Quantifying bladder prolapse in patients – how to improve patient care

The quantification of the anatomical result of bladder prolapse in symptomatic patients with stage 2 or more cystocele before and after the anterior colporrhaphy surgery visualized with an upright MRI

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Contents

1 Introduction

Pelvic organ prolapse (POP) is the descent of pelvic structures into the vagina due to ligament or muscular weakness [1]. Around 50 percent of women above the age of 50 get a prolapse [2, 3]. Patients who have a bladder prolapse (cystocele) can be asymptomatic or can experience symptoms such as difficulty urinating, urinary tract infections, and a ball feeling between the legs [4, 5]. The stage of the prolapse is measured during physical examination using the pelvic organ prolapse quantification (POP-Q) system [6, 7]. With this system, the prolapse is measured in a supine position during a staining maneuver (Valsalva). With the information about the symptomatic prolapse and the physical examination, treatment options can be discussed. The most effective and commonly accepted treatment options for patients with a cystocele are pelvic physiotherapy, pessary treatment, or surgery [3, 8]. The choice of therapy is dependent on patient preference. When pelvic physiotherapy and pessary treatment are unsuccessful, surgery is the last treatment option. In the Netherlands, surgical therapy based on a primary prolapse (no recurrence) will generally be based on a vaginal approach, which is native tissue repair. In the case of a cystocele, this means anterior colporrhaphy surgery.

The goal of anterior colporrhaphy surgery [9, 10, 11, 12] is to reposition the bladder to a non-prolapsed position. This is done by making an incision in the anterior vaginal wall, where the fibromuscular vesicovaginal fascia is identified. With a fascial plication suture, the tissue will create improved support for the bladder. However, with this native tissue repair surgery, around 30% of the patients get a symptomatic recurrence of the prolapse [9, 13, 12].

At this moment, there is little research on the recurrence after native tissue surgery [11, 12]. In most research, only symptomatic recurrences are reported. Wong et al. [12] did research the anatomical recurrence (cystocele stage 2 or more) and the symptomatic recurrence after 3-4 years. However, the repositioned location of the bladder at the six-week follow-up was not researched. It is therefore unknown in which timeframe the patients are most likely to get a recurrence. Zhang et al. [14] researched the prolapse before and one month after the surgery with magnetic resonance imaging (MRI) in a supine position. However, this research was mostly focused on the pelvic floor and not the anatomical result of the pelvic organs after the surgery. Furthermore, several studies [15, 16, 17] already demonstrated the significant difference in POP assessment on the MRI between supine and upright positions.

This study consists of three parts. In the first part, the main research question will be answered. For this question, the anatomical position of the bladder is compared before and six weeks after the anterior colporrhaphy surgery, and the position of the bladder is visualized with the upright MRI. In previous studies [18, 19, 14], the anatomical position is quantified with the lowest point of the bladder. In this study, two new methods are introduced for the quantitative measurement of the bladder in MRI images, the movement of the bladder and the volume under the reference line. These methods aim for a better understanding of bladder prolapse. In the second part, a comparison is made between the measured lowest point of the bladder on the MRI and the physical examination, the POP-Q [20, 21]. The upright MRI in rest and the supine MRI during straining are compared to the value measured in the POP-Q.An attempt is made for a correlation between the lowest point of the bladder of the POP-Q and the MRI using a new reference line. The third part consists of a comparison between the MRI scan and the AUGS tool. The AUGS tool is a visualization of the patient-specific POP with the POP-Q measurements as a guideline. The tool is made to help the patient in understanding their anatomy and symptoms. With the comparison of the AUGS tool to the MRI, the accuracy of the AUGS tool is researched.

2 Quantification of bladder prolapse

2.1 Introduction

Patients with a cystocele and a treatment preference for an anterior colporrhaphy surgery have a 30 percent chance of a recurrence of their bladder prolapse [13]. Unfortunately, little research has been done about why and how a recurrence occurs. Furthermore, the recurrences researched in the larger studies, include mostly symptomatic patients [9]. Only Wong et al. [12] researched the symptomatic and anatomical recurrence in patients after 3-4 years. The question about why and how the recurrence occurs is still not answered. With these questions answered, patient care can be improved which would result in fewer recurrences after the surgery and higher patient satisfaction.

The first step in understanding the recurrences is analyzing the anatomical relocation of the bladder created with the surgery. In earlier research for analyzing the bladder location on MR images, the lowest point of the bladder is compared to a reference line [18, 14, 19]. The MRI images were all made in a supine position during straining. Several studies already demonstrated an underestimation of the POP assessment during supine and upright positions [15, 16, 17]. In this study, the aim is to quantify the anatomical result of bladder prolapse in symptomatic patients with stage 2 or more anterior vaginal wall prolapse before and six weeks after the anterior colporrhaphy surgery visualized with an upright MRI.

The quantification of the bladder location will be analyzed by comparing the lowest point of the bladder to the reference to the MRI scans before and after the surgery. This comparison should show a reduction in the lowest point of the bladder after the surgery. Two new methods will be introduced to analyze their additional value. The first of these methods is the movement of the bladder. It is hypothesized that the bladder moves less after the surgery because the sutured tissue should provide improved support when compared to before the surgery. The second method is the 3D bladder volume under the reference line. It is hypothesized that this volume is a quantifying measurement of the ball feeling between the legs that the patients experience with a POP. The additional value of these two new methods is hypothesized to give an extra understanding of the cystocele and to be a predictive value for the recurrence of POP.

2.2 Materials and methods

2.2.1 Patient inclusion

This prospective study was conducted with symptomatic POP patients from the Ziekenhuis Groep Twente (ZGT) in Hengelo and Almelo, the Netherlands. In March 2022 the inclusion for this research started and this will end with 65 patients. The inclusion criteria are confirmed bladder prolapse $\geq$ stage 2, symptomatic POP, and planned for anterior colporrhaphy surgery. The exclusion criteria for this study are previous POP surgery, combined incontinence surgery, inability to stand for 20 minutes, not eligible for MRI, and an abdominal circumference greater than 143 cm.

All the patients were asked to fill in questionnaires (PFIQ-7, PISQ-12, and PDFI-20 before the surgery and PGI-I after the surgery) and a physical examination was performed, including POP-Q.

2.2.2 Data collection and registration

The data collection consists of the medical history, general information, and the outcome of the physical examination, which was gathered from the electronic patient file (HiX). The personal data, pseudonymized, were registered and saved in the online secure database Research Manager [Deventer, the Netherlands], which was made specifically for this study. The data collection also included the questionnaires and the MRI scan data.

2.2.3 MRI protocol

The magnetic resonance images were acquired with the 0.25-T scanner [G-Scan, Esaote, Genoa, Italy] in upright position at the University of Twente. Before the MRI scan, the patients were asked to empty their bladder. The patient was first positioned in upright position. With the FSE (fast spin echo) scan (echo time (TE): 25 ms, repetition time (TR): 3840 ms, slice thickness: 5 mm, number of slices: 11, resolution: 200x225 pixels, total scan time: $\pm$2 min), the pelvic region was visualized in the sagittal direction. After the FSE, the 2D dynamic HYCE (hybrid contrast enhancement) was set to the FSE slice with the lowest visible point of the bladder (TE: 3.5 ms, TR: 7 ms, slice thickness: 15 mm, resolution: 200x210 pixels, scan time: $\pm$3 seconds per slice). During this dynamic scan, patients were instructed to perform the Valsalva maneuver. This maneuver is performed by inhaling deeply and performing a straining motion to the pelvic floor for 10 seconds. The dynamic scan makes a new image every 2-3 seconds, which makes it possible to visualize the movement of the pelvic organs and to visualize the maximum movement of the bladder during straining. The final scan is the 3D HYCE (TE: 4 ms, TR: 8 ms, slice thickness: 0.5 mm, number of slices: 328, resolution: 450x500 pixels, scan time: $\pm$5 min), which was performed last to visualize the finer details of the pelvic region with also the option to visualize the pelvic region in 3D.

2.2.4 Data analysis

2.2.4.1 MATLAB

The analysis of the 2D HYCE and 3D HYCE MRI images was performed with MATLAB [The Mathworks, R2021b; Natick, Massachusetts]. In this script, three points (os pubis, sacrococcygeal joint and the lowest point of the bladder) were selected in the calculations for the lowest point of

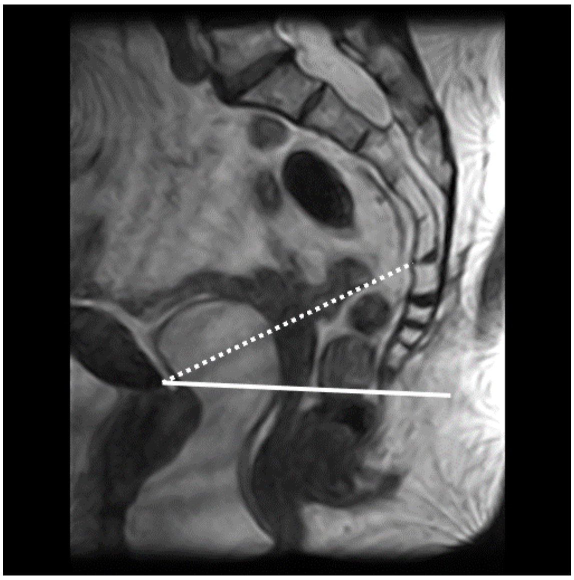


Figure 1: Explanation of PICS line. The dotted line is the SCIPP line made from the os pubis and the sacrococcygeal joint. The full line is the PICS line after 29°clockwise rotation from the SCIPP line.

the bladder. The lowest point of the bladder is compared to the PICS (Pelvic Inclination Correction System) reference line [22, 23]. The PICS line is made from the SCIPP line (sacrococcygeal-inferior pubis point), containing the dorsal edge of the os pubis and the sacrococcygeal joint (between the fifth sacral vertebrae and the coccyx). The SCIPP line was transformed to the PICS line with a 29°angle in a clockwise rotation for the upright MRI scan. The visual interpretation of this line is shown in Figure 1. The lowest point of the bladder is measured before and after the surgery in relation to the PICS line at a 90°angle. The measured distance is saved in Excel [Microsoft Corportation]. The average distance of the lowest point of the bladder is measured in the 2D HYCE and the 3D HYCE in the scans before and after the surgery. These differences are also compared per individual patient.

The movement of the bladder is measured with the lowest points of the bladder in the 2D HYCE and 3D HYCE. The upright scan at rest shows the standard location of the bladder and the upright scan in straining shows the maximum location of the bladder. The difference between the upright scan in straining and the upright scan in rest is depicted as the movement of the bladder.

2.2.4.2 Analysis of 3D segmented bladder

The 3D HYCE MRI scan was used for a 3D analysis of the volume of the bladder. A 3D segmentation of the pre- and post-operative bladder was performed manually using 3D Slicer [Slicer 5.0.2, https://www.slicer.org/]. The bladder was drawn in eight to ten slices in all three views (sagittal, coronal and transverse). With the function "seed growing", the 3D volume of the bladder was made, after which smoothing was applied to the 3D bladder for a better match of the 3D volume to the MRI scan. MATLAB was used for the comparison of the pre- and post-operative 3D bladder volume. The points of the os pubis and SC joint were used to make the PICS line in the 3D volume [24]. The total volume of the 3D segmented bladder and the volume measured under the PICS were compared per patient between the pre- and post-operative scans. The outcome of the 3D bladder volume under the PICS is compared to the outcome of the questionnaire containing the question about the ball-feeling between the legs.

2.3 Results

Between March 2022 and September 2022, 7 (out of the total number of 65) patients were included in this study. These 7 patients underwent the MRI scan before the surgery and the six-week follow-up scan. 6 out of the 7 patients also had a surgery for their uterus prolapse and 4 patients had a posterior colporrhaphy surgery for their posterior vaginal wall prolapse. The patient demographic of this study is shown in Table 1.

The average distance of the lowest point of the bladder to the PICS before the surgery is +2.7 cm and +4.7 cm for the upright MRI in rest and upright MRI during straining, respectively. A

Table 1: Patient demographic

	Mean (SD)
Age (years)	56 (13)
Parity	3 (1)
Body Mass Index (kg/m2)	30 (6)
POP-Q stage (Aa)	2.0 (1.5)
Operations	
Uterus:	
Manchester	4 (57%)
Sacrospinous fixation (SSF)	2 (29%)
Posterior vaginal wall:	
Posterior colporrhaphy	4 (57%)

Table 2: The total volume of the 3D segmented bladder and the volume of the bladder under the PICS reference line. Both volumes are measured in ml.

Patient	**Before surgery**		**After surgery**	
	Total volume (ml)	*Volume under PICS (ml)*	*Total volume (ml)*	*Volume under PICS (ml)*
1	150	76	106	28
2	378	0	101	0
3	123	0	55	0
4	56	0	74	0
5	51	17	46	1
6	112	15	177	13
7	53	19	98	9

negative value is the location of the lowest point of the bladder above the PICS line and a positive measured value is the lowest point of the bladder below the PICS line. The average distance of the lowest point of the bladder to the PICS line six weeks after the surgery is reduced to +0.5 cm for the upright scan in rest and +1.4 cm for the upright scan during straining. These average values and their standard deviation are visualized in a boxplot in Figure 2. The change in the distance of the lowest point of the bladder to the PICS line specified per patient and for both scans is shown in Figure 3.

The mean value for the movement of the bladder before the surgery is 2.0 cm and 0.9 cm after the surgery, where the zero value means no difference between the upright MRI in rest and during straining, see Figure 4. Before the surgery, the maximum descent of the lowest point of the bladder from rest to straining was more than 3 cm for 3 patients. After the surgery, the movement of the lowest point of the bladder was less than 1.5 cm for all patients.

The bladder volume is calculated by means of a 3D segmented bladder for all the patients in the pre- and post-operative scans. In Figure 5, an MRI image is shown of the pre-operative and post-operative scan with the segmented bladder visualized in this image as well. The total 3D segmented bladder is also shown separately for both scans. Figure 6 shows the 3D bladder volume under the PICS line, with the PICS line visualized as the white line. The volumes are measured in ml and Table 2 shows the outcome of the total volume of the bladder and the volume under the PICS line per patient. For 3 patients, the volume under the PICS was not below the PICS line. The volume for 3 patients was reduced with 10 ml or more when comparing the 3D segmented volume of the bladder before and after the surgery. Table 3 shows the outcome of the questionnaires containing the questions about the ball-feeling symptom. The questionnaire PFDI-20 is used to answer the presence of the ball-feeling before the surgery. The PGI-I questionnaire is answered for their symptom improvement after the surgery.

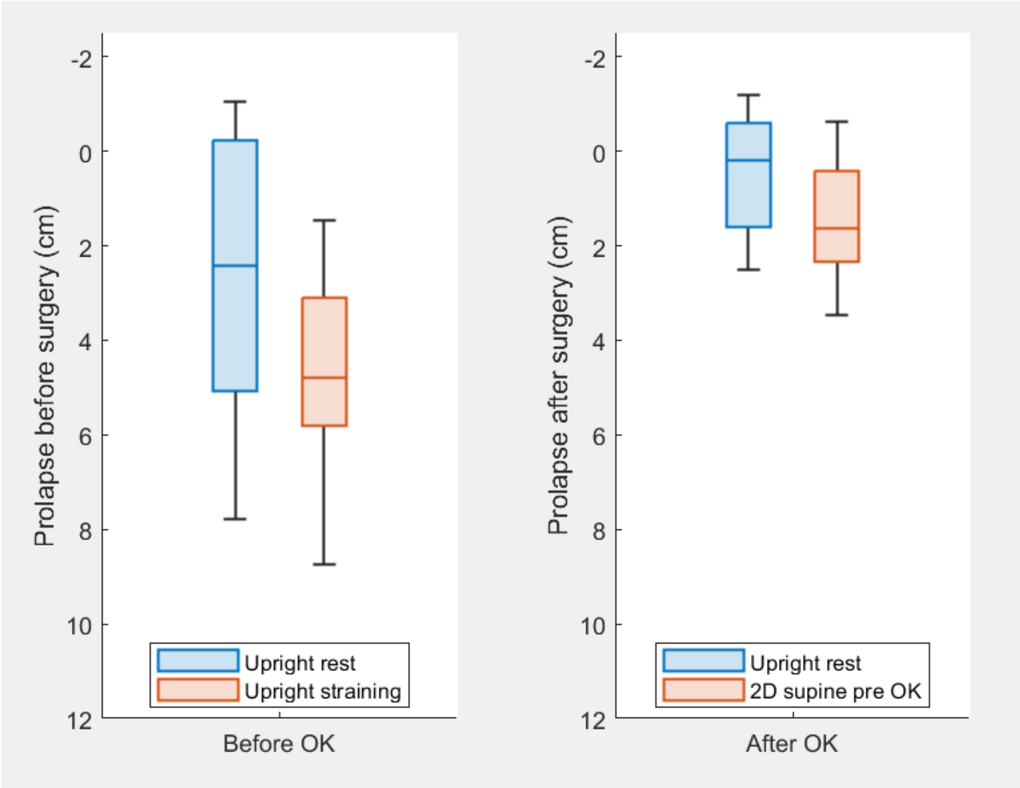


Figure 2: Boxplot of the location of the lowest points of the bladder for the upright MRI in rest and upright MRI during straining. The first boxplot shows the lowest points before the surgery and the second boxplot shows the points of the six-week follow-up scan.

Table 3: The questionnaire of the symptom ball-feeling.

Patient	**Before surgery** (4 scale*)	**After surgery** (7 scale**)
1	Almost always	Much better
2	Often	Very much better
3	Often	Very much better
4	Sometimes	Much better
5	Sometimes	Very much better
6	Almost always	Very much better
7	Sometimes	Much better

* Four point scale consists of: never (1), sometimes (2), often (3), almost always (4). ** Seven point scale consists of: very much better (1), much better (2), little better (3), no difference (4), little worse (5), much worse (6), very much worse (7).

2.4 Discussion

In this study, the comparison between the pre- and post-operative MRI scans was made for patients with a symptomatic anterior vaginal wall prolapse. With the standardized analysis of the lowest point of the bladder on the MRI scan [16, 14], 6 of the 7 patients showed a reduction in the location of the lowest point comparing the before and after surgery scans. This was for the upright MRI scan in rest as well as the upright MRI scan during straining. The movement of the bladder, which is the descent of the bladder from upright rest to upright straining, showed a decrease in movement after the surgery. Before the surgery, the movement was more than 3 cm for 3 patients and this was reduced to less than 1.5 cm for all 7 patients after the surgery. The final measurement was the 3D volume of the segmented bladder and its volume under the PICS reference line. This measurement showed a volume of the bladder under the PICS line for 4 patients, which was reduced after the surgery for all of them.

The first newly introduced quantitative measurement of the bladder was the movement of the bladder in its descent from upright rest to upright straining. This quantitative measurement is based on the connective tissue and its weakness as a risk factor [25, 3, 26, 5]. The sutured tissue

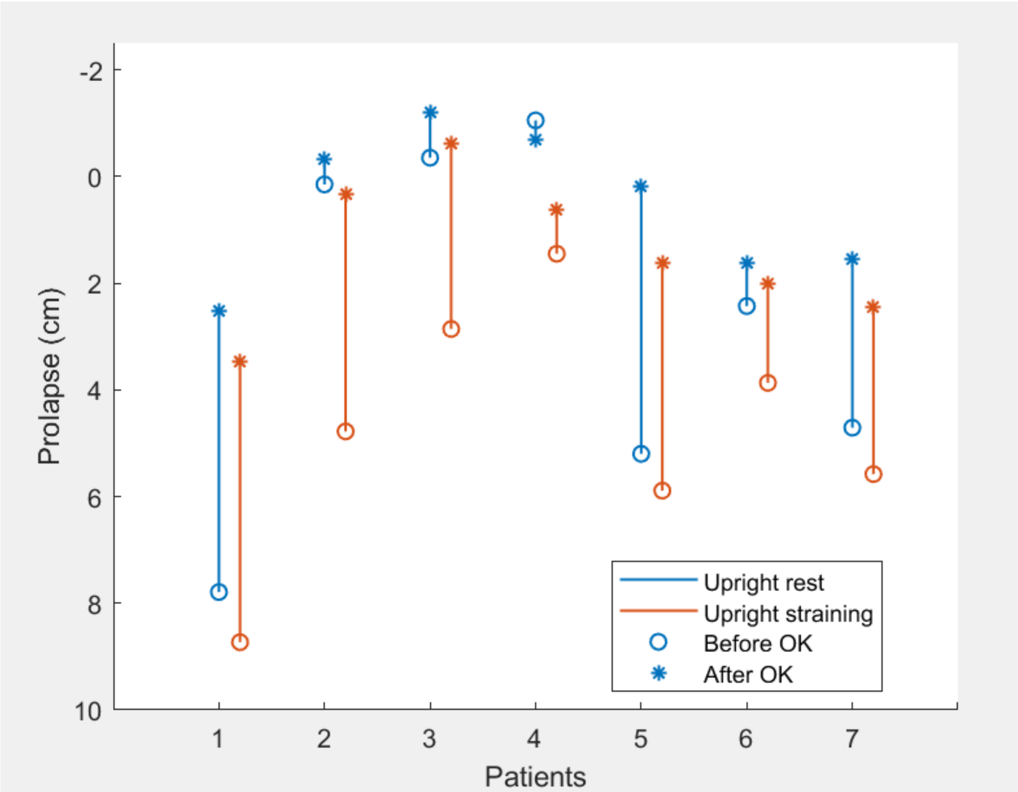


Figure 3: Change location of the lowest points specified per patient before and after the surgery for the MRI scan in upright position in rest and during straining.

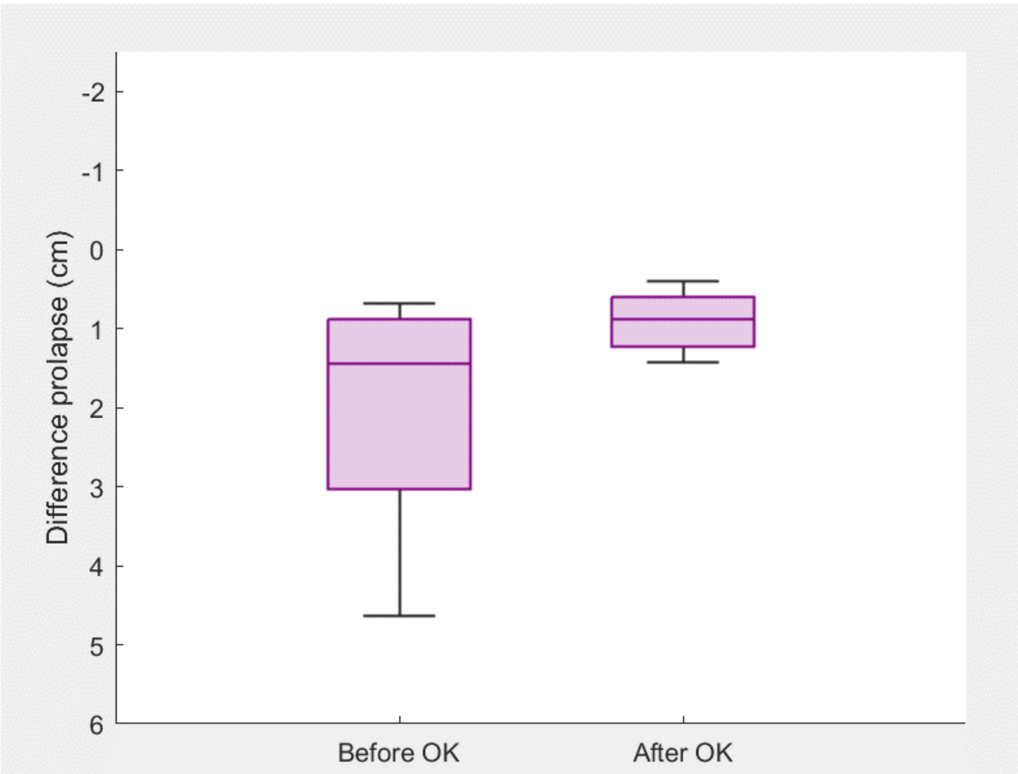
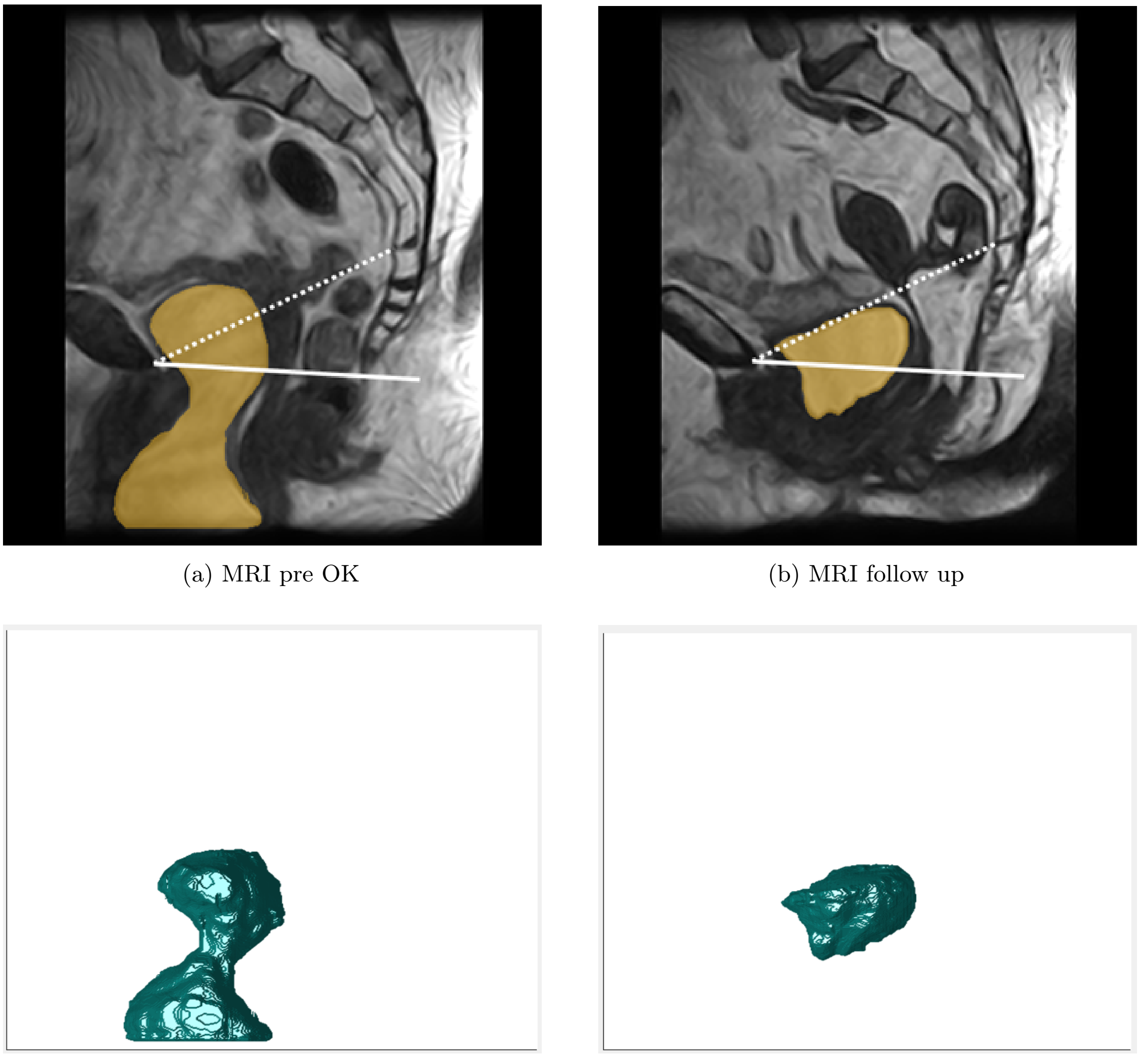


Figure 4: Movement of the bladder comparing the upright MRI in rest and straining before and after the surgery. At the value of zero, it would mean no difference between the scans.



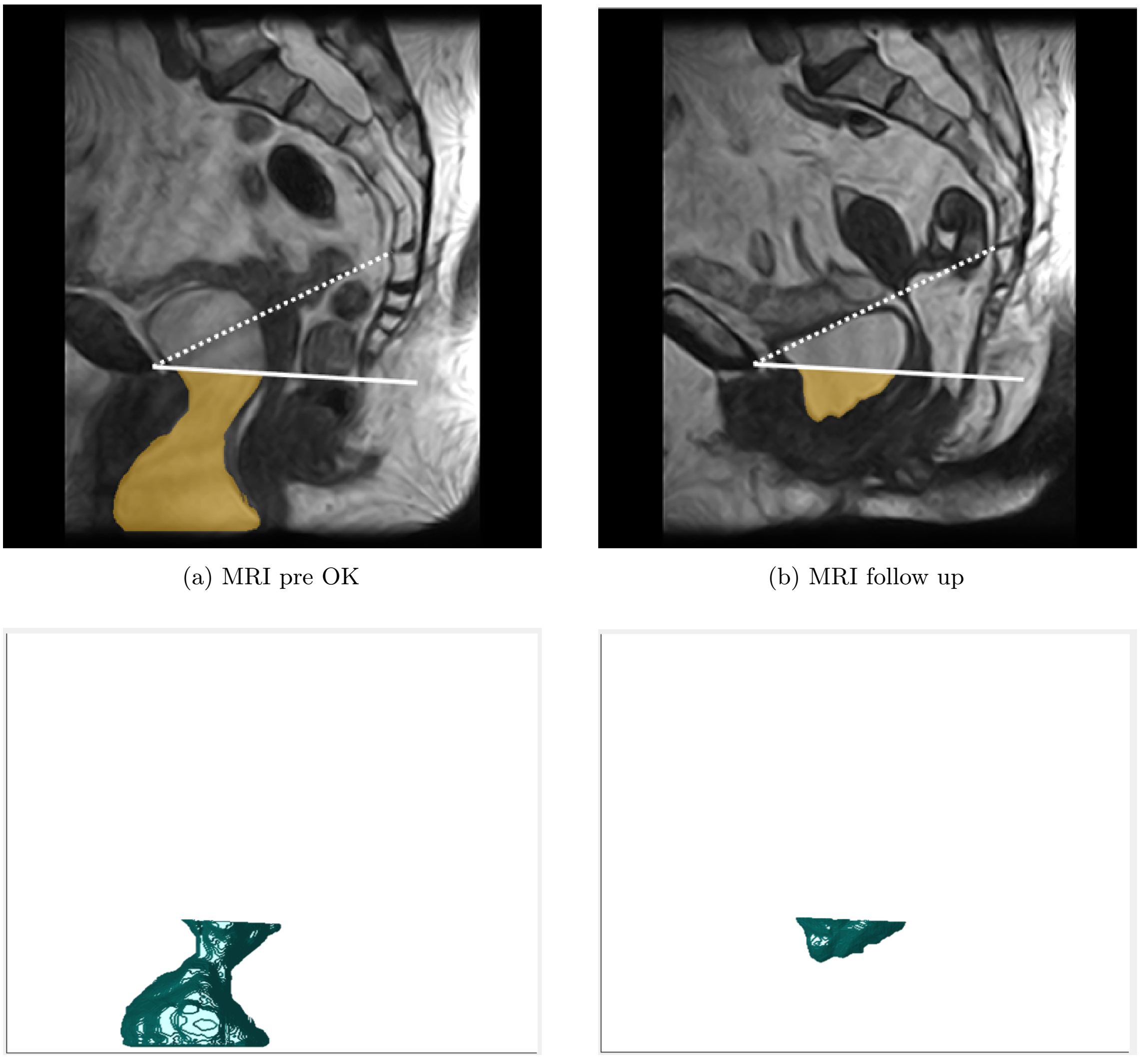
(a) MRI pre OK

(b) MRI follow up

(c) 3D volume pre OK

(d) 3D volume follow up

Figure 5: The 3D segmented volume of the bladder before and after the surgery. The bladder is visualized in yellow in the MRI scan with the PICS line shown in white (a,b) and (c,d) the total volume as a segmented bladder.



(a) MRI pre OK (b) MRI follow up

(c) 3D volume pre OK (d) 3D volume follow up

Figure 6: The 3D segmented volume under the PICS line of the bladder before and after the surgery. The bladder is visualized in yellow in the MRI scan with the PICS line shown in white (a,b) and (c,d) the total volume as a segmented bladder.

after the surgery should provide improved support. A large descent of the bladder during straining suggests that the new support is not sufficient enough to support the bladder in the long term. The movement of the bladder is therefore a quantitative measurement that could predict a recurrence of the anterior vaginal wall prolapse.

The volume of the 3D segmented bladder was analyzed and hypothesized to be a quantitative measurement of the ball-feeling between the legs symptom. The assumption is that the bladder below the hymen can be felt by the patient, which is described by most patients as a ball-feeling. The correlation between the PICS line, or other pelvic floor reference lines [27], and the hymen are not yet researched. However, the results of the volume under the PICS can show an indication of the severity of the ball-feeling that the patient experiences. For only four patients, this measurement could be analyzed, because the other 3 patients did not have a bladder below the PICS line in the upright MRI scan at rest. This measurement could only be performed on the 3D MRI scan and not the 2D scan. Unfortunately, the maximum descent of the bladder can only be found in the upright scan during straining. The outcome of the 3D volume of the bladder under the PICS line can at this moment not be compared to the ball-feeling symptoms that are experienced.

The measurements of the MRI scans were hand-selected by one expert and these points were pinpointed as precisely as possible, but small differences could be found when revising these scans. These differences were mostly found in the 2D HYCE (the upright straining) MRI images. This is because the visibility of the lowest point of the bladder was difficult to pinpoint and caused by the low resolution and the artifacts of the images.

The 7 patients included in this study already showed a wide variety of bladder prolapse as well as the other compartments involved in the symptoms. This small sample size demonstrates the importance of a larger study population, which will be concluded to 65 patients in the larger study. The larger sample size could make it possible to create subgroups and possible predictive values for a high or low chance of prolapse recurrence [28]. The knowledge of these subgroups and the corresponding chance of recurrence will help in patient care to find the most suitable options for the reduction of their symptoms.

2.5 Conclusion

In this study, new quantitative measurements were introduced to help understand the prolapse before and after the surgery. The 3D segmented volume of the bladder under the PICS reference line could not be compared to the ball-feeling symptom in this study population. This measurement does therefore not have an additional value in understanding bladder prolapses and the correlation to the ball-feeling symptom. The upright scan in rest and the upright scan in straining have an additional value in analyzing the bladder prolapse and these MRI scans are essential for analyzing the movement of the bladder. This second quantitative measurement of the movement bladder can be used as a predictive value for the recurrence of bladder prolapse.

3 Comparison between POP-Q and MRI

3.1 Introduction

The pelvic organ prolapse quantification system (POP-Q) is used to quantify the severity of pelvic organ prolapse (POP) patients [29]. The POP-Q is measured during the physical examination where the patient is asked to perform a straining maneuver in supine position [6, 7]. In this examination, the prolapse of the bladder, uterus en rectum are measured relative to the hymenal ring.

Studies have been performed to correlate the POP-Q to a reference line on the MRI [19, 21]. All these studies contain MRI images in supine position during straining, which is performed in the same manner as the POP-Q. Furthermore, a new reference line, the Pelvic Inclination Correction System (PICS) [22], is not yet studied. Moreover, most patients experience their symptoms when they are in upright position. Earlier research even showed an underestimation when comparing the supine straining MRI scans to the upright rest MRI scans [15, 16, 17]. However, a comparison with the POP-Q was not made in these studies. The aim of this study is to compare the lowest points of the bladder in the upright MRI in rest and the supine MRI during straining to the lowest point of the bladder measured in the POP-Q while using the PICS reference line. The hypothesis is that values of the lowest point in the bladder from the MRI scan in supine straining and the POP-Q should be most comparable. The values of the upright MRI scan should show a more prolapsed bladder.

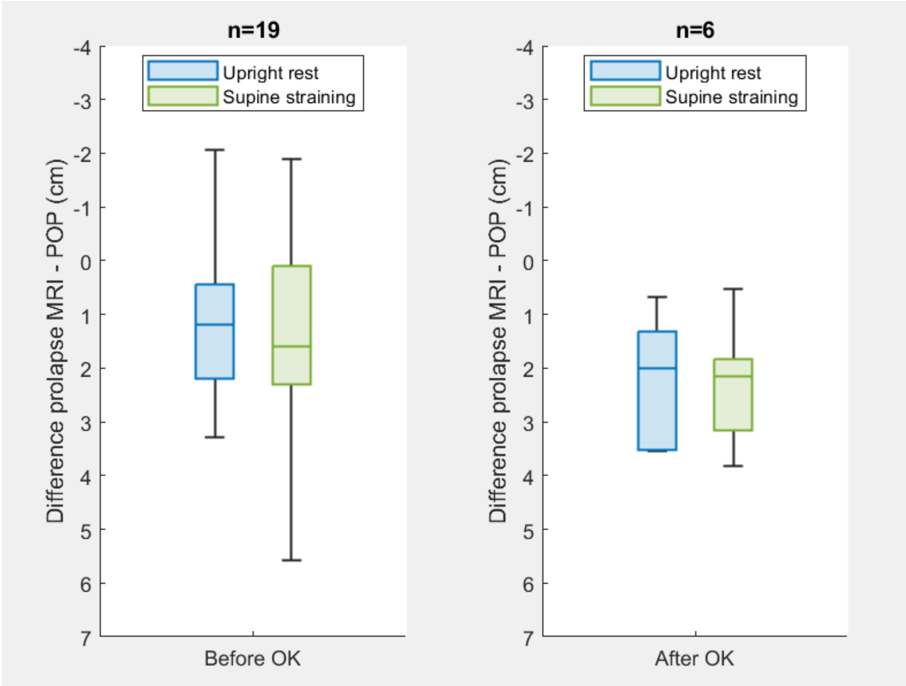


Figure 7: A boxplot of the difference between the POP-Q and the upright MRI scan in rest and the difference between the POP-Q and the supine straining scan. The zero line shows a comparison of the MRI scan to the POP-Q. A positive value means a larger prolapse on the MRI and the negative value means a more severe prolapse measured with the POP-Q.

3.2 Method

This study was conducted with symptomatic POP patients from the Ziekenhuis Groep Twente (ZGT) in Hengelo and Almelo, the Netherlands. In March 2022 the TORBO (Twents Onderzoek naar Recidieven na Bekkenbodem Operaties) study started the inclusion for a total of 65 patients. Between march 2022 and august 2022, 19 patients were included. These patients had a POP-Q measured during Valsalva.

The magnetic resonance images were acquired with the 0.25-T scanner [G-Scan, Esaote, Genoa, Italy] in upright and supine positions at the University of Twente. The FSE, 2D HYCE and the 3D HYCE scan are made in upright and supine position. The protocol of the acquisition and the analysis of these scans were consistent with the first part.

3.3 Results

The measured values for the lowest point of the bladder compared to the PICS line for the upright MRI in rest and the supine MRI during straining were compared to the POP-Q. The average values with the standard deviation are shown for 19 patients for the pre-operative scans and for 6 patients for the post-operative scans, which are shown in Figure 7. The average outcome of the pre-operative scans to the corresponding POP-Q shows a difference of +1.1 cm (1.5 cm SD), with three outliers excluded, and +1.6 cm (1.8 cm SD), for the upright MRI in rest and the supine MRI during straining, respectively. The differences between the post-operative scan and the POP-Q are +2.2 cm (1.1 cm SD) and +2.3 cm (1.0 cm SD), for the upright MRI in rest and the supine MRI during straining, respectively.

3.4 Discussion

In this study, the lowest points of the bladder in the upright MRI in rest and the supine MRI during straining were compared to the lowest point of the bladder measured in the POP-Q with the use of the PICS reference line. A good comparison of the bladder prolapse stage between the MRI and POP-Q was difficult. This is partly due to the hymenal ring that is not visible in the 0.25-T scanner. The PICS reference line attempts to replicate the location of the hymenal ring [30, 23], but it is mostly made to adjust for the pelvic inclination. Furthermore, the hymenal ring migrates during the straining motion, while the PICS line remains in the same position. The differences between the POP-Q and the distance of the lowest point of the bladder to the PICS show a broad range for the pre-operative analysis, with 3 (16%) out of the 19 patients as an outlier when comparing the upright MRI to the POP-Q. However, this broad range is also found when comparing the supine MRI during straining and the POP-Q. The hypothesis of a more comparable outcome between the supine MRI during straining and the POP-Q does not apply.

The comparison of the MRI to the POP-Q for the six-weeks post-operative scan show a smaller interval compared to the pre-operative analysis. The lowest points of the bladder are located closer together between the study population in the post-operative analysis. The results also show a similar outcome between the upright MRI and the supine MRI and the POP-Q for the post-operative analysis.

In this study, only the bladder prolapse was compared between the MRI and the POP-Q measurements. This is due to the supine scan during straining. This scan is set up to the lowest point of the bladder and visualizes its movement during straining in one slice. For many patients, the selected slice does not visualize the uterus. The uterus can therefore not be analyzed. Furthermore, the visibility of the uterus, if it is in the same slice as the lowest point of the bladder, is difficult to interpret during the straining motion. A contrast agent needs to be added for a clearer visualization of the uterus. For these reasons, only the bladder was analyzed during this study.

There are many variables that can explain the broad range in the difference between the MRI and POP-Q before the surgery. Firstly, the measurements of the POP-Q can be different between gynecologists, where the values are always stated as rounded centimeters. Different values from one gynecologist to the other could therefore result in large variable differences when compared to the MRI. However, the research for measurement of a prolapse show a high interobserver reliability [6]. Secondly, the maximum straining of the prolapse is acquired with positive encouragement for seven seconds [31], but also after several attempts and this is not always implemented in the clinical practice. However, these variables cannot explain the large differences between patients in the comparison of the POP-Q to the MRI.

This study shows a comparison of the POP-Q with the MRI to differ by 2 cm when comparing the lowest values of the bladder for the post-operative scan. A generalized outcome for the pre- and post-operative scans cannot be made with the study population of 19 and 6 patients, respectively. More patients with an upright MRI scan and a POP-Q need to be included to create a generalized outcome. With a larger sample size, a corrective value can be determined for the comparison of the anterior compartment, but also of the uterus or posterior compartment. The aim of the comparison of the POP-Q to the MRI is still to find a association between the two examinations of the POP.

3.5 Conclusion

In this first study of the comparison of the POP-Q to the MRI images with the PICS reference line, a good and generalized comparison could not be made. Both the upright MRI in rest as the supine MRI during straining show the same differences. Further research with a larger study population could make a association between the POP-Q and the MRI scans a possibility.

4 Comparison of the AUGS tool to MRI

4.1 Introduction

Patients who experience symptoms of prolapse do often not understand what the exact anatomical cause is of their symptoms. To help the gynecologist in answering the patient's questions on how the organs are located in the pelvic region, an AUGS (American UroGynecology Society, https://pop-q.netlify.app/) tool was made to help the patients in understanding their bodies. The AUGS tool uses the information gathered by the gynecologist during the Pelvic Organ Prolapse Quantification (POP-Q). These nine measurements can be filled into the AUGS tool, see Figure 8. However, this tool was made without the reference of an upright MRI scan, while the patients experience the most symptoms in upright position. With the upright MRI, the anatomical structures in upright position can be visualized. The aim of this study is to compare the AUGS tool to the upright MRI images for patients with a symptomatic POP.

4.2 Method

This study was conducted with symptomatic POP patients from the Ziekenhuis Groep Twente (ZGT) in Hengelo and Almelo, the Netherlands. In March 2022 the TORBO (Twents Onderzoek

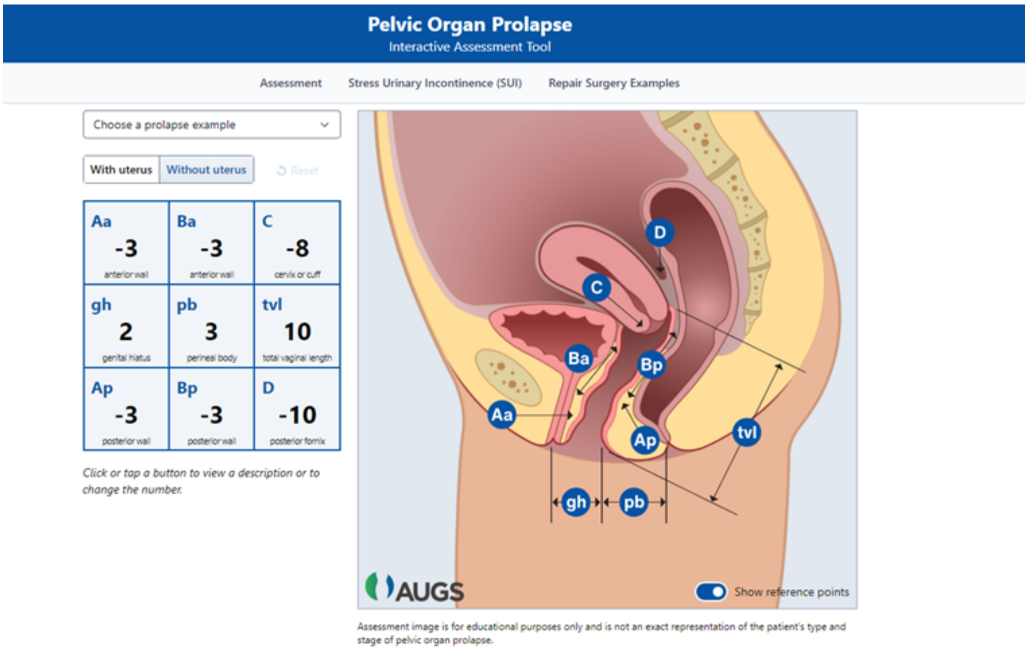


Figure 8: The AUGS tool on the website shows the variables that need to be filled in for the assessment of the pelvic region. These nine variables are measured during the POP-Q by the gynecologist [screenshot of the website taken from: https://pop-q.netlify.app/].

naar Recidieven na een Bekkenbodem Operatie) study started the inclusion for a total of 65 patients. These patients had the POP-Q measured during Valsalva in supine position. The outcome of the POP-Q was filled into the AUGS tool.

Before the MRI scan, the patients were asked to empty their bladder. MRI images were acquired with the 0.25-T scanner [G-scan, Esaote, Genoa, Italy] in upright position to visualize the pelvic region. The 3D HYCE (hybrid contrast enhancement) scan visualized the pelvic floor. This scan had a repetition time and echo time of 8 ms and 4 ms, respectively. The slice thickness is 0.5 mm, with a total number of slices of 328. The scan time was around 5 minutes. The resolution is 450x500 pixels.

Two experts on prolapses (a gynecologist and a Technical Physician) were asked to individually compare the MRI images to the AUGS tool comparing the size, location, and volume of the bladder and uterus. These comparison points were divided in "no", "small", and "large" differences. These were defined in the experts' opinion.

4.3 Results

In the time the TORBO study was conducted, 12 patients were included for the comparison of the upright MRI images to the AUGS tool. The outcome of the comparison of the upright MRI scans to the AUGS tool show a "large" difference for 6 (50%) of the scans in bladder shape. The bladder size and location show "no" to "little" difference for 10 (83%) patients. The outcome of the uterus shows a "large" difference in location for 8 (67%) patients and "no" to "little" difference in size and shape for 11 (92%) patients. Figure 2 shows a comparison of the "no" to "little" difference for all compared variables. In Figure 3, large differences in the MRI scan compared to the AUGS tool for the uterus for its size and location are visualized. The outcome of this research specified for the size, shape and location for both the bladder and the uterus can be found in Appendix A.

4.4 Discussion

The MRI images compared to the AUGS tool give an overall good resemblance for two out of three variables for the bladder and uterus. Only the shape of the bladder and the location of the uterus show large differences. The difference of location of the uterus could be caused by the performed POP-Q, which is measured during supine straining, while the MRI scans are made in upright position. This can lead to underestimation in most cases [16]. As a final remark, the comparison of the size of the bladder shows a large difference for 4 patients and gives a decent comparison to

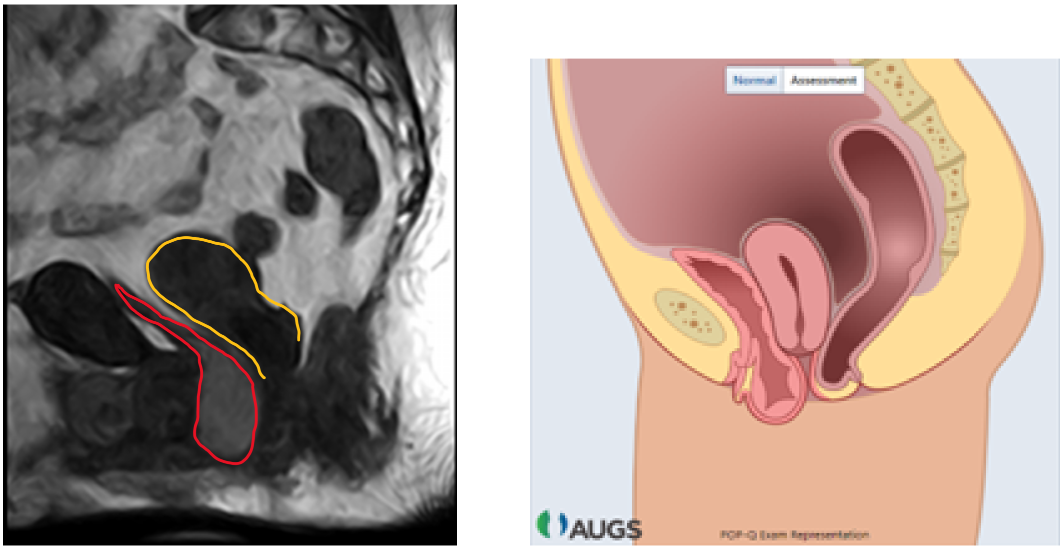


Figure 9: Comparison of MRI to AUGS tool with little to no difference. An example of the MRI scan, with the red outlined bladder and yellow outlined uterus, compared to the AUGS tool with the POP-Q measurements of this patient. The size and location of the bladder show “no” difference with regards to the volume of the bladder below the os pubis. The location of the uterus shows “no” difference.

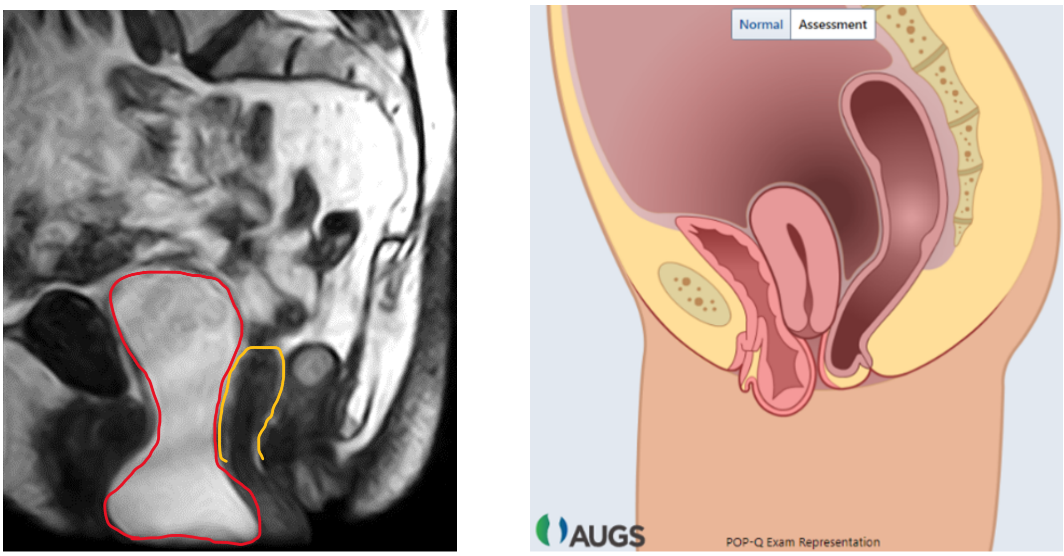


Figure 10: Comparison of MRI scans and AUGS tool with “large” difference in uterus location and size: The first image shows the MRI scan upright in rest, with the red outlined bladder and yellow outlined uterus. The uterus is smaller in size compared to the AUGS tool; the uterus is also positioned lower.

the AUGS tool. The patients were asked to empty their bladder before the scans, however some patients could not empty their bladder properly. The AUGS tool only shows emptied bladders.

Unfortunately, in this study, it was not possible to compare the rectum for the AUGS tool and the MRI. Without the insertion of a contrast agent, the shape, size, and location of the rectum are difficult to interpretate.

Most of the patients who experience symptoms of prolapse are above the age of 50 and are post-menopausal. This means that the uterus will become smaller since it loses its function. A small adjustment could be made to show a more realistic view of the size of the uterus. This would mean a larger uterus for women before the menopause and the uterus becoming smaller with a bigger age. The size of the uterus has an effect on the force it applies to the bladder, which could change the shape and location of the bladder. The bladder shows a more indented shape at the location of the uterus, which can be seen in the MRI scans.

A comparison of the MRI images to a visualized POP-Q is not for all patients sufficient. The POP-Q is measured in a supine position during straining. These values were filled into the AUGS tool and the AUGS tool was compared to an upright MRI scan. Some discrepancies can be found. A few examples include: patients that cannot perform a sufficient Valsalva, which can therefore not show the full extent of the prolapse when comparing this to their upright scans; and on the other side: patients that only show a prolapse during straining, not when they are at rest. However, these examples are not visible in all patients but are exceptions. This occurred in one of the twelve patients. The AUGS tool aims to show an example of the reality in which it succeeds relatively well for these twelve patients. More comparisons can be done for a more generalized result.

4.5 Conclusion

The AUGS tool shows a representable comparison to the MRI scans. The AUGS tool images could help the patient visualize the position of the organs in the pelvic region, which provides a better interpretation and understanding of their symptoms. The shape of the bladder and the location of the uterus can show a large difference in the comparison. However, the AUGS tool shows a good example of the reality of the patients anatomy and this tool can therefore be used in the explanation of the patients symptoms. More comparisons between the AUGS tool and the MRI scans could be done for a more generalized, and perhaps more patient specific, AUGS tool.

5 Summary

This study consisted of three parts, to quantify the bladder prolapse before and after the surgery, and to compare the MRI images to the physical examination as well as the AUGS tool, which is a visualization of the physical examination.

The first part was about the quantification of the bladder prolapse before and after the anterior colporrhaphy surgery. In this part of the study, two new quantification methods were introduced besides the standard MRI analysis of the lowest point of the bladder. The first quantification method was the movement of the lowest point of the bladder. The movement is stated as the downwards descent of the bladder from the upright rest position to the upright straining position in the MRI. This quantification method showed to be a possible predictive value for the recurrence of the bladder prolapse. The second quantification method aims to relate the MRI images to the ball-feeling symptom that the patients experience. This method uses the 3D segmented bladder to calculate the bladder volume under the reference line. Unfortunately, this quantitative measurement could not be compared to the symptoms the patients experience. However, with the new quantitative measurement of the movement of the bladder, it will be an additional method in analyzing bladder prolapses. With this information, the recurrence after the anterior colporrhaphy surgery could hopefully be reduced.

The second part of this study aimed to find a comparison between the POP-Q, the physical examination, and the MRI images. A new reference line, the PICS, was used in the calculation of the lowest point of the bladder. The calculation of the lowest point of the bladder was made in the upright MRI in rest and the supine MRI during straining. It was hypothesized that the measurements of the supine MRI during straining would be most comparable to the lowest point of the bladder measured in the physical examination (POP-Q). In the results, the upright MRI in rest and the supine MRI during straining showed the same margin of error when compared to the POP-Q. This was for both the analysis before the surgery as well as six weeks after the surgery. Further research with a larger study population could show a comparison between the POP-Q and MRI scan, where the location of the uterus and rectum could be added for a complete analysis.

Further research could help to find a good comparison to the physical examination and the MRI with the same measured outcomes.

The third part of this study analyzed the AUGS tool (a visualization of patient specific physical examination in a digital tool) and the MRI scan between patients to analyze the comparison. This tool could help the patient in better understanding her symptoms because of the visual interpretation of the POP-Q. The results show a representable comparison, where only the shape of the bladder and the size of the uterus show large differences between the images. The representable AUGS tool to the MRI scan can help patients in visualizing the positions of their organs and its corresponding symptoms.

The three studies together are aimed to help the patient care in the gynecology department. The quantification methods of the bladder prolapse, the differences between the location of the bladder and its reaction to the surgery can be analyzed. The analysis will help improve the current surgery to reduce the amount of patients with a recurrence after the surgery. With the second part of the study, the PICS reference line was compared to the physical examination to help improve the analysis taking place with the MRI. The final part of the AUGS tool will help the gynecologist in explaining the prolapse and the AUGS tool will help the patient in understanding her symptoms.

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A Appendix

Table 4: Bladder expert 1

	No	Little	Large
Size	7	0	5
Shape	10	0	2
Location	10	0	2

Table 5: Bladder expert 2

	No	Little	Large
Size	1	7	4
Shape	1	5	6
Location	3	7	2

Table 6: Uterus expert 1

	No	Little	Large
Size	12	0	0
Shape	11	1	0
Location	2	2	8

Table 7: Uterus expert 2

	No	Little	Large
Size	0	11	1
Shape	2	8	2
Location	0	5	7