Women's Imaging ORIGINAL ARTICLE

Preoperative uterine volume estimation: transvaginal ultrasound (TVUS) versus MRI (ellipsoid volume formula and 3D volumetry)

Dahila Amal Djema[1], Jean Dubuisson[2], Meriem Boukrid[2], Nicolas Villard[1], Anastasia Kalovidouri[1], Diomidis Botsikas[1]

[1]*Division of Radiology, Geneva University Hospitals, Switzerland*

[2]*Division of Gynaecology, Geneva University Hospitals, Switzerland*

SUBMISSION: 24/5/2019 | ACCEPTANCE: 15/9/2019

ABSTRACT

Purpose: Preoperative uterine volume estimation is a major consideration for surgeons as the choice of the optimal surgical approach between vaginal, laparoscopic or abdominal hysterectomy depends on uterine volume. Volume estimation can be done clinically, by ultrasound and magnetic resonance imaging (MRI) if available. The aim of this study was to compare the accuracy of different methods of preoperative uterine volume calculation including transvaginal ultrasound (TVUS) and MRI.

Material and Methods: Data of all women who underwent hysterectomy for a benign pathology between January 2013 and December 2015 and had preoperative TVUS and MRI were retrieved. Uterine volume was calculated by application of the ellipsoid volume formula (EVF) based on TVUS and MRI and also by freehand 3D MRI volumetry. Pathology was the standard of reference.

Results: Sixty-seven women were included in this retrospective study. For eight of them, TVUS measurements were not feasible, mainly due to the large size of the uteri. For the remaining 59 women, there was no difference between uterine weights (mean 384.2 g+/-425.8) and volumes calculated by MRI based on EVF (mean 404.3 g +/- 477.5, p >0.9999), and by 3D MRI volumetry (mean 391.8g +/- 446.1, p>0.9999). The difference between the standard of reference and the volumes calculated by TVUS (mean 334.0 g +/- 370.6, p=0.0011) were statistically significant.

Conclusions: According to our results, preoperative

CORRESPONDING AUTHOR, GUARANTOR

Diomidis Botsikas, MD PD: Division of Radiology, Geneva University Hospitals, 30 Boulevard de la Cluse, 1211 Geneva, Switzerland,
E-mail: Diomidis.Botsikas@hcuge.ch

uterine volume calculation is more accurately performed by means of MRI compared to TVUS. When available, uterine volume estimation should be obtained from MRI measurements. For this purpose, EVF can be safely used without the need of time-consuming 3D volumetry.

KEY WORDS Uterus volumetry; Pelvic MRI; Transvaginal Ultrasound; Hysterectomy

Introduction

Hysterectomy is a common gynaecological surgical procedure. Its indications vary greatly but it is most often performed so as to alleviate the severe symptoms associated with benign conditions such as leiomyoma and adenomyosis [1]. To select the optimal surgical approach between vaginal, laparoscopic or abdominal hysterectomy, preoperative uterine weight estimation is a major consideration for surgeons. A larger uterine volume is associated with a higher risk of surgical complications [2, 3]. According to the American College of Obstetricians and Gynaecologists (ACOG), the definition of an enlarged uterus is not clear in the literature; the term is used for uterus weights of more than 250 or 280 g [3, 4]. Most international guidelines recommend performing a hysterectomy via a minimally invasive approach, including laparoscopic and vaginal routes [4]. Abdominal hysterectomy results in less favourable medical outcomes [5]. However, the choice between a minimally invasive approach and a laparotomic route is not well standardised and is not generally based on a formal decision process in practice. The decision may be supported by a number of various factors: personal patient history, uterine pathology, clinical assessment (size and mobility of the uterus), imaging, personal operator's preference and experience, patient's choice and institutional access to minimally invasive procedures. Furthermore, the surgeon has to take into consideration the need to perform a uterine morcellation in link with uterus size for extraction during minimally-invasive procedures. Women should be clearly informed and agree with this procedure in case of undiagnosed malignancy [6]. Thus, determining a precise preoperative uterine weight is essential to choose the optimal route for hysterectomy and to anticipate all difficulties that could occur during minimally invasive procedures.

Uterine volume is usually estimated by means of bimanual vaginal examination or based on the measurements of transvaginal ultrasound (TVUS) most commonly using the prolate ellipsoid volume formula (EVF), which incorporates measurements of the (maximum) length x anteroposterior x width x 0.52 [7]. Pelvic magnetic resonance imaging (MRI) is increasingly used for the preoperative mapping of uterine leiomyomas but also for evaluation of adenomyosis and endometriosis. It is especially recommended for patients with large uterine volumes and/or numerous leiomyomas of great size, as ultrasound is less performing in this context [8]. In this setting, uterine volume can be calculated based on MRI images. MRI allows either indirect calculation of uterine volume based on mathematic models-formulas as the EVF that is used for ultrasound, or direct freehand three-dimensional (3D) volumetry. The latter is believed to be the most accurate technique to calculate the uterine volume but it is generally considered more complex and time-consuming for routine clinical use.

The aim of this study was to compare the accuracy of different methods of preoperative uterine volume calculation including TVUS and MRI.

Material and Methods

Patient population

In this study, approved by the ethics commission of the canton of Geneva, we retrospectively retrieved the data of all women who underwent a hysterectomy between 1st January 2013 and 31th December 2015, and had a preoperative TVUS and MRI within two months of the operation date.

Studies of women undergoing hysterectomy for benign disease (uterine fibroids, heavy menstrual bleeding and/or suspicion of adenomyosis) were eli-

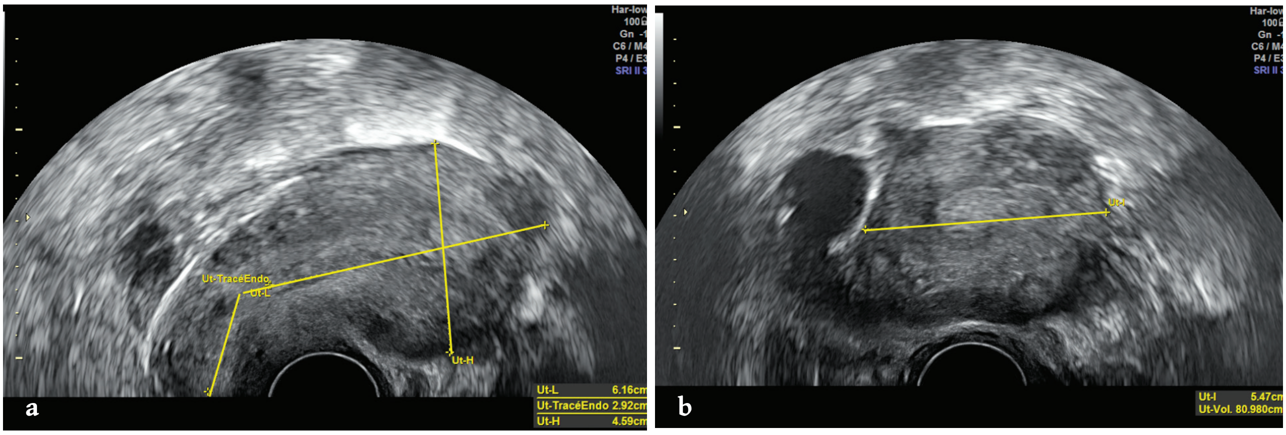

Fig. 1. *51-year-old woman with uterine adenomyosis. Ultrasound images in sagittal **(a)** and axial **(b)** planes show signs of adenomyosis with heterogeneous myometrial echotexture, obscure endometrial-myometrial border and asymmetric myometrial thickening of the posterior wall of the uterus. Yellow lines show the way measurements of maximal length (broken line) and anteroposterior dimension were made in the mid-sagittal plane and of the maximal width in the axial plane, respectively.*

gible for inclusion. All subjects were premenopausal.

We excluded studies of women with gynaecological cancer. In such cases, the histopathologic examination didn't allow measuring the exact uterine weight for all cases. The uterus was invaded and indistinguishable from other structures.

Time of imaging

Examinations were performed at different times of the menstrual cycle; the uterus weight variation during the different phases of the menstrual cycle are negligible for pathologic uteri with large volumes as the changes interest only the endometrium [9].

TVUS

Six different gynaecologists with 2 to 7 years' experience performed the TVUS according to the clinical indication. Examinations were performed with a Voluson E8 Expert (GE Healthcare, Chicago, Il USA) system using a 6.5 MHz transducer. Three uterine dimensions were systematically obtained: the uterine length (L) corresponding to the distance between the external cervical os to the dome of the uterus (this measurement was performed by the means of a straight, curved or skewed line, according to the degree of flexion of the uterus); the maximal uterine width (W) and maximal anteroposterior (AP) diameters were measured in a plane perpendicular to the axis of the length of the uterus. All dimensions were recorded in centimeters. **Fig. 1** shows the placement of calipers in the corresponding planes in order to obtain these measurements.

MRI

MRI was performed by using a 1.5 T Siemens Avanto MRI system (Siemens Healthcare, Erlangen, Germany), equipped with a phased array body coil.

Prior to every female pelvic MRI in our institution, all patients received 20 mg of Buscopan® (Boehringer Ingelheim, Schweiz, GmbH) intramuscular, to reduce the motion artefacts due to bowel peristalsis and uterine contractions, so as to improve image quality.

In our institution, the standard female pelvic MRI examination includes non-contrast fast spin-echo T2-weighted images centered at the uterus and ovaries (TR/TE, 4000-7000/85 ms; echo train length, 15; 3-mm slice thickness; no interslice gap; FOV= 200-230 cm; matrix, 240 x 320; no flip angle) in the sagittal, coronal and axial planes.

All image datasets were transferred to a dedicated workstation (OsiriX MD; Pixmeo, Bernex, Switzerland). A radiologist with eight years' experience in female pelvic imaging calculated the three dimensions of the uterus, similarly to ultrasound. He was blinded to the corresponding TVUS measurements and to the final weight of the uterus on pathology.

Surgical approach

Hysterectomies were divided into two groups: minimally-invasive hysterectomy, including vaginal route

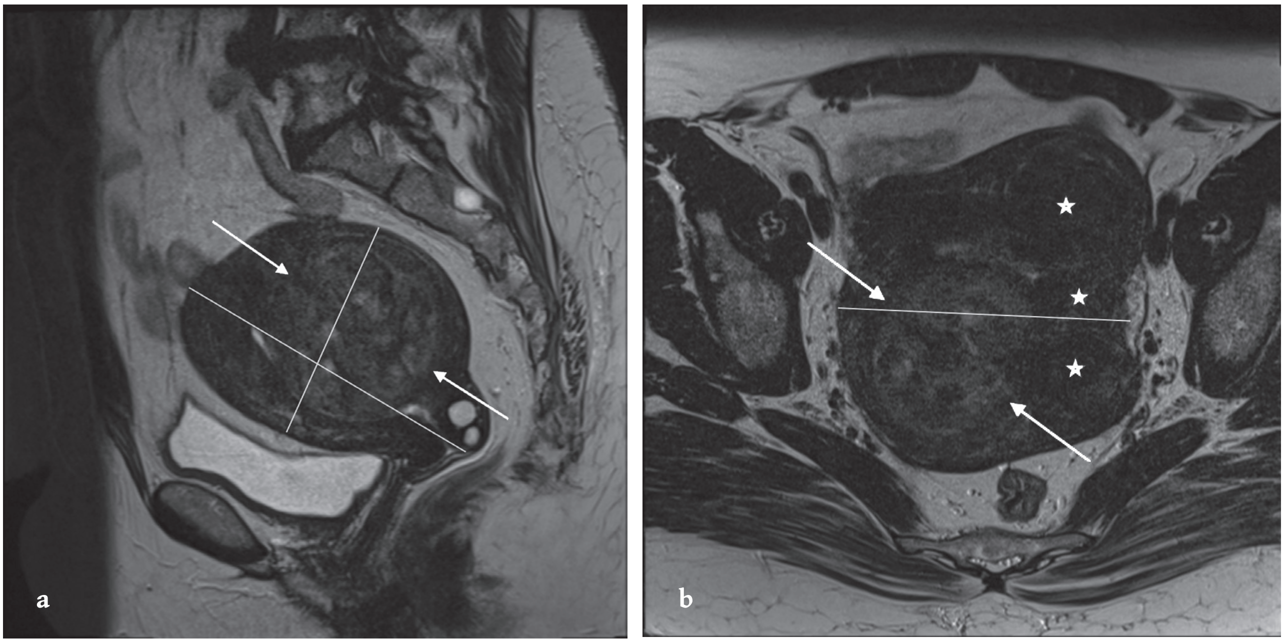

Fig. 2. *52-year-old woman with multiple symptomatic uterine leiomyomas. The patient underwent pelvic MRI for preoperative mapping of leiomyomas. MR images in sagittal* ***(a)*** *and axial* ***(b)*** *planes show measurements of maximal length and antero-posterior dimensions of the uterus in the true mid-sagittal plane and of maximal width in the true axial plane. Note the largest submucosal leiomyoma with mainly intermediate T2 signal shown with white arrows (**a** and **b**), associated with deformation of the endometrial cavity and multiple other leiomyomas (white stars in **b**).*

and laparoscopy, and abdominal hysterectomy (laparotomy). For minimally-invasive surgery, the need to perform a uterine morcellation during uterus extraction and the type of surgical technique used in this case were also collected.

Uterine volume estimation

Uterine volumes were obtained in TVUS **(Fig. 1)** and MRI **(Fig. 2)** using the formula that is based on the ellipsoid shape of the uterus: V=L x W x AP x 0.52 [7, 10] (L is the maximal length of the uterus in the sagittal plane, W is the maximal uterine width and AP the maximal anteroposterior uterine diameter).

Additionally, freehand 3D volumetry of the uterus on the basis of MRI images was performed by using OsiriX MD software (OsiriX MD, Pixmeo, Berne, Switzerland). Estimation of uterine volume was subsequently obtained by the software. In a first step a radiologist with eight years' experience in pelvic female imaging traced the uterus circumference on each slice that was depicted. In a second step the dedicated software calculated uterine volumes by multiplying the drawn areas by the thickness of the slices and adding all resulting partial volumes **(Fig. 3)**. The whole process of 3D volumetry took no more than 6 minutes, depending on the size of the uteri.

Standard of reference

As part of the routine histopathologic examination, the removed uteri were systematically weighed after surgery. The exact uterine weight obtained from pathology reports was used as the standard of reference in this study. Uterine volume was expressed in grams (g). We worked under the assumption that the density of uterine tissue practically equals that of water as it is mainly composed of muscle with a density of p=1.0597 g/mL [11] uterine volume in mL practically equals uterine weight in g [10].

Statistical analysis

Normality of data sets was tested with Kolmogorov-Smirnov test. Non-normally distributed data sets were compared with ANOVA test with Dunn's post-hoc analysis. P values ≤0.05 were considered statistically significant. For statistical analysis, the Graphpad Prism 6 ® (Graphpad California USA) was used.

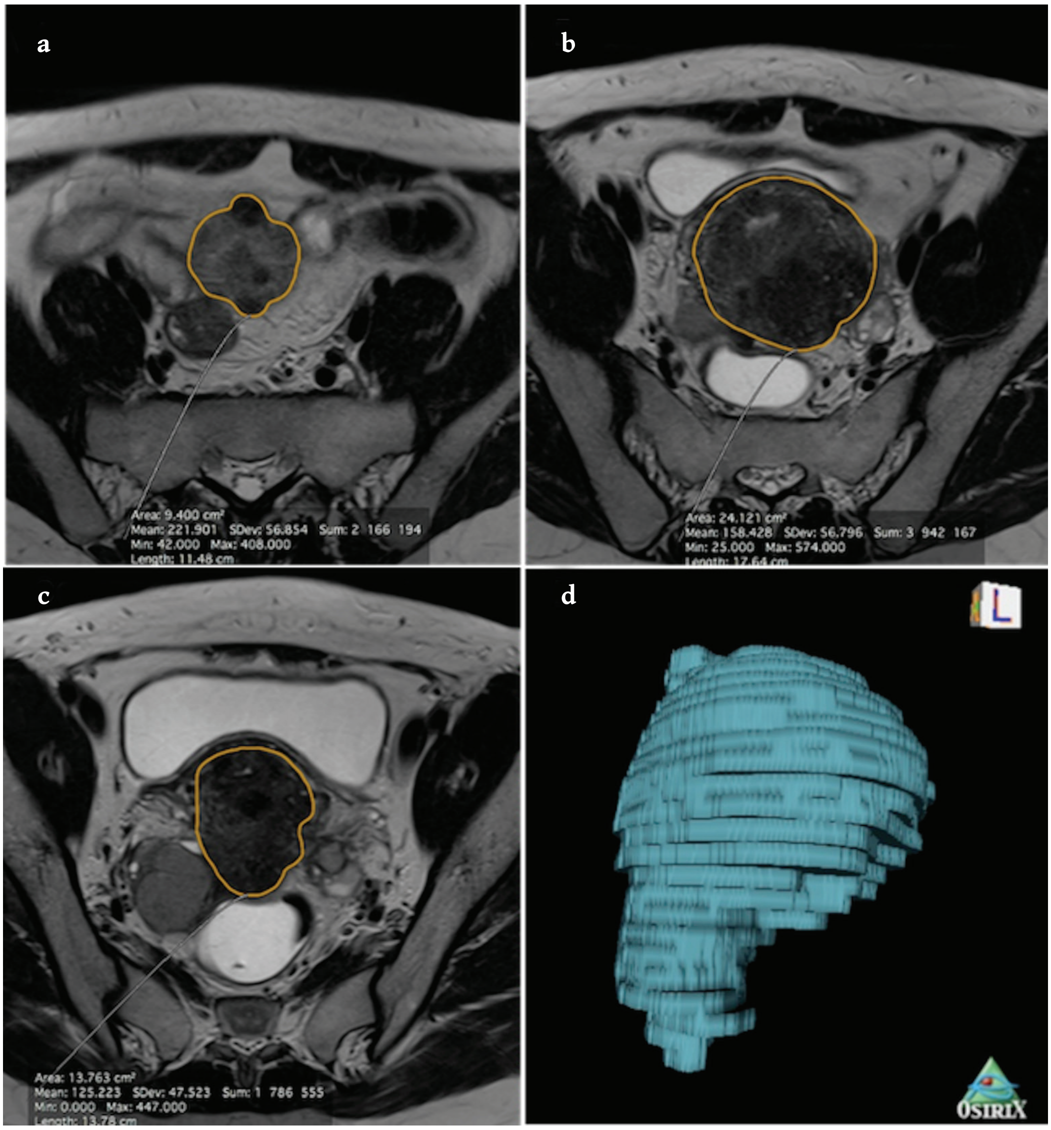

Fig. 3. *43-year-old woman with endometriosis and uterine leiomyomas who underwent preoperative pelvic MRI before hysterectomy. Figures* ***a, b*** *and* ***c*** *show axial MR images demonstrating free hand ROIs in different positions that were used for freehand uterine volume calculation using a dedicated software, creating a 3D-uterus illustration* ***(d).***

Results

From a total of 68 patients that underwent hysterectomy fulfilling our inclusion criteria, one was excluded due to absence of histological confirmation. The remaining 67 patients (mean age 48.03 +/- 7.53 years; mean BMI 26.38 +/- 4.89 kg/m^2) formed the final study cohort.

In eight patients (mean age 49.25 +/- 6.75; mean BMI 23.66 +/- 4.15 kg/m^2), TVUS measurements were uninterpretable, because of the large size or position of the uterus. For the 59 remaining patients, the pre-procedural TVUS, MRI and uterine weight after the hysterectomy were recorded. **Fig. 4** describes the flow of women and the available measurements for each imaging modality.

The results of comparison of uterine weight with the volume as calculated by TVUS, MRI by the means of EVF and MRI 3D volumetry are shown on **Table 1**. MRI measurements were not statistically different from the standard of reference (p>0.9999), while for TVUS measurements the difference was statistically significant (p=0.0011).

For the cases in which preoperative ultrasound measurements were uninterpretable, the results are shown on **Table 2**. There was no statistically significant differ-

Table 1. Comparison of uterus weight with the volume as calculated by TVUS, MRI by means of EVF and MRI 3D volumetry

US measurement feasible			n=59	
	Mean (g)	SD (g)	Range (g)	p-value
Uterus Weight	384.2	425.8	58-2379	N/A
US EVF	334.0	370.6	33-1938	0.0011
MRI EVF	404.3	477.5	36-2425	>0.9999
MRI 3D Volumetry	391.8	446.1	42-2534	>0.9999

Table 2. Comparison of uterine measurements by means of EVF and 3D volumetry in patents for whom the pre-operative ultrasound measurements were not available.

US measurement not feasible		n=8		
	Mean (g)	SD (g)	Range (g)	p-value
Uterus Weight	679	367	179-1430	N/A
US EVF	N/A	N/A	N/A	N/A
MRI EVF	527	278	198-983	0.56
MRI 3D Volumetry	666	271	249-1056	0.93

ence between measurements by the means of EVF and 3D volumetry although there was a trend for better correlation with the 3D volumetry method.

Concerning the surgical approach, 86.6% (n=58) of all hysterectomies were performed in a mini-invasive way, most of them by laparoscopy (n=57), and 13.4% (n=9) by laparotomy. Mean uterine weight was 1236 g (range 653-2379) in case of abdominal hysterectomy versus 289 g (range 58-788) in case of mini-invasive approach. Uterine morcellation was needed for 18 out of the 58 (31%) women who underwent laparoscopic or vaginal hysterectomy. Morcellation was always needed if uterine weight was more than 442 g. Mean uterine weight in case of uterine morcellation was 520 g; 66.7% of uterine morcellations were performed transvaginally, 22.2% were performed by power morcellation and 11.1% by mini-laparotomy.

For the histopathologic examination of hysterectomy specimen, 71.6% (n=48) were uterine fibroids, 2.9% (n=2) endometriosis, 4.4% (n=3) adenomyosis, 4.4% (n=3) uterine fibroids associated with endometriosis and 16.4% (n=11) uterine fibroids associated with adenomyosis.

Discussion

Prior to planning a hysterectomy, a precise pre-operative estimation of the uterine volume is needed in order to choose the optimal surgical approach.

Bimanual examination, TVUS and MRI can all be used for this purpose. Many researchers have addressed the question of the validity of different methods of preoperative calculation of uterine size. Ultrasound, despite having been criticised for its significant operator-dependence, resulting in inferior reproducibility [12, 13], is still the most widely used and relatively low cost method for preoperative imaging of the uterus. In this setting it is widely used for pre-operative uterine volume estimation. Cantuaria et al. showed a significant correlation between ultrasound dimensions and uterine size determined by bimanual examination and histopathology, although weight estimation was not assessed [14]. Three studies proved that preoperative ultrasonographic uterine dimensions correlated with the corresponding dimensions of the uterine specimens in histopathology [10, 15, 16]. In our study, uterine vol-

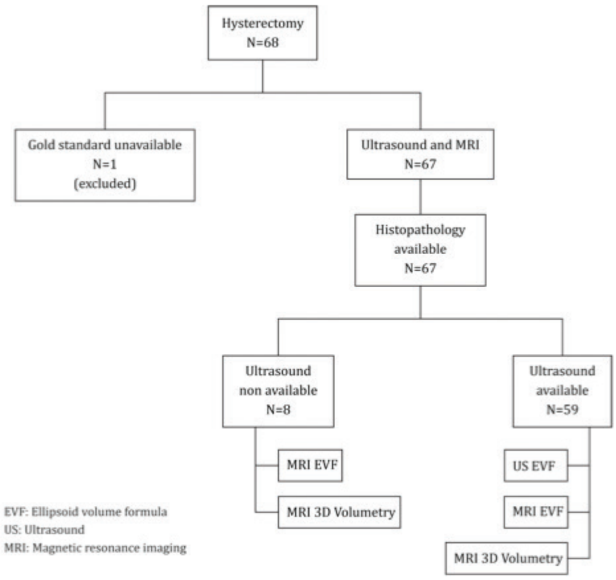

Fig. 4. *Flow chart showing the flow of women and the available measurements for each imaging modality.*

umes calculated with TVUS were statistically different with histopathological weights. This can possibly be explained by the fact that we compared uterine volumes as calculated by the EVF formula and not uterine dimensions as was the case in the literature.

Rovio et al. developed a new formula combining the ellipsoid (for the corpus) and cylinder formulas (for the cervix). However, the study included only twelve patients and the differences were not significant [17].

Three-dimensional (3D) ultrasound has been described as an accurate method of determining uterine volume [18]. However it is not as widely available as 2D ultrasonography and is not systematically performed for all patients that undergo TVUS. Due to its retrospective nature, our study did not include 3D ultrasound as it was not available for all patients. The principal reason was that for many patients, this technique could not be applied due to the size and orientation of the uterus.

Due to the excellent soft-tissue contrast, its ability to cover larger field of views and its reproducibility, MRI is frequently used in the preoperative management of gynaecological patients for the evaluation of pelvic abnormalities, such as location, and volume of leiomyomas or masses [19, 20]. For patients in whom the large size or the position of the uterus does not allow ultrasound evaluation, MRI is the only reliable technique for better coverage and uterine volume estimation. Additionally, MRI, although more costly, has been shown to be the most sensitive method for uterine and gynaecologic evaluation, particularly for the detection of small leiomyomas [21].

MRI, with multiplanar acquisitions, offers the possibility of calculating uterine volume. This can be achieved either indirectly by the same EVF formula using the three dimensions measured in the different plane acquisitions, or by using direct freehand 3D volumetry. To our knowledge, our study is the first to evaluate the performance of MRI for preoperative calculation of uterine volume. We showed that both direct (3D volumetry) and indirect (EVF) MRI methods of volume calculation provided excellent results with values being very similar to pathological reports of uterine weight ($p>0.9999$).

A disadvantage of the 3D volumetry technique is that it is time consuming. On each slice, multiple points outlining the perimeter of the uterus must be marked with calipers manually, until the entire perimeter has been defined. This process takes longer compared to the indirect volume calculation by the means of the EVF. However, our study shows that both methods can be used with similar results. Thus, indirect calculation of uterine volume using the EVF formula based on MRI measurements can be proposed as a valid and rapid technique.

The EVF method can be associated with major drawbacks. Quinn et al. suggested that, although the ellipsoid volume formula is the quickest and most simple method, it does not reflect the true volume of an irregular ovoid object [22]. This is even more pronounced for multiple or irregular fibroids that can easily transform the uterus into a non-ellipsoid shape, in which case, the formula apparently cannot provide adequate results. This is probably the reason for which pre-operative volumes calculated with ultrasound were significantly different.

However, in our study, when applied with MRI measurements, the same EVF formula provided results that were not statistically different compared to the standard of reference. This could possibly be explained by the fact that, for uteri of large size including deformations of their shape due to leiomyomas, MRI shows the whole organ in one image series and the radiologist has a better view of its maximal diameters.

For surgeons, one possible clinical application of this study is to determine whether morcellation will be required or not. When uterine weight is estimated more than around 400 g, uterine morcellation is expected when choosing a mini-invasive approach. In this study, the surgical approach was chosen according to the own surgeon's experience. Women should be systematically clearly informed of this possibility and take part in the decision concerning the technique chosen for uterine extraction.

Our study has limitations. First, it is a retrospective study. In this context, ultrasound was only performed once, by a single operator, in the clinical context of the patient. Thus reproducibility of the technique can not be confirmed. Substantial disparities have been observed in previous studies when results are obtained by different observers using ultrasound, whereas MRI produced highly reproducible results [13]. Further prospective studies are needed to assess more accurately the reproducibility of ultrasound measurements.

Conclusion

According to our results, preoperative calculation of uterine volume is more accurately performed by means of MRI compared to TVUS. Therefore, when MRI and TVUS are performed in the preoperative setting, uterine volume estimation should be obtained based on MRI measurements and not on TVUS. Moreover, as both MRI methods for volume calculation are accurate, the indirect method, using the ellipsoid volume formula, can be safely used without the need of time consuming 3D volumetry. R

Conflict of interest

The authors declared no conflicts of interest.

References

1. Carlson KJ, Nichols DH, Schiff I. Indications for hysterectomy. *N Engl J Med* 1993; 328(12): 856-860.
2. Unger JB, Paul R, Caldito G. Hysterectomy for the massive leiomyomatous uterus. *Obstet Gynecol* 2002; 100(6): 1271-1275.
3. Kovac SR. Guidelines to determine the route of hysterectomy. *Obstet Gynecol* 1995; 85(1): 18-23.
4. ACOG Committee Opinion No. 444: choosing the route of hysterectomy for benign disease. *Obstet Gynecol* 2009; 114(5): 1156-1158.
5. Aarts JW, Nieboer TE, Johnson N, et al. Surgical approach to hysterectomy for benign gynaecological disease. *Cochrane Database Syst Rev* 2015; (8): CD003677.
6. Adelman MR. The morcellation debate: The history and the science. *Clin Obstet Gynecol* 2015; 58(4): 710-717.
7. Harb TS, Adam RA. Predicting uterine weight before hysterectomy: ultrasound measurements versus clinical assessment. *Am J Obstet Gynecol* 2005; 193(6): 2122-2125.
8. Stoelinga B, Huirne J, Heymans MW, et al. The estimated volume of the fibroid uterus: a comparison of ultrasound and bimanual examination versus volume at MRI or hysterectomy. *Eur J Obstet Gynecol Reprod Biol* 2015; 184: 89-96.
9. Piiroinen O, Kaihola HL. Uterine size measured by ultrasound during the menstrual cycle. *Acta obstetricia et gynecologica Scandinavica* 1975; 54(3): 247-250.
10. Platt JF, Bree RL, Davidson D. Ultrasound of the normal nongravid uterus: correlation with gross and histopathology. *J Clin Ultrasound* 1990; 18(1): 15-19.
11. Ward SR, Lieber RL. Density and hydration of fresh and fixed human skeletal muscle. *J Biomech* 2005; 38(11): 2317-2320.
12. Dueholm M, Lundorf E, Hansen ES, et al. Evaluation of the uterine cavity with magnetic resonance imaging, transvaginal sonography, hysterosonographic examination, and diagnostic hysteroscopy. *Fertil Steril* 2001; 76(2): 350-357.
13. Dueholm M, Lundorf E, Sorensen JS, et al. Reproducibility of evaluation of the uterus by transvaginal sonography, hysterosonographic examination, hysteroscopy and magnetic resonance imaging. *Hum Reprod* 2001; 17(1): 195-200.

14. Cantuaria GH, Angioli R, Frost L, et al. Comparison of bimanual examination with ultrasound examination before hysterectomy for uterine leiomyoma. *Obstet Gynecol* 1998; 92(1): 109-112.
15. Dekel A, Farhi J, Levy T, et al. Pre-operative ultrasonographic evaluation of nongravid, enlarged uteri--correlation with bimanual examination. *Eur J Obstet Gynecol Reprod Biol* 1998; 80(2): 205-207.
16. Flickinger L, D'Ablaing G, 3rd, Mishell DR, Jr. Size and weight determinations of nongravid enlarged uteri. *Obstet Gynecol* 1986; 68(6): 855-858.
17. Rovio PH, Luukkaala T, Vuento M, et al. Ultrasonographic assessment of weight of the myomatous uterus: a pilot study using a new combined geometrical formula. *Eur J Obstet Gynecol Reprod Biol* 2008; 137(2): 193-197.
18. Zivkovic N, Zivkovic K, Despot A, et al. Measuring the volume of uterine fibroids using 2- and 3-dimensional ultrasound and comparison with histopathology, *Acta Clin Croat* 2012; 51(4): 579-589.
19. Cornfeld D, Israel G, Martel M, et al. MRI appearance of mesenchymal tumors of the uterus. *Eur J Radiol* 2010; 74(1): 241-249.
20. Griffin Y, Sudigali V, Jacques A. Radiology of benign disorders of menstruation. *Semin Ultrasound* CT MR 2010; 31(5): 414-432.
21. Dudiak CM, Turner DA, Patel SK, et al. Uterine leiomyomas in the infertile patient: preoperative localization with MR imaging versus US and hysterosalpingography. *Radiology* 1988; 167(3): 627-630.
22. Quinn SD, Vedelago J, Kashef E, et al. Measurement of uterine fibroid volume: a comparative accuracy and validation of methods study. *Eur J Obstet Gynecol Reprod Biol* 2013; 171(1): 161-165.

Ready - Made Citation

Djema DA, Dubuisson J, Boukrid M, Villard N, Kalovidouri A, Botsikas D. Preoperative uterine volume estimation: transvaginal ultrasound (TVUS) versus MRI (ellipsoid volume formula and 3D volumetry). *Hell J Radiol 2019*; 4(4): 1-9.