Assessing the Efficacy of High-Intensity Focused Ultrasound for Uterine Fibroids Using Dynamic Contrast-Enhanced-Magnetic Resonance Imaging

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ABSTRACT

Objective: To evaluate the efficacy of high-intensity focused ultrasound (HIFU) the treatment of uterine fibroids using dynamic contrast-enhanced-magnetic resonance imaging (DCE-MRI).

Study Design: Descriptive study.

Place and Duration of the Study: Department of Radiology, Liuzhou Hospital of Guangzhou Women and Children's Medical Centre, Liuzhou, China, from November 2019 to November 2022.

Methodology: A total of 52 patients with 66 uterine fibroids were selected using random sampling to test treatment differences. The treatment effect was evaluated by analysing preoperative and postoperative T1WI, T2WI, and T1WI contrast-enhanced scans, comparing fibroid size, signal changes, and the degree of enhancement before and after treatment. The signal intensity ratio (SIR) was analysed using the Wilcoxon and paired t-test, while the non-perfused volume ratio (NPVR) was assessed using the Shapiro-Wilk test and the Kruskal-Wallis test.

Results: The NPVR of the low-enhancement group was 35.99 cm^3, the equal-enhancement group was 82.87 cm^3, and the high-enhancement group was 96.00 cm^3. The NPVR values for the low-, equal-, and high-enhancement were 86.19, 78.17, and 64.60, respectively. The NPVR was significantly higher in the low-enhancement group than in the other two groups, with a significant difference of $p < 0.05$. The postoperative NPVR was significantly correlated with varying degrees of enhancement ($p < 0.05$). The NPVR was the highest in the low-enhancement group (86.19%), followed by the equal-enhancement group (78.17%), and the lowest in the high-enhancement group (64.60%).

Conclusion: DCE-MRI plays a crucial role in assessing HIFU treatment efficacy for uterine fibroids. The degree of enhancement in uterine fibroids inversely correlates with ablation effectiveness, and DCE-MRI, utilising a high-concentration gadolinium-based contrast agent, provides a clearer depiction of the enhancement features of these fibroids.

Key Words: *Uterine fibroids, Dynamic contrast-enhanced-MRI, High-intensity focused ultrasound, Non-perfused volume ratio.*

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INTRODUCTION

Uterine fibroids (leiomyomas or myomas) are the most common benign tumours in women of reproductive age. While often incidentally detected during clinical examination or imaging in asymptomatic cases, 30-40% of the affected women require treatment due to symptoms such as dysmenorrhoea, hypermenorrhoea, irregular uterine bleeding, pelvic discomfort, or infertility.[1] Therapeutic options include pharmacological therapy, surgical intervention, and minimally invasive techniques (thermal ablation), with the choice depending on patient age, fertility goals, and fibroid characteristics (size and location).

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However, conventional surgery remains the preferred approach for large fibroids (>10 cm) due to high risk of intraoperative haemorrhage associated with alternative treatments.[2] Despite its efficacy, surgical resection carries inherent risks, and the optimal management strategy for large fibroids — balancing invasiveness, blood loss, and fertility preservation — remains debated. Thus, further research is needed to evaluate non-invasive or hybrid techniques that could reduce surgical risks while maintaining therapeutic outcomes for this subset of patients.

High-intensity focused ultrasound (HIFU) has emerged as a promising non-invasive therapeutic option for uterine fibroids, demonstrating a significant clinical value in recent applications.[3] Magnetic resonance imaging (MRI) has become indispensable for preoperative evaluation and treatment efficacy prediction due to its multi-parametric imaging capabilities.[4] However, current non-perfused volume ratio (NPVR) prediction models remain limited by their reliance on conventional T2-weighted imaging (T2WI) alone.[5] This singular imaging approach fails to fully exploit MRI's comprehensive diagnostic potential, particularly for assessing treatment outcomes across diverse fibroid types. Therefore, there is a critical need to develop more sophisticated prediction models that incorporate advanced MRI sequences and quantitative parameters to improve the accuracy of HIFU outcome assessment.

However, the existing perfusion assessment methods for uterine fibroids, including conventional MRI enhancement and semi-quantitative dynamic contrast-enhancement MRI (DCE-MRI), are limited by subjective interpretation and inability to provide direct haemodynamic measurements, potentially compromising outcome accuracy.[6,7] This methodological gap highlights the need for more objective, quantitative approaches to evaluate treatment response. The current study aimed to develop a DCE-MRI-based predictive model for immediate HIFU treatment outcomes and to establish standardised response criteria for HIFU therapy in symptomatic uterine fibroids, thereby providing a reliable framework for clinical decision-making.

METHODOLOGY

Fifty-two patients (66 fibroids, nine patients had more than one fibroid) with uterine fibroids underwent treatment with HIFU at the Department of Radiology, Liuzhou Hospital of Guangzhou Women and Children's Medical Centre, Liuzhou, China, from November 2019 to November 2022 were enrolled, with an average age of 37.85 ± 2.7 years. The inclusion criteria included informed consent, non-pregnant status, and no immediate intentions of conceiving in the near future. MRI examination was performed within 3-7 days before and after the HIFU treatment. Prior to undergoing the MRI examination, the patients had not undergone any biopsy, surgical intervention, or alternative therapeutic procedures. The MR images met the necessary criteria for analysis, ensuring satisfactory quality. Due to factors such as patient tolerance and other considerations, ablation was performed on a single uterine fibroid, regardless of the total number of fibroids present. The exclusion criteria included the presence of MRI artefacts causing image distortion, lesions with indeterminate diameters, the existence of other distinct categories of uterine fibroids or leiomyosarcomas necessitating surgical intervention, contraindications to MRI examination, and pregnancy during treatment or follow-up.

During this study, patients underwent MRI examinations, and adjustments in physical status evaluation and antibiotic administration were made to ensure treatment safety, avoid adverse events, and prevent potential risks. Examinations were completed within three days before HIFU treatment and repeated within three days after HIFU treatment; patients underwent follow-up to assess their basic conditions. Philips 1.5T Achieva scanning equipment was used. While scoring, patients were positioned supine, and scans were carried out in different axial positions to achieve a comprehensive, detailed, and objective evaluation of their physical condition. Gadobutrol (7.5 ml) was injected at a rate of 2 ml/s, followed by axial, sagittal, and coronal scans.

HIFU treatment was performed using the Model JC focused ultrasound tumour therapeutic system (Chongqing Haifu Medical Technology, Chongqing, China). Before HIFU treatment, patients were asked to complete specific bowel and routine skin preparation. Prior to undergoing HIFU treatment, patients were instructed to consume semi-liquid to liquid diets for two days. On the morning of the treatment, following a 12-hour fast, patients were administered an enema. Each patient shaved the abdominal wall from the interior border of the umbilical region to the superior margin of the pubic symphysis. The skin was subsequently cleaned with 70% ethanol and degassed water. Prior to the HIFU procedure, a urinary catheter was inserted to manage bladder volume by infusing normal saline during treatment, ensuring a safe acoustic window. During the operation, the operator first located the leiomyoma in different directions, then completed ablation from point to surface to volume according to the shapes of the target area at each level, with the whole process of sedation and analgesia, and observed the patients' condition during the process. The immediate efficacy of the treatment is judged by the change of ultrasound grayscale and ultrasonography.

The parameters related to uterine fibroids were further refined. MRI diagnosis was performed three days before and after the HIFU treatment. Signal changes in the ablation zone of uterine fibroids and normal myometrium were measured on T1WI fat-suppressed and contrast-enhanced sequences before and after the operation. The region of interest (ROI) was outlined by two senior attending physicians. The ROI for the myometrium was chosen from normal myometrium with a slightly wider range to avoid denatured tissue. Each measurement was performed at least three times, and the average value was taken. The ROI was selected at the same level and area in preoperative and postoperative. The signal intensity ratio (SIR) was calculated as X1/X2 (X1 representing the average signal value of fibroids, and X2 representing the average signal value of the myometrium). At the same time, the data changes, blood perfusion, and other related conditions of patients before and after treatment were carefully observed and recorded, and the analysis and clinical effects were carried out.

The data on fibroid size were assessed on T1WI. According to the ellipsoid mathematical calculation model, uterine fibroid volume was calculated with V (cm^3) = πabc/6; the non-perfused volume (NPV) in the leiomyomas was calculated on T1WI contrast-enhanced; and the percentage of the volume of the NPVR was calculated with

$$\frac{NPV - V}{NPV}\%.$$

Data were collected on a structured proforma via simple random sampling, including the size of fibroids before and after treatment, NPVR, signal change and degree of enhancement before and after the treatment, which was collected from medical records. Preoperative and postoperative T1WI, T2WI, and T1WI contrast-enhanced scans were determined by the Wilcoxon and the paired t-test. For the NPVR, descriptive statistics were expressed as mean ± standard deviation (SD) for normally distributed data and as median (interquartile range, IQR) for skewed distributions. Statistical analysis was performed using SPSS 24.0, (IBM SPSS, Armonk, New York, USA). A p-value of <0.05 was considered statistically significant. Normality was assessed using the Shapiro-Wilk test. Variables that do not follow the assumption of normality were analysed using the Kruskal-Wallis test, and those following the assumption of normality were analysed by ANOVA.

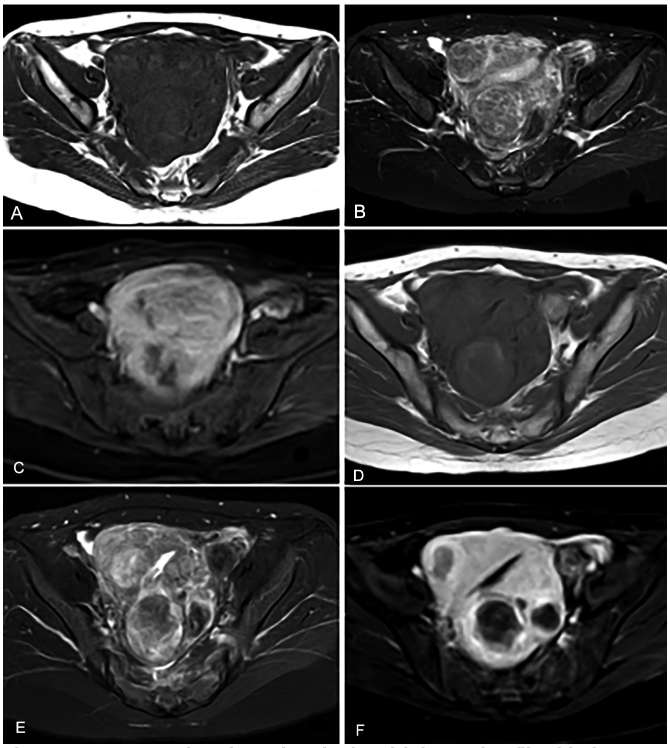

Figure 1: A 30-year female patient had multiple uterine fibroids for more than three years. (A-C) Before the HIFU treatment, multiple fibroids were identified in the myometrium, showing equisignal on T1WI and slightly high intensity in T2WI-STIR. The dynamic contrast-enhanced scan demonstrated significant enhancement, comparable to the degree of myometrium enhancement. (D-F) After the HIFU treatment, the fibroids appeared slightly higher on T1WI and showed mixed high- and low-intensity signals on T2WI-STIR. On the DCE-MRI, unenhanced liquefaction necrosis areas were observed in the central part of the lesion.

Table I: Comparison of SIR in HIFU-treated uterine fibroids preoperative and postoperative.

Sequence	Preoperative	Postoperative	p-values
T1WI	1.12	1.19	<0.001
T2WI	1.16 ± 0.05	1.35 ± 0.09	<0.001
T1WI contrast-enhanced	0.10	0.41	<0.001

Wilcoxon and paired t-test for non-normally distributed continuous variables. Statistically significant p-value.

RESULTS

There were 52 cases of 66 uterine fibroids; the average diameter was 5.7 ± 1.3 cm. Before and after the treatment, the SIR values of T1WI scan were 1.12 *vs.* 1.19, T1WI enhancement was 0.10 *vs.* 0.41, and T2WI scan was 1.16 ± 0.05 *vs.* 1.35 ± 0.09. The differences in the SIR values between the preoperative and postoperative T1WI plain, T2WI, and T1WI contrast-enhanced scans of the myometrial fibroids in the ablated areas of the uterine leiomyomas were statistically significant (p <0.05; Table I). The NPV of the low-enhancement group was 35.99 cm^3, the equal-enhancement group was 82.87 cm^3, and the high-enhancement group was 96.00 cm^3. The NPVR values for the low-, equal-, and high-enhancement were 86.19, 78.17, and 64.60, respectively. The NPVR was significantly higher in the low-enhancement group than in the other two groups, with a significant difference of p <0.05 (Table II).

DISCUSSION

Uterine fibroid growth is hormonally driven (oestrogen-induced hypertrophy and progesterone-stimulated hyperplasia), but its pathophysiology is fundamentally vascular. The characteristic whorled architecture becomes disrupted as fibroids outgrow their blood supply, leading to various ischaemic degeneration patterns.[8,9] They have undergone hyaline degeneration, charactersied by central avascular necrosis and stromal homogenisation. Cystic degeneration due to liquefactive necrosis follows hyaline change. Red degeneration-haemorrhagic infarction may occur, particularly in pregnancy-induced hyperemia. Sarcomatous transformation may occur in rapidly growing, hypoxic tumours. Dystrophic calcification may occur due to end-stage avascular changes in subserosal fibroids.

The management of uterine fibroids requires careful consideration of tumour characteristics, symptom severity, and patient preferences. While medical therapy provides symptomatic relief, surgical interventions including myomectomy and hysterectomy remain definitive treatments for larger or symptomatic tumours. Among the emerging alternatives, HIFU has gained recognition as a non-invasive, uterus-preserving option, though its efficacy varies significantly based on tumour biology and imaging characteristics. MRI has become indispensable for treatment planning and response assessment (Figure 1).

Table II: Short-term effects of HIFU ablation of uterine fibroids.

Degree of enhancement	Upper and lower diameter (a), (cm)		Left and right diameter (b), (cm)		Anteroposterior diameter (c), (cm)		Volume (V) cm^3		NPV (cm^3)	NPVR (%)
Treatment	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**		
Low-enhancement group	6.93	5.33 ± 0.14	4.22 ± 0.21	2.01 ± 0.29	3.46	1.48	88.96	74.98	35.99	86.19
Equal-enhancement group	7.27	6.38 ± 0.04	4.26 ± 0.40	3.76 ± 0.04	3.73	2.52	75.65	59.02	82.87	78.17
High-enhancement group	6.88	6.39 ± 0.06	4.38 ± 0.09	4.28 ± 0.08	3.59	3.53	99.86	95.19	96.00	64.60
F/Z	4.182	985.344	1.795	954.655	2.630	57.472	3.197	14.798	57.542	56.421
p-values	0.124	<0.001	0.175	<0.001	0.269	<0.001	0.202	<0.001	<0.01	<0.01

Normality was assessed by the Shapiro-Wilk test, and the variables that do not follow the assumption of normality were analysed by the Kruskal-Wallis test, and those following the assumption of normality were analysed by ANOVA. Statistically significant p-value.

Key imaging features that influence therapeutic outcomes include vascular patterns and degenerative changes. Hypovascular fibroids tend to demonstrate a superior response to HIFU, and the presence of non-enhancing regions on post-treatment imaging confirms coagulative necrosis.[10,11] Chen *et al*. reported that preoperative uterine fibroids were mostly equisignal on T1WI, while the postoperative ablation area showed slightly higher signal intensity, with no enhancement after contrast injection,[12] findings that are consistent with this study. Hypervascular lesions correlated with reduced ablation rates (62.8% in the current study) and higher recurrence.[13,14] Combined uterine artery embolisation (UAE) and HIFU approach improved outcomes for vascular tumours.[15,16] Degenerative changes (haemorrhage and calcification) showed favourable ablation profiles; fibrous content significantly impacted energy deposition and treatment efficacy.

HIFU demonstrated favourable efficacy for degenerated fibroids, particularly in symptomatic relief and volume reduction, since the coagulative necrosis induced by thermal energy was less affected by pre-existing degenerative changes.[17] Meanwhile, the present study confirmed that degenerative or metaplastic leiomyomas, with haemorrhage, calcification, necrosis, and hyaline degeneration, mostly showed mild inhomogeneous enhancement or non-enhancement, which had a better ablation effect and was not prone to recurrence after the operation. MRI technology was pivotal for pre-therapeutic assessment, offering superior soft-tissue resolution to show fibroid location, size, and degeneration patterns (*e.g.*, T2 signal heterogeneity).[18,19] However, the limitations included the overestimation of ablation zones post-HIFU due to oedema as well as false-positive enhancement in non-viable tissue.

DCE-MRI excelled by providing temporal resolution of perfusion kinetics, differentiating viable from necrotic tissue *via* early arterial enhancement and washout patterns.[20] This enhanced post-HIFU monitoring accuracy, ensuring precise evaluation of treatment success and residual disease.

The present study also found that uterine smooth muscle tumours, especially those with a rich blood supply, showed a stronger detectability after using a high concentration of gadolinium contrast agent. The chance of adverse reactions in the low-enhancement group was lower than in the high-enhancement group. The number of cases in the present study was limited; therefore, the author will continue to collect cases in the future. Further differentiation is still needed between the enhancement characteristics of uterine leiomyosarcoma and uterine sarcoma, and other malignant tumours, which have higher enhancement than the uterine myometrium group, along with T_2 signal intensity characteristics.

The present study has certain limitations. Firstly, the number of cases included in this study was small. Uterine fibroid T2WI signal characteristics have also affected the efficacy of HIFU treatment. This paper is purely based on the MRI enhancement grade in the analysis.

CONCLUSION

MRI can be used to evaluate changes in volume, T1WI signal, and blood supply of uterine leiomyomas before and after HIFU treatment. In summary, HIFU is more effective in ablating leiomyomas with a low degree of enhancement on DCE-MRI. However, leiomyomas with a rich blood supply remain an unfavourable factor that needs to be overcome in minimally invasive treatments. The results revealed a negative correlation between the ablation effect of uterine fibroids and degree of enhancement. Future investigations should explore additional techniques for uterine fibroid treatment, aiming to minimise the factors influencing NPVR prediction and to enhance the predictive precision.

ETHICAL APPROVAL:
The study was approved by the Ethics Committee of Liuzhou Hospital of Guangzhou Women and Children's Medical Centre, Liuzhou, China.

PATIENTS' CONSENT:
Individual consent for this retrospective analysis was waived.

COMPETING INTEREST:
The authors declared no conflict of interest.

AUTHORS' CONTRIBUTION:
MW: Conception, design of the study, and manuscript writing.
JL: Provision of study materials or patients.
LH: Collection and assembly of data.
JW: Data analysis and interpretation.
HQ: Administrative support.
WQ: Final approval of the manuscript.
All authors approved the final version of the manuscript to be published.

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