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UNSPECIFIED

ORIGINAL ARTICLE

Sacral injury and influencing factors after ultrasonic ablation of uterine fibroids ≤30 mm from the sacrum

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PURPOSE

To study sacral injuries and influencing factors after ultrasonic ablation of uterine fibroids no more than 30 mm from the sacrum.

METHODS

A total of 406 patients with uterine fibroids who underwent percutaneous ultrasound ablation were analyzed retrospectively. All patients underwent contrast-enhanced magnetic resonance imaging (MRI) scans before and after high-intensity focused ultrasound. The abnormal signal intensity (low signal intensity on T1WI and high signal intensity on T2WI) on the postoperative MRIs was indicative of a sacral injury. The patients were divided into a sacrum injury group and a sacrum non-injury group. The relationship between fibroid characteristics, ultrasound ablation parameters, and injury was analyzed using univariate and multivariate analyses.

RESULTS

There were 139 cases of sacral injury (34.24%). When the distance from the fibroid's dorsal side to the sacrum was 0–10 mm, the risk assessment showed that the danger of sacral injury increased by 1.85 times and 3.03 times compared with that at a distance of 11–20 or 21–30 mm. Furthermore, the risk of sacral injury increased by 1.89 times and 3.23 times when the therapeutic dose (TD) of a fibroid was >500 KJ compared with that of a fibroid with TD= 250–500 KJ and <250 KJ.

CONCLUSION

A distance of 10 mm or less and a TD of >500 KJ were significantly correlated with sacral injury. The distance from the fibroid's dorsal side to the sacrum and the TD were the main causes of injury to the sacrum. A distance of 10 mm or less and a TD of >500 KJ carried higher injury risks, while a distance of 21–30 mm and a TD of <250 KJ were the most appropriate circumstances to reduce the risk of sacral injury.

KEYWORDS

High-intensity focused ultrasound (HIFU), magnetic resonance imaging, sacrum injury, ultrasound ablation, uterine fibroids

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With an incidence of 20%–40%,[1,2] uterine fibroids are the most common benign tumors found in the female reproductive system. As a non-invasive emerging technology, high-intensity focused ultrasound (HIFU) has been widely recognized in clinical practice.[3-5] However, due to its physical characteristics (refraction, reflection, etc.) and biological effects (cavitation effect and thermal effect),[6] its ultrasonic waves may cause varying degrees of thermal damage to surrounding tissues, resulting in abdominal wall damage,[7] sacrum and nerve pain,[8,9] abnormal vaginal discharge,[10] and other adverse effects. The greater the transmission distance from the transducer's ultrasound beam to the fibroids, the more complex the interaction between the ultrasound and the tissue. In addition, the incidence of adverse reactions increases.[11]

Magnetic resonance imaging (MRI) is characterized by its high-resolution imaging of soft tissue. The technique can be used to show the differences between tissue characteristics be-

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fore and after HIFU and is often utilized to evaluate an injury after HIFU. Cun et al.[8] reported that 135 of 346 patients with single fibroids (39.0%) suffered a sacral injury after HIFU. Moreover, Li et al.[9] stated that 87 of 267 patients (32.6%) developed MRI signal intensity changes in the sacrum. After analyzing the factors of sacral injury, they found that the distance from the dorsal side of the fibroid to the sacrum was significantly correlated with MRI signal intensity changes in the sacrum. The shorter the distance, the higher the risk of sacral injury. Although the correlation between abnormal sacral signal intensity and clinical adverse events has not been reported, the long-term effects still require further attention, as minimizing secondary injury is an important strategy to avoid long-term complications in clinical practice. Therefore, a safe distance between fibroids and the sacrum should be ensured to avoid sacral injury.[12] A previous study suggested that >25 mm would be a safe distance.[13] However, Li et al.[9] believed that the transducer's focus should be kept at least 30 mm away from the sacrum. Such a case-screening strategy would result in the exclusion of too many patients with uterine fibroids. Therefore, it is necessary to further study sacral injuries and the influencing factors after the ultrasonic ablation of uterine fibroids adjacent to the sacrococcygeal region to provide a basis for a more accurate clinical selection of cases.

This study aimed to use MRI to evaluate sacral injuries after the ultrasonic ablation of uterine fibroids adjacent to the sacrococcygeal region and to analyze the risk factors. It provides the basis for a selection of ultrasonic ablation indicators, the formulation of an ablation surgical plan, and the adjustment of the therapeutic dose (TD) for uterine fibroids adjacent to the sacrococcygeal region.

Main points

- Ultrasonic ablation of uterine fibroids adjacent to the sacrococcygeal region can produce satisfactory ablation.
- Sacral injury will occur after the ultrasonic ablation of uterine fibroids adjacent to the sacrococcygeal region. The incidence remained similar to that of previous studies on undefined uterine fibroids adjacent to the sacrococcygeal region.
- A distance no greater than 10 mm and a TD greater than 500 KJ carried higher risks of injury. A distance of 21–30 mm and a TD less than 250 KJ were the most appropriate parameters for focused ultrasound ablation of uterine fibroids.

Methods

General data

Before HIFU treatment, the details were discussed with all patients, who then signed a consent form. This retrospective study was approved by our institutional review board (Ethics approval number: 2013–16), and informed consent was waived because the data were anonymized. All procedures followed were in accordance with ethical standards of the hospital and the Declaration of Helsinki.

The data from 406 patients who received ablation therapy in the First Affiliated Hospital of Chongqing Medical University between January 2014 to December 2018 were collected and analyzed. The inclusion criteria were: 1) patients over 18 years of age, married, and with no recent fertility requirements, 2) patients with fibroids ranging in size from 4–10 cm, and 3) patients with uterine fibroids adjacent to the sacrococcygeal region, with the distance between the fibroids' dorsal sides and the sacrum being no more than 30 mm. The exclusion criteria were: 1) patients with preoperative fibroid degeneration and contrast-enhanced MRIs showing no perfusion area presence, 2) patients with a preoperative history of HIFU, uterine artery embolization, or myomectomy, and 3) patients with a MRI contraindication or MRI contrast agent allergy.

HIFU ablation

Before HIFU ablation, all patients underwent bowel and skin preparation. A Model-JC Focused Ultrasound Tumor Therapeutic System (Chongqing Haifu Medical Technology Co., Ltd, Chongqing, China) was used for ablation. The working frequency of the ultrasonic transducer used in this study was 0.8 MHz, and the physical focal area was 1.5 × 1.5 × 10 mm. Each patient was placed on the treatment table in a prone position so that the skin of the abdomen was immersed in low-temperature degassed water. In addition, for conscious sedation, they were intravenously administrated with fentanyl citrate (Yichang Renfu Pharmaceutical Co., Ltd, Yichang, China) and midazolam (Jiangsu Enhua Pharmaceutical Co., Ltd, Jiangsu, China). Ablation was performed under the real-time guidance of the ultrasonographic device. The starting point was 10 mm from the boundary of the fibroid's (sacral side) deep surface, and the distance from the focal point to the surface of the sacrum had to be greater than 15 mm. During the procedure, the acoustic power, sonication time, and cooling time were adjusted until the patient was comfortable. The acoustic power was maintained within 300–400 W, with a sonication time above 700 s per hour. When the monitoring ultrasound observed a significant increase in the target area's grayscale, the treatment could be terminated if the scope covered the planned treatment area completely. The perfusion in the fibroid was further observed by contrast-enhanced ultrasound. If there was almost no blood perfusion in the fibroid, the ablation was considered satisfactory. If the ablation was unsatisfactory, supplementary treatment was performed after 10 min. If the imaging was unsatisfactory due to the deep location of the fibroid, the treatment was ended at the planned dose calculated per unit volume. All the treatment parameters were recorded immediately after HIFU, including average power, treatment time, sonication time, TD, and post-treatment adverse effects. The dose–time intensity, energy efficiency factor (EEF) [i.e., the energy required for tissue ablation per unit volume (J/cm^3)] were calculated.

MRI examination

All patients underwent MRI examinations within 1 week before HIFU and within 3 days following HIFU. An HDxt 3.0-T MRI scanner (Signa HD Excite, GE Healthcare, USA) and 8-channel phased-array abdominal coils were used. The patient was asked to lie in the supine position, and the scanning range was the iliac crest to the lower edge of the symphysis pubis. The scanning sequence and parameters were as follows: 1) plain scanning: T1 weighted image (T1WI) FSE (TR 270 ms, TE 2.1 ms, slice thickness 5 mm, slice spacing 1 mm), 2) plain scanning: T2 weighted image (T2WI) FRFSE (TR 3400 ms, TE 110 ms, slice thickness 5 mm, slice spacing 1.5 mm), and 3) enhanced scanning of LAVA (TR 4.2 ms, TE 2.0 ms, slice thickness 2.5 mm, slice spacing 0.5 mm). A gadolinium bisamine injection was used as the contrast-enhancing agent (Omniscan, General Electric Pharmaceutical Co., Ltd, Shanghai, China) (0.5 mmol/mL, 15–20 mL).

MRI evaluation

The uterine position, fibroid position, and fibroid type were observed on the preoperative T2WI. The thickness of the abdominal wall, the long diameter, anteroposterior diameter, transverse diameter of the uterine and fibroid, the shortest distance from the ventral side of the fibroid to the skin, the shortest distance from the center of the fibroid to the sacrum, and the shortest dis-

tance from the dorsal side of the fibroid to the sacrum were measured. On the postoperative contrast-enhanced MRI, the long diameter, anteroposterior diameter, and transverse diameter of the non-perfusion area were determined. The uterine, fibroid, and non-perfusion area volumes were calculated. The volume calculation formula was $V= 0.5233 \times D_1 \times D_2 \times D_3$, and non-perfused volume rate (NPVR)=non-perfused volume (NPV)/fibroid volume × 100%. Compared with the preoperative MR images, the postoperative MR images showed the following: the sacrum displayed varying degrees of strip signal intensity changes, a low signal intensity on T1WI, a high signal intensity on T2WI, and a high signal intensity or non-enhanced area on the contrast-enhanced MRI.[8] The analyses and measurements of the imaging data were performed by two experienced radiologists. In the event of a discrepancy, there were consultations and discussions with senior radiologists.

Statistical analysis

Statistical analyses were performed using SPSS 23.0 (IBM, USA) software. Measurement data that conformed to a normal distribution were expressed as mean ± standard deviation. Skewed distribution data were expressed as median and interquartile ranges, and categorical data were expressed as percentages. With the sacral injury as a dependent variable, the clinical characteristics of patients and ultrasonic ablation parameters were considered covariates. The different influencing factors were subjected to univariate analysis. An independent-sample t-test was used for the normally distributed data measured, and the Mann–Whitney U test was used for skewed distribution data. In addition, the χ^2 test or Fisher's exact test was used to compare count data. The significant independent variables in the univariate analysis were included in the multivariate analysis and were analyzed in a binary logistic regression analysis. The Hosmer–Lemeshow test was used to evaluate the fit of the model, while multicollinearity diagnosis was performed for all the independent variables. Furthermore, the linear relationship between the independent variables and the outcome variables was analyzed, and an assessment was conducted on the extreme values that might have affected the model's construction. The results of the multivariate analysis were set as dummy variables, and a logistic regression model was used for risk assessment. A value of $P < 0.05$ was statistically different.

Results

The general situation

A total of 406 patients were included, with an average age of 39 ± 6.54 years (range: 21–53 years). There were 406 fibroids, including 123 (30.3%) on the anterior wall, 138 (34.0%) on the posterior wall, 114 (28.8%) on the lateral wall, and 31 (7.6%) on the fundus. In addition, there were 279 intramural fibroids (68.7%), 92 subserosal fibroids (22.7%), and 35 submucosal fibroids (8.6%). The distance from the fibroid's dorsal side to the sacrum was 0–30 mm, with an average distance of 14.6 ± 8.6 mm. The NPVR was 25.1%-100.0%, with an average of 71.5 ± 18.4%.

Sacral injury

Among the 406 patients, 139 (34.24%) developed sacral injuries. The MRIs of the sacrum injuries showed normal sacrum morphologies and structures. Areas with signal intensity changes were strip-shaped and often noticed via high signal intensity or high–low mixed signal intensity on the T2WIs, with slightly enhanced or non-enhanced areas on contrast-enhanced MRIs (Figures 1, 2).

Relationship between sacral injury and clinical features

The 406 patients were divided into two groups: 139 in the sacrum injury group and 267 in the sacrum non-injury group. There were statistically significant differences between the two groups in fibroid location and the distance from the dorsal side of the fibroid to the sacrum ($P < 0.05$). The incidence of sacral injury for fibroids on the posterior wall was 42.8% (ranking the highest). The incidences of sacral injury on patients with fibroid on the anterior wall, lateral wall, and the fundus were 27.6%, 29.85%, and 38.7%, respectively. In the sacrum injury group, the distance from the dorsal side of the fibroid to the sacrum was shorter than that of the non-injury group (Table 1).

Relationship between sacral injury and ultrasonic ablation parameters

There were statistically significant differences between the two groups in treatment time, sonication time, TD, dose–time intensity, NPVR, and EEF (all $P < 0.017$). The NPVR of the sacrum injury group was lower than that of the non-injury group. Moreover, the treatment time, sonication time, TD, dose–time intensity, and EEF of the injury group were all higher than those of the non-injury group (Table 2).

Risk assessment of sacral injury

The univariate analysis revealed all the factors related to the sacral injury, including

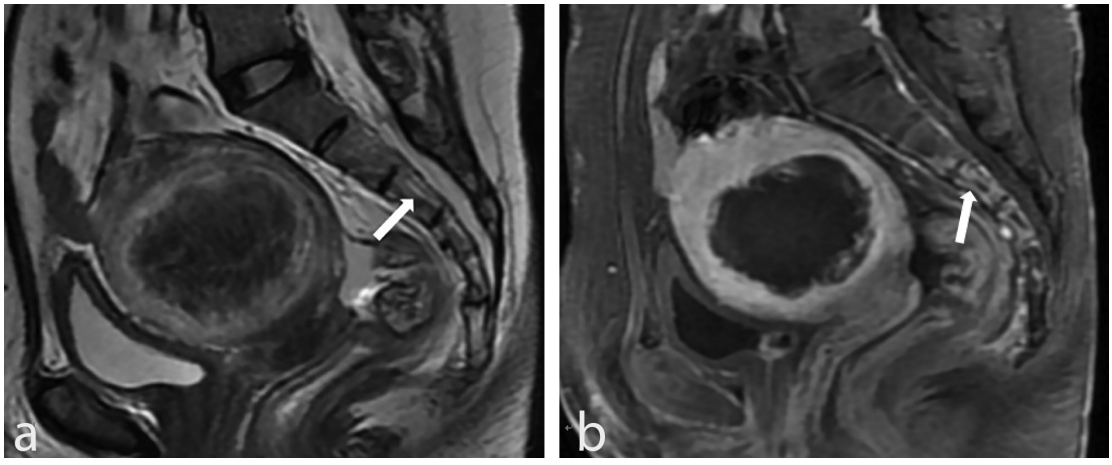

Figure 1. Sacral injury: sagittal view of MRI results obtained from a 44-year-old patient with uterine fibroids after high-intensity focused ultrasound showed normal morphology and structure in the sacrum. **(a)** The postoperative T2WI showed a strip-shaped high signal intensity of the 2nd–4th cones in the sacrum (arrow). **(b)** The postoperative contrast-enhanced MRI showed a slightly enhanced strip-shaped high signal intensity (arrow). MRI, magnetic resonance imaging.

the fibroid location, distance from the dorsal side of the fibroid to the sacrum, treatment time, sonication time, TD, dose–time intensity, NPVR, and EEF. These variables were included in the multivariate analysis, and the binary logistic regression analysis revealed that the distance from the dorsal side of the fibroid to the sacrum and TD were independent influencing factors on sacral injury. The shorter the distance from the dorsal side of the fibroid to the sacrum, the more easily the sacrum could be damaged. The higher the TD, the higher the incidence of sacral injury. The distances from the dorsal sides of the fibroids to the sacrum were 0–10, 11–20, and 21–30 mm. Meanwhile, the incidence rates of sacral injury were 51.1% (71/139), 31.7% (44/139), and 17.3% (24/139), respectively. The incidences of sacral injury at TD > 500 KJ, 250–500 KJ, and <250 KJ were 44.6% (62/139), 38.1% (53/139), and 17.3% (24/139), respectively. The risk of sacral injury increased by 1.85 and 3.03 times when the distance from the dorsal side of a fibroid to the sacrum was 0–10 mm, compared with 11–20 or 21–30 mm. The risk of sacral injury in fibroids with a dose of >500 KJ was 1.89 times and 3.23 times higher, respectively, than with a dose of 250–500 KJ and <250 KJ (Table 3).

Adverse events after HIFU

Among the 406 patients, 95 (23.40%) developed adverse effects after HIFU. A total of 118 adverse effects were observed. Of these, 84.74% (100/118) were classified as Class A, 14.41% (17/118) were classified as Class B, and 0.85% (1/118) were classified as Class C. However, no Class D, E, or F adverse effects were observed in this study. The major adverse events were abdominal discomfort, sacrococcygeal pain, abnormal vaginal discharge, and pain or numbness of the lower limbs. The incidence of sacrococcygeal pain was 8.6% in the sacrum injury group and 9% in the non-injury group, which were similar at $P = 1.000$. However, in the sacrum injury group, two patients experienced obvious pain, which disappeared 3 and 7 days, respectively, after NSAIDs were administered for pain relief. With Class B adverse effects, there was no statistical significance in incidence between either group ($P > 0.05$). In the non-injury group, one patient (0.4%) experienced pain and numbness in their lower limbs. The pain disappeared 3 months after using NSAIDs (Table 4).

Discussion

The principle of HIFU ablation for uterine fibroids is to focus the in vitro ultrasonic waves on the *in vivo* tumor tissues so that the temperature of the target area can be instantaneously increased to 60°C–100°C, leading to coagulative necrosis of tissues and tumor

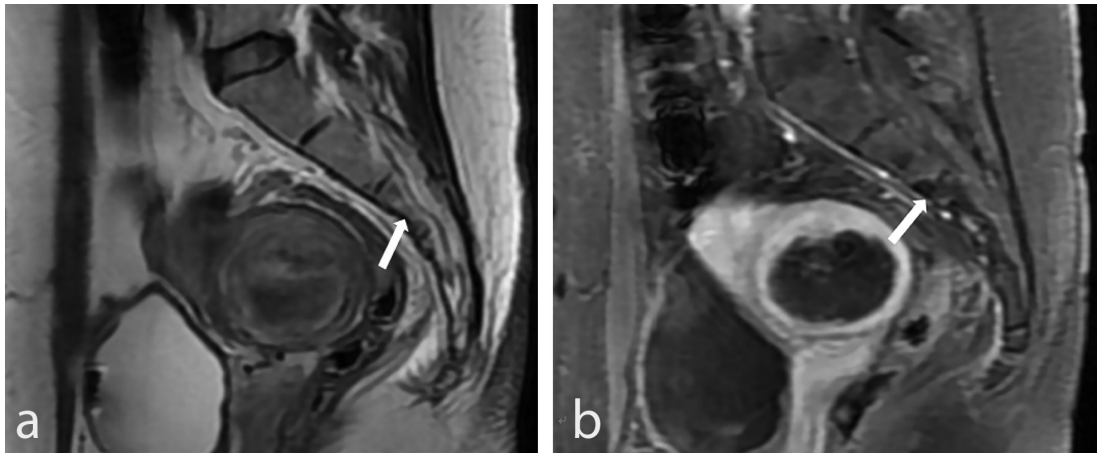

Figure 2. Sacral injury: sagittal view of MRI obtained from a 36-year-old patient with uterine fibroids after high-intensity focused ultrasound showed normal morphology and structure in the sacrum. **(a)** The postoperative T2WI showed a strip-shaped high–low mixed signal intensity of the 2nd–4th cones in the sacrum (arrow). **(b)** The postoperative contrast-enhanced MRI showed a non-enhanced area (arrow). MRI, magnetic resonance imaging.

Table 1. A comparison between the clinical features of the sacrum injury group and the sacrum non-injury group

	Injury group (n = 139)	Non-injury group (n = 267)	*P*
Age (years)	41 (21–52)	41 (21–53)	0.86
Height (cm)	158 (146–173)	158 (144–178)	0.78
Weight (kg)	55 (39–80)	55 (40–87)	0.10
BMI (kg/cm^2)	22.6 (15.8–30.5)	22.3 (15.4–35.7)	0.72
Thickness of abdominal wall (mm)	22 (9–38)	22 (8–52)	0.098
Position of the uterus (anteverted, mid-position, retroverted)	88/17/34	149/40/78	0.35
Volume of fibroid (cm^3)	282.4 (42.1–1121.3)	268.6 (64.6–862.4)	0.12
Location of fibroids (adjacent, posterior wall, lateral wall, fundus)	34/59/34/12	89/79/80/19	0.044
Type of fibroid (intramural, subserosal, submucosal)	103/22/14	170/70/21	0.056
Volume of fibroid (cm^3)	93.4 (33.9–549.2)	85.4 (34–584)	0.21
Fibroid ventral side to the skin (mm)	48 (14–117)	42 (11–119)	0.34
Fibroid center to the sacrum (mm)	42 (9–70)	42 (21–75)	0.11
Fibroid dorsal side to the sacrum (mm)	10 (0–30)	14 (0–30)	<0.001

BMI, body mass index.

death.[14,15] Previous studies have confirmed that HIFU ablation of uterine fibroids is safe and effective.[3,16-18] However, in the process of ultrasonic transmission, tissues along the acoustic pathway absorb energy and cause thermal damage. Also, thermal diffusion during the heating of the target tissue may cause thermal damage to the surrounding tissues. Previous studies have found that changes in signal intensity in the sacrum can be observed on MRIs after HIFU.[8,9] Therefore, a safe distance from the fibroid to the sacrum should be maintained during treatment. Some scholars believe that a distance above 25 mm is appropriate.[13] In this study, real-world data were used to focus on the sacral injury after the ultrasonic ablation of uterine fibroids ≤30 mm from the sacrum. This was to study its influencing factors and investigate whether the uterine fibroid adjacent to the sacrococcygeal region was an indicator for ultrasonic ablation. This study provides the basis of the ablation scheme for the uterine fibroid adjacent to the sacrococcygeal region.

In this study, the distance from the focus to the surface of the sacrum was controlled by more than 15 mm during ultrasonic ablation, and the safety of the ablation was controlled based on patient tolerance. Among the 406 patients with uterine fibroids, the distance from the dorsal side of the fibroid to the sacrum was 0–30 mm, with an average distance of 15.4 ± 8.7 mm. The average NPVR was 71.5 ± 18.4%, which is slightly lower than the results of other studies on HIFU therapy for undefined fibroids adjacent to the sacrococcygeal region.[16,19]

The effect of ultrasonic ablation depends on the energy deposition in the acoustic pathway. In this study, the lesion was adjacent to the sacrococcygeal region and located deep in the pelvic cavity. On the one hand, when focused ultrasound ablates deep lesions, the acoustic pathway is more complex than that of superficial lesions. Each tissue and interface will absorb, reflect, and scatter ultrasound, which results in energy loss. Therefore, tissue ablation requires high-

Table 2. A comparison between the ultrasonic ablation parameters of the sacrum injury group and the sacrum non-injury group

	Injury group (n = 139)	Non-injury group (n = 267)	*P*
Average power (w)	400 (300–400)	400 (269–401)	0.67
Treatment time (mins)	98 (16–247)	73 (10–233)	<0.001
Sonication time (s)	1200 (156–3803)	858 (95–7085)	<0.001
TD (KJ)	465.280 (52.2–1500)	324.8 (20–1400)	<0.001
Dose-time intensity (KJ/h)	290.909 (44.6–681.48)	271.629 (17.14–468.51)	0.043
NPV (cm^3)	66.6 (15.3–388.6)	63.5 (15.5–307)	0.97
NPVR (%)	69.4 (25.1–100)	74 (28.8–100)	0.016
EEF (J/mm^3)	4.6 (0.8–52.5)	3.7 (0.6–27.6)	0.002

NPV, non-perfusion volume; NPVR, non-perfusion volume rate; EEF, energy efficiency factor; TD, therapeutic dose.

Table 3. Risk assessment of the distance from the fibroid's dorsal side to the sacrum and TD on sacral injury

		OR	95% CI		*P*
			Lower	Upper	
Fibroid dorsal side to the sacrum (mm)	Relative distance (mm)				
0–10	11–20	1.854	1.041	3.302	0.035
11–20	21–30	3.026	1.749	5.235	<0.001
	21–30	1.632	1.012	2.631	0.044
TD (KJ)	Relative TD (J)				
<500	250–500	1.893	1.083	3.308	0.024
250–500	<250	3.229	1.837	5.676	<0.001
	<250	1.706	1.062	2.740	0.027

CI, confidence interval; OR, Odds ratio; TD, therapeutic dose.

Table 4. Postoperative adverse effects

SIR classification	Adverse event	Injury group (n = 139)	Non-injury group (n = 267)	*P*
Class A	Abdominal discomfort	12 (8.6%)	47 (17.6%)	0.017
	Sacrococcygeal pain	10 (7.2%)	24 (9%)	0.58
	Abnormal vaginal discharge	5 (3.6%)	2 (0.7%)	0.049
Class B	Abdominal pain	0	2 (0.7%)	0.55
	Sacrococcygeal pain	2 (1.4%)	0	0.18
	Abnormal vaginal discharge	4 (2.9%)	6 (2.2%)	0.74
	Lower limb pain or numbness	1 (0.7%)	2 (0.7%)	1.00
Class C	Lower limb pain or numbness	0	1 (0.4%)	1.00
Class D~F	-	0	0	-

SIR, Society of Interventional Radiology.

er energy, which increases the difficulty of destroying tissue through thermal diffusion. On the other hand, due to the influence of lesion depth, ultrasonography is sometimes not clear enough for deep imaging to accurately determine the ablation range. Furthermore, as the lesion is close to the sacrococcygeal region, the posterior field energy decay decreases. This results in energy deposition in the sacrococcygeal region. During the ultrasound ablation procedure, the sacral discomfort of patients was aggravated, and the dose–time intensity (the total dose per unit treatment time) needed to be reduced, which affected the ablation effects. In this study, the NPVR of 55% (224/406) of patients was more than 70%. Therefore, the uterine fibroid adjacent to the sacrococcygeal region could be satisfactorily ablated; however, the depth of the lesion and the distance from the fibroid from the sacrum are still the influencing factors on the ablation effect.

In this study, 34.24% of patients developed abnormal signal intensity in the sacrum. Although the distance of uterine fibroids from the sacrum was ≤30 mm in all patients, the incidence was still similar to that of previous studies on undefined uterine fibroids adjacent to the sacrococcygeal region.[8,9,20] This study's NPVR was within 20%–100%, which was less than the NPVR reported by Li et al.[9] This may be a protective factor. Compared with Cun et al.'s[8] results, the TD of this study was lower. This suggests that this study's surgical ablation procedure for fibroids adjacent to the sacrococcygeal region was beneficial to the protection of the sacrum.

However, the incidence of sacral injury was still high after HIFU, and effective measures should be taken to reduce the incidence of injury after further clarification of its influencing factors, which remain the focus of attention in HIFU ablation. The MRIs of sacral injuries showed normal sacral morphology and structure. The injuries mostly occurred in the 2nd–4th cones of the sacrum. Striped high signal intensity or high–low mixed signal intensity was seen on T2WI. In addition, a slightly high signal intensity or non-enhanced region was seen on the contrast-enhanced MRIs. Changes in signal intensity in the sacrum are often associated with increased water content due to acute edema of the bone marrow. However, the non-enhanced area observed in the contrast-enhanced MRIs may be related to a thermal deposition injury, obstruction of blood vessels during the sonication, or compression of blood vessels due to edema.[8]

The reason for sacral injuries is that the bone has a strong ability to absorb ultrasound energy, and the acoustic impedance at the interface between the fibroid and the bone is quite different. When ultrasonic waves pass through two media that possess a great difference in acoustic impedance, obvious reflection and refraction will occur, and the bone will absorb a large amount of thermal energy, resulting in sacral injury. In addition, the blood supply to the sacrum mainly emanates from the distal vessels, and the relatively slow blood flow may induce an increased probability of thermal injury to the sacrum because the energy cannot dissipate easily through the circulation.[8] However, there was no pathological evidence of coagulative necrosis in the non-enhanced area shown on the contrast-enhanced MRIs, which requires further clarification via imaging and pathological studies.

In the univariate analysis, the location of uterine fibroids and the distance from the dorsal side of the fibroid to the sacrum were related to sacral injuries. The incidence of sacral injury was the highest in the posterior wall fibroid (42.3%). When the same ablation effect is achieved due to the posterior wall fibroid coming closer to the sacrum, more energy is needed than in the anterior wall, lateral wall, and fundus fibroids.[21] The posterior field energy attenuation lessens, leading to the sacrum becoming more vulnerable to injury. Further use of the multivariate logistic regression analysis concluded that the distance from the dorsal side of the fibroid to the sacrum was a protective factor for sacral injury. The incidence of sacral injury in fibroids 21–30 mm from the sacrum was only 17.3%. According to the risk assessment, the threat of sacral injury was 1.85 and 3.03 times higher for fibroids 0–10 mm from the sacrum than for fibroids at 11–20 and 21–30 mm, respectively. The closer the fibroid is to the sacrum, the less ultrasonic attenuation it will be. Moreover, the more ultrasonic energy absorbed by the sacrum, the higher the chance of sacral injury. Therefore, to avoid sacral injury during the ablation of fibroids adjacent to the sacrococcygeal region, an oblique angle ultrasound path can be considered to avoid the far-field sacrum. The initial treatment target can also be targeted at the anterior part of the fibroid, which is not close to the bone. After a few months, subsequent treatment can be conducted after fibroid shrinkage has increased the distance between the tumor and the sacrum.[13]

The energy required for the ablation of uterine fibroids of identical volume is positively correlated with focal depth.[22] The myoma requires more energy the deeper it is, so clinical long-term, high-dose treatments are generally used to ablate uterine fibroids adjacent to the sacral coccyx. The EEF, which is used to indicate the energy for ultrasound ablation of fibroid tissue per unit volume, reflects the relationship between dose and ablation efficiency.[21] The larger the EEF, the more energy a unit volume of a fibroid requires, and the more difficult it becomes to ablate. The univariate analysis showed that among the factors affecting sacral injury, the NPVR of the sacrum injury group was smaller than that of the non-sacrum injury group. Furthermore, the treatment time, sonication time, TD, dose–time intensity, and EEF of the injured group were all higher than those of the non-injury group. This suggests that the more difficult it is to ablate a fibroid, the more likely it is to cause injury to the sacrum. These indicators were incorporated into the multifactor logistic regression analysis to further identify TD as a risk factor for sacral injury. The larger the TD, the easier it is for the sacrum to be injured. In this study, it was concluded that the risk of sacral injury from TD >500 KJ was 1.89 times and 3.23 times higher than TD= 250–500 KJ and <250 KJ, respectively. Therefore, TD reduction is necessary. In clinical practice, the TD of a single procedure should be limited, and a divided session strategy should be considered if necessary. Researchers have also investigated other methods of TD reduction by changing the tissue's acoustic environment and enhancing local energy deposition.[23] However, the safety impacts caused by increased intervention factors still need to be examined.

In this study, 95 of 406 patients (23.40%) developed postoperative adverse effects, with a total of 118 adverse effects. According to the classification standard of the International Association of Interventional Radiology,[24] 84.74% of them were classified as Class A and spontaneously recovered within 1 week without treatment. Although the distance of fibroids from the sacrum in this group was 30 mm, the incidence and study degree of sacrococcygeal pain and lower limb pain did not increase compared with studies on the large sample.[10,25] In the sacrum injury group, two patients developed sacrococcygeal pain, which was completely relieved within 1 week after symptomatic treatment with NSAIDs. One patient (0.2%) developed lower limb pain in the sacrum non-injury group, which may have been caused by nerve stimulation. The pain disappeared within 3 months after treatment with NSAIDs and a vitamin agent.

The results revealed that MRI showing sacral injury does not increase the incidence and severity of clinically adverse effects; however, its long-term impact on patients needs to be explored.

In conclusion, the MRI results revealed the likelihood of sacral injury after ultrasonic ablation of uterine fibroids, and the incidence remained similar to that of previous studies on undefined uterine fibroids adjacent to the sacrococcygeal region. The location of fibroids, the distance from the fibroid's dorsal side to the sacrum, TD, and EEF showed significant associations with sacral injury. Among these, the distance from the fibroid's dorsal side to the sacrum and TD were the main causes of sacral injury. A distance of 10 mm or less and a TD greater than 500 KJ carried higher injury risks. Moreover, a 21–30-mm distance and TD <250 KJ were the most appropriate parameters for ultrasonic ablation of fibroids. Although subjects did not develop serious complications, these influencing factors should be carefully considered in uterine fibroids ≤30 mm to optimize the scheme for the focused ultrasound ablation of uterine fibroids.

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Conflict of interest disclosure

The authors declared no conflicts of interest.

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