Evaluation of anatomical factors affecting stress urinary incontinence in female patients via dynamic pelvic floor magnetic resonance imaging

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Abstract

Objective. To evaluate the anatomical factors affecting stress urinary incontinence (SUI) in female patients via dynamic pelvic floor magnetic resonance imaging (DP-MRI).

Methods. This prospective study was conducted on 43 female patients, including 22 patients with SUI (disease group) and 21 patients without SUI (control group). All patients underwent DP-MRI. The length, volume, transverse/anteroposterior diameter, and outer/inner layer thickness of the urethra were measured on static (T2W) pulse sequences. Urethral angle, posterior urethro-vesical angle (PUVA), bladder neck-pubococcygeal angle, and position of the bladder neck and cervix relative to the pubococcygeal line were measured on dynamic (Cine) pulse sequences at rest and during evacuation phase. These parameters were compared between the groups to evaluate which anatomical factors affected SUI. The area under the ROC curve (AUC) and threshold of the sensitivity and specificity of these parameters for the diagnosis of SUI were calculated.

Results. The mean age of the patients was 57.3±13.8 years (disease group: 53.9±12.6 years; control group: 60.8±14.4 years). The mean number of childbirths was 2.2±0.65, and vaginal delivery accounted for 73% in each group. There was no significant difference between the two groups in terms of length, transverse diameter, outer layer thickness of the urethra, urethral angle, bladder neck-pubococcygeal angle, position of bladder neck relative to the pubococcygeal line in both resting and evacuation phases (p>0.05). There was a significant difference between the two groups regarding volume (p=0.014), anteroposterior diameter (p=0.01), inner layer thickness of the urethra (p=0.04), and PUVA (p=0.001) at rest and evacuation phases and cervix position at evacuation phase (p=0.001). The AUC of the PUVA for SUI diagnosis was 0.9 at rest and 0.98 during evacuation phases. For the threshold 133.5° at rest phase and 153.5° at evacuation phase, the sensitivity and specificity of PUVA were 0.86 and 0.86 at rest phase and 0.91 and 0.95 at evacuation phase, respectively.

Conclusions. PUVA was the anatomical factor that had the greatest effect on SUI and provided high sensitivity and specificity for SUI diagnosis. Clin Ter 2023; 174 (6):491-497 doi: 10.7417/CT.2023.5015

Key words: dynamic pelvic floor MRI, stress urinary incontinence, posterior urethro-vesical angle

Introduction

Stress urinary incontinence (SUI), as defined by the International Continence Society (ICS), is a disorder in which the urine leaks involuntarily from the external urethral orifice due to increased intra-abdominal pressure, such as during sneezing, coughing, laughing, or exertion. The prevalence of SUI is 49% among all female patients with urinary incontinence. This disorder affects women’s psychology and physical health, leading to decreased quality of life.

The pathogenesis of SUI is closely related to the anatomy of the urethra and the supporting structures around the bladder neck (BN)-proximal urethra. Delaney proposed the “hammock” hypothesis, in which the levator ani muscle, anterior vaginal wall, pubo-urethral ligament, and pelvic fascia form a lifting-holding system for the BN-proximal urethra. This system acts as a support to ensure that the intra-abdominal pressure is transmitted uniformly to the urethra and bladder base. If this system is weak or defective, the transmitted intra-abdominal pressure will not be equal, and a gradient pressure between the bladder base and the proximal urethra will develop. When this gradient exceeds the threshold of urethral closure (under stress conditions), SUI disorders develop.

Anatomical elements of the urethra and periurethral supportive structures can be detected by ultrasound or dynamic magnetic resonance imaging (MRI). Due to its high soft tissue resolution and objective imaging and reporting, dynamic pelvic floor MRI (DP-MRI) is increasingly being used to identify the anatomical pathogenesis of SUI.

Several descriptive studies have investigated the anatomical elements related to SUI via DP-MRI; however, the factors that have the greatest effect on SUI have not yet been defined. We conducted this study to evaluate the anatomical factors of the urethra and periurethral supporting structures and to compare them between control and disease groups to identify the anatomical factors that have the greatest influence on SUI.
Patients and methods

The study was conducted at Hanoi Medical University Hospital from August 2020 to September 2022 on 43 female patients, including 22 patients with SUI (disease group) and 21 patients without SUI (control group). The study was approved by the Scientific Review Board of Hanoi Medical University. All patients provided written informed consent and underwent DP-MRI. DP-MRI for the patients of the control group was indicated by other non-SUI clinical symptoms, such as organ prolapse, obstructed defecation syndrome, and constipation.

Age, history of childbirth (number and type of delivery), and duration and severity of SUI were recorded in the disease group, and clinical symptoms were recorded in the control group. Patient information was saved in the study database.

DP-MRI was performed using a 1.5 Tesla Essenza (Siemens Healthineer) MR scanner. The acquisition protocol consisted of high-resolution T2-weighted (T2W) sequences (static sequence) in axial, coronal, and sagittal planes. Dynamic sequences (SSFP-Cine) were obtained at rest, and holding and evacuation phases were recorded via a single sagittal slice along the urethral axis.

On the static images, the outer urethral layer thickness (low signal intensity corresponding to the striated muscle layer), inner urethral layer thickness (high signal intensity, including the smooth muscle, submucosa, and mucosa), urethral length (connecting the BN to the external urethral orifice), and urethral anteroposterior and transverse diameters were measured. The urethral volume was calculated by the formula $V = \pi \times (\text{height}/2) \times (\text{anteroposterior}/2) \times \text{length}$.

On the dynamic sequences, the urethral angle (UA; formed by the vertical axis and the urethral axis), posterior urethro-vesical angle (PUVA; formed by the tangent line to the bladder base and urethral axis), bladder neck-pubococcygeal angle (BNPCA; formed by the lower margin of the pubic symphysis-BN line and pubococcygeal line [PCL]), and BN and cervical positions relative to the PCL were determined.

The data were processed using SPSS 20.0 software. Quantitative variables are expressed as mean ± standard deviation or median. Qualitative variables are expressed as percentage. The Shapiro–Wilk test was used to assess the normality of the data distribution. Because the variables were non-normally distributed, they were compared using Mann–Whitney tests. Differences between qualitative variables were assessed using Chi-squared and Fisher’s exact tests. All differences with $p<0.05$ were considered statistically significant. The mean and standard deviation of these measured parameters were calculated and compared between the two groups at both resting and evacuation phases. The receiver operating characteristic (ROC) curve of parameters with significant $p$-values was constructed to determine the area under the ROC curve (AUC) and the threshold value for its highest sensitivity and specificity for SUI diagnosis.

Results

The mean age of the patients was 57.3±13.8 years (disease group: 53.9±12.6 years; control group: 60.8±14.4 years). The mean number of childbirths was 2.2±0.65, and vaginal delivery accounted for 73% in each group.

In the control group, 15/21 (71%) patients with defecation disorders and 6/21 (29%) patients with urinary disorders without SUI underwent DP-MRI.

In the disease group, 45.5% of the patients had suffered from SUI for 1–3 years and 27.3% had suffered from SUI for over 5 years. The mean duration of SUI was 52.4±40.3 months. Most patients (68%) had severe SUI, 14% had mild SUI, and 18% had moderate SUI.

The anatomical features of the urethra between the disease group and the control group are presented in Table 1. There were significant differences between the disease group and control group regarding the urethral inner layer thickness ($p=0.04$), urethral anteroposterior diameter ($p=0.01$), and urethral volume ($p=0.01$). There were significant differences between the two groups regarding the urethral outer layer thickness, urethral length, or urethral transverse diameter ($p>0.05$).

<table>
<thead>
<tr>
<th>Urethral morphology</th>
<th>Inner layer thickness (mm)</th>
<th>Outer layer thickness (mm)</th>
<th>Length (mm)</th>
<th>Transverse diameter (mm)</th>
<th>Anteroposterior diameter (mm)</th>
<th>Volume (cm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>D</td>
<td>C</td>
<td>D</td>
<td>C</td>
<td>D</td>
<td>C</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>5.1±0.47</td>
<td>5.4±0.66</td>
<td>2.2±0.53</td>
<td>2.4±0.45</td>
<td>30.8±6.2</td>
<td>33.9±6.7</td>
</tr>
<tr>
<td></td>
<td>15.4±2.8</td>
<td>16.5±2.2</td>
<td>14.4±2.2</td>
<td>16.2±2.3</td>
<td>5.5±2.1</td>
<td>7.1±1.9</td>
</tr>
<tr>
<td>P</td>
<td>0.04*</td>
<td>0.08</td>
<td>0.13</td>
<td>0.17</td>
<td>0.01*</td>
<td>0.014*</td>
</tr>
</tbody>
</table>

* Chi-squared; $p<0.05$. 

Table 1. Anatomical features of the urethra, measured on static T2W images, between the disease (D) and control (C) groups.
The periurethral supporting system at rest and evacuation phase between the disease and control groups is presented in Table 2. There were significant differences between the disease and control groups regarding PUVA in both the resting and evacuation phases (p<0.001) and in the cervix position at the evacuation phase (p=0.001). There were significant differences between the two groups regarding UA, BNPCA, or BN position at either resting or evacuation phases or regarding cervix position at rest (p>0.05).

The AUC of the PUVA was 0.9 at rest and 0.98 at evacuation phase (Fig. 1, Table 3). For the threshold of 133.5° at rest and 153.5° at evacuation phase, the sensitivity and specificity of PUVA for SUI diagnosis were 0.86 and 0.86 at rest and 0.91 and 0.95 at evacuation phase, respectively.

### Table 2. Periurethral supporting system, measured on dynamic sequences at rest and evacuation phase, between the disease and control groups.

<table>
<thead>
<tr>
<th>Periurethral measurement</th>
<th>UA (°)</th>
<th>PUVA (°)</th>
<th>BNPCA (°)</th>
<th>BN position (mm)</th>
<th>Cervix position (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase</td>
<td>Rest</td>
<td>Evac.</td>
<td>Rest</td>
<td>Evac.</td>
<td>Rest</td>
</tr>
<tr>
<td>Disease group</td>
<td>18.1 ±10.4</td>
<td>53.8 ±37.4</td>
<td>145.3 ±13</td>
<td>171.2 ±13.5</td>
<td>52.6 ±18.3</td>
</tr>
<tr>
<td>Control group</td>
<td>17.2 ±9.1</td>
<td>56.2 ±29.7</td>
<td>123.2 ±13.3</td>
<td>121.4 ±20.6</td>
<td>57.8 ±28.2</td>
</tr>
<tr>
<td>P</td>
<td>0.79</td>
<td>0.81</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
<td>0.46</td>
</tr>
</tbody>
</table>

* Chi-squared; P<0.05

UA, urethral angle; PUVA, posterior urethro-vesical angle; BNPCA, bladder neck-pubococcygeal angle; BN, bladder neck.
Discussion

The anatomical elements of the urethra and its supporting structures play a key role in urinary control. Urethral incompetence or impaired pelvic floor structures can lead to a decrease in the urethral closure pressure, causing SUI. Defects in specific anatomical factors affecting SUI can be recognized directly or indirectly by comparing patients with SUI and without SUI using ultrasound or MRI. Regarding urethral morphology, our study revealed that there was no significant difference in the outer layer thickness between the two groups (p>0.08); however, the inner layer of the disease group was significantly thinner than that of the control group (p=0.04) (Table 1). This result contrasts that of a study by Kim et al6 in which the striated muscle layer was significantly thinner in the SUI group than in continent patients (p<0.001); however, in the other layers, similar thicknesses were recorded in both groups (p>0.05). Tasali et al8 evaluated three layers (striated muscle, smooth muscle, mucosa and submucosa) of the urethra and reported that all layers in the disease group were significantly thinner than in the control group (p<0.01). In our opinion, although the striated and smooth muscle layers of urethra produce the urethral tone, this resistance pressure is very weak compared with the intra-abdominal pressure; therefore, intrinsic sphincter deficiency may lead to urinary incontinence but is not as important in SUI.

Average urethral length in our study was 30.8±6.2 mm in the disease group and 33.9±6.7 mm in the control group. These measurements were in line with those reported by Li et al9 (disease group: 31.8±5 mm; control group: 34.4±3.5 mm), who reported no significant difference in urethral length between stress incontinent and continent women. However, the urethral volume of the disease group was significantly smaller than that of control group (p<0.01). In our opinion, although the striated and smooth muscle layers of urethra produce the urethral tone, this resistance pressure is very weak compared with the intra-abdominal pressure; therefore, intrinsic sphincter deficiency may lead to urinary incontinence but is not as important in SUI.

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Lesions of the urethral supporting structures, such as peri-urethral ligament disruptions or levator ani muscle defects, can be detected via MRI1; however, most of these impairments can also be detected by evaluating the relationship between the urethra and the surrounding structures. The UA is formed by the vertical axis and urethral axis, representing the urethral angular orientation. In our study, there was no significant difference in UA between the two groups at rest or during evacuation phase (p>0.05). This result was in line with the findings reported by Li et al9.

The BNPCA (or α angle) is created by the BN-lower margin of symphysis pubis line and the PCL; it represents the orientation of the urethrovaginal junction. Its value is positive when the angle is located above the PCL and vice versa. The mobility of the urethrovaginal junction was evaluated by the range (absolute value) of this angle between rest and the evacuation phase (Fig. 2). Ansquer et al9 reported that this angle was associated with global laxity of the pelvic floor. In our study, we found no significant difference in this angle between the control and disease groups (p>0.05).

BN position relative to the PCL reflects the intra-abdominal location or prolapse of the bladder (Fig. 3). Like BNPCA, the value is positive when the BN is located above the PCL and vice versa. These parameters were reported in several studies using ultrasound or MRI10-11. In our study, there was no significant difference in bladder position between the disease and control groups at rest or during the evacuation phase (p>0.05). Furthermore, Lucanovic reported no difference in the resting position of the BN in the horizontal or vertical planes between continent women and women with SUI. These results may explain why several women have a cystocele without SUI.

In our study, the cervix position relative to the PCL was not significantly different at rest (p=0.57) but was significantly different at evacuation phase (p=0.001). This can be caused by the damage of the pubo-cervical facia/ligament that leads to the gliding of the cervix under stress conditions12.

The PUVA (also referred to as the β angle or retrovesical angle) was measured as the intersection between lines drawn along the urethra and the bladder (Fig. 4). In our study, the PUVA of the disease group was 145.3±130° at rest and 171.2±13.50° during the evacuation phase, which was significantly larger than in the control group (123.2±13.30° at rest and 121.4±20.60° during the evacuation phase) (p<0.001). The diagnostic threshold value in our study was larger than in a study by Zidan13 (≥96° at rest and 115.5° at evacuation) but was similar to most ultrasound and MRI studies14-16. This effect can be explained by the “hammock” hypothesis of De Lancey et al13, in which the periurethral supporting structures form a firm “backing plate” for the urethra so that it can be held and closed against the intra-abdominal pressure.

Table 3. AUC and PUVA threshold at rest and evacuation phase between the disease and control groups.

<table>
<thead>
<tr>
<th>PUVA</th>
<th>Threshold</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>AUC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resting phase</td>
<td>133.5°</td>
<td>0.86</td>
<td>0.86</td>
<td>0.9</td>
</tr>
<tr>
<td>Evacuation phase</td>
<td>153.5°</td>
<td>0.91</td>
<td>0.95</td>
<td>0.98</td>
</tr>
</tbody>
</table>

PUVA, posterior urethrovaginal angle; AUC, area under the receiver operative characteristic curve.
Fig. 2. Measurement of BNPCA at rest (A) and evacuation phase (B) on sagittal T2W sequence of a patient with SUI.

Fig. 3. Measurement of BNPCA at rest (A) and evacuation phase (B) on sagittal T2W sequence of a patient in the control group.
Our study revealed that the PUVA (β angle) had the greatest effect on SUI. With the threshold of 133.50° at rest, PUVA had a high sensitivity (86%) and specificity (86%) to diagnose SUI (AUC=0.9). In the evacuation phase, PUVA provided a very high sensitivity (91%) and specificity (95%), with the threshold of 153.50° for the diagnosis of SUI.

This study had several limitations. First, because our study population size was relatively small, it might only partially represent the affected population. Second, the control group in our study were not healthy participants; they were admitted to the hospital due to other non-SUI clinical symptoms, such as organ prolapse, obstructed defecation syndrome, and constipation. Further research will be conducted on a larger sample of female patients with SUI and a control group of healthy volunteers.

Conclusion

Our study evaluated the effect of anatomical features of the urethra and the periurethral supporting structures on SUI. The results indicate that the PUVA (or β angle) was the anatomical factor that had the greatest effect on SUI. These findings will aid in determining the choice of treatment and management for patients with SUI.

Ethical approval

The Ethics Committee of Biomedical Research at Hanoi Medical University accepted the study as it complied with biomedical research ethics rules.

Informed consent

Informed consent was waived for the study’s retrospective nature, and the analysis used anonymous clinical data.

Availability of data and material

The datasets generated and/or analysed during the current study are not publicly available due to privacy concerns but are available from the corresponding author on reasonable request.

Conflicts of interest

The authors declare no conflict of interests.

Funding

This research received no external funding.

References


