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Role of MRI in the Evaluation of the Female Urethra in Patients with Stress Urinary Incontinence

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Ethics approval and consent to participate
The study was a prospective study. This study was approved by the Research Ethics Committee of the Faculty of Medicine at Ain shams University in Egypt. All patients included in this study gave written informed consent to participate in this research

Consent for publication All patients included in this research gave written informed consent to publish the data contained within this study. when consent for publication was requested, written informed consent for the publication of this data was given by their legal guardian

Abstract

Background:

Urinary incontinence, defined as involuntary leakage of urine, is one of the most common conditions in the female population that causes significant anxiety and negatively affects the quality of life. Urinary incontinence also has a considerable impact on health care costs. **(Lalwani et al.,2013).**

Dynamic evaluation of the urethral sphincter is possible with MRI and simultaneous functional and morphologic assessment may assist in classification of incontinent patients into hypermobility and intrinsic sphincter deficiency categories. The additional information on the status of the urethral sphincter and supporting ligaments provided by MR imaging may contribute to the diagnosis and staging of urinary incontinence in the female population. **(Peng et al.,2016).**

Treatment of patients with urinary incontinence depends on the type of sphincter abnormality. MR imaging contributes findings that characterize the urethral dysfunction and may guide the choice of therapy and posttreatment follow-up in the future. **(Tasali , et al.,2012).**

The aim of the study was to evaluate the female urethra and its supporting structures in patients with stress urinary incontinence and to differentiate between urethral sphincter defect and urethral hypermobility as a cause of stress urinary incontinence.

Results:

In our study, 50% have history of vaginal delivery trauma as compared to 30% in control group (P =0.451).

There was no significant difference between the continent volunteers and incontinent patients in body habitus as assessed by the body mass index.

Both bladder neck funneling (absent *vs* present) and the functional suprapubic urethra sphincter length were found to be significantly associated with UDs diagnosis of SUI due to pure UH *vs* SUI with ISD component.

MRI has shown good prediction statistics with 83.33% sensitivity ,100% positive predictive value, 94.74% negative predictive value and 100% specificity for funneling of the bladder neck and 83.33% sensitivity , 41.7% positive predictive value, 91.7% negative predictive value and 61.1% specificity respectively for suprapubic urethral length.

Conclusion:

MRI plays an important role in assessing the contribution of urethral hypermobility and sphincteric dysfunction to the stress urinary incontinence in women when considering treatment options.

Keywords:

Dynamic pelvic MRI, urodynamics study, urethral hypermobility, intrinsic sphincter defect, stress urinary incontinence.

Background

Stress urinary incontinence (SUI) is the observation of involuntary urinary loss from the urethra synchronous with exertion, sneezing, or coughing. Urodynamic stress incontinence is noted during urodynamic testing and is defined as the involuntary leakage of urine during increases in abdominal pressure in the absence of a detrusor contraction. SUI is one of the most common conditions among women with a significant impact on the quality of life due to psychosocial and hygienic problems. **(Lalwani et al.,2013)**

Two main etiologic factors have been implicated in the urethral dysfunction leading to SUI, urethral hypermobility (UH) and intrinsic sphincter deficiency (ISD). In UH, it is the weakness of pelvic floor support that results in a rotational descent of the vesical neck and urethra during increases in abdominal pressure with subsequent leakage. In ISD, there is malfunction of the urethral sphincter which leads to low urethral closure pressures **(Bitti et al.,2014)**.

The type of urinary incontinence determines choice of surgical treatment, to prevent UH by repositioning the urethra into the pelvis to equalize pressure transmission between the bladder and urethra, and for women with low urethral resistance in ISD to increase the urethral closure pressures. Studies investigating the effects of UH and ISD on the outcome of the commonly performed procedures, such as transobturator tape (TOT) used to treat UH reported that the lack of UH as a contributing factor to SUI may be a risk factor for TOT failure**(Elsayed et al.,2017).**

Also, Sand et al studied women who failed retropubic suspension and found a higher failure rate in those with ISD. It has been shown that SUI caused by ISD is the most challenging to treat; with failure rates as high as 54%.**(Sand et al.,1987).**

These failures were attributed to the correction of UH without concomitant increase of urethral closure pressures.

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Traditionally, the diagnosis of SUI is made based on history, clinical exam and urodynamics (UDs) or videourodynamics. Urethral pressure profilometry [which allows to measure maximum urethral closure pressure (MUCP)] may be combined with videourodynamics. This indirect method has limitations, as only the physiologic effect of sphincteric dysfunction can be assessed, without the evaluation of any morphological defects leading to SUI (**(Peng et al.,2016).**

With its excellent soft tissue contrast and multiplanar acquisition, magnetic resonance imaging (MRI) allows visualization of the female urethra and periurethral tissues relevant to SUI. MRI findings related to SUI caused by UH and ISD in women have been described. Previous studies of MRI in female patients with SUI were focused on the assessment of lesions of the urethral support mechanism, defects of the levator ani muscle, and paravaginal fascia, as well as on the kinematics of pelvic floor muscles function **(Tasali , et al.,2012).**

To date, however, the role of MRI in the specific diagnosis of SUI caused by UH and/or ISD has not been documented. Therefore, the purpose of this pilot study was to define the MRI parameters differentiating UH and ISD types of incontinence and assess their ability to predict the type of SUI with UDs as a reference standard **(Ramadan and Elebeisy ,2013).**

Therefore, the purpose of this study was to define the MRI parameters differentiating UH and ISD types of incontinence and assess their ability to predict the type of SUI with UDs as a reference standard.

Methods:

Study-specific written consents were obtained from all subjects. Patients were recruited from the Urogynecology unit for this study, in which prospectively collected data from consecutive women who met the enrolment criteria and participated in the study were analysed. A target accrual of 24 patients with SUI and 10 volunteers was established for this study. A total of 34 women were recruited. The inclusion criteria were as follows: (1) SUI documented on UDs (for patients with SUI) or no clinical symptoms of SUI (for volunteers); (2) study-specific informed consent signed prior to study entry; (3) no contraindications to MRI. Subject exclusion criteria were as follows: (1) unable to give valid informed consent; (2) unable to undergo MR, *e.g.*, patients with contra-indications to MR imaging; (3) pregnancy and and lactating females.

Patient preparation

All patients had undergone a rectal enema with warm water the night before the MR imaging examination and were asked to void 2 hours before the examination. Proper full history was taken, detailed procedure explanation was done and informed consent was obtained. No oral or intravenous contrast agent was administered.

Image acquisition

MR examination was done using a 1.5 T machine (Achieva and Ingenia, Philips medical system, Eindhoven, Netherlands) using phased array pelvic coil.

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The study consisted of static MR sequences and dynamic sequences using pelvic phased array coil. Survey views for the pelvis were first done. The slices started from level of upper margin of the urinary bladder denoted from T2-weighted images down to level of external meatus level in planes perpendicular and parallel to the long axis of the urethra. For static images, high resolution T2-weighted images (T2WI) (Turbo Spin Echo, TSE) in three planes were acquired. The patient was positioned supine with the knees elevated (e.g. on a
Pillow with firm consistency) as this was found to facilitate straining.
For dynamic sequences, the patients were instructed to squeeze as if trying to prevent the escape of urine or faeces and hold this position for the duration of the sequence.
For maximum straining, the patient was instructed to bear down as much as she could, as though she was constipated and was trying to defecate.
The dynamic sequence should not exceed 20 seconds each, as breath holding is required.

Image interpretation

Image analysis and interpretation was done by an experienced radiologist. Imaging findings in the evaluation of female urethral sphincter anatomy and function can be divided into assessment of the status of the urethral sphincter muscle itself and the status of urethral support structures. We assessed the following parameters in both the patient and the volunteer groups: (1) urethral length including the length of the suprapubic urethra and the functional urethral length; (2) Vesicourethral angle ; (3) width of the retropubic space; (4) vaginal shape; (5) urinary bladder neck descent; (6) bladder neck funneling; (7) status of the puborectalis muscle (PRM); (8) pubo-vaginal distance (PVD); (9) the presence of cystocele.
The bladder neck descent was measured as a distance (cm) between its position at rest and strain in reference to the pubococcygeal line (PCL, a line drawn from the inferior margin of the pubic bone to the last coccygeal joint). he normal vaginal shape, assessed as an H-shaped contour on axial images, was deemed as a sign of the normal vaginolevator attachments. The loss of the H-shape vaginal morphology on axial images was interpreted as the presence of abnormal vaginolevator attachments (paravaginal defect) reflecting the loss of vaginal support. Laterality of the paravaginal defect was assessed. The PVD was measured as a distance between the posterior margin of the pubis and the anterior margin of the vagina at the mid urethra level (mid urethra defined at 50% of the sphincter length from the internal meatus).
The urethral sphincter length was measured at rest on the coronal and sagittal views, and a mean from both measurements was obtained as the total sphincter length. In addition to the total sphincter length, we assessed the functional length of the sphincter above the pelvic floor level (above the inferior pubic margin) and expressed it as a percentage of the total sphincter length.
We assessed the presence or absence of the bladder neck funneling, defined as an opening of the internal meatus of the urethral sphincter at rest or during strain.
The status of the PRM was evaluated at the mid urethra level. The muscle thickness (measured at mid length of the muscle), its length, and an angle between the PRM and an obturator internus muscle were assessed.

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Statistical analysis:

Data were fed to the computer and analyzed using IBM SPSS software package version 20.0. (Armonk, NY: IBM Corp). Qualitative data were described using number and percent. The Kolmogorov-Smirnov test was used to verify the normality of distribution Quantitative data were described using range (minimum and maximum), mean, standard deviation, median and interquartile range (IQR). Significance of the obtained results was judged at the 5% level. The used tests were
Chi-square test for categorical variables to compare between different groups ,Fisher's Exact or Monte Carlo correction for chi-square when more than 20% of the cells have expected count less than 5 , Student t-test for normally distributed quantitative variables to compare between two studied groups and Mann Whitney test for abnormally distributed quantitative variables, to compare between two studied groups. Diagnostic performance indices including sensitivity, specificity, positive and negative predictive values and overall accuracy were calculated using contingency tables. Data was presented by graphs, bar charts, and pie charts as well as tables.

Results:

Thirty-four women recruited for this study were considered in the analysis, 24 with SUI and 10 volunteer controls. The characteristics of participants according to continent vs incontinent status and obstetric history are listed in Tables (1) and (2).

Table (1):

	Cases (n= 24)	**Control (n= 10)**	**t**	**p**
Age (years)				
Min. – Max.	32.0 – 65.0	19.0 – 45.0	4.146*	<0.001*
Mean ± SD.	46.92 ± 9.53	32.0 ± 9.63		
Median (IQR)	46.0 (39.0 – 55.0)	34.0 (22.0 – 39.0)		
BMI (kg/m^2)				
Min. – Max.	16.0 – 34.0	8.0 – 30.0	1.659	0.107
Mean ± SD.	26.38 ± 5.18	22.80 ± 6.92		
Median (IQR)	28.0 (24.0 – 30.0)	25.50 (18.0 – 28.0)		

t: Student t-test
IQR: **Inter quartile range** SD: **Standard deviation**
p: p value for comparing between the studied groups
*: Statistically significant at p ≤ 0.05

Table (2):

	Cases (n= 24)		**Control (n= 10)**		**Test of sig.**	**p**
	No.	**%**	**No.**	**%**		

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Parity						
Nullipara	0	0.0	2	20.0	χ^2= 4.489	MC p= 0.083
Primry para	1	4.2	0	0.0		
Multipara	23	95.8	8	80.0		
Min. – Max.	1.0 – 7.0		0.0 – 4.0		U= 65.0*	0.038*
Mean ± SD.	3.83 ± 1.69		2.30 ± 1.42			
Median (IQR)	3.0(3.0 – 5.0)		2.50(2.0 – 3.0)			
Mode of delivery						
CS	9	37.5	3	37.5	χ^2= 0.0	FE p= 1.000
Vaginal	15	62.5	5	62.5		
OB trauma						
No	12	50.0	7	70.0	χ^2= 1.145	FE p= 0.451
Yes	12	50.0	3	30.0		
Menstrual status						
Premenopausal	15	62.5	10	100.0	χ^2= 5.100*	FE p= 0.034*
Postmenopausal	9	37.5	0	0.0		

χ^2: **Chi square test** MC: **Monte Carlo** FE**: Fisher Exact** **U: Mann Whitney test**
IQR: **Inter quartile range** SD: **Standard deviation**
p: p value for comparing between the studied groups
*: Statistically significant at $p \le 0.05$

Incontinent women tended to be older with a mean (SD) age of 46 years vs 32 years for controls (P < 0.001, t-test). There was no statistically significant difference between the continent volunteers and incontinent patients in body habitus as assessed by the body mass index (BMI).

Among the MRI variables, urethral length, suprapubic urethral length and functional urethral length were found to be significantly associated with incontinence status (P<0.001) as listed in Table (3)
Table (3)

	Cases (n= 24)	**Control (n= 10)**	**Test of sig.**	**p**
Urethral length				
Min. – Max.	2.10 – 3.60	3.10 – 4.40	t= 5.521*	<0.001*
Mean ± SD.	2.94 ± 0.42	3.79 ± 0.38		
Median (IQR)	2.95 (2.70 – 3.25)	3.85 (3.50 – 4.0)		
Length of the suprapubic urethra				

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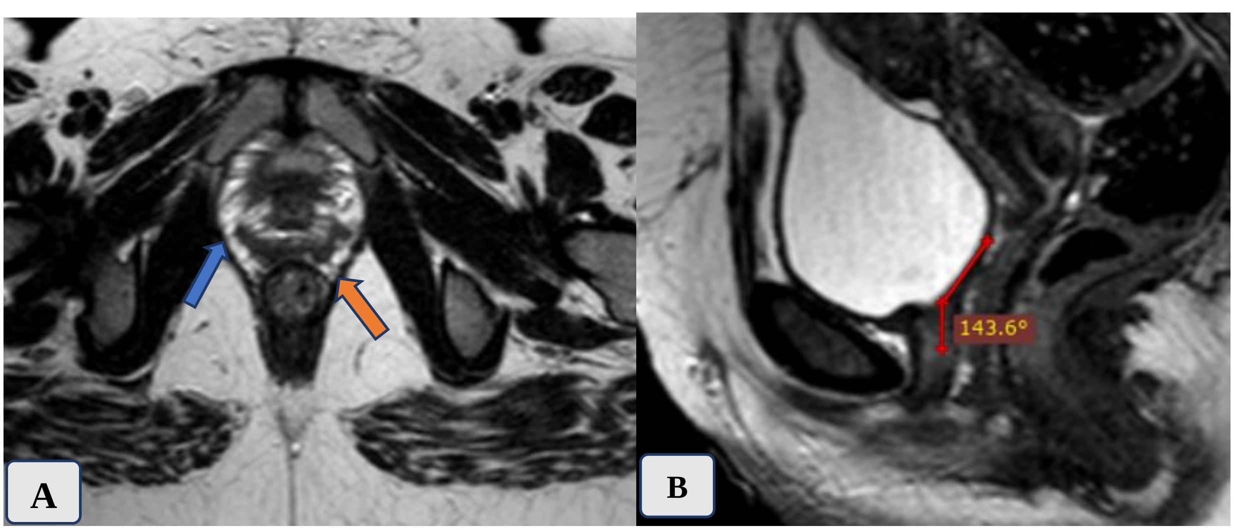
Min. – Max.	1.0 – 3.0	2.80 – 4.0	U= 6.50*	<0.001*
Mean ± SD.	2.23 ± 0.56	3.49 ± 0.40		
Median (IQR)	2.35 (1.80 – 2.60)	3.50 (3.20 – 3.80)		
Functional urethral length (%)				
Min. – Max.	48.0 – 94.0	88.0 – 95.0	t= 5.975*	<0.001*
Mean ± SD.	75.08 ± 13.05	91.80 ± 2.70		
Median (IQR)	78.0 (64.50 – 84.50)	91.0 (90.0 – 95.0)		

t: Student t-test **U: Mann Whitney test**
IQR: **Inter quartile range** SD: **Standard deviation**
p: p value for comparing between the studied groups
*: Statistically significant at $p \leq 0.05$

No statistically significant difference was found among the pubovaginal distance and the vaginal shape between the cases and control groups. Six of the 10 control patients (60%) had preserved H shape vaginal configuration, as opposed to only 8 of the 24 incontinent (33.3%) women (P = 0.252).

When we looked at the relationship of UDs diagnosis in patients who had complete UDs (SUI due to pure UH in 6 patients vs SUI with ISD component in 18 patients) and the MRI data, both bladder neck funneling (absent vs present) and the functional suprapubic urethra sphincter length were found to be significantly associated with UDs diagnosis. The prediction statistics were quite good, giving a 83.3% sensitivity and 100% specificity for bladder neck funelling and 83.3% sensitivity and 61.1% specificity for the length of the suprapubic urethra **(Fig.1).**



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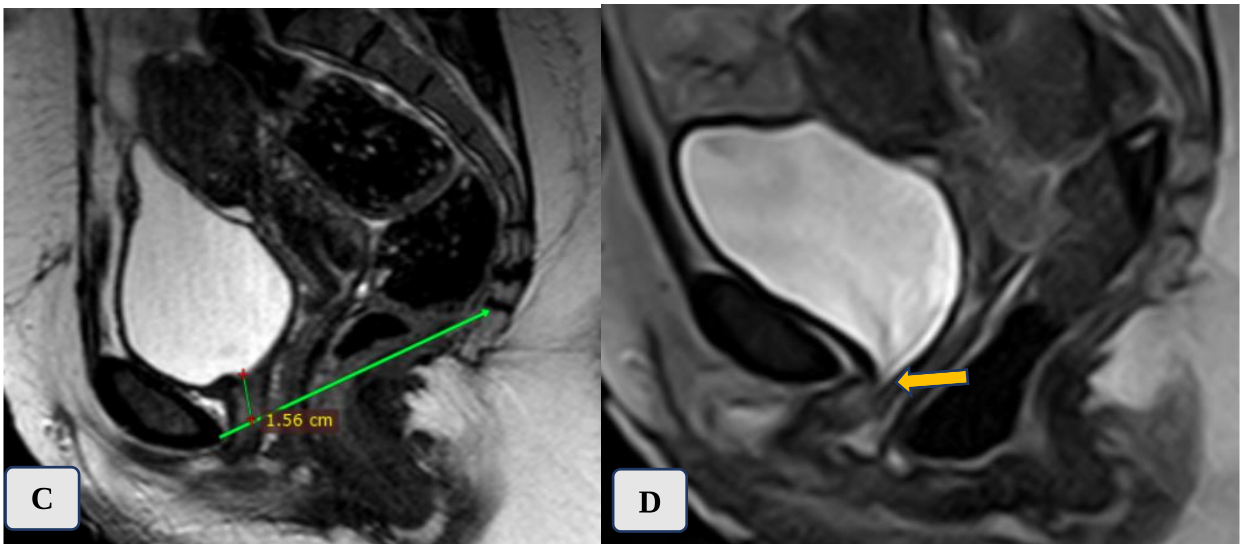

Fig. 1: 52 years old , presented with SUI. UDs show VLPP=75cmH2O, MUCP=50cmH2O. (A)Axial T2WI shows loss of H shape configuration of the vaginal with bilateral symmetrical thinning of the PRM. (B) Sagittal T2WI shows increased vesicourethral angle measuring about 143°. (C) Sagittal T2WI shows decreased length of the suprapubic urethra. (D) Dynamic MRI of the pelvis with maximum straining shows funneling of the UB neck.

Discussion:

The underlying causes of SUI are due to either urethral hypermobility (UH) or intrinsic sphincter defect (ISD). UH is due to weakness of the urethral supporting structure with subsequent rotation of the urethra with increased abdominal pressure. ISD is related to malfunction of the urethral sphincter. ***(Baessler et al., 2018).***

The causes of SUI are multifactorial and can be related to the weakening and/or ineffectiveness of support structures in cases of UH. Risk factors include vaginal delivery, multiparity, hysterectomy, advanced age, connective tissue disorders, obesity, hypoestrogenism, chronic pulmonary disorders, and conditions associated with increased abdominal pressure. The greatest associated risk factors are advanced age and vaginal parity ***(Luciana et al., 2018).***

The mode of delivery and parity have a significant impact on the development of SUI. SUI is more prevalent in female patients with prior vaginal deliveries and increased parity. ***(Gurol-*****Urganci et al., 2018).** In our study incontinent women tended to be older with a mean (SD) age of 46 years vs 32 years for controls ($P < 0.001$, t-test). Also, statistically significant difference was found between the incontinent and continent group in the mean parity (P=0.038). The mean parity for the incontinent group was 3.83 vs 2.30 for the continent group.

Dynamic magnetic resonance (MR) imaging of the pelvic floor is a well-established modality with high-resolution images yielding detailed anatomic information and dynamic sequences yielding functional data ***(Luciana et al., 2018).***

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The majority of incontinent patients in our study have shown larger vesicourethral angle (mean 143.42°) vs smaller vesicourethral angle seen in our continent group (mean 113.1°) (P <0.001).Previous study by has also shown significant statistical difference between the incontinent group (mean 144.3°)and the continent group (mean 123.2°) in terms of the vesicourethral angle (P=0.045).

Statically significant difference was found between the cases (mean=8.25 ± 2.07) and control (mean=5.20 ± 1.62) groups in the width of the retropubic space (P<0.001). In our study the PVD was also found to be significantly associated with incontinence status. Incontinent women had a shorter PVD than the control volunteers. Previous studies demonstrated that the volume of paravaginal fascia (connective tissue that contained venous plexus anterior to vagina) was reduced in patients with stress incontinence compared to reference continent subjects, therefore our finding of shortening of the distance between the anterior vaginal wall and pubic wall in incontinent women may indirectly relate to diminishing volume of paravaginal tissue noted by deSouza et al.

However, in the study by Tasali et al., authors documented lack of association between the dimension of the retropubic space and the SUI.Notably, in our study there was no difference in BMI between the incontinent patients and continent volunteers, therefore our results should not be influenced by the contribution of retropubic fat pad to the PVD in our study sample.

Clinical *Q* test without visualization of urethral attachment defects may not be a reliable test, as continent women may also demonstrate hypermobility of the urethra. In our study groups there was an overlap between urethral mobility angles for continent women and incontinent women when assessed based on MRI. MRI can demonstrate not only the presence of hypermobility, but also other associated findings. UH is often accompanied by moderate to severe bladder descent with anterior bulging of the vagina. Bladder neck descent can be quantified and its competence/coaptation can be assessed on MRI along with hypermobility. We found an inverse correlation between bladder neck strain and MUCP that supports the hypothesis that, with increased inferior translation of the bladder neck due to loosening of the bladder neck attachment, there is decreasing urethral closure pressure caused by loss of coaptation of the sphincter as it descends. We also noted a correlation approaching significance between the increasing total urethral sphincter length and increasing VLPP, the longer the sphincter, the higher the leak point pressure.

We used the Baden Walker Halfway grading system in the clinical staging of pelvic organ prolapse in our patients**.** However, the pelvic organ prolapse quantification system (POP-Q) system was used by ***Wang Y et al., 2016.***

As to the concordance of dynamic MR imaging findings with physical examination, we found that in the anterior compartment there was non-significant relation between MR imaging findings and physical examination regarding the presence or absence of cystocele, with **8 (33.3%)** of the patients having similar findings in both. MRI detected 2 cases of cystocele that was missed by physical examination. In our study group, bladder neck descended to mean distance 2.35 cm below PCL in incontinent women.

Other findings associated with UH is abnormal vaginal configuration (loss of normal H-shape vaginal contour, or dropping vaginal fornix), best seen on axial images, and widening of the

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para-vaginal attachments. In our study group, normal vaginal shape was maintained in 66.7% of continent volunteers and 33.3% of incontinent women.

The levator ani muscle signal and integrity can be well evaluated on MR images, on axial and coronal T2-weighted images. Levator ani should be symmetric without defects or fraying. Abnormal signal in the levator muscle, when compared to the obturator internus, and thinning can be observed in patients with stress incontinence and can be a result of fatty infiltration and atrophy as well as direct muscle injury[24]. Interruption of the muscle fibers, lateral deviation of the muscle that is frequently associated with vaginal shape distortion on the affected side, can be observed. In our study group however, there was no significant difference between the configuration between incontinent and continent women.

In patients with SUI, there are some imaging findings that are more likely to be associated with ISD, such as a short urethra, urethral muscle thinning, or bladder neck weakness demonstrated by funneling. Previous study by Macura et al. demonstrated that when the total urethral sphincter is shorter than 3.0 cm, or when the segment of urethral sphincter above the pelvic floor level is less than 3.0 cm, this decreased functional length of the urethra can lead to incontinence with urethral sphincter weakening associated with ISD on UDs. Also, funneling at the bladder neck, which is the opening of the urethrovesical junction at rest or during strain, can be seen on MRI in patients with SUI. An open bladder neck and proximal urethra was shown to indicate an ISD **(Luciana et al.,2018)** , however funneling can be also found in some postmenopausal continent women. In our study, funneling was seen in 79.2% of incontinent women and only in 1 (10%) continent volunteer. In a recent study by Pontbriand-Drolet et al[18] women with SUI symptoms were more likely to exhibit bladder neck funneling and a larger posterior urethrovesical angle at rest than both continent and mixed urinary incontinence women.

When we looked at the relationship of UDs diagnosis (SUI with pure UH *vs* SUI with ISD component) and the MRI data, both bladder neck funneling and the suprapubic urethral sphincter length were found to be predictive of UDs diagnosis. A study by Asfour et al.,2020 has also shown similar results and mentioned an association between funneling and ISD secondary to weakness of the urethral sphincter (**Asfour et al., 2020)**.

In contrast, increasing suprapubic urethral sphincter length was highly associated with a UDs diagnosis of pure UH, as the dysfunction of the sphincter results from the inferior translation of the urethra that is poorly supported rather than from shortening or intrinsic weakness of the sphincter itself. The prediction statistics for this model was good, giving a 83.33% sensitivity and 100% specificity for UB neck funelling and 83.33% senstivity and 61.1% specificity for the suprapubic urethral length. However, due to a small size of the sample, the confidence intervals are large. A larger cohort study is needed to address these findings.

A limitation of our study is a relatively small sample size for incontinent group as only 24 incontinent women had a complete UDs exam to be included in the logistic regression model. The mean age of the incontinent group was 46 years vs mean age of 32 years for the continent group. They were matched by BMI. There was no significant difference in the incidence of OB trauma, with 50% of incontinent patients reporting at least one incident of episiotomy, perineal laceration, or forceps deliveryvs 30% of OB trauma was reported in the control group. This finding indirectly may relate to a known risk of pelvic floor injury during vaginal delivery as a cause of SUI. However, since the study sample was small, we were unable to control for individual types of injury to directly correlate the MRI findings with the severity of pelvic floor trauma. Another potential limitation of our study is imaging in the supine position, which is not a physiological position when patients experience SUI. However, we performed dynamic pelvic floor strain imaging to allow assessment of the changes in the urethra that take place during increases of intra-abdominal pressures.

In conclusion, our study demonstrated that there are specific morphological defects in women with SUI detectable on MRI that can be evaluated to differentiate incontinence related to the pure UH *vs* incontinence that has a component of ISD. Currently, MRI is usually considered in the diagnostic work-up of women who failed prior surgeries for incontinence or who have severe and complex pelvic organ prolapse. Further studies are needed to address the effects of aging, parity, pelvic floor injury, and hormonal status on SUI, in the context of specific anatomical defects related to SUI that can be observed and quantified on MR images, in order to evaluate the role of MRI in the assessment and treatment planning of women with SUI.

Conclusion:

State clearly the main conclusions and provide an explanation of the importance and relevance of the study to the field.

Added value of MR examination in cases of stress urinary incontinence could be summed up in its value in detection of defects in the urethral supporting structures, defining the parameters used in accurate differentiation between urethral hypermobility and intrinsic sphincter defects and influencing the choice of surgical treatment based on the type of stress incontinence.

List of abbreviations:

BMI: Body Mass Index
ISD: Intrinsic Sphincter Defect
MRI: Magnetic Resonance Imaging
MUCP: Maximum Urethral Closing Pressure
NPV: Negative predictive value
OB: Obstetric
PCL: Pubococcygeal Line
PPV: Positive predictive value
PRM: Puborectalis Muscle
PVD: Pubovaginal Distance
SUI: Stress Urinary Incontinence
UB: Urinary Bladder
UDs: Urodynamics
UH: Urethral Hypermobility
VLPP:Valsalva Leak Point Pressure

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