Urologia Internationalis

Research Article

Urol Int
DOI: 10.1159/000545009

Received: January 7, 2025
Accepted: February 26, 2025
Published online: March 21, 2025

Impact of 3D Reconstruction Combined with Engineering Software Analysis of Pelvic Floor Muscle Morphology on Sexual Dysfunction in Patients with Pelvic Organ Prolapse

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Keywords

Pelvic organ prolapse · Female sexual dysfunction · 3D reconstruction · Muscle model embodiment

Abstract

Introduction: The aim of the study was to evaluate the relationship between the deformation of pelvic floor muscles, which primarily participate in sexual activity, in non-prolapse patients compared to those with pelvic organ prolapse (POP), using MRI combined with 3D reconstruction and engineering software. ***Methods:*** This study retrospectively analyzed 100 patients with sexual activity needs, including 53 diagnosed with POP and 47 without POP. MRI images of relevant pelvic floor muscles were reconstructed in 3D using Mimics software. The IGS models generated with Geomagic Wrap software were assigned material properties and analyzed in SolidWorks. The muscle models were transformed into visualized solid models, yielding results for the mass, volume, and surface area of the pelvic floor muscles involved in sexual activity. These parameters were visualized among POP and non-POP patients, allowing for a comparative analysis. ***Result:*** Significant differences ($p < 0.05$) were observed between the two groups in terms of the volume, mass, and measurable thickness range (thicker regions) of the bulbospongiosus muscle, as well as the surface area of the pubococcygeus muscle and the levator ani. ***Conclusion:*** By using 3D reconstruction and engineering software to visualize muscle models, morphological changes in the bulbospongiosus, pubococcygeus, and levator ani muscles are highlighted. This study lays a theoretical foundation for understanding the functional factors contributing to sexual dysfunction in patients with POP.

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Introduction

Pelvic organ prolapse (POP) is a common pelvic floor dysfunction that affects middle-aged and older women. It is characterized by the protrusion of tissue from the vaginal opening, sometimes accompanied by urinary or bowel disorders and sexual dysfunction. Current research mostly focuses on the correlation between the onset of POP and damage or degeneration of the pelvic floor

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muscles [1, 2], and the relationship between defective ligamentous collagen and POP [3, 4]. However, due to personal shame and social taboos, investigations into the relationship between POP and female sexual dysfunction are rare.

In recent years, with societal progress and living standard improvement, attitudes toward sexuality and the psychological significance of reproductive organs have changed. Sexual dysfunction caused by POP can lead to psychological issues, family conflicts, and social problems, increasing attention to POP and its treatment. Nonetheless, research linking POP with sexual function decline remains limited.

MRI, as a non-invasive, radiation-free, safe, and convenient imaging method with high resolution for soft tissues, can clearly reveal changes in the morphology of pelvic muscles and connective tissue [5, 6]. Its application in assessing female pelvic anatomy and function has significantly advanced pelvic floor imaging.

This study involved MRI examinations of 47 patients without POP and 53 patients with POP. Through 3D reconstruction and engineering software analysis, based on real human imaging data, it determined and compared the morphological parameters of pelvic floor muscles associated with POP and female sexual dysfunction, including the obturator internus, bulbospongiosus, ischiocavernosus, pubococcygeus muscle, and levator ani. This research aimed to enhance clinicians' understanding of the true muscle loss and deformation in POP patients. For patients with sexual activity needs, it is essential to focus not only on restoring their anatomical structure but also on improving muscle function related to sexual activity during treatment. Postoperatively, targeted muscle training can be incorporated into personalized treatment plans, and efforts can be made to promote postoperative outcomes and improve the quality of sexual life by activating relevant muscle groups.

Materials and Methods

Study Subject

This study included 145 patients who visited the Department of Obstetrics and Gynecology at Southern Medical University Nanfang Hospital from May 2022 to May 2024. Among them, 100 patients expressed a need for sexual activity, comprising 47 patients without POP and 53 patients with POP. All patients experienced vaginal delivery and had no history of macrosomia and forceps delivery. Prior to surgery, all patients underwent MRI examinations. For the 53 patients with POP symptoms, clinical symptoms were carefully evaluated by researchers, who conducted POP-Q scoring (POP grading in II-IV degrees). Exclusion criteria for MRI included (1) conditions that could alter pelvic floor anatomy, such as large uterine fibroids, significant pelvic masses, or pelvic deformities; (2) claustrophobia. All patients that excluded contraindications for the MRI examination provided informed consent.

POP-Q Assessment

POP-Q evaluation was performed by urogynaecology specialists according to the POP-Q system [7]. Organ descent or protrusion was assessed during a maximum Valsalva maneuver (lasting at least 5–6 s), measuring six points in the vagina in centimeters relative to the hymen. Points above the hymen were recorded with negative values, the hymen point was set at 0, and points below the hymen were assigned positive integers. The distances from the anterior vaginal wall point (Ba), posterior vaginal wall point (Bp), and the lowest point of the uterus (C) to the hymenal margin were gauged, with points below marked as "+" and those above as "–". At rest, total vaginal length (TVL), genital hiatus (GH) point, and perineal body (PB) point were recorded. POP was classified into four degrees: 0 cm indicating no POP (0°), −3 to −1 cm denoting I-degree prolapse, −1 to +1 cm representing II-degree prolapse, +1 to (TVL-2) cm indicating III-degree prolapse, and > (TVL-2) cm signifying IV-degree prolapse.

MRI Examination Instruments and Equipment

The MRI was conducted using a Philips Achieva TX 3.0 T system (the Netherlands) with an eight-channel abdominal coil. Static scans included conventional T2W_TSE sequences in axial, sagittal, and coronal planes. The axial plane extended from the fifth lumbar vertebra to 1 cm below the perineum. The sagittal plane encompassed both sides of the ischial spines. The coronal plane extended from the pubic symphysis in the front to the sacrococcygeal area in the back. Key parameters for the static scans included repetition time (TR)/echo time (TE): 3,000–5,000 ms/85 ms; Flip angle: 180°; Field of view: 260 mm × 360 mm × 262 mm; Matrix: 512 × 512; Slice thickness: 3.0 mm; Slice gap: 0.5 mm. The scanning duration was 7–8 min.

3D Reconstruction, Automated NURBS Surface Conversion, Material Property Assignment, and Model Parameter Measurement

Image Selection and 3D Reconstruction

The T2W_TSE scanning sequence was selected for static scans. The DICOM 3.0 raw cross-sectional images obtained from the scans were directly imported into the

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3D reconstruction software Mimics 21.0 (Materialise, Belgium). Cross-sections were edited to identify structures such as the obturator internus, bulbospongiosus, ischiocavernosus, pubococcygeus muscle, and levator ani muscle. Masks were created to completely outline these structures. The software's erasing and drawing tools were used to refine the mask boundaries and remove irrelevant edge noise and redundant data, yielding accurate boundaries of the pelvic organ structures. The images were then converted into a 3D model and saved in STL format.

NURBS Surface Automatic Conversion

The relevant pelvic floor soft tissues identified in section 2.1 (including the obturator internus, bulbospongiosus, ischiocavernosus, pubococcygeus muscle, and levator ani muscle) were imported into Geomagic Wrap (3D Systems, USA) as STL files. A highly detailed polygon model and mesh structure were extracted, enabling automated conversion to NURBS surfaces. During the preprocessing phase of point cloud data, outliers were removed, the data were relaxed and denoized, holes were patched, and surface smoothing was applied, resulting in polygon meshes. In the precise surface stage, various operations, such as contour exploration, editing, construction, and repair, were conducted to reconstruct surface patches. Finally, grids were constructed and repaired to form fitted surfaces. The generated solid model was automatically diagnosed and verified, then saved and exported in IGS format.

Material Property Assignment

SolidWorks (Dassault Systèmes, France) was used to assign material properties to the solid model, specifically based on literature or experimental measurements. For muscle tissue, the following properties were defined: elastic modulus (kPa): 0.0004, Poisson's ratio: 0.45, density (kg/m^3): 1,057 [8].

Model Parameter Measurement

The IGS model generated by Geomagic Wrap was exported to SolidWorks. In SolidWorks, material properties were assigned to the solid model (as detailed in section 2.3). Then, tissue characteristics were evaluated by clicking the quality attribute in the SolidWorks tabs, allowing for automatic analysis of results such as mass, volume, and surface area. The thickness analysis option in the SolidWorks tabs identified regions of varying thickness and displayed them in different colors, providing a reference range for the solid model's thickness from the thinnest to the thickest areas.

Results

Data analysis was conducted using SPSS 26.0 software.

General Data

No statistically significant differences ($p > 0.05$) were found in age, weight, and BMI. Refer to Table 1 for details.

Comparison of Muscle Morphological Parameters between the Two Groups

The volume, mass, and measurable thickness range (thicker regions) of the bulbospongiosus muscle were analyzed (Fig. 1a: parameters for non-POP patients; Fig. 1b: parameters for POP patients). The surface areas of the pubococcygeus muscle (Fig. 2a: non-POP patients; Fig. 2b: POP patients; Fig. 2c: MRI image of pubococcygeus muscle; Fig. 2d: Mimics 3D reconstruction of the pubococcygeus muscle) and the levator ani (Fig. 3a: non-POP patients; Fig. 3b: POP patients) showed statistically significant differences between the two groups ($p < 0.05$). Refer to Table 2 for details.

Discussion

Sexual issues significantly impact the quality of life and emotional health, representing an essential aspect of human experiences. Female sexual dysfunction includes disorders related to sexual interest, arousal, orgasm, and sexual pain [9]. This condition is prevalent among women. It has been reported outside China that the incidence rate is up to 30%–50% in the general population [10]. Patients with POP and/or urinary incontinence typically suffer degradation in sexual function or sexual health [11, 12]. Due to cultural differences and varying attitudes toward sex, research on sexual activity among Chinese women is rare. A joint study from Peking University People's Hospital discovered that approximately 63% of sexually active women of reproductive age with POP experience some degree of sexual dysfunction [13]. POP, characterized by the protrusion of tissue through the vaginal opening, leads to urinary urge incontinence, nocturnal, obstructive defecation, fecal incontinence, and pain [14–18]. This can further damage the vaginal mucosa and prolapsed organs, as well as induce bleeding, secondary infections, diminished genital sensation, and perineum contamination from urine and feces. Consequently, many patients may refuse sexual activity due to embarrassment or concerns about their partner's satisfaction. They may further develop a fear of sexual intimacy. This can

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Table 1. Comparison of general conditions between the POP and non-POP groups

	Non-POP	POP	t/Z	*p*
Age, years	56 (53, 61)	58.5 (56, 65)	−1.793	0.073
Weight, kg	57 (51, 63)	58 (50.188, 61.775)	−0.314	0.753
BMI, kg/cm^3	23.31 (20.2, 25.24)	23.205 (21.985, 25.16)	−0.666	0.505
Parity, time	2 (1, 2)	2 (2, 3)	−1.951	0.051

Fig. 1. Parameters of the bulbocavernosus muscle. **a** Parameters of the bulbocavernosus muscle in non-POP patients. **b** Parameters of the bulbocavernosus muscle in POP patients. POP, pelvic organ prolapse.

profoundly undermine their mental health, family stability, and overall quality of life.

The bulbospongiosus and pubococcygeus muscles play critical roles in sexual arousal during female sexual activity. The bulbospongiosus muscle originates from the central tendon of the perineum, extends forward along both sides of the vagina to attach to the cavernous body of the clitoris, and crosses and mingles with the external anal sphincter at the back. Contraction of the bulbospongiosus muscle enhances vaginal tightness and assists clitoral erection by compressing the cavernous body of the clitoris and dorsal vein, thereby promoting sexual pleasure. The pubococcygeus muscle is a component of the levator ani muscle group and is situated on the medial side. The muscle fibers originate from the inner surface of the descending branch of the pubic bone, extend along the vaginal and rectal regions, and terminate at the coccyx. A small portion of the muscle fibers also concludes near the vagina and rectum, contributing to rhythmic contractions during orgasm. It collaborates with the bulbospongiosus muscle to enhance the vaginal grip on the penis by stimulating the anterior vaginal wall complex [19]. The levator ani muscle, a key pelvic floor muscle that seals the pelvic outlet, is situated at the innermost layer of the pelvic floor. Its muscle fibers run from the inner surface of the ischiopubic ramus, encircle the vagina and rectum, and terminate at the coccyx, forming the primary support structure of the pelvic floor. Studies show that women with stronger pelvic floor muscle strength, whether of reproductive age or postmenopausal, generally exhibit better sexual function and quality of sexual life compared to those with weaker pelvic floor strength [20, 21].

Historically, the sexual function of women with POP has received little attention. POP can alter the appearance of female genitalia and negatively impact body image [22], leading to depression and a lack of confidence [23]. It is only in the past decade that sexual function has become a significant outcome measure in post-surgical evaluations [24, 25]. Research outside China has indicated that surgical treatment can ameliorate sexual function [26, 27]. However, the focus in evaluating treatment outcomes for POP has often been on restoring anatomical rather than functional results [22]. The

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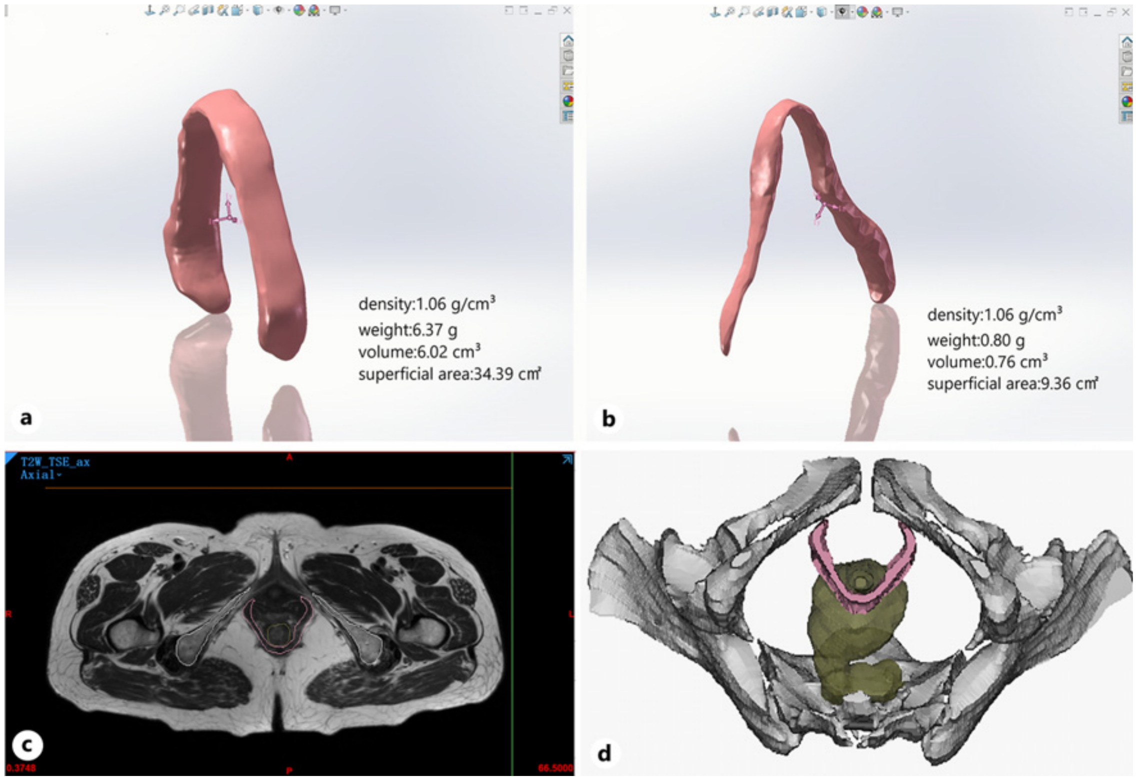

Fig. 2. Parameters of the pubic visceral muscle. **a** Parameters of the pubic visceral muscle in non-POP patients. **b** Parameters of the pubic visceral muscle in POP patients. **c** In the MRI image, the border is outlined as the pubic rectal muscle, the brown-green circle is the rectum, and the white is the pelvic part. **d** Mimics 3D reconstruction of the pubic rectal muscle (pink), rectum (brown and green), and pelvis (white). POP, pelvic organ prolapse.

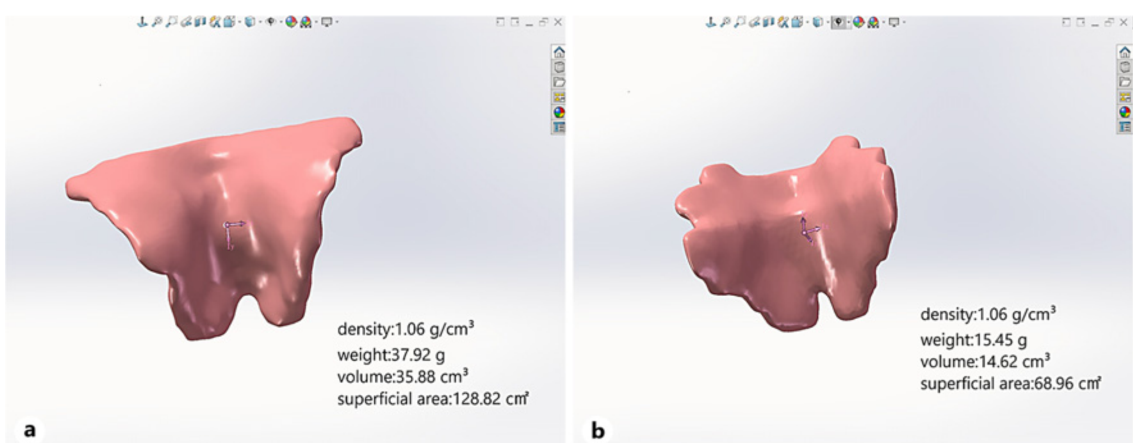

Fig. 3. Parameters of the levator ani muscle. **a** Parameters of the levator ani muscle in patients with POP. **b** Parameters of the levator ani muscle in patients with non-POP. POP, pelvic organ prolapse.

collaborative role of the bulbospongiosus, pubococcygeus muscle, and levator ani muscles in women's sexual activity is pivotal. The findings in this study demonstrated statistically significant differences in the volume, mass, and measurable thickness (thicker regions) of the bulbospongiosus muscle, as well as in the surface area of the

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Table 2. Comparison of muscle morphological parameter values between the POP and non-POP groups

	Patient		*t/Z*	*p*
	POP	no POP		
Total volume of obturator internus	48.26 (41.2, 55.23)	50.44 (43.37, 56.97)	1.466	0.143
Total surface area of obturator internus	152.09±20.7	154.44±22.86	0.584	0.56
Total weight of obturator internus	51.03 (43.7, 58.37)	53.31 (45.85, 60.22)	1.292	0.196
Total volume of bulbospongiosus	1.94 (1.13, 3.81)	3.19 (2.15, 4.86)	2.917	0.004
Total surface area of bulbospongios	23.47±7.75	20.72±9.27	1.738	0.085
Total weight of bulbospongios	2.05 (1.22, 4.02)	3.37 (2.28, 5.13)	2.907	0.004
The smallest thickness of bulbospongios	0.11 (0.08, 0.14)	0.13 (0.1, 0.14)	1.918	0.055
The largest thickness of bulbospongios	0.4 (0.28, 0.51)	0.5 (0.41, 0.57)	3.793	0
Total volume of ischiocavernosus	2.32 (1.78, 3.61)	2.58 (1.59, 4.16)	0.512	0.609
Total surface area of ischiocavernosus	18.72 (16.34, 25.17)	20.23 (14.94, 28.16)	0.754	0.451
Total weight of ischiocavernosus	2.45 (1.88, 3.82)	2.72 (1.68, 4.35)	0.499	0.618
The smallest thickness of ischiocavernosus	0.12 (0.09, 0.14)	0.12 (0.1, 0.14)	0.433	0.665
The largest thickness of ischiocavernosus	0.46 (0.34, 0.51)	0.48 (0.4, 0.54)	1.263	0.206
The distance between the two feet of ischiocavernosus	8.37±1.26	8.18±1.06	0.9	0.37
Total volume of pubococcygeus muscle	2.32 (1.69, 3.25)	2.67 (1.71, 5.41)	1.794	0.073
Total surface area of pubococcygeus muscle	19.11 (15.33, 23.96)	22.95 (16.08, 32.67)	2.01	0.044
Total weight of pubococcygeus muscle	2.45 (1.79, 3.43)	2.82 (1.81, 5.72)	1.786	0.074
The smallest thickness of pubococcygeus muscle	0.14 (0.11, 0.15)	0.12 (0.1, 0.15)	1.833	0.067
The largest thickness of pubococcygeus muscle	0.49 (0.42, 0.55)	0.5 (0.41, 0.59)	0.72	0.471
Total volume of levator ani	23.01 (18.46, 25.96)	22.5 (17.87, 26.11)	0.459	0.646
Total surface area of levator ani	104.71 (89.57, 123.26)	97.56 (83.78, 110.68)	2.099	0.036
Total weight of levator ani	24.32 (19.49, 27.94)	23.78 (18.89, 27.59)	0.522	0.602
The smallest thickness of levator ani	0.21 (0.18, 0.25)	0.22 (0.18, 0.25)	0.066	0.947
The largest thickness of levator ani	0.8 (0.69, 0.91)	0.88 (0.73, 0.99)	1.881	0.06

pubococcygeus muscle and levator ani muscles between the two groups. This suggests that POP may lead to morphological changes in pelvic floor muscles involved in sexual activity, thereby increasing the incidence of sexual dysfunction among patients with POP. Research by Verbeek and Zhuo et al. [22, 28] also supports a higher incidence of sexual dysfunction associated with POP, though they did not examine specific morphological changes in pelvic floor muscles. Therefore, in addressing POP and related sexual dysfunction in women, it is essential to focus not only on restoring anatomical structures but also on the functional recovery of the muscles involved in female arousal and orgasm. Tailed treatment plans should be formulated to better meet the needs of patients.

Conclusion

This study examined 47 patients without POP and 53 patients with POP. Actual human imaging and 3D reconstruction were employed to create biological models of muscle morphology using engineering software, accurately depicting the morphological characteristics of specific pelvic floor muscle tissues. The volume, mass, surface area, and measurable thickness (thicker regions) of the pelvic floor muscles primarily involved in sexual activity in both POP and non-POP women were analyzed. This study effectively visualized the deterioration (volume and mass) and coloboma of these essential pelvic floor muscles in the context of POP, providing a theoretical basis for recognizing the anatomical regions in

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women with POP that are more likely to induce sexual dysfunction. In the treatment of POP, it is pivotal to prioritize the restoration of sexual function post-surgery. Developing targeted training programs for the pelvic floor muscles can heighten the strength and coordination of weakened muscles, ultimately improving patients' sexual function and quality of sexual life.

Statement of Ethics

This study was conducted in accordance with the declaration of Helsinki. This study was conducted with approval from the Medical Ethics Committee of Hainan General Hospital, Approval No. Med-Eth-Re [2025]24. Written informed consent was obtained from the participants.

Conflict of Interest Statement

All authors declare that they have no conflict of interests.

Funding Sources

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sector.

Author Contributions

L.S. and H.B. contributed to conceiving and designing the study, collecting the data, analyzing and interpreting the data, writing the manuscript, providing critical revisions that are important for the intellectual content, and approving the final version of the manuscript.

Data Availability Statement

The data that support the findings of this study are not publicly available due to their containing information that could compromise the privacy of research participants but are available from L.F.S. upon reasonable request.

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