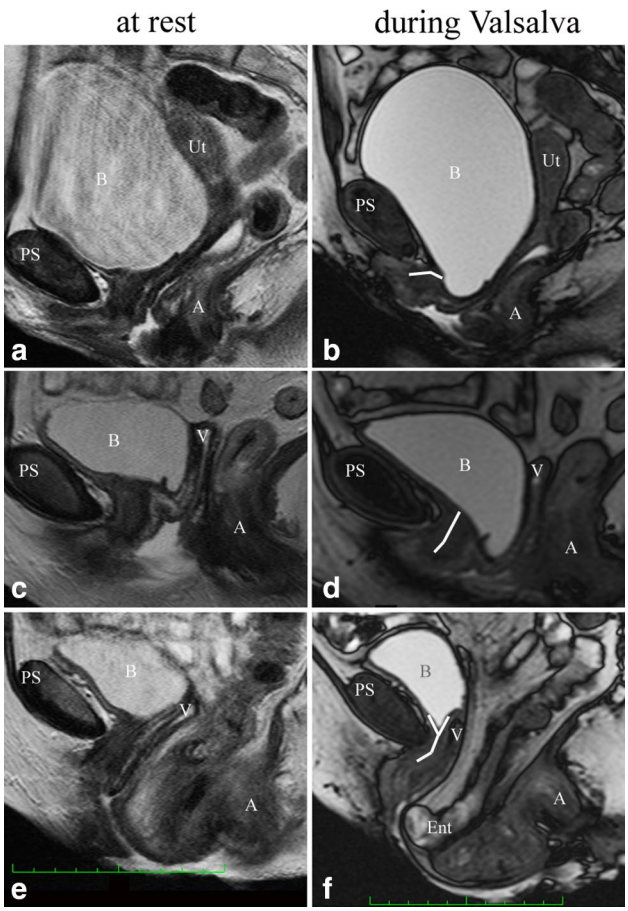

Fig. 3 Images gained from dMRI in three different women. **a**, **b** Presentation of RBD and a cystocele. **c**, **d** Presentation of VBD. **e**, **f** Presentation of urethral funneling. In this patient, urethral measurement and detection of bladder neck behavior were impossible using introital ultrasound due to the large enterocele. *PS* pubic symphysis, *B* bladder, *Ut* uterus, *V* vaginal vault, *Ent* enterocele, *A* anus

plane at rest (TR 3460 ms, TE 85 ms, matrix 512, slice thickness 5 mm, FOV 380 mm) and T2-weighted images in the sagittal plane at maximum strain (TR 4.3 ms, TE 2.15 ms, matrix 256, slice thickness 5 mm, FOV 330) were evaluated at a later time by an experienced radiologist with 6 years of specialization in pelvic floor imaging who was blinded to the clinical and ultrasound results. In accordance with the ultrasound evaluation, dMRI was used to measure the total urethral length along its long axis with the same endpoints defined by ultrasound and document the presence of bladder neck descent or urethral funneling (Figs. 1, 3).

Statistical analysis

Differences in the measurements between the imaging modalities (introital 2D ultrasound and dMRI) at the different examination time points (presurgery and postsurgery) and different functional status of the pelvic floor (at rest and during the Valsalva maneuver) were evaluated by assessing the confidence interval for the difference in means between the respective sets of data using bootstrap analysis. In particular, data were sampled at random (with replacement) 500,000 times, and the respective differences were recorded. We deemed the differences between the two sets to be robust and, therefore, statistically relevant if the two-sided 95% confidence interval did not include zero. This approach has the advantage over classical statistical testing in that it allows an inference of the underlying population rather than restricting the inference to within-sample effects. Congruency in the detection of bladder neck changes was treated as a classification problem and was likewise evaluated by bootstrap resampling. In particular, we treated the ultrasound measurement as the standard and assessed the accuracy of MRI relative to ultrasound; i.e., we calculated the percentage of cases in which the two modalities yielded the same result.

Results

Study population

Forty women had undergone urogynecological surgery (Supplement Fig. 1) both imaging modalities at the pre- and 3-months postsurgical examinations at rest and during the Valsalva maneuver were available and were included in the study. In total, 320 image series (160 per modality) were evaluated.

The median age of the study population was 66 years (range 45–83 years), and the median body mass index was 25.5 kg/m^2 (range 19.2–34.6 kg/m^2).

Urethral length measurement

The urethra could be clearly measured on every pre- and postsurgical dMRI dataset. The measurement could not be performed on the preoperative ultrasound images of nine women during the Valsalva maneuver, mainly due to a large cystocele. The measurement of the urethral length was not performable in the postsurgical ultrasound images of one woman. The absolute values from the study cohort are given in Table 1.

The estimation of the mean difference distribution for the results of the dMRI evaluation compared to those of the introital ultrasound based on 500,000 bootstrap resamples indicated that the urethral length was shorter as measured by dMRI than as measured by ultrasound presurgery at rest, with a median of − 0.24 cm (95% CI − 0.43 to 0.06 cm), postsurgery at rest, with a median of − 0.31 cm (95% CI − 0.50 to 0.14 cm), and postsurgery during the Valsalva maneuver, with a median of − 0.16 cm (95% CI − 0.31 to 0.04 cm) (Fig. 4a, b, d). However, at the presurgical examination during the Valsalva maneuver, the estimation of the mean difference distribution indicated that the urethral length as measured by MRI was longer, with a median of 0.02 cm (95% CI − 0.17 to 0.21 cm) (Fig. 4c).

Table 1 Absolute values of urethral length measurement in our study cohort

	dMRI				
	Number	Mean	SD	95% CI	Range
Urethral length measurement (cm)					
Presurgical (rest)	$n=40$	2.15	0.38	2.03;2.27	1.29–2.98
Presurgical (Valsalva)	$n=40$	2.18	0.39	2.06;2.31	1.32–3.07
Postsurgical (rest)	$n=40$	2.04	0.38	1.92;2.16	1.21–2.75
Postsurgical (Valsalva)	$n=40$	1.99	0.42	1.86; 2.12	1.04–2.74
Introital ultrasound					
Presurgical (rest)	$n=39$	2.39	0.44	2.25;2.53	1.40–3.30
Presurgical (Valsalva)	$n=30$	2.12	0.49	1.93;2.28	1.15–2.80
Postsurgical (rest)	$n=40$	2.35	0.48	2.20;2.50	1.20–3.70
Postsurgical (Valsalva)	$n=39$	2.15	0.41	2.03; 2.29	1.37–3.17

dMRI dynamic magnetic resonance imaging, *SD* standard deviation, *CI* confidence interval

Detection of bladder neck changes

Rotated bladder neck descent and urethral funneling were diagnosed most in the preoperative settings in both modalities, while only a small number of patients were diagnosed with vertical bladder neck descent (Table 2). The direct comparison per patient in our cohort showed concordance ranging from 67 to 74%, while the estimation of the concordance indicated slightly poorer outcomes with 50–72% (Fig. 5).

Urethral funneling was diagnosed on dMRI in more than three-quarters of the patients postsurgery and on ultrasound in less than one-third of the patients (Table 2). The detection rate of bladder neck descent decreased from the pre- to postsurgical setting, except for vertical bladder neck descent (Table 2). The direct within-patient comparison in our cohort showed concordance ranging from 53 to 70%, while the estimation of the concordance indicated poorer outcomes with 40–68% (Fig. 5).

Discussion

Studies comparing results that were obtained by introital 2D ultrasound and pelvic dMRI in the same cohort, evaluating whether dMRI can give comparable quantitative information, are seldom found in the literature to date [10]. The aim of this study was, therefore, to directly compare the two imaging modalities of dMRI and introital ultrasound with each other with regard to one measurement (urethral length) and three qualitative parameters (urethral funneling yes/no and vertical and rotated bladder neck descent yes/no), which were proposed to be crucial for gaining a presurgical impression of the anterior compartment [10].

By comparing the performance of the measurement of the urethral length and the diagnosis of bladder neck changes on introital ultrasound and dMRI in forty women before and after pelvic floor surgery, the following results were observed: (i) measurement of the urethral length might be hampered in the introital ultrasound images during the Valsalva maneuver in women with extended pelvic floor disorders, while it is feasible on dMRI in a manner independent of the individual pelvic floor condition; (ii) dMRI measurement of the urethral length is comparable to that of introital ultrasound; and (iii) the diagnostic agreement between dMRI

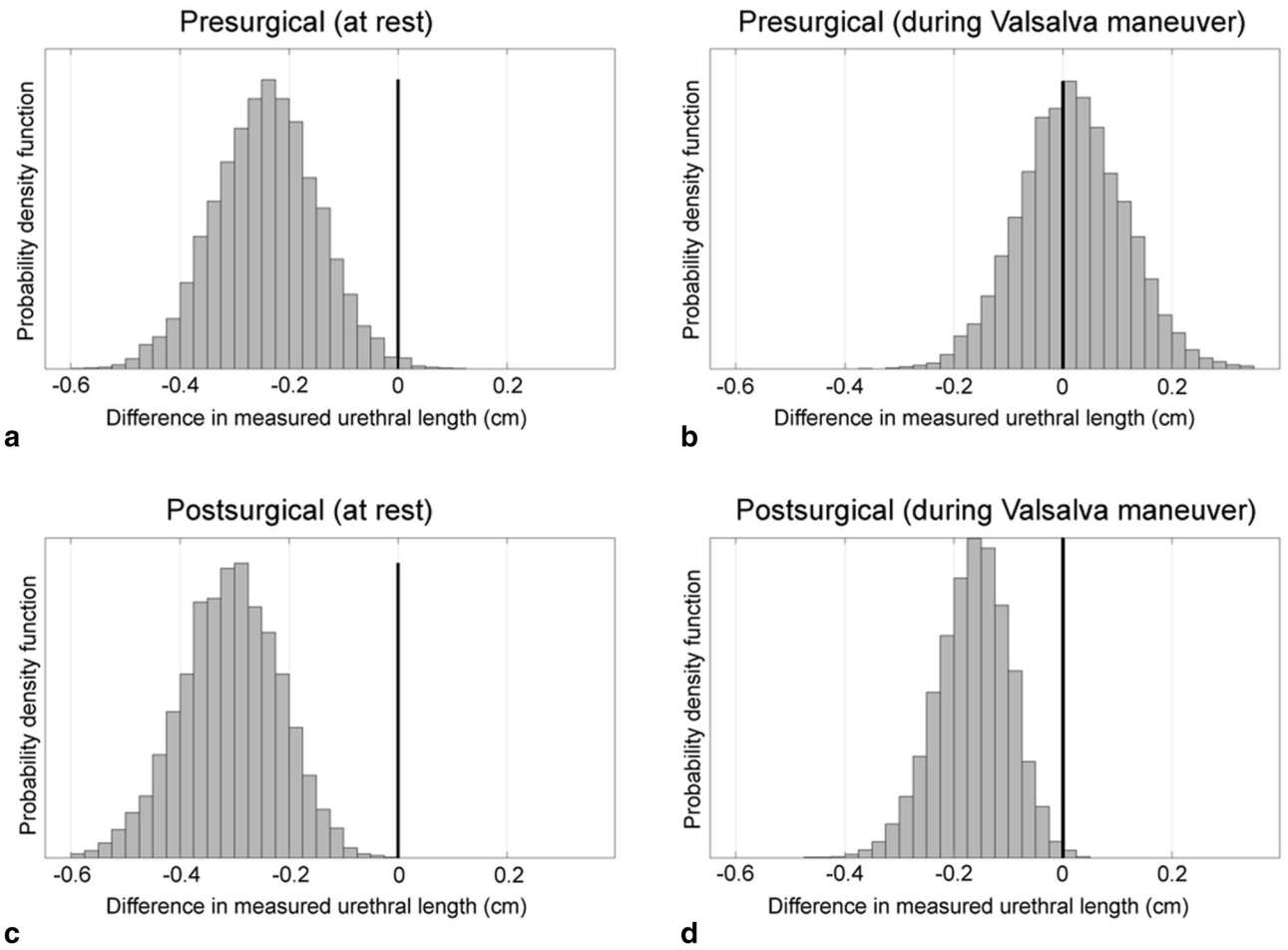

Fig. 4 Estimation of the mean difference distribution for the measurement values of the urethral length (value measured on MRI minus value measured on ultrasound) based on 500,000 bootstrap resamples for both time points (presurgery and postsurgery) at rest and during the Valsalva maneuver. Negative values indicate that the urethral length was measured as shorter on MRI than on US. *MRI* magnetic resonance imaging, *US* ultrasound

Table 2 dMRI and introital ultrasound results and the within-patient concordance in the study cohort

	dMRI	IU	Concordance (%)
Presurgical			$n=39$
RBD	22	20	29 (74.0) [16 yes, 13 no]
VBD	6	7	28 (72.0) [1 yes, 27 no]
UF	24	20	26 (67.0) [15 yes, 11 no]
Postsurgical			$n=40$
RBD	13	8	27 (67.5) [4 yes, 23 no]
VBD	10	7	28 (70.0) [3 yes, 25 no]
UF	31	12	21 (52.5) [12 yes, 9 no]

dMRI dynamic magnetic resonance imaging, *IU* introital ultrasound, *RBD* rotated bladder neck descent, *VBD* vertical bladder neck descent, *UF* urethral funneling, *yes* both modalities detected the pathology, *no* the pathology was not detected on either modality

and introital ultrasound for bladder neck changes is only mild to moderate.

Due to several advantages, e.g., its widespread availability, cost-effectiveness and ability to produce real-time viewing, introital ultrasound remains the mainstay for most clinical situations regarding pelvic floor disorders [21]. Nevertheless, introital ultrasound is dependent on the examiner, and the image datasets might be difficult to evaluate, especially at a later time point, e.g., during an interdisciplinary in-house conference for treatment planning when severe or multicompartment prolapse conditions are present. The dMRI method, however, has its pivotal strength in objectively visualizing all pelvic compartments free of overlap, and it gives a reproducible impression of the pelvic organ behavior during the Valsalva maneuver using a cine mode [3, 8, 9, 22]. Comparing the values of the urethral length described by Pomian et al. using ultrasound (mean 3.01 cm, range 1.9–4.5 cm) and Umek et al. using axial MR images

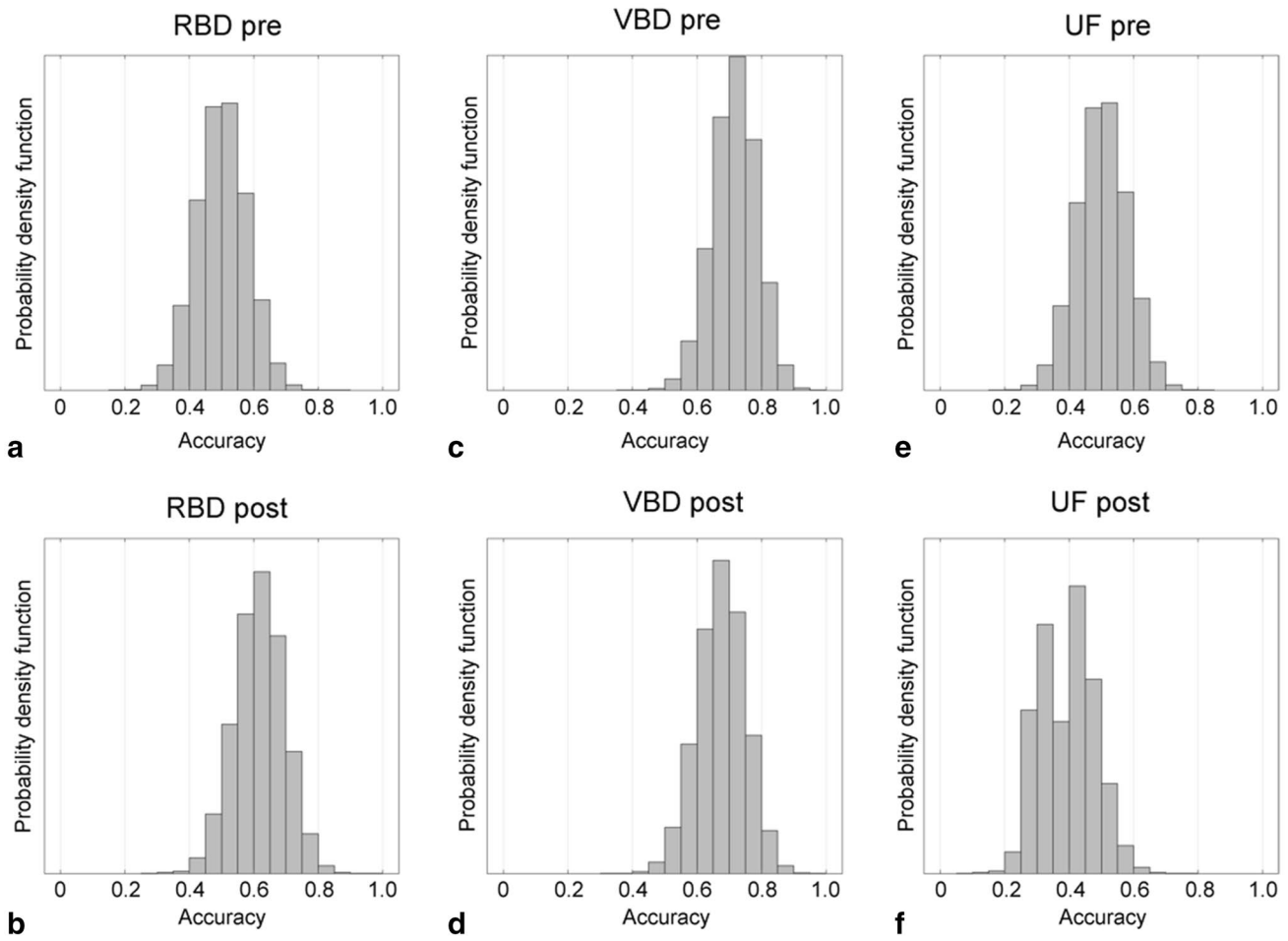

Fig. 5 Estimation of the mean difference distribution for the overall accuracy of both imaging modalities regarding the presence or absence of bladder neck changes based on 500,000 bootstrap resamples. *RBD* rotated bladder neck descent, *VBD* vertical bladder neck descent, *UF* urethral funneling, *pre* presurgical, *post* postsurgical

(mean 2.40 cm, range 2.0–3.5 cm), the urethral length was measured shorter for each modality in our study cohort [10, 23]. Comparing the values of the functional urethral length described by Nager et al. [24] during urodynamics (3.20 cm, range 0.1–5.0 cm), the mean values of our cohort were lower, however, the absolute values were in the given range. This supports the statement of Pomian et al. [10] that there is a fairly wide dispersion of urethral lengths, regardless from the used method. Based on our results, however, the expected intermodality difference of 0.2–2.4 mm between introital ultrasound and dMRI in the same cohort, when estimating a large cohort using bootstrap analysis, can be ignored. A larger study cohort is needed to prove these results.

The detection of bladder neck changes, however, showed more heterogeneous results. The diagnostic agreement between dMRI and introital ultrasound was best for vertical bladder neck descent, followed by the diagnosis of rotated bladder neck descent and last of all for urethral funneling. A reason for these discordant results might be a variance in the bladder filling at the different examination time points. The bladder volume is known to have an influence on the mobility of the urethrovesical junction, and funneling is more easily observed with a full bladder [17]. Another explanatory aspect might be the fact that the ultrasound investigator was not blinded to the diagnosis defined during clinical examination as was the radiologist, which might have biased the assessment of bladder neck changes, especially funneling. Additionally, variation in patient positioning (supine position during dMRI compared to the more upright sitting position during introital ultrasound) or an unintentional pressure with the ultrasound probe might have an impact on the visualization of bladder neck changes in the direct comparison of each patient and image modality. Another explanatory aspect for these divergent results might be a varying personal behavior of an individual woman who is potentially embarrassed while a physician is examining her with an ultrasound probe simultaneously during the Valsalva maneuver,

whereas no such interaction takes place during the dMRI examination. Since introital ultrasound served as the gold standard, we were unable to evaluate whether the dMRI-based diagnosis was true in an individual patient when the ultrasound did not show bladder neck changes. This might be an interesting question to be answered in further studies.

It is obvious that there are far more possibilities to observe and evaluate when using introital 2D ultrasound and dMRI; however, this study focused on the comparability of the two different image modalities regarding urethral behavior.

Despite the fact that we are of the opinion that dMRI can be very valuable in the preoperative assessment of patients suffering from PFD, we are aware of the time-consuming and expensive nature of dMRI in a normal clinical setting, which thus limit its use. We acknowledge that our database contained a relatively small number of patients who underwent introital 2D ultrasound during a urogynecological examination and we, therefore, statistically enlarged the cohort by performing a bootstrap analysis.

Conclusion

From our results, we conclude that metric information on the total urethral length from dMRI is comparable to that from introital ultrasound and is, therefore, suitable for treatment planning. The dMRI method is more advantageous in cases with an extended organ prolapse during the Valsalva maneuver. To date, however, dMRI does not give the same diagnosis on bladder neck changes as introital ultrasound does.

Author contributions CDA: data analysis, manuscript writing, and manuscript editing. SMK: data collection and data management. PH: protocol development and manuscript editing. CS: project development and manuscript editing. HUK: project development. SBE: statistical analysis, data analysis, and manuscript editing. KAB: protocol development, data management, data analysis, and manuscript editing

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Compliance with ethical standards

Conflict of interest KA Brocker reports personal fees in the past by Serag Wiessner, Naila, Germany, outside the submitted work. All other authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. This article does not contain any studies with animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants who were included in the study.

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