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Diagnostic performance of preoperative MR imaging findings for differentiation of uterine leiomyoma with intraligamentous growth from subserosal leiomyoma

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Abstract

Purpose To evaluate the diagnostic performance of MRI findings for differentiating uterine leiomyoma with intraligamentous growth, or broad ligament fibroid, from subserosal leiomyoma.

Methods This study included 37 patients with surgically confirmed uterine smooth muscle tumors (36 leiomyomas and one smooth muscle tumor of uncertain malignant potential) with intraligamentous growth (IL) and size-matched control of 37 patients with subserosal leiomyoma (SS). Two radiologists independently evaluated eight preoperative MRI findings: tumor shape, degeneration, attachment to uterus, ovary elevation, ureter displacement, bladder deformation, rectal displacement, and separation of round ligament (RL) and uterine artery (UA). The diagnostic values of these findings and interobserver agreement were assessed. Receiver-operating characteristic (ROC) analysis of the number of positive MRI findings for diagnosing IL was performed. Clinical outcomes including surgical method, operation time, intraoperative blood loss, perioperative complications, and postoperative hospital stay of the two groups were compared.

Results Significant differences in tumor shape, attachment to uterus, ovary elevation, ureter displacement, and separation of RL and UA were found between IL and SS. Four of these findings, excluding ureter displacement, showed moderate to substantial interobserver agreement. When two or more of these four findings were positive, sensitivity, specificity, and area under the ROC curve were 91%, 77%, 0.90 in reader 1 and 82%, 89%, 0.91 in reader 2. The operation time was significantly longer for IL than for SS.

Conclusion Tumor shape, attachment to uterus, ovary elevation, and separation of RL and UA are useful MRI findings for differentiating intraligamentous leiomyoma from subserosal leiomyoma.

Keywords Intraligamentous leiomyoma · Magnetic resonance imaging · Subserosal leiomyoma · Uterine leiomyoma

Introduction

Uterine leiomyoma is the most common gynecologic tumor, occurring in more than 20% of women older than 30 years of age [1, 2]. Uterine leiomyomas are classified by their location as submucosal, intramural, and subserosal [3]. They sometimes grow laterally between the folds of broad ligaments and subsequently extend into the retroperitoneum, called intraligamentous leiomyoma, accounting for 6.3% of uterine leiomyoma [4–8]. They tend to become large without symptoms and impinge on the ureter or fallopian tube, causing hydronephrosis or infertility [4–9].

Although the term intraligamentous leiomyoma or broad ligament fibroid sometimes refer to leiomyoma of broad ligament origin which is not continuous with uterus, the term

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intraligamentous leiomyoma in this study designates subserosal leiomyoma of uterus origin with intraligamentous growth [10]. The term subserosal leiomyoma included as controls in this study was limited to uterine subserosal leiomyoma protruding into peritoneal space not into the broad ligament or retroperitoneum. Anatomically, the double layer of the broad ligament encloses the ovary and the round ligament as shown in Fig. 1. The uterine artery and the ureter are at the base of the broad ligaments [11, 12]. Consequently, the ovary, round ligament, uterine artery, and ureter as well as bladder and rectum share spatial continuity to the uterus.

Preoperative diagnosis of intraligamentous growth of uterine leiomyoma is necessary because it poses surgical risks of complications such as massive bleeding, urinary tract injury, and intestinal injury. After examining 2050 laparoscopic myomectomies, including 130 cases of intraligamentous leiomyoma, Sizzi et al. reported significantly higher risk for major complications for patients with intraligamentous leiomyomas [8]. Their large size, close association with adjacent organs and restricted operative field are regarded as posing increased risk of surgical complications [4, 8, 13–15]. Accurate preoperative diagnosis of intraligamentous growth of uterine leiomyoma would allow careful preoperative planning to reduce these surgical risks: selection of the surgical method, the possibility of fertility preservation, and measures to avoid injury of the ureter, bladder, and intestine. If necessary, preoperative countermeasures such as ureteral stenting, participation of multi-specialist operators, and preparation of autologous blood transfusion can be considered [4, 9, 13, 16].

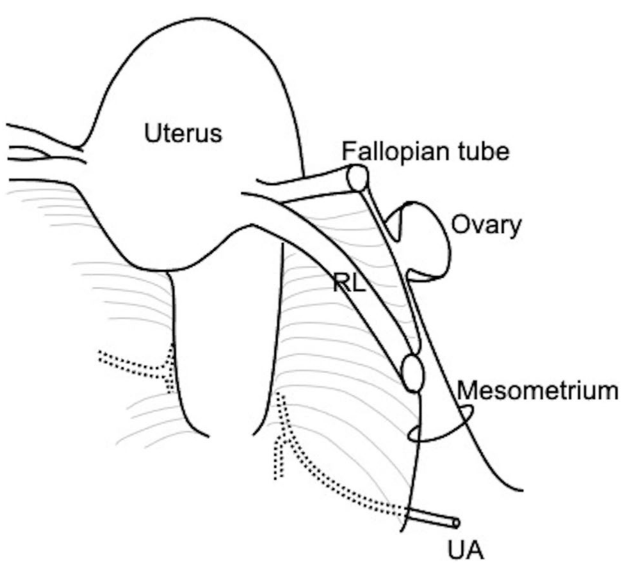

Fig. 1 Schema of the broad ligament and surrounding structures. The broad ligament suspends the ovary on its posterior aspect via mesovarium and encloses the round ligament (RL) on its anterior aspect. Uterine artery (UA) runs through the basal part of the mesometrium

No established method exists to distinguish intraligamentous leiomyoma from subserosal leiomyoma. Results of some studies have demonstrated that magnetic resonance imaging (MRI), because of its excellent tissue characterization and wide field of view, is superior to ultrasonography for the localization of uterine leiomyoma [17, 18]. Only one English language report has described a study of preoperative MRI findings for the differentiation of intraligamentous leiomyoma from subserosal leiomyoma, which examined the ipsilateral ovary position relative to leiomyoma [19]. Several Japanese reports on this issue have described findings of uterine artery, round ligament, bladder, rectum, and feeding vessels, but no report has presented multiple MRI findings [20].

We hypothesized that we could know the specific MRI findings for IL by understanding the spatial relationship between IL and normal structure on MRI. We also speculated that there could be characteristic findings in the location, shape and degree of degeneration of the intraligamentous leiomyoma.

The objective of this study is to investigate preoperative MR imaging findings that are useful for creating an accurate and reproducible diagnostic model for uterine leiomyoma with intraligamentous growth with size-matched control of subserosal leiomyoma.

Materials and method

Our institutional review board approved this single-center retrospective study (approval number #R2760). The requirement for written informed consent was waived.

Patients

A flowchart for participant inclusion is shown in Fig. 2. Two groups were recruited: patients of uterine smooth muscle tumor with intraligamentous growth (IL group) and those with uterine subserosal smooth muscle tumor (SS group). Regarding the IL group, consecutive surgical and pathological records collected at our institute were searched for uterine leiomyoma and smooth muscle tumor of uncertain malignant potential (STUMP) with intraligamentous or retroperitoneal growth from January 2005 through July 2019. Exclusion criteria were the following: patients who were pregnant ($n=1$), those with coexisting gynecological malignancy ($n=4$), and those without evaluable preoperative MRI ($n=0$). Cases with coexisting gynecological malignancy were excluded because advanced malignancy may interfere anatomical relation of pelvic organs by invasion or adhesion.

Regarding the SS group, consecutive surgical and pathological records collected at our institute from January 2016

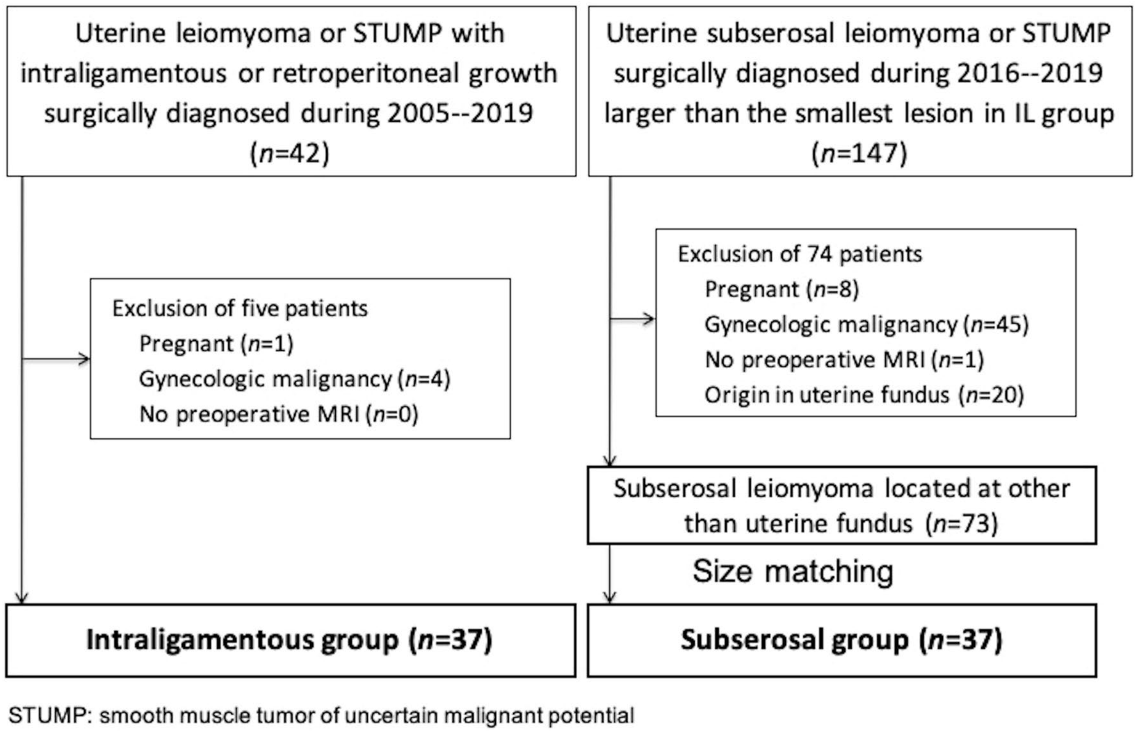

Fig. 2 Flow diagram of patient selection

through December 2019 were searched for uterine subserosal leiomyoma and STUMP larger than the smallest lesion in the IL group. The term subserosal leiomyoma included as controls in this study was limited to uterine subserosal leiomyoma protruding into peritoneal space not into the broad ligament or retroperitoneum. From this population (*n* = 147), the following patients were excluded: patients who were pregnant (*n* = 8), those with coexisting gynecological malignancy (*n* = 45), those without evaluable preoperative MRI (*n* = 1), and those with the lesion located at the uterine fundus (*n* = 20). Patients with subserosal lesion at the uterine fundus were excluded, because they seldom grow into a broad ligament and they can be readily distinguished from patients with intraligamentous leiomyoma. The largest lesion was selected for evaluation if multiple lesions of one patient met the criteria above. From this population (*n* = 73), a size-matching process was implemented to achieve comparable size distributions of lesions in both groups. Each IL case was matched to the closest tumor size in SS cases. Finally, this study examined IL cases (*n* = 37) and SS cases (*n* = 37).

Clinical characteristics

Clinical information of patients was extracted from patient charts, surgical records and pathology reports: patient age, history of gynecological surgery, preoperative diagnosis (intraligamentous or subserosal), preoperative ureteral stenting, histologic subtype (leiomyoma or STUMP), surgical diagnosis of tumor extension (intraligamentous or subserosal), surgical procedure (laparotomy or laparoscopic surgery, and hysterectomy or tumorectomy), operation time, scheduled operation time, intraoperative blood loss, perioperative complications, and postoperative hospital stay.

The following perioperative complications were included: bleeding requiring allogenic blood transfusion, conversion from laparoscopy to laparotomy, surgical site infection requiring postponement of discharge, readmission because of complication, and intestinal, ureteral, or bladder injury requiring intraoperative suture or postoperative invasive procedures. The data curation above were done by one board-certified radiologist with seven years of experience in gynecological radiology.

MRI protocol

For this study, MRI was performed using a 1.5-T device (Avanto; Siemens Healthineers, Erlangen, Germany) or a 3.0-T device (Trio, Skyra, Prisma; Siemens Healthineers, Erlangen, Germany) equipped with a phased-array coil. Before MRI examination, 20 mg of butyl scopolamine (Buscopan; Nippon Boehringer Ingelheim, Tokyo, Japan) was administered intramuscularly to reduce bowel motion, unless contraindicated. Our routine MR images included sagittal and axial T2-weighted image (T2WI) and coronal half-Fourier acquisition single-shot turbo spin-echo (HASTE). The parameters of T2WI were the following: 4000–5020 ms/81–108 ms repetition time/echo time; 4 mm/1 mm slice thickness/intersection gap; 250 kHz bandwidth; field of view, 211 × 260 mm/mm for sagittal and 320 × 320 mm/mm for axial; matrix size, 312–328 × 448–512 for sagittal and 384–512 × 512 for axial. The parameters of HASTE were the following: 1000 ms/87–102 ms repetition time/echo time, 3 mm slice thickness, 268–405 kHz bandwidth, 330–340 × 330–340 mm/mm field of view, 256–346 × 256–384 matrix size.

Image analysis

One radiologist (the same radiologist who performed data curation) measured the tumor maximum diameter on T2WI. Two other board-certified radiologists, respectively with 8 and 11 years of experience in gynecological radiology (BLIND) independently reviewed preoperative MRI. Readers only evaluated T2WI and coronal HASTE to assess the following findings. Although they were allowed to refer to other sequences adjunctively, they used only T2WI and coronal HASTE to determine whether the findings are positive or negative. They were blinded to clinical characteristics, surgical and pathological findings. The readers visually evaluated eight MRI findings: (1) shape deformity, (2) prominent degeneration, (3) low attachment to the uterus, (4) ovarian elevation, (5) ureter displacement, (6) bladder deformation, (7) rectal displacement, and (8) separation of round ligament (RL) and uterine artery (UA). (1) "Shape deformity" was defined as positive in cases where the tumor had undulating margin, molding its shape to conform to the adjacent structures. It was defined as negative when its shape was round or oval (Fig. 3). (2) Prominent degeneration was scored as positive when more than half of the lesion showed high signal intensity on T2WI. Signal intensity on T2WI was compared with normal uterine myometrium. (3) The lesion attachment to the uterus was defined as low (positive) when it was closer to the external cervical os than to uterine fundus (Fig. 4). (4) Ovary elevation was regarded as positive when the ipsilateral ovary was directly displaced cranially by leiomyoma (Fig. 5). In positive cases, the ovary was adjacent to the leiomyoma and was above the epicenter of the leiomyoma. In cases where the ovary was considered in its proper position, that is bilateral ovaries exist just beside the uterus, it was regarded as negative regardless of the relation with the leiomyoma. (5) Ureter displacement was regarded as positive when the ipsilateral ureter was displaced anteriorly or posteriorly by leiomyoma referring to the contralateral ureter. In cases where the ureter was displaced laterally toward the pelvic wall but not displaced anteriorly or posteriorly, it was regarded as negative because this finding was not considered to be related to whether the leiomyoma was IL or SS. (6) The degree of bladder deformation by leiomyoma was assessed using a 10% increment referring to coronal HASTE. (7) Rectal displacement was scored as positive when the rectum deviated from the midline at the mid-femoral head level of axial T2WI. (8) Separation of RL and UA was defined as positive when the tumor sits between RL and UA and widened the distance between them (Fig. 6). Readers assessed spatial relation of the leiomyoma with these two structures and made judgement

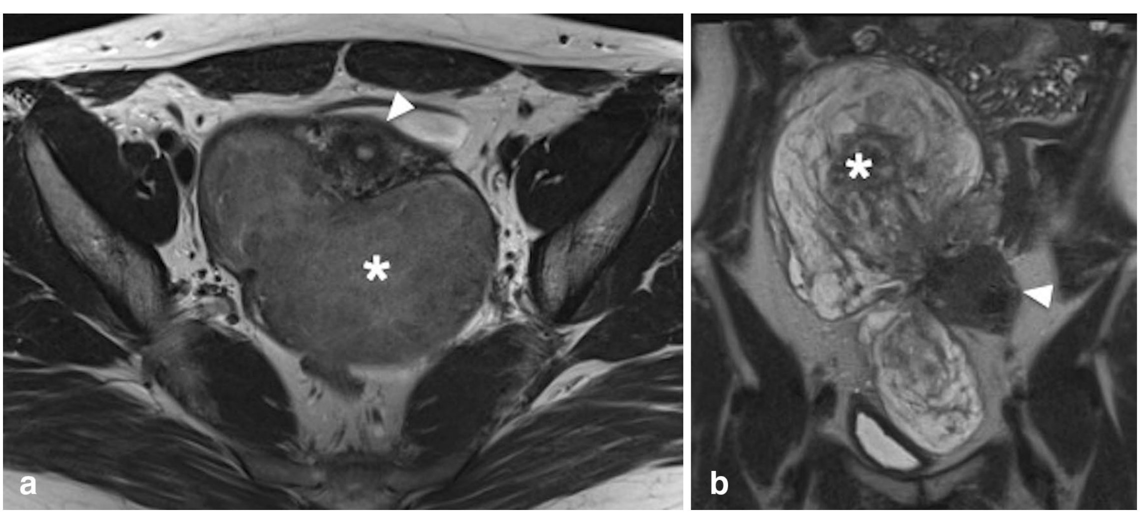

Fig. 3 Representative cases (**a** 33-year-old female, **b** 44-year-old female) of shape deformity with surgically and pathologically confirmed diagnosis of intraligamentous leiomyoma (asterisk) on T2WI. Both lesions have undulating margin, molding its shape to conform to the adjacent structures, not round or oval. Uterus is indicated by white arrowheads

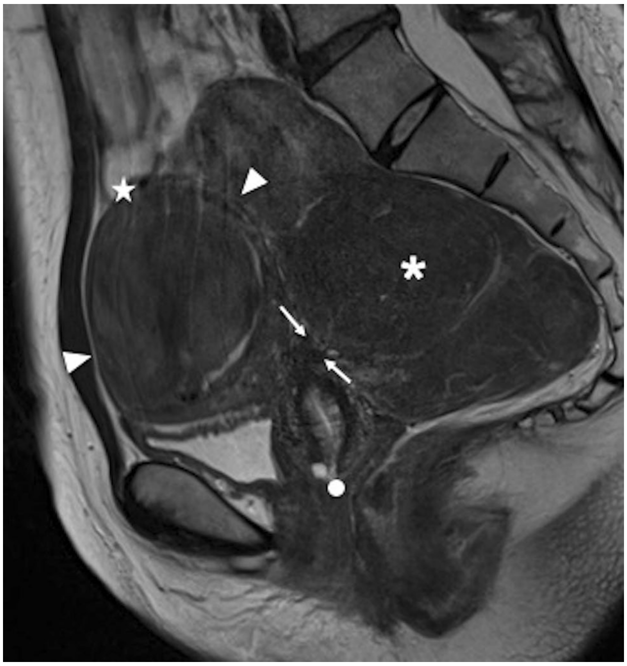

Fig. 4 Representative case (40-year-old) of lower origin of surgically diagnosed intraligamentous leiomyoma (asterisk) located posterolateral to the uterus (white arrowheads) on T2WI. The tumor origin from uterus (white arrows) is closer to external cervical os (white circle) than to uterine fundus (white star). There is an intramural leiomyoma in the anterior wall of the uterus

referring to the contralateral side. Ovary elevation, ureter displacement, and separation of RL and UA were scored as indeterminate when the ovary, ureter, RL, or UA could not be identified with confidence to ascertain the presence or absence of displacement. The other findings were scored as positive or negative. These MR imaging findings are summarized in Table 1.

Statistical analysis

Statistical analyses were performed using software (R 4.0.2; The R Foundation for Statistical Computing, Vienna, Austria). Student's *t* test was applied to compare ages between IL and SS groups. Tumor size, operation time, intraoperative blood loss, and postoperative hospital stay were compared using the Mann–Whitney *U* test. The frequencies of gynecological surgical history, histologic subtype, surgical method, prolongation of operation time, the presence of perioperative complications, and each imaging finding were compared using Fisher's two-sided exact test. The Youden index was used to set a cut-off point of bladder deformation. The sensitivity, specificity, and positive and negative likelihood ratio were calculated excluding indeterminate cases.

The degree of interobserver agreement for MRI findings was calculated using kappa statistics. Regarding ovary elevation, ureter displacement, and separation of RL and UA, cases which both readers categorized as indeterminate were treated as concordant cases. A kappa value of 0.21–0.40 was

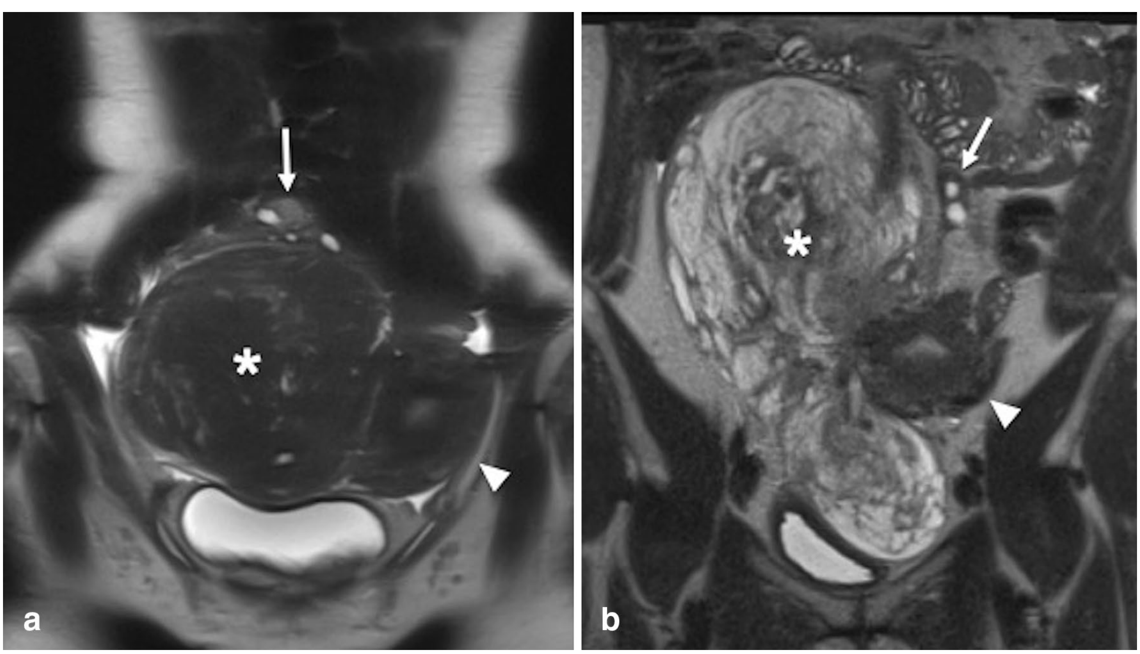

Fig. 5 Representative cases of ovary elevation by intraligamentous leiomyoma with surgical diagnosis (**a** 45-year-old, **b** 44-year-old). **(a)** The ipsilateral ovary (white arrow) is elevated cranially by intraligamentous leiomyoma (asterisk) on T2WI. **(b)** The ipsilateral ovary (white arrow) was also displaced medially and even to contralateral by intraligamentous leiomyoma (asterisk) with significant extension into the retroperitoneal space on HASTE. Uterus is indicated by white arrowheads

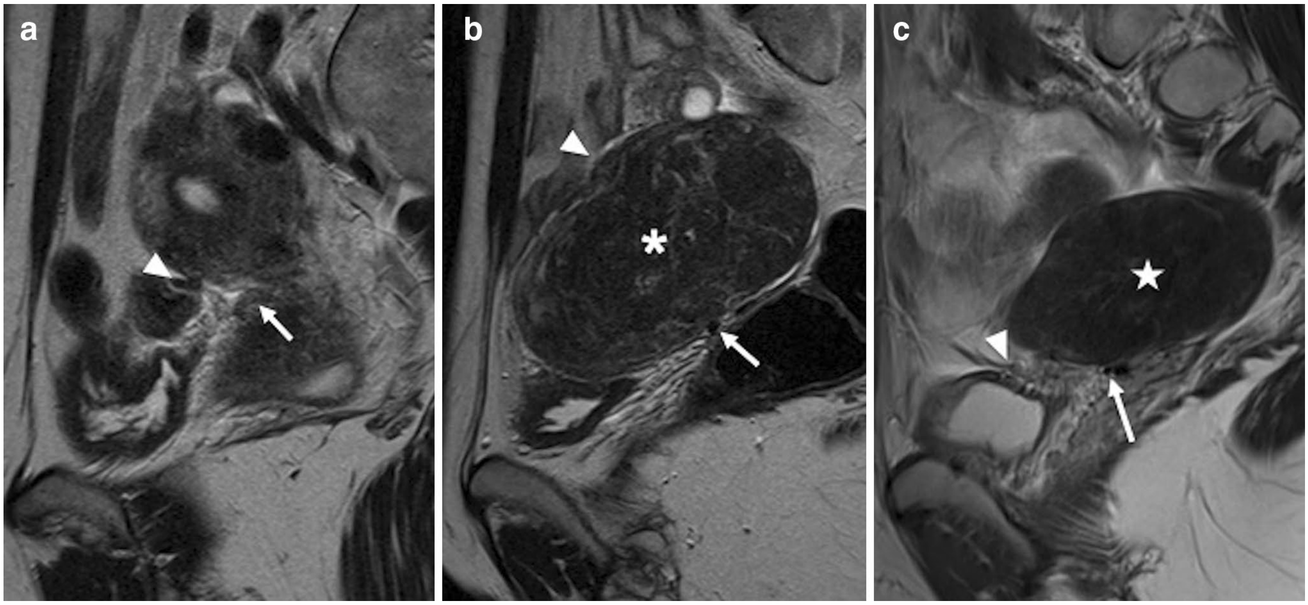

Fig. 6 **a**, **b** Representative case (41-year-old) of separation of round ligament (RL) and uterine artery (UA) by the intraligamentous (IL) leiomyoma on T2WI. **a** On the unaffected side, RL (white arrowhead) and UA (white arrow) run close beside the uterus. **b** On the affected side, the distance between RL (black arrow) and UA (white arrow) is widened by the leiomyoma (asterisk) extending into the broad ligament. **c** Representative case (36-year-old) of subserosal leiomyoma. The subserosal leiomyoma (star) does not separate RL (white arrowhead) and UA (white arrow)

Table 1 List of MR imaging findings and their definitions

MR imaging findings	Definition
Shape deformity	Undulating margin of the lesion, molding its shape to conform to the adjacent structures, not round or oval
Degeneration	High signal intensity on T2WI in more than half of the lesion
Low attachment to the uterus	Origin of the lesion from the uterus is closer to external cervical os than to uterine fundus
Ovary elevation	Direct displacement of the ipsilateral ovary to the cranial direction by compression of the lesion
Ureter displacement	Displacement of the ureter in the anterior or posterior direction by compression of the lesion
Bladder deformation	Bladder deformation of more than 40% from its proper shape by compression of the lesion
Rectal displacement	Deviation of the rectum from the midline at the mid-femoral head level by compression of the lesion
Separation of RL and UA	The lesion sits between RL and UA, and widen the distance between two structures by referring to the contralateral side.

RL round ligament, *UA* uterine artery

inferred as fair agreement, 0.41–0.60 as moderate agreement, 0.61–0.80 as substantial agreement, and 0.81–1.00 as excellent agreement [21].

Sensitivity, specificity, positive and negative likelihood ratio of each MRI finding were calculated. Regarding MRI findings with significant difference and moderate to substantial interobserver agreement, the optimal cut-off number of positive MRI findings for the differentiation of IL from SS was determined using receiver operating characteristic (ROC) curve analysis. The optimal cut-off number of positive MRI findings was defined using the Youden index. The area under the ROC curve (AUC) of the number of positive MRI findings for differentiating IL from SS was calculated. Significance was inferred for p of less than 0.05.

Results

Clinical characteristics

Results of clinical characteristics are presented in Table 2. No patient in the IL group had multiple intraligamentous lesions. The range of the tumor size measured in MRI was

47–244 mm in the IL group and 48–276 mm in the SS group. The mean and range of difference in size between IL and SS leiomyoma were 10 mm, 0–34 mm. One case of IL was STUMP. The others were leiomyoma (Table 2). The operation time of IL (median 254 min, interquartile range 200–282) was significantly longer than that of SS (median 201, interquartile range 173–235) ($p = 0.005$). The frequency of exceeding the scheduled operation time was significantly higher in IL ($n = 22$) than in SS ($n = 11$) ($p = 0.019$). No significant difference was found in patient age, tumor size, blood loss, postoperative hospital stay, and gynecological surgical history, histological subtype, surgical method, and perioperative complications. Perioperative complications were allogenic blood transplantation ($n = 3$), rectal injury ($n = 1$), small intestine injury ($n = 1$) in the IL group, and allogenic blood transplantation ($n = 1$) in the SS group.

Image analysis

Results of the evaluation of MRI findings are presented in Table 3. The frequency of shape deformity, low attachment to the uterus, ovary elevation, ureter displacement, and separation of RL and UA were significantly higher in IL than in SS for both readers (all $p < 0.01$). Regarding ureter displacement, 9 cases were rated by reader 1 and 27 cases were rated by reader 2 as indeterminate. No significant difference was found for tumor degeneration, bladder deformation, or rectal displacement. Regarding these five MRI findings with significant difference, diagnostic value and kappa value are presented in Table 4. Among these five MRI findings, four imaging findings, including shape deformity, low attachment to uterus, ovary elevation, and separation of RL and UA, showed moderate to a substantial interobserver agreement. These were used to create a diagnostic model. The diagnostic value of the number of positive MRI findings and ROC analysis are presented in Table 5 (Fig. 7, ROC curves of the two readers). From this analysis, cases which include the evaluation of 'indeterminate' in any of ovary elevation and separation of RL and UA were excluded (four cases in reader 1 and five cases in reader 2). The Youden index was two or more for both readers, and with this cutoff, sensitivity, specificity, and AUC for differentiating IL from SS were 91%, 77%, 0.90 for reader 1, and 82%, 89%, 0.91 for reader 2.

Discussion

This report is the first of a study performing a comprehensive analysis of multiple MR findings to diagnosis IL leiomyomas. Our results revealed four key imaging findings to differentiate IL from SS with moderate to substantial interobserver agreement: tumor shape deformity, lower attachment

Table 2 Clinical characteristics of intraligamentous leiomyoma (IL) and subserosal leiomyoma (SS) groups

	IL ($n = 37$)	SS ($n = 37$)	p value
Age (years)	45.3 ± 10.8	42.1 ± 9.7	.19
Tumor size (mm)	112 (89–154)	108 (88–137)	.48
History of gynecologic surgery (cases)	4	6	.74
STUMP (cases)	1	0	> .99
Preoperative diagnosis of intraligamentous growth (cases)	12	1	**.001**
Preoperative ureteral stenting (cases)	4	2	.67
Operation mode (cases)			
Laparotomy	25	26	> .99
Laparoscopy	12	11	
Hysterectomy	22	18	.48
Myomectomy	15	19	
Operation time (min)	254 (200–282)	201 (173–235)	**.005**
Exceeding scheduled operation time (cases)	22	11	**.019**
Blood loss (mL)	320 (209–1314)	250 (120–540)	.18
Perioperative complications (cases)	5	1	.20
Postoperative hospital stay (days)	8 (6–10)	7 (5–8)	.070

Bold values represent significant differences ($p < .05$)

Data are presented as mean ± standard deviation for age, and median (IQR 25, 75) for tumor size, operation time, intraoperative blood loss, and postoperative hospital stay

STUMP smooth muscle tumor of uncertain malignant potential, *IL* intraligamentous leiomyoma, *SS* subserosal leiomyoma

Table 3 MR imaging findings for intraligamentous leiomyoma (IL) and subserosal leiomyoma (SS)

MR imaging finding	IL		SS		*p* value		Kappa value
	R1	R2	R1	R2	R1	R2	
Shape deformity	68% (25/37)	51% (19/37)	22% (8/37)	14% (5/37)	**< .001**	**< .001**	.75
Degeneration	35% (13/37)	49% (18/37)	27% (10/37)	30% (11/37)	.616	.153	.82
Low attachment	59% (22/37)	84% (31/37)	16% (6/37)	24% (9/37)	**< .001**	**< .001**	.58
Ovary elevation	83% (29/35)	79% (27/34)	26% (9/35)	11% (4/36)	**< .001**	**< .001**	.56
Ureter displacement	36% (12/33)	43% (10/23)	6% (2/32)	4% (1/24)	**.005**	**.002**	.36
Bladder deformation	27% (10/37)	30% (11/37)	14% (5/37)	11% (4/37)	.25	.081	.50
Rectal displacement	14% (5/37)	11% (4/37)	11% (4/37)	11% (4/37)	> .99	> .99	.80
Separation of RL and UA	84% (31/37)	76% (28/37)	25% (9/36)	17% (6/36)	**< .001**	**< .001**	.58

Bold values represent significant differences ($p < .05$)

Data are presented as percentages of positive cases (number of positive cases among determinate cases)

R1 Reader 1, *R2* Reader 2, *IL* intraligamentous leiomyoma, *SS* subserosal leiomyoma, *RL* round ligament, *UA*, uterine artery

Table 4 Diagnostic performance of MR imaging findings for discriminating IL (intraligamentous leiomyoma) from SS (subserosal leiomyoma)

MR imaging finding	Reader 1				Reader 2			
	Sen (%)	Spe (%)	PLR	NLR	Sen (%)	Spe (%)	PLR	NLR
Shape deformity	68	78	3.1	0.41	51	86	3.8	0.56
Low attachment	59	84	3.7	0.48	84	76	3.4	0.21
Ovary elevation	83	74	3.2	0.23	79	89	7.1	0.23
Ureter displacement	36	94	5.8	0.68	43	96	10.4	0.59
Separation of RL and UA	84	75	3.4	0.22	76	83	4.5	0.29

RL round ligament, *UA* uterine artery, *Sen* sensitivity, *Spe* specificity, *PLR* positive likelihood ratio, *NLR* negative likelihood ratio

Table 5 Diagnostic performance of the number of positive MR imaging findings for discriminating IL (intraligamentous leiomyoma) from SS (subserosal leiomyoma)

Number of positive imaging findings	Reader 1 ($n = 70$)			Reader 2 ($n = 69$)		
	Sen (%)	Spe (%)	AUC	Sen (%)	Spe (%)	AUC
≥ 1	100	60	0.90	100	63	0.91
≥ 2	91	77		82	89	
≥ 3	74	89		62	91	
4	31	94		41	94	

Number of positive MR imaging findings among four imaging findings: shape deformity, low attachment to the uterus, ovary elevation, and separation of round ligament and uterine artery. The optimal cutoff point defined by Youden index was two or more positive imaging findings

Sen sensitivity, *Spe* specificity, *AUC* area under receiver operating characteristic curve

to the uterus, ovary elevation, and separation of RL and UA. Although none of these MR findings alone was sufficient for diagnosis, the combination of these MR findings provides high diagnostic ability. When two or more of these four MR findings were positive, high diagnostic ability was obtained with AUC of 0.90. The longer operation time in IL group in our results confirmed the clinical significance of preoperative diagnosis of IL leiomyomas.

MRI findings of ovary elevation, ureteral displacement, and separation of RL and UA are based on the anatomy of

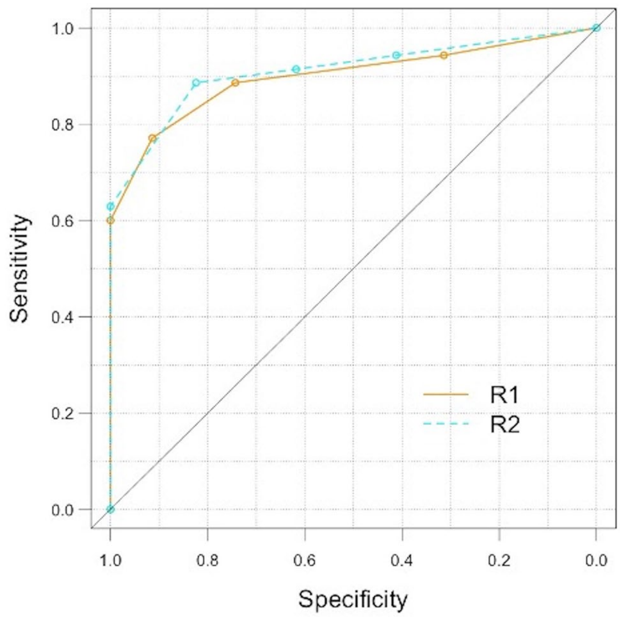

Fig. 7 Receiver operating characteristic (ROC) curves of the number of positive imaging findings for intraligamentous leiomyoma among four imaging findings: tumor shape deformity, lower attachment to the uterus, ovary elevation, and separation of round ligament and uterine artery

the broad ligament and surrounding structures. The broad ligament of the uterus, a double layer of peritoneum that extends from the sides of the uterus to the lateral pelvic walls, suspends the ovary on its posterior aspect via mesovarium and encloses the round ligament on its anterior aspect. The ureters cross under uterine arteries at the base of the broad ligaments [11, 12]. As shown in Fig. 1, the ovary, round ligament, uterine artery, and ureter share spatial continuity to the uterus. This spatial relation enables IL leiomyoma to compress these structures directly, while subserosal leiomyoma compress them only indirectly, if at all. Perhaps for this reason, these structures are more frequently displaced in IL cases than in SS cases, as found in the present study. Elevation of the ovary is easy to diagnose. It has been reported previously: the ovary position was more frequently cranial relative to leiomyoma in cases of intraligamentous leiomyoma than in subserosal leiomyoma [19]. Our study also revealed that IL leiomyoma more frequently displaces the ovary and that its elevation was observed in more than 79% of IL cases (Fig. 5). The difference from the earlier study was how to assess the relative position of the ovary to leiomyoma. They simply assessed whether the ovary is cranial or caudal relative to the epicenter of leiomyoma [19]. Our definition was whether the leiomyoma directly displaces the ovary to the cranial direction or not, leading to higher specificity but lower sensitivity, with false negative cases where the small intraligamentous leiomyoma extended ventrally or caudally.

This report is the first describing separation of RL and UA by IL leiomyoma as a key imaging finding to differentiate IL from SS. RL and UA are anatomically close in part of their course, as shown in Fig. 1. Actually, IL leiomyoma can grow between RL and UA and widen their distance, a characteristic finding in more than 76% of the IL cases examined for this study. A Japanese language article (English abstract available online) reported that elongation of UA by leiomyoma might be a characteristic MR finding for IL leiomyoma [20]. Interobserver agreement was not assessed, but it might be difficult to make an objective assessment of the elongation or displacement of UA or RL. In contrast, our finding of separation of RL and UA showed moderate interobserver agreement (kappa = 0.58). Our results show that displacement of the ureter was more frequent in IL cases, but interobserver agreement was low (kappa = 0.36). Its cause might be the difficulty of identifying the course of the ureter clearly, especially in the case with large leiomyoma. Nonetheless, preoperative information about the ureter displacement is important for a gynecologist to avoid ureteral injury [22–24]. Even for cases in which the ureter cannot be identified directly, diagnosis of IL leiomyoma can alert the operator to the possibility of ureteral deviation. The ureter is located near RL and UA. Therefore, the RL and UA displacement suggests that the ureter might also be displaced.

No report of the relevant literature describes a study that has specifically examined the shape or attachment of IL leiomyoma. Because the leiomyoma slowly enlarges in a limited space, such as in the broad ligament or retroperitoneum, it might be deformed to fit the surrounding structures (Fig. 3) [7]. Particularly, some IL leiomyomas were indented by the proper ligament or suspensory ligament of ovary, which might be a characteristic finding for IL leiomyoma. However, it is noteworthy that some SS cases had complex shapes leading to false positive findings. This study also revealed that the attachment of IL leiomyoma is frequently lower than that of SS leiomyomas: closer to the cervix than to the fundus (Fig. 4). The potential space between the anterior and posterior leaves of the mesometrium is larger on the basal side near the uterine artery than on the upper side near the fallopian tube, as shown in Fig. 1 [11, 25]. This potential space might make it easier for leiomyoma of lower origin to progress into the broad ligament in its lateral expansion.

Our study has several limitations. First, this was a retrospective study with a small sample size. A larger study must be conducted to validate the results. Second, educational effects on physicians who do not specialize in diagnostic imaging of gynecological field should be confirmed.

In conclusion, four key imaging findings were made to differentiate IL from SS. They showed moderate to substantial interobserver agreement, including tumor shape deformity, lower attachment to the uterus, ovary elevation, and separation of RL and UA. A combination of more than two of these imaging findings can produce high diagnostic value with acceptable interobserver agreement to diagnose IL leiomyomas.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent The local institutional review board approved this retrospective study, and informed consent was waived (approval number #R2760).

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CORRECTION

Correction to: Diagnostic performance of preoperative MR imaging findings for differentiation of uterine leiomyoma with intraligamentous growth from subserosal leiomyoma

Ryo Yajima[1] · Aki Kido[1] · Ryo Kuwahara[2] · Yusaku Moribata[1] · Yoshitsugu Chigusa[3] · Yuki Himoto[1] · Yasuhisa Kurata[1] · Yuka Matsumoto[1] · Satoshi Otani[1] · Naoko Nishio[1] · Sachiko Minamiguchi[4] · Masaki Mandai[3] · Yuji Nakamoto[1]

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The original version of this article unfortunately contained a mistake in Fig. 7.

The correct Fig. 7 is given below.

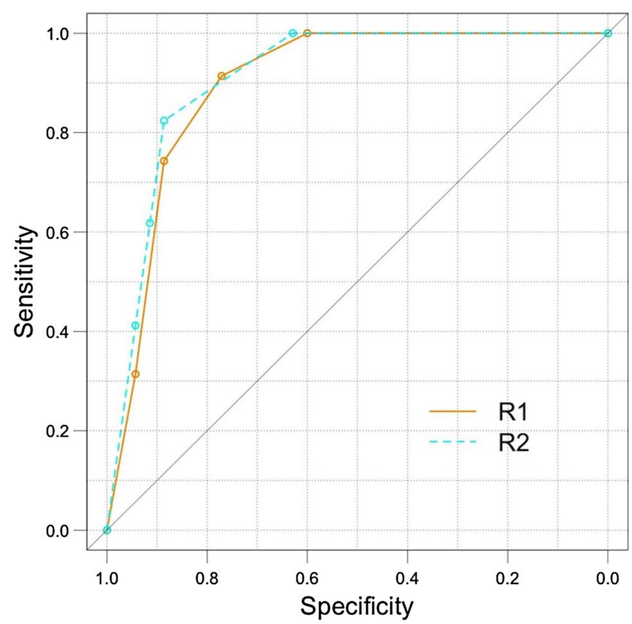

Fig. 7 Receiver operating characteristic (ROC) curves of the number of positive imaging findings for intraligamentous leiomyoma among four imaging findings: tumor shape deformity, lower attachment to the uterus, ovary elevation, and separation of round ligament and uterine artery

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