Changes in Levator Ani Anatomical Configuration Following Physiotherapy in Women With Stress Urinary Incontinence

C. Dumoulin,*,† Q. Peng,† H. Stodkilde-Jorgensen,‡ K. Shishido† and C. Constantinou†

From the University of Montreal, Montreal, Quebec, Canada

Purpose: We quantified the effect of pelvic floor muscle training on the anatomical configuration of the levator ani using magnetic resonance imaging.

Materials and Methods: Five female participants with stress urinary incontinence underwent magnetic resonance imaging before and after participating in a pelvic floor muscle physiotherapy program. Axial T1-weighted images of the levator ani were taken with the participant in a supine position. Source images were then manually segmented and surface modeling was applied to build a 3-dimensional model of the levator ani. Models were then measured to determine the levator ani surface area as well as the encircled volume at rest and during voluntary contraction. The percentage of levator ani retraction and symphysis pubis movement during voluntary contraction before and after physiotherapy were also measured.

Results: After physiotherapy the levator ani surface area at rest was significantly smaller than before physiotherapy, decreasing from 677.11 ± 45.00 to 620.48 ± 36.14 mm^2 ($p = 0.04$). The relative reduction in volume encircled by the levator ani during contraction increased significantly from −11.66 ± 7.42 to −26.02 ± 13.52 mm^3 ($p = 0.04$). Levator ani surface retraction during a voluntary contraction increased significantly from 65.61% ± 17.07% to 81.70% ± 16.30% ($p = 0.02$). Symphysis pubis movement during pelvic floor muscle contraction decreased from 1.45 ± 1.32 to 0.44 ± 0.61 mm ($p = 0.05$).

Conclusions: Findings from this preliminary study indicate that pelvic floor muscle training results in anatomical changes in the levator ani and reduction of pubic movement. These results provide insight into the possible anatomical mechanisms through which physiotherapy enables the pelvic floor muscle to minimize urine leakage.

Key Words: magnetic resonance imaging; pelvic floor; physical therapy modalities; urinary incontinence, stress; imaging, three-dimensional

Pelvic floor muscle training has been proven to be effective in reducing stress and mixed UI in women.[1] However, the underlying anatomical and physiological mechanisms through which PFM training prevents urine leakage are not yet fully understood. One hypothesis is that a strong PFM contraction, as taught in physiotherapy, clamps the urethra and increases urethral closure pressure, thus preventing urine leakage upon effort.[2] Another hypothesis is that the bladder neck receives support from PFM muscle tone limiting its downward movement upon effort.[3] Indeed, the rationale behind PFM physiotherapy is that it improves PFM strength and tone.[2,3] Therefore, to better understand the role of the PFM it is important to examine the effect of physiotherapy programs on the PFM anatomy, especially the levator ani portion at rest and during contraction.

To date, changes in the anatomical configuration of the LA after PFM training have not been systematically studied. This article introduces a new approach using 3-dimensional reconstruction modeling of the LA, which quantitatively describes the morphology at rest and computes the changes that occur during voluntary contraction. Using 3D reconstruction modeling, we present the effects of PFM physiotherapy on the anatomical configuration of the LA at rest and during voluntary contraction.

MATERIALS AND METHODS

Participants

In quasi-experimental pre-test/post-test designed study we examined MRI data before and after physiotherapy. Incontinent women were recruited at the Skejby University Hospital, Denmark through urologist/gynecologist referrals. To be eligible participants had to have urodynamically proven stress UI and no prior surgery, MRI incompatibility or PFM training within the last year. Five women participated in the study after giving informed consent. No financial compensation was provided. Mean patient age was 44.40 ± 7.77 years (range 33 to 53). Mean body mass index was 24.88 ± 3.51 kg/m^2 (range 22.60 to 30.10) and mean parity was 2.4 ± 0.55 babies.[2,3]

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Study received institutional review board approval.

* Correspondence: School of Rehabilitation, University of Montreal, CP 6128 succursale, Centre-Ville, Montreal, Quebec H3C 3J7 Canada (telephone: 514-577-1793; FAX: 514-344-1991; e-mail: chantal.dumoulin@umontreal.ca; dumoulin@sympatico.ca).

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Experimental Setting

A physiotherapist specializing in PFM training instructed the participants on how to correctly perform PFM contractions using vaginal palpation. For 2.5 months they participated in 7 group exercise sessions 1 hour each of strengthening and motor relearning exercises. They were also expected to perform these exercises at home 7 days a week throughout treatment.[4,5]

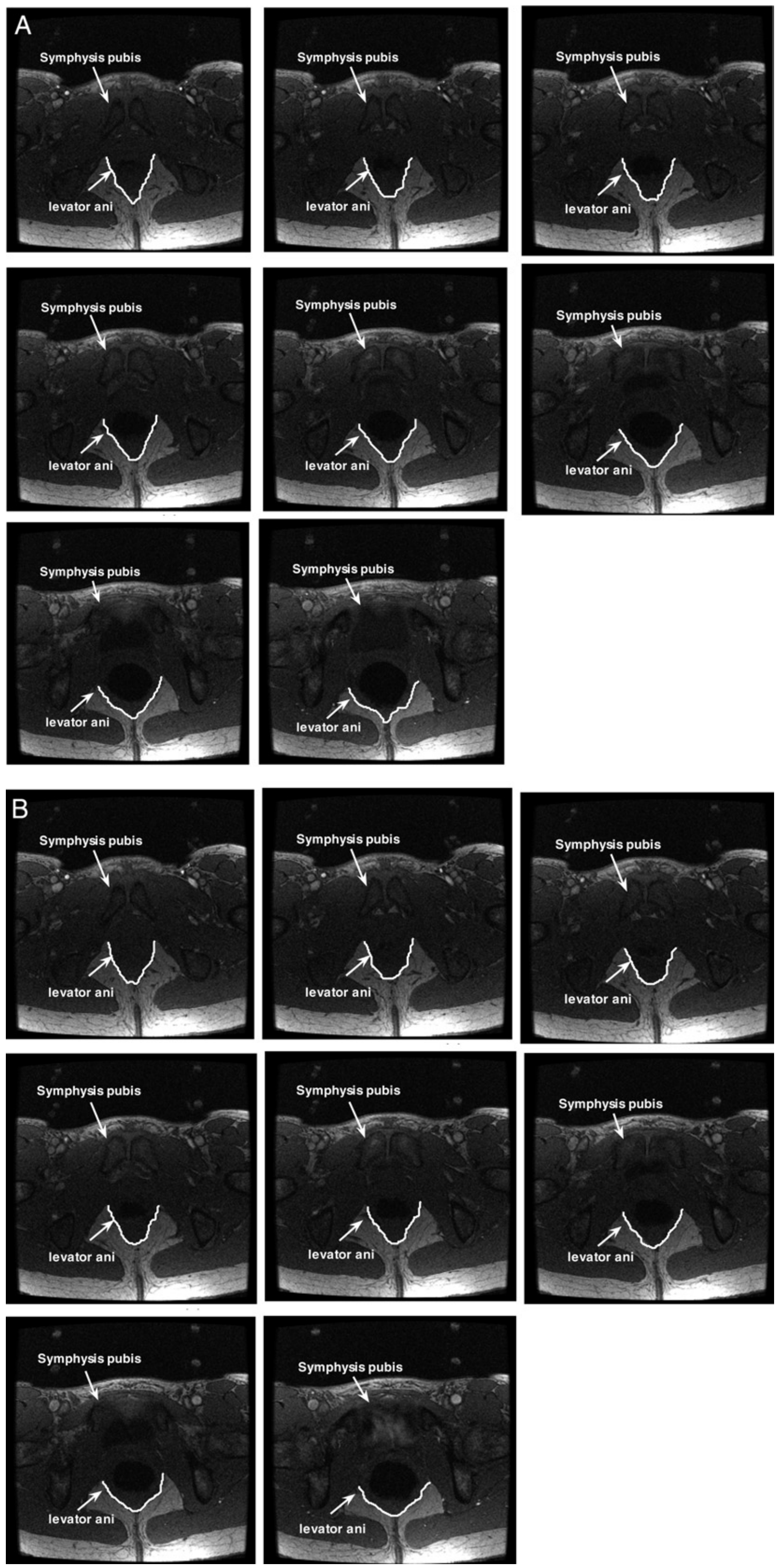

FIG. 1. *A*, T1-weighted axial image of 47-year-old participant with manual segmentation of LA at rest. *B*, T1-weighted axial image of same participant with manual segmentation of LA during voluntary contraction.

Image data were obtained using a General Electric Signa® 1.5T Twin Speed. A phased array torso coil tuned for PFM imaging was centered on the symphysis pubis. A spoiled gradient sequence of T1-weighted images was used with the parameters of repetition time 70 ms, echo time 3.3 ms, flip angle 60 degrees, field of view 24 cm, slice thickness 5 mm, gap 2.5 mm, matrix 256 × 256, number of excitations 2 and scan time 36 seconds. Eight axial images were taken of 2 conditions, that is at rest and during a PFM voluntary contraction. Before scanning participants adopted a supine position on the MRI table with hips and knees flexed, supported by pillows. For images at rest they were instructed to relax the PFM while breathing in and out normally for 36 seconds. The women remained in the same position and maintained a voluntary PFM contraction for 36 seconds while the second set of images was taken. This MRI acquisition sequence was performed before the first and just after the last physiotherapy session in the program.

Imaging Processing

Image processing algorithms based on the Matlab® platform were developed to quantitatively analyze changes in the 3D geometry of the LA before and after PFM physiotherapy. The image processing algorithms included 4 steps of 1) manual segmentation of the LA, 2) automatic registration of the SP, 3) 3D reconstruction of the LA geometry and 4) quantitative calculation of the LA geometric parameter. The contours of the LA were manually segmented on all the axial images at rest and during voluntary PFM contraction, before and after PFM physiotherapy, by 2 evaluators (CD, QP) (fig. 1). To compare the LA geometry at rest and during contraction it was necessary to register both sets of images using the SP because it offered the most stationary, rigid, nondeforming structure. Thus, an automatic algorithm was developed to register MRI images of the SP at rest and during a PFM contraction. Initially a template of the SP was manually defined in the MRI image at rest. Then the template was compared with the corresponding MRI image of a PFM contraction with different offsets in x and y directions. Registration of the SP was performed in the 8 axial images at rest, and before and after physiotherapy. Figure 2 shows the SP template, the value of the difference function and the matched position of the SP in the MRI image with contraction.

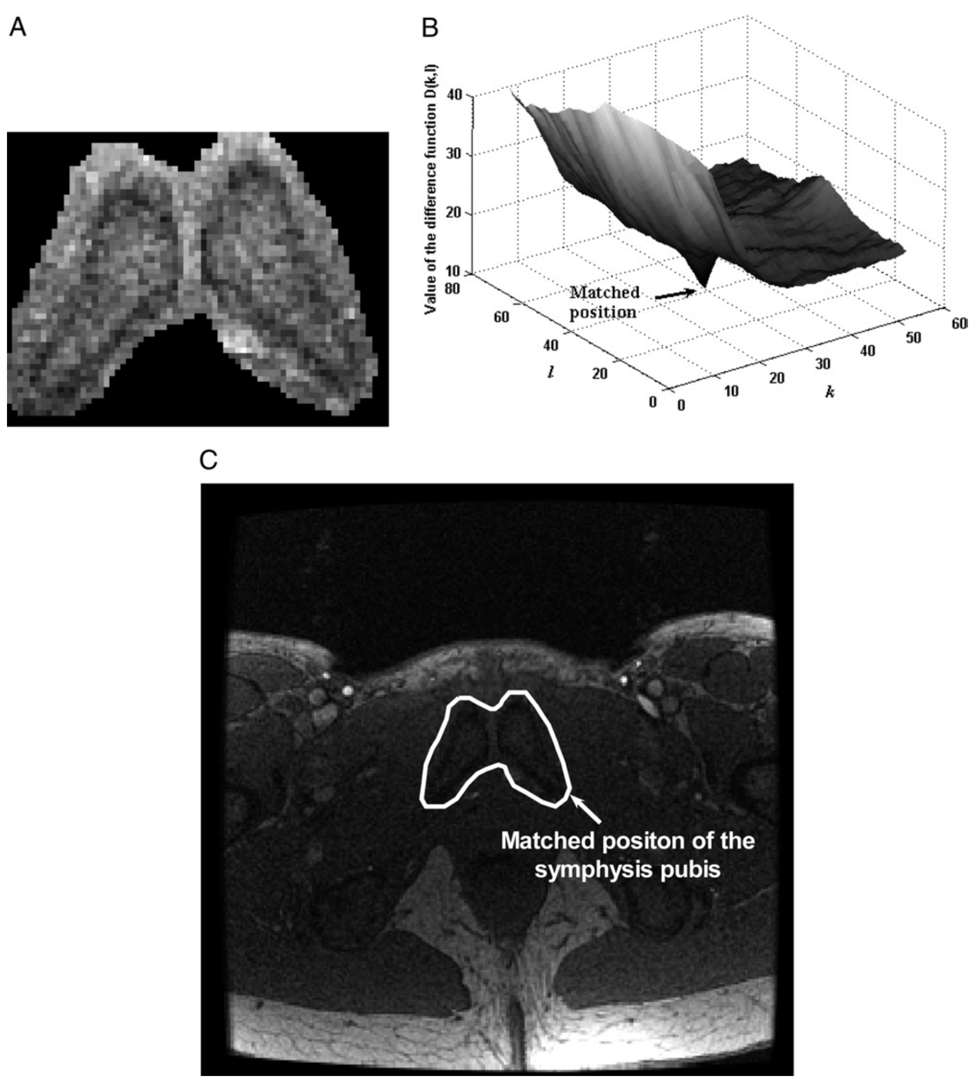

FIG. 2. Matching images at rest and with PFM contraction using symphysis pubis as fixed anatomical structure. *A*, template of SP at rest. *B*, value of difference function. *C*, matched position of SP in MRI with PFM contracted.

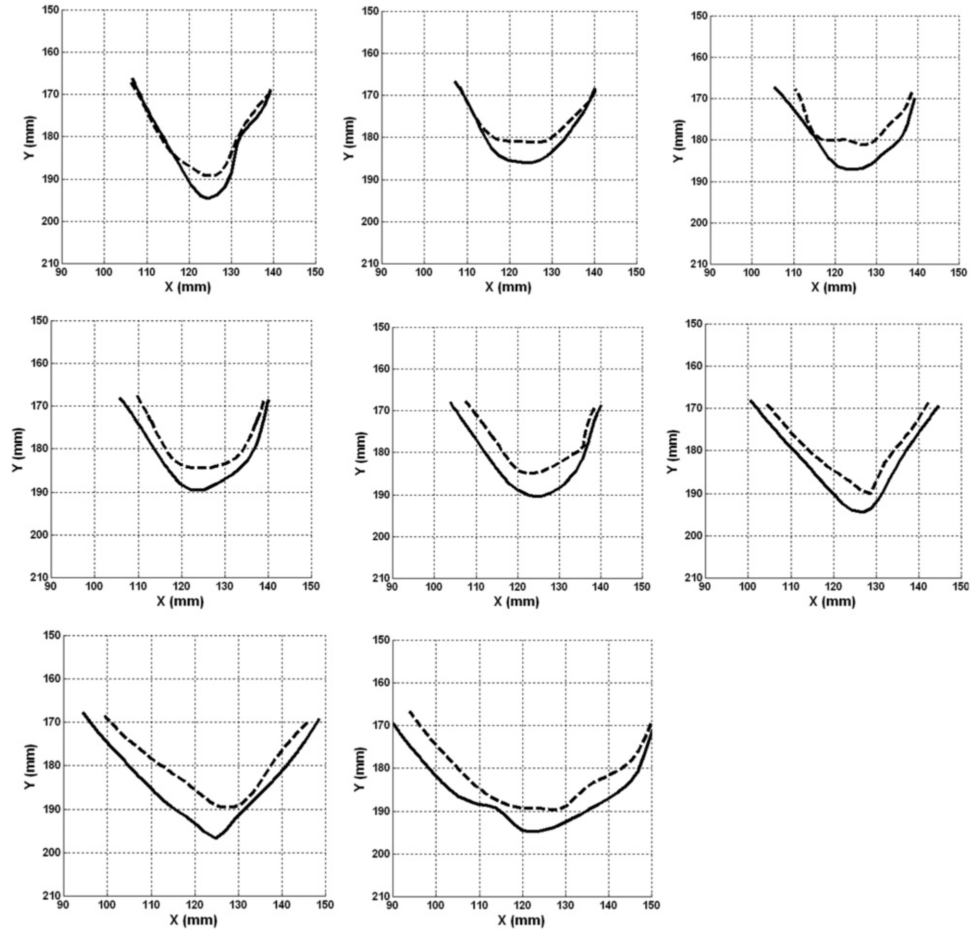

FIG. 3. Results of segmentation of LA contour for 8 pairs of images in 47-year-old participant. Solid line represents resting state and broken line represents PFM contraction state.

Figure 3 compares the LA contours with and without a PFM contraction. Body movements were corrected using SP registration. The 3D views of the LA at rest and during contraction were then reconstructed and overlapped to highlight any differences.

Quantitative Analysis

Assuming that during a PFM contraction the LA retracts and squeezes toward the SP, giving more support to tissues such as the bladder and increasing urethral closure pressure, it is important to quantitatively calculate the extent of these changes on the anatomical configuration of the LA. Several parameters were developed to enable this calculation.

LA surface area (S): S (mm^2) is the contour of the LA in the 3D reconstruction model. S_{rest} and $S_{contraction}$ are the LA surface areas at rest and during contraction. To calculate S_{rest} and $S_{contraction}$ accurately, the surface between 2 neighboring MRI slices was divided evenly into 72 small pieces. The area of the whole surface was then calculated by summing the area of all the small pieces.

Relative change in LA surface area (R_s):

$$R_s = \frac{\Delta S}{S_{rest}} = \frac{S_{contraction} - S_{rest}}{S_{rest}} \times 100\%$$

where R_s(%) is the relative change in LA surface area between an image at rest and during a PFM contraction. According to this equation if R_s is greater than 0, the surface of the LA expands during a PFM contraction. If R_s is less than 0 then the surface of the LA retracts during a contraction.

Volume encircled by LA (V): V (mm^3) is the volume inside the LA contour of a 3D reconstruction model. V_{rest} and $V_{contraction}$ are the volumes encircled by the LA contours at rest and during contraction.

Relative change in volume encircled by LA surface (R_v):

$$R_v = \frac{\Delta V}{V_{rest}} = \frac{V_{contraction} - V_{rest}}{V_{rest}} \times 100\%$$

where R_v(%) is the relative change in volume encircled by the LA between the image at rest and during a PFM contraction. According to this equation R_v is greater than 0 if the volume increases during a contraction and R_v is less than 0 if the volume decreases during a contraction.

Percentage of LA surface area during PFM contraction inside LA surface area at rest:

$$R_c = \frac{S_{inside}}{S_{rest}} \times 100\%$$

where S_{inside} is the LA surface during a contraction. According to this equation when R_c is less than 50%, the LA surface shows greater retraction than expansion during a contraction. When R_c is greater than 50% the LA surface shows more expansion than retraction during a contraction.

To study the balance between the left and right sides, the LA was divided into quadrant I (left LA) and quadrant II (right LA). The 3 parameters (3 equations) were measured in each quadrant and the 2 quadrants combined (quadrants I and II). Close examination of the images indicates that the SP exhibited nonnegligible movement during a PFM contraction. To compare the changes in the 3D geometry of the LA, the relative movement of the SP was corrected using the image registration method (fig. 2). However, because SP movement could have been related to participant difficulty in contracting the PFM, SP movements before and after physiotherapy during PFM contraction were compared.

Statistical Analysis

The measurements of the 5 parameters taken by the 2 evaluators were assessed for inter-rater agreement. Intraclass correlation coefficients were applied and 95% confidence intervals were computed to estimate reliability coefficients. For each individual the mean of the 2 evaluator measurements for the 5 parameters before and after treatment were compared using paired t tests.[6] Two-sided p values <0.05 were considered significant. All analyses were performed using SPSS® for Windows (version 13.0) software.

RESULTS

Figure 4 presents a 3D reconstruction and visualization of the LA after physiotherapy changes. It shows the typical LA geometric differences at rest and during contraction. Figure 5 shows before and after measurements of 4 major parameters for each participant. The table gives group means before and after physiotherapy, and results of the paired t test.

Surface Area

As indicated in the table the LA surface area at rest (S_{rest}) was significantly reduced following physiotherapy. The relative change in the LA surface area value in quadrants I and II (R_SL+R) was less than 0, before and after physiotherapy, implying that the LA area retracted during contraction. Moreover, the post-intervention (R_SL+R) value tended to be smaller than the pre-intervention (R_SL+R) value. This suggests that after physiotherapy the LA surface area tends to retract more during contraction. The right LA quadrant (R_SR) presented similar results, although the left LA quadrant (R_SL) value after physiotherapy was significantly smaller than the value before physiotherapy.

Volume

As indicated in the table the volume encircled by the LA at rest (V_{rest}) was smaller after physiotherapy, albeit not significantly, suggesting that it may be reduced as a result of the treatment protocol. The relative change in volume encircled by the LA surface in quadrants I and II (R_vL+R) was less than 0, before and after physiotherapy, implying that the volume decreases during a contraction. There was a significant difference between (R_vL+R) before and after physiotherapy, the latter being smaller. The left and right LA quadrants (R_vL, R_vR) presented similar results but did not reach significance.

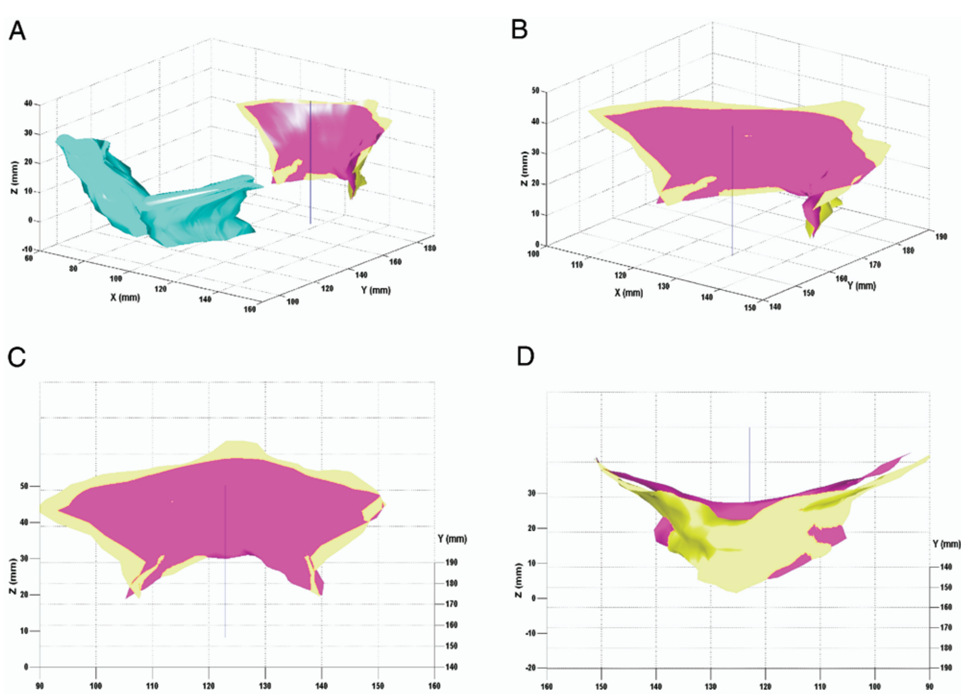

FIG. 4. 3D reconstruction and visualization of LA after physiotherapy intervention. PFM at rest and during voluntary contraction are shown in yellow and pink, respectively. *A*, 3D view of LA and SP. *B–D*, 3D views of LA from different angles. Entire surface of LA during PFM contraction is inside (toward pubis) and both sides of LA seem to behave in same way.

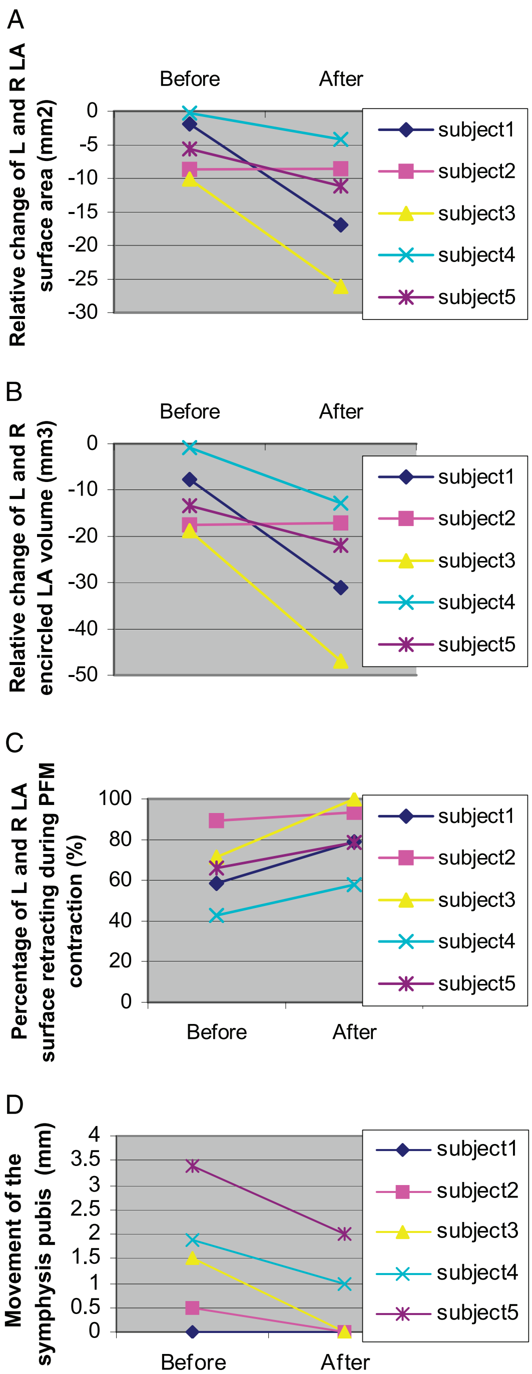

FIG. 5. Values before and after physiotherapy for 5 participants according to 3D reconstruction parameter. *A*, relative change of left and right LA surface area. *B*, relative change of left and right encircled LA volume. *C*, percentage of left and right LA surface retracting during PFM contraction. *D*, movement of symphysis pubis.

Percentage of LA Retraction During Voluntary Contraction

As indicated in figure 5 the percentage of the LA surface area inside quadrants I and II (R_cL+R) was greater than 50% for 4 of 5 participants before physiotherapy. This implies that for 4 participants the LA surface area demonstrated greater retraction than expansion during a PFM contraction before physiotherapy. After physiotherapy quadrants I and II (R_cL+R) exceeded 50% for all 5 participants. This suggests that after physiotherapy all participants could produce a PFM contraction in which retraction was more pronounced than expansion. There was a significant difference between (R_cL+R) values before and after physiotherapy, the latter being larger. This implies that (R_cL+R) increases significantly following physiotherapy. The left and right LA quadrants (R_cL, R_cR) showed similar results but did not reach significance.

Pubic Movement

Pubic movement during PFM contraction was significantly reduced following physiotherapy (from 1.45 ± 1.32 to 0.44 ± 0.61 mm, $t = 2.64$, $p = 0.05$), suggesting that the PFM voluntary contraction can generate a more focused muscle activation as a result of PFM physiotherapy.

The intraclass correlation coefficients were all excellent, indicating an excellent reliability for those measurements. For LA surface area 95% CI was (0.969; 0.998), and the left and right surfaces estimations of reliability were (0.806; 0.986) and (0.886; 0.990), respectively. For volume the 95% CI was (0.799; 0.985) and for left volume only the interval was (0.825; 0.987). For retraction the 95% CI was (0.850; 0.989), and the left and right retraction estimations of reliability were (0.812; 0.986) and (0.772; 0.983), respectively. For SP movement the 95% CI was (0.959; 0.998).

DISCUSSION

Strength training aims to change muscle morphology by increasing muscle cross-sectional area and tone.[7] It also increases muscle strength and improves neuromuscular functioning.[7] To our knowledge this is the first reported study using MRI to measure changes in muscular anatomical configuration after physiotherapy. Results suggest the presence of anatomical changes in LA at rest and during contraction following physiotherapy.

At rest following physiotherapy the LA surface area was smaller, suggesting an increase in levator passive tone. Although further assessment using PFM dynamometry would be needed to confirm this hypothesis, our results lend strong support to the biological rationale that strength training enhances PFM passive tone. Good LA stiffness is believed to facilitate more effective automatic motor unit firing, and to limit backward and downward movement during effort and exertion, thereby preventing UI.[2,8] Other groups have observed, albeit indirectly, a potential increase in levator stiffness following PFM training. Using a pressure probe inside the vagina, Griffin et al showed a significant difference in PFM resting pressure 3 to 4 weeks after starting PFM physiotherapy.[9] Furthermore, Balmforth et al reported increased urethral stability at rest and during effort following PFM physiotherapy.[10] In addition, using MRI Hoyte et al compared continent women and women with stress UI, and reported that the latter group demonstrated a higher mean width value of the levator hiatus at rest.[11]

During voluntary contraction the relative changes in the volume encircled by the LA and the percentage of LA surface retraction were significantly greater after physiotherapy. These changes support the hypothesis that PFM physiotherapy increases levator strength and forward-squeeze movement around the urethra, vagina and rectum.[2,3] These results are consistent with several randomized clinical trials showing an increase in PFM strength as indirectly measured with a pres-

Measurement of LA anatomical configuration changes before and after physiotherapy intervention

	Mean (SD)			
	Before Physiotherapy	After Physiotherapy	Paired t Test	p Value*
LA surface area (mm^2)	677.11 (45.00)	620.48 (36.14)	2.97	0.04*
Relative change of lt + rt LA surface area (mm^2)	−5.20 (4.40)	−13.39 (8.49)	−2.59	0.06
Relative change of lt LA surface area (mm^2)	−5.33 (3.50)	−11.13 (7.04)	−2.90	0.04*
Relative change of rt LA surface area (mm^2)	−5.85 (6.35)	−17.28 (12.90)	−1.20	0.13
Vol encircled by LA (mm^3)	8,691.97 (1,108.95)	7,524.61 (660.98)	1.91	0.13
Relative change of lt + rt LA encircled vol (mm^3)	−11.66 (7.42)	−26.02 (13.52)	−2.79	0.04*
Relative change of lt LA encircled vol (mm^3)	−12.17 (5.84)	−22.47 (11.06)	−2.71	0.06
Relative change of rt LA encircled vol (mm^3)	−11.12 (9.52)	−28.13 (17.18)	−2.30	0.08
% Lt + rt LA surface retracting during contraction	65.61 (17.07)	81.71 (16.30)	3.92	0.02*
% Lt LA surface retracting during contraction	64.45 (13.26)	75.17 (22.92)	1.40	0.24
% Rt LA surface retracting during contraction	66.53 (21.58)	87.04 (15.95)	2.31	0.82

* Paired t test $p < 0.05$.

sure probe following PFM physiotherapy.[4,12] MRI studies of morphological changes from resting state to voluntary contraction support the forward-squeeze observation. However, none of them looked at before and after treatment or incontinent-continent comparisons.[13–16]

Finally SP movement during PFM contraction was reduced following physiotherapy. It is hypothesized that this finding can be related to an improvement in PFM neuromuscular functioning as a consequence of muscle training. The findings of this study are consistent with those of Russell et al, who found that PFM training significantly improved isolated and focused activation of PFM in participants with incorrect contraction before training.[17] Thus, physiotherapy seems to affect the LA anatomical configuration at multiple levels as well as SP movement.

While this initial study contributes new information to earlier studies on the anatomical and physiological impact of physiotherapy, it has the inherent limitations of a pilot study. As an uncontrolled study we cannot definitively conclude whether the MRI results were due to the effectiveness of the training program, or to other environmental or lifestyle factors. Additionally, a 36-second contraction was needed to obtain the image quality necessary for 3D reconstruction. While participants did not indicate any difficulty maintaining a 36-second contraction, the possibility exists that before the PFM training MRI measurements may have been affected by the inability to maintain a strong contraction for this length of time. Despite these limitations the results were consistent with the findings of previous studies on other LA functional changes after physiotherapy as well as morphological differences between continent and incontinent females. The concept of using 3D reconstruction modeling of the LA permitted the qualitative and quantitative description of the LA morphology at rest and during contraction. MRI provides an opportunity for further insight into the mechanisms through which rehabilitation prevents urine leakage. Further studies using larger sample populations are needed to explore LA morphological changes following PFM physiotherapy.

CONCLUSIONS

This study suggests that PFM physiotherapy produces changes in the anatomical configurations of the PFM at rest as well as during contraction. Additionally, participants perform voluntary contractions in a more effective way after physiotherapy. These results offer further insight into the underlying anatomical and physiological mechanisms by which rehabilitation prevents urine leakage.

Abbreviations and Acronyms

3D	=	3-dimensional
LA	=	levator ani
MRI	=	magnetic resonance imaging
PFM	=	pelvic floor muscle
R_c	=	percentage of levator ani surface area during a pelvic floor muscle contraction inside the levator ani surface area at rest
R_s	=	relative change in levator ani surface area
R_v	=	relative change in volume encircled by levator ani between rest and during pelvic floor muscle contraction
SP	=	symphysis pubis
UI	=	urinary incontinence

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