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Preoperative Uterine Weight Estimation Using UroNav in Robot-Assisted Total Laparoscopic Hysterectomy: An Exploratory Study

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Abstract

Objective:
The accuracy of uterine weight estimation using the UroNav MR/Ultrasound Fusion Biopsy System, originally developed for prostate imaging and intervention, has not been investigated in gynecologic surgery. We evaluated the accuracy of UroNav-based three-dimensional uterine volume measurement for preoperative estimation of uterine weight in patients undergoing robot-assisted total laparoscopic hysterectomy (RA-TLH).

Subjects and Methods:
We evaluated 51 patients who underwent RA-TLH for benign uterine tumors and who had not received preoperative gonadotropin-releasing hormone agonists or antagonists. Uterine volume was measured using three-dimensional reconstructions generated from MRI obtained within 3 months before surgery. Predicted uterine weight was calculated assuming a tissue density of 1.0 g/mL. Agreement between UroNav-predicted and retrieved uterine weight (RUW) was assessed. The caliper technique was also evaluated for comparison.

Results:
The mean RUW was 676 g, and the mean UroNav-predicted weight was 668 g, with a mean difference of −8.0 g. Forty-two of 51 cases (82.4%) had prediction errors within ±10% of the RUW, and the mean absolute percentage error (MAPE) was 6.82%. The RUW was strongly associated with the UroNav-predicted weight (R^2 = 0.9903). In comparison, the caliper technique yielded a mean predicted weight of 617 g, a MAPE of 15.25%, and prediction errors within ±10% in 16 of 51 cases (31.4%).

Conclusion:
UroNav-based three-dimensional reconstruction showed good agreement with RUW and provided more accurate weight estimation than the caliper technique. This novel application of an MR/ultrasound fusion platform may assist in preoperative selection of specimen retrieval strategies during RA-TLH.

Introduction

Robot-assisted total laparoscopic hysterectomy (RA-TLH) has expanded the feasibility of minimally invasive surgery for patients with large uteri [1, 2]. However, retrieval of a large uterus after excision remains challenging [3] and may require different strategies, including transvaginal retrieval vis in-bag morcellation [4.5], or abdominal retrieval via a small incision [6, 7]. The choice of retrieval method can affect operative time [8] and may require modification of the surgical plan if the uterine size is underestimated. Therefore, accurate preoperative estimation of uterine weight may facilitate surgical planning and selection of an appropriate specimen retrieval strategy.

Several methods have been used to estimate uterine volume from preoperative imaging. The caliper technique is simple and clinically practical because it estimates uterine volume from three orthogonal diameters. However, approximation of an irregularly shaped uterus as an ellipsoid may result in

measurement errors, particularly in patients with multiple or irregularly distributed fibroids. More detailed volumetric methods, such as the Cavalieri method, may provide accurate measurements but require systematic assessment of multiple cross-sectional images and can be labor-intensive in routine clinical practice.

The UroNav MR/Ultrasound Fusion Biopsy System (Philips, Best, the Netherlands) was originally developed for MRI/ultrasound fusion-guided prostate biopsy and focal therapy. The system incorporates three-dimensional visualization, segmentation, image measurement, and image registration functions. Although these functions are primarily used for prostate imaging and intervention [9, 10], the underlying three-dimensional image reconstruction capability may be applicable to volumetric assessment of other organs.

We hypothesized that UroNav could be adapted for three-dimensional measurement of the uterus using preoperative magnetic resonance imaging (MRI). The purpose of this exploratory study was therefore to evaluate the accuracy of UroNav-based uterine volume measurement for preoperative estimation of uterine weight by comparing the predicted weight with the actual weight of resected specimens. The caliper technique was also evaluated as a conventional comparator.

Materials and Methods

This retrospective single-center exploratory study included patients who underwent robot-assisted total laparoscopic hysterectomy (RA-TLH) for benign uterine tumors at our institution between May 2022 and October 2025. Patients were eligible if preoperative pelvic MRI was available within 3 months before surgery and if they had not received preoperative gonadotropin-releasing hormone agonist or antagonist therapy. Patients receiving preoperative hormonal therapy were excluded because treatment-related changes in uterine or fibroid volume could introduce discrepancies between MRI-derived volume and postoperative specimen weight.

The study was approved by the institutional ethics committee (approval no. 2025-0006). Written informed consent was obtained from all participants. All methods were performed in accordance with the relevant guidelines and regulations. We then collected the following data: age, comorbidities, body mass index (BMI), patient background, surgical outcomes, operative time, console time, tissue retrieval time, blood loss weight of the resected tissue, and hospitalization duration.

Pelvic MRI acquired within 3 months before surgery was imported into the UroNav system. The uterine contour was manually delineated on each relevant cross-sectional MRI image, and the contours were combined to generate a three-dimensional reconstruction of the uterus (Fig. 1). Pedunculated fibroids that were clearly separated from the uterine corpus were independently contoured and their volumes were added to the uterine volume (Fig. 2). The volume of the cervix and all uterine fibroids included in the resected specimen was incorporated into the total preoperative volume. Structures not included in the surgical specimen, such as the ovaries or bowel, were excluded from the reconstruction. Two radiologic technologists performed the image analysis, and a gynecologic surgeon reviewed the reconstructed

images to confirm the inclusion of the cervix and pedunculated fibroids and to exclude non-uterine structures.

UroNav-predicted uterine weight was calculated by multiplying the measured volume by a tissue density of 1.0 g/mL. Additional analyses were performed using assumed tissue densities ranging from 1.01 to 1.10 g/mL.

We also conducted a systematic comparison of results obtained using the caliper method [11]—a simplified calculation method for measuring uterine volume that was adopted due to its ease of use and potential for routine clinical application.

This method utilized the maximum length D1 (length from the internal os) of the uterus on the plane with the largest area in the sagittal T2-weighted MRI image, the maximum length D2 perpendicular to D1, and the maximum left-right length D3 in the transverse plane. Assuming an elliptical shape, we calculated the volume (V) using the following formula: $V = D1 \times D2 \times D3 \times \pi/6$. In addition, for parts protruding from the main body of the uterus—such as pedunculated uterine fibroids or the cervix—measurements were taken separately, and the results were calculated in the same manner and added to the total.

The da Vinci X or Xi Surgical System (Intuitive Surgical, Inc., Sunnyvale, CA, USA) was used for the surgery. Under general anesthesia, patients were placed on a levitator in the lithotomy position and tilted into a 30° head-down position.

RA-TLH was performed as a four-port solo surgery [12, 13]. Without an assistant port, four 8-mm da Vinci ports were positioned horizontally 4 cm above the umbilicus, spaced 8 cm apart in parallel. Using a proprietary “port hopping” technique [13], the surgeon moved the endoscope and three forceps sequentially to different ports as needed. In particular, the third arm was positioned on the left side for procedures on the right side of the uterus, and vice versa.

The retrieved uterine specimen was weighed immediately after surgical removal and before pathological fixation.

Statistical Analysis

The primary outcome was the agreement between UroNav-predicted uterine weight and retrieved uterine weight. Continuous variables were summarized using means and standard deviations or medians and interquartile ranges, as appropriate.

The association between predicted and retrieved uterine weights was assessed using Pearson’s correlation coefficient and linear regression analysis. Agreement between the two measurements was evaluated using Bland–Altman analysis, with the mean difference (bias) and 95% limits of agreement (LoA) calculated. The relationship between measurement error and uterine weight was visually assessed to identify potential proportional bias.

Prediction accuracy was also assessed using the mean absolute percentage error (MAPE), calculated as the mean of the absolute percentage difference between predicted and retrieved uterine weight. The proportion of cases in which the prediction error was within ± 10% of the retrieved weight was also calculated.

The same analyses were performed for the caliper technique. The UroNav method and caliper methods were compared descriptively with respect to prediction error, MAPE, and Bland–Altman agreement.

All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 31 (IBM Corp., Armonk, NY, USA). A two-sided p-value < 0.05 was considered statistically significant.

Results

The demographics and surgical outcomes of the 51 patients who underwent RA-TLH were as follows. The mean age was 49.7 years and the mean BMI was 23.7. Regarding surgical outcomes, the mean values for the operative time, console time, blood loss, and hospitalization duration were 164 min, 120 min, 61 ml, and 6.4 days, respectively.

Moreover, the mean retrieved uterine weight (RUW) was 676 g. Conversely, the mean predicted weight calculated by UroNav analysis was 668 g, resulting in − 8.0 g difference from the actual measured weight. The error rates ranged from − 13.8% to 40.7%, but 42 of the 51 cases (82.4%) fell within ± 10%. In addition, the mean absolute percentage error (MAPE) was 6.82%. The error rates for the nine cases exceeding ± 10% were ranged from − 13.8% to 40.3%. The case with the highest error rate (40.3%) had a RUW of 590 g, whose fibroid exhibited hydropic degeneration. The remaining 8 cases included 4 cases of multiple fibroids (10 or more), 2 cases of pedunculated (434 g) or large (940 g) subserosal fibroids, 1 case of large adenomyosis (521 g), and 1 case of submucosal fibroid (255 g).

When the percentage of cases in which the predicted weight was within ± 10% of the actual RUW was analyzed by retrieved weight category, a high percentage (75.0% – 87.0%) was observed in every RUW group (Table 1). Meanwhile, the mean predicted weight using the caliper technique was 617 g, with − 59 g difference from the actual measured weight. The error rates ranged from − 30.9% to 60.1%, with only 16 of the 51 cases (31.4%) obtaining within ± 10%, and the MAPE was 15.25%.

Table 1
Comparison of the proportion of cases with a margin of error within ± 10%, based on measurement methods and retrieved uterine weight (RUW)

Measurement method	RUW (g)	< 250	250 ≦ < 500	500 ≦ < 750	750 ≦ < 1000	1000≦	total
	No. of cases	**4**	**23**	**14**	**4**	**6**	**51**
UroNav	No. of cases with a margin of error within ± 10% (%)	3 (75.0)	20 (87.0)	11 (78.6)	3 (75.0)	5 (83.3)	42 (82.4)
Caliper	No. of cases with a margin of error within ± 10% (%)	1 (25.0)	8 (34.8)	2 (14.3)	2 (50.0)	2 (33.3)	15 (29.4)

Additionally, using scatter plots, we examined the relationship between the RUW and the predicted weight via linear simple regression analysis. The regression lines were as follows: $y = 0.9641x + 16.803$ ($R^2 = 0.9903$) for the UroNav method, and $y = 0.7978x + 78.071$ ($R^2 = 0.9321$) for the caliper technique. Figure 3 shows a comparison of weight predictions using the two methods. The UroNav method yielded a predicted weight nearly equivalent to the RUW.

To evaluate the agreement between the predicted uterine weight calculated using the two measurement methods and the actual RUW, we conducted the Bland–Altman analysis. It demonstrated a mean difference of − 7.25 g between UroNav-predicted weight and RUW, with 95% limits of agreement (LoA) ranging from − 131.07 to 116.58 g. The 95% confidence interval for the mean difference was − 25.01 to 10.52 g (Supplementary Fig. S1.). In contrast, the mean difference between Caliper-estimated weight and RUW was − 58.56 g, with 95% LoA ranging from − 416.03 to 298.91 g and a 95% confidence interval for the mean difference of − 109.86 to − 7.27 g (Supplementary Table S1). Regression analysis of the differences against the mean of the two measurements showed a significant association for both UroNav (slope, − 0.0316; $P = 0.030$) and caliper technique (slope, − 0.1935; $P < 0.001$).

Next, the effect of uterine tissue density on the predicted weight was examined by adjusting the RUW using density values of 1.01–1.10. Results showed that the predicted weights at densities of 1.01, 1.02, 1.06, and 1.10 were 675 g, 682 g, 709 g, and 735 g, respectively.

When corrected for specific gravities of 1.01, 1.02, 1.06 and 1.10, the mean errors between the RUW and the predicted weight for each case were − 1 g, 6 g, 33 g, and 59 g, respectively. In addition, the error rates ranged from − 13.0% to 41.7%, − 12.1% to 43.1%, − 8.7% to 48.7%, and − 5.2% to 54.3%, and the MAPE increased as the specific gravity increased, reaching 6.76%, 6.80%, 7.85%, and 10.73%, respectively (Table 2).

Table 2
Comparison of the mean retrieved uterine weight: 676 ± 618g (mean ± SD) with the weight predicted by the UroNav and corrected for specific gravity

Specific gravity	**1**	**1.01**	**1.02**	**1.06**	**1.1**
Mean predicted weight (g) by UroNav (mean ± SD)	668 ± 598	675 ± 604	682 ± 610	709 ± 634	735 ± 658
No. of cases with a margin of error of ± 10% (%)	9 (17.6)	10 (19.6)	12(23.5)	15 (29.4)	21 (41.2)
MAPE*	6.8	6.8	6.8	7.9	10.7
*The mean absolute percentage error					

Discussion

The principal finding of this study was that UroNav-based three-dimensional reconstruction provided accurate preoperative estimation of uterine weight in patients undergoing RA-TLH. The mean difference between UroNav-predicted and retrieved uterine weight was − 8.0 g, 82.4% of cases were within ± 10% of the retrieved weight, and the MAPE was 6.82%. In comparison, the caliper technique showed a larger prediction error, with a MAPE of 15.25% and only 31.4% of cases within ± 10%. These findings suggest that three-dimensional image reconstruction using UroNav may provide a more accurate approach to preoperative uterine weight estimation than a conventional three-dimensional diameter-based method.

In minimally invasive surgery (MIS), methods for safely retrieving large uteri from the body remain challenging. Traditionally, excised tissue is retrieved using morcellators; however, following the Food and Drug Administration recommendation [14], their use has come to be evaluated with greater caution. Consequently, various institutions have devised retrieval methods (e.g., “in-bag morcellator” [15] and the small incision technique [16]) aimed at reducing tissue scattering risk. Meanwhile, with the spread of robot-assisted surgery, the indications for MIS are expanding. Apart from maintaining a minimally invasive approach, surgeons performing MIS should avoid prolonging the operative time and making intraoperative changes to the surgical plan. Therefore, to perform MIS on a large uterus safely and according to plan, they are recommended to consider the method of retrieving the resected uterus preoperatively, and as a prerequisite for this retrieval, the weight of the resected specimen should be predicted as accurately as possible.

Matsuzaki et al. [4] reported that, taking the surgeon’s concentration into account and setting the time required for retrieval at 30 min or less, transvaginal retrieval is feasible for weights of approximately 750 g and retrieval via a small incision for weights exceeding 1000 g. Thus, preoperative prediction of the resected uterus’ weight not only estimates the specimen weight but also serves as an indicator for optimizing the overall surgical plan. Specifically, it is considered clinically significant in terms of enabling the preoperative selection of an appropriate retrieval method, providing a detailed explanation to the

patient to obtain informed consent, and reducing the risk and time loss associated with changing the retrieval method intraoperatively.

To predict the resected uterus' weight, the surgeon needs to first accurately assess uterine volume according to preoperative images. The main methods used to assess uterine volume are the Cavalieri method [17] and the caliper technique [11]. The Cavalieri method calculates volume by summing the cross-sectional areas in MRI images. Conversely, the caliper technique estimates volume according to the prolate ellipsoid formula, using measurements taken in three directions: the long-axis diameter, anteroposterior diameter, and transverse diameter.

The Cavalieri method is based on Cavalieri's principle, proposed by the 17th-century Italian mathematician Cavalieri; it is a stereometric technique that exhibits minimal design bias and may provide consistent accuracy. It reportedly demonstrates good reproducibility and efficiency in the volumetric measurement of the uterus and fibroids using MRI [18]. However, given that the calculation process is cumbersome, its continuous use in routine clinical practice remains challenging.

Although less accurate than the Cavalieri method, the caliper technique is simpler and easier to implement in clinical practice. However, considering that it approximates the entire uterus as a simple ellipsoid, it may be suitable for evaluating relatively large, solitary fibroids or adenomyosis that is spherical in shape; conversely, in patients with multiple subserosal or intramural fibroids, this method may be difficult to accurately assess the volume. In this study as well, the caliper technique showed a significant difference as RUW increased. In contrast, the UroNav method demonstrated that the difference was not affected by the weight of the RUW, indicating that it is a reliable prediction method even for large uteri.

Thus, these existing volume assessment methods demonstrate a certain trade-off between accuracy and ease of use. To address this challenge, UroNav—an image analysis support system originally designed for the prostate—may be applicable to three-dimensional volume assessment based on MRI images. In this study, we used UroNav to measure the volume of the uterus scheduled for removal according to MRI images obtained during routine clinical practice and examined the correlation of the UroNav-predicted weight with the actual weight of the resected specimen.

The tissue retrieved during a total hysterectomy includes uterine fibroids, adenomyosis, normal uterine muscle layer, and the cervix. These tissues have different histological compositions; thus, their specific gravity may vary. In uterine fibroids, which are often the primary component, their specific gravity might be slightly greater than that of water, similar to normal uterine tissue, because they are benign tumors composed of smooth muscle and connective tissue [19, 20].

In this study, the effect of specific gravity during the process of estimating weight from volume was examined by adjusting the predicted weights to account for specific gravity. Both the predicted weight and MAPE increased as the specific gravity increased; when adjusted for a specific gravity of 1.01, the values closest to the actual measured weights were obtained. Thus, in this cohort, estimates based on

unadjusted volume or those using a specific gravity of 1.01 exhibited the smallest mean bias These results reflect the possibility that the specific gravity of uterine tissue is slightly greater than that of water.

Meanwhile, the actual weight after excision does not necessarily match the weight simply calculated from the preoperative uterine volume. Given the outflow of blood and fluid components during the shredding process, as well as the loss of fluids contained in degenerated fibroids, the actual measured weight may be lower than the weight estimated preoperatively. Therefore, although the specific gravity-corrected values approximating the actual measured weight is an important finding, the predicted weight from UroNav without correction may be clinically useful as a preoperative indicator for selecting the retrieval method.

Regarding the prediction of uterine weight using UroNav, as demonstrated in this study, an evaluation of agreement with RUW using the Bland–Altman analysis showed that the mean difference for UroNav method was small and the LoA was relatively narrow. Furthermore, while caliper technique tends to underestimate uterine volume as it increases, UroNav method exhibits a much weaker tendency toward underestimation (Fig. 4); as a result, it corrects the morphological errors that often arise with existing simple volume estimation methods and facilitates the selection of a preoperative method for retrieving the resected uterus.

In particular, for cases involving large uteri, determining preoperatively whether transvaginal removal is feasible or whether a small incision should be used may shorten operative times and help avoid changes in strategy intraoperatively. In this regard, this method may have clinical significance in enhancing the accuracy of surgical planning while maintaining the minimally invasive nature of MIS.

This study has several limitations. First, the specific gravity of uterine tissue may vary according to tissue composition, including the proportion of fibroid tissue, adenomyosis, and degenerative changes. Such variation may contribute to discrepancies between MRI-derived volume and postoperative specimen weight. Second, the interval between MRI acquisition and surgery may have introduced measurement error because uterine or fibroid volume can change over time. Third, UroNav-based volume measurement required manual contouring and trained personnel, and the reproducibility of the measurement was not formally assessed in this study. Fourth, UroNav is primarily designed for prostate imaging and intervention, and its application to uterine volumetry has not been independently validated across institutions. Finally, although accurate preoperative weight estimation may facilitate selection of a specimen retrieval strategy, the present study did not directly evaluate whether use of UroNav reduces operative time, prevents intraoperative changes in retrieval strategy, or improves clinical outcomes. Further multicenter studies are therefore warranted to assess accuracy, reproducibility, and clinical utility.

Conclusion

In this exploratory single-center study, UroNav-based three-dimensional reconstruction showed good agreement with retrieved uterine weight and provided more accurate preoperative weight estimation than the conventional caliper technique. Although UroNav was originally developed for prostate imaging and intervention, its three-dimensional reconstruction capability may have broader applications in surgical planning. Preoperative uterine weight estimation using UroNav may assist in selecting an appropriate specimen retrieval strategy during robot-assisted total laparoscopic hysterectomy. Further multicenter studies are required to validate the accuracy and reproducibility of this approach and to determine its clinical utility in robotic gynecologic surgery.

Abbreviations

RA-TLH, robot-assisted total laparoscopic hysterectomy; MRI, magnetic resonance imaging; MAPE, mean absolute percentage error; RUW, retrieved uterine weight; LoA, limits of agreement; MIS, minimally invasive surgery

Declarations

Funding declaration

This research received no funding whatsoever.

Author Contribution

Motoki Nakai conceived the idea of measuring uterine fibroid volume using an alternative measurement method. Keiichi Isaka conceived the application of UroNav for estimating uterine fibroid weight. Makoto Ohori provided access to the UroNav system and contributed to the study design. Yoshihiko Matsuzaki and Haruka Kyo collected the clinical data. Hirotake Sato and Hiroki Miyazawa, radiologic technologists, performed UroNav-based measurements and estimated uterine fibroid weight. Hiroe Ito, Keiichi Isaka, Kiyoaki Tsutsumi, and Yasukazu Sagawa analyzed and interpreted the data. Hiroe Ito and Keiichi Isaka drafted the manuscript. All authors critically revised the manuscript for important intellectual content and approved the final version for publication. All authors agree to be accountable for all aspects of the work, ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Data Availability

The data supporting the findings of this study are provided in the Supplementary Information (Supplementary Table S2).

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Figures

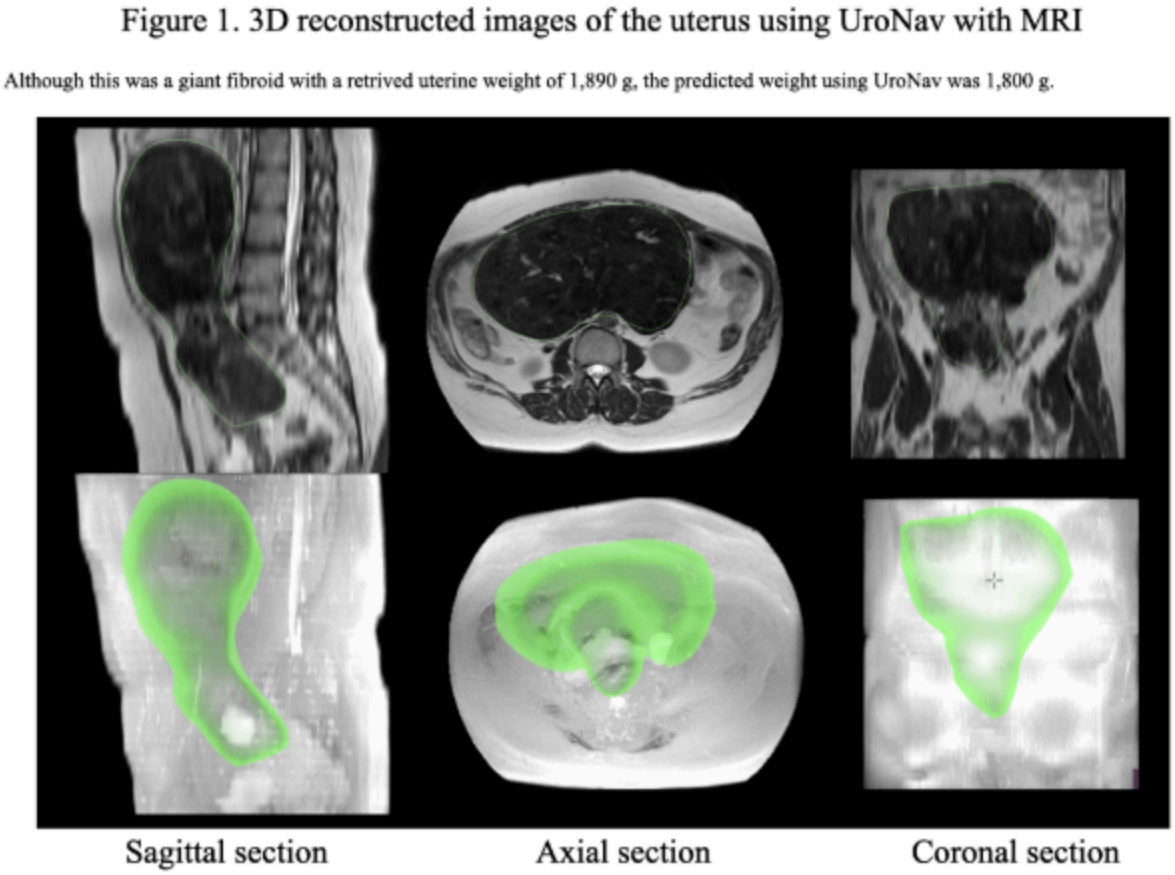


Figure 1

3D reconstructed images of the uterus using UroNav with MRI

Although this was a giant fibroid with a retrieved uterine weight of 1,890 g, the predicted weight using UroNav was 1,800 g.

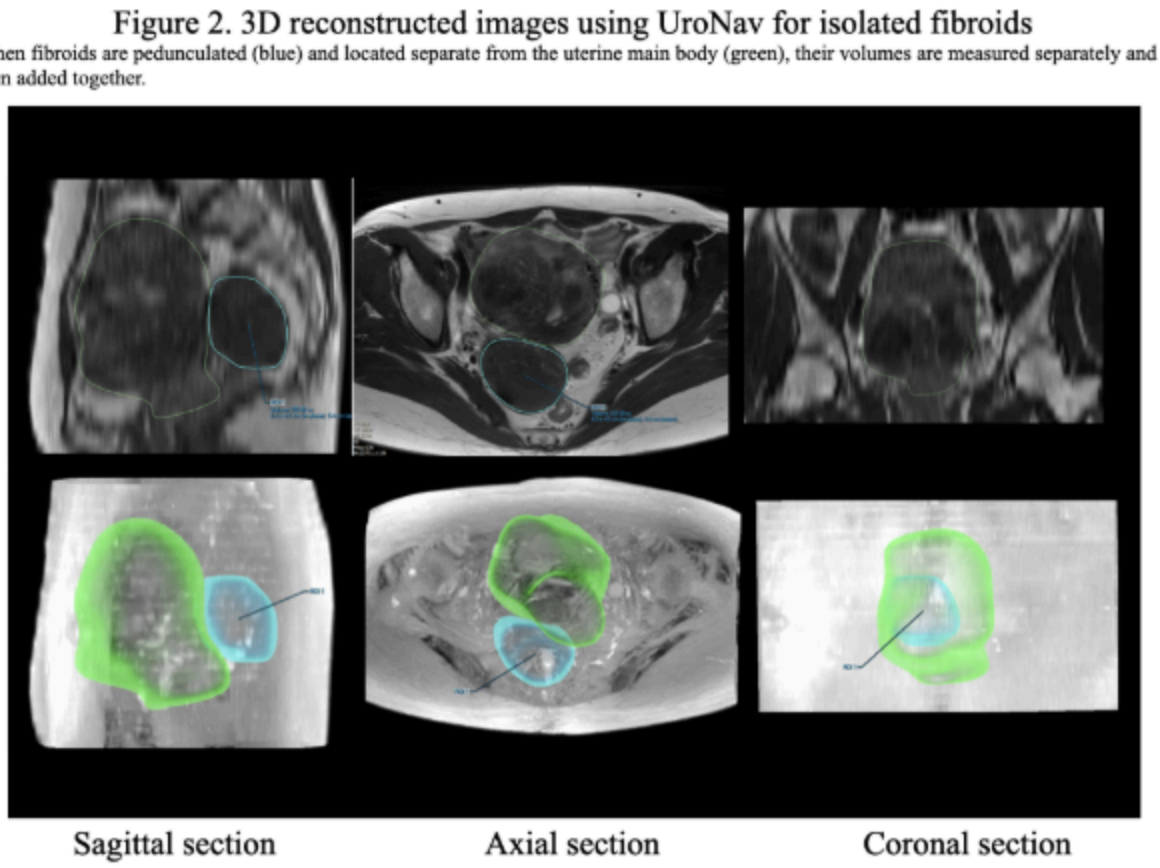


Figure 2

3D reconstructed images using UroNav for isolated fibroids

When fibroids are pedunculated (blue) and located separate from the uterine main body (green), their volumes are measured separately and then added together.

Figure 3. Comparison of Weight Predictions Using the UroNav Method and the Calliper Method

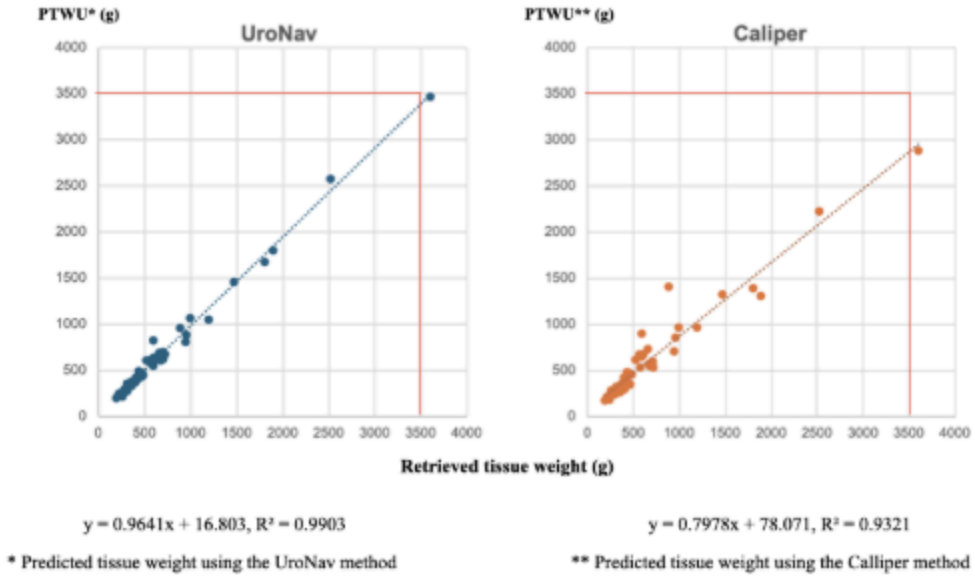


Figure 3

Comparison of Weight Predictions Using the UroNav Method and the Calliper Method

UroNav: y = 0.9641x + 16.803, R^2 = 0.9903, Caliper : y = 0.7978x + 78.071, R^2 = 0.9321

* Predicted tissue weight using the UroNav method, ** Predicted tissue weight using the Calliper method

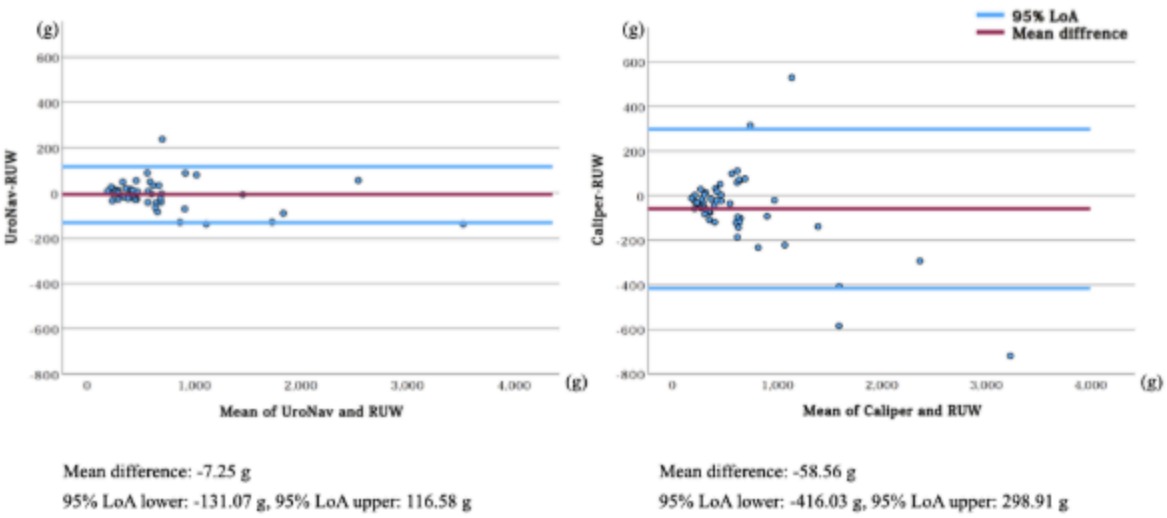


Figure 4

Evaluation and comparison of the agreement between weights predicted using the NroNav method and the caliper technique and the retrieved uterine weight

UroNav: Mean difference: -7.25 g, 95% LoA lower: -131.07 g, 95% LoA upper: 116.58 g

Caliper: Mean difference: -58.56 g, 95% LoA lower: -416.03 g, 95% LoA upper: 298.91 g

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryInf.pdf