Journal of Health and Aging
Published online at https://tcsuckhoelaohoa.vn

Review Article

CURRENT APPLICATIONS, CLINICAL EFFICACY, AND FUTURE DIRECTIONS OF HIGH-INTENSITY FOCUSED ULTRASOUND ABLATION SURGERY IN THERAPEUTIC MEDICINE

Lian Zhang[1,2,*] **MD**

1. State Key Laboratory of Ultrasound in Medicine and Engineering ,College of Biomedical Engineering, Chongqing Medical University, Chongqing 400016, China.
2. Chongqing Haifu Hospital, Chongqing 401121, China

* *Corresponding author: Lian Zhang, MD* ✉ *lianwzhang@yahoo.com*

ABSTRACT: Surgical treatment has been the standard of care in selected cases with solid tumors or uterine benign diseases. However, a majority of patients are unable to undergo surgical resection because of the tumor locations, advanced stages, or poor general condition. For patients who are not suitable for surgery or unwilling to undergo surgical treatment, high-intensity focused ultrasound (HIFU) ablation surgery is a new option. HIFU is a novel non-invasive technique that can generate coagulative necrosis at a precise focal point within the body, without damaging to the surrounding structures of the target lesions, even within the path of the beam. Ultrasound guided HIFU (USgHIFU) was first used in the treatment of bone tumors in the 1990s. Over the last two decades, this technology has made significant progress and is now widely used in the treatment of various solid tumors and benign diseases of certain organs. Currently, both magnetic resonance imaging guidance focused ultrasound surgery (MRgFUS) and USgHIFU are commercially available. Each of these two types of HIFU systems has its own advantages in guidance. USgHIFU has higher treatment efficiency, with shorter treatment time, and can treat a wider range of diseases than that of MRgFUS. Recently, HIFU has been proven to be beneficial as an adjunct in the treatment of cardiovascular diseases. In addition, MRgFUS allows for non-invasive treatment of intracranial lesions is another significant advancement in the field of therapeutic ultrasound. Histotripsy was recently approved by the U.S. Food and Drug Administration (FDA) for hepatic targets. Last year, the Focused Ultrasound Foundation announced that focused ultrasound has been used for the treatment of over 170 diseases. As advances in engineering technology, including guidance techniques for the fusion of ultrasound and MRI, as well as optimization of transducer, are making HIFU treatments easier, safer, and more efficacious. This technique may play a key role in future clinical practice.

Keywords: HIFU, ablation surgery, therapeutic medicine

Received: 13/09/2025 Accepted: 20/10/2025 Published: 01/11/2025
Copyright: © Author(s). Published by *Journal of Health and Aging*.

1. INTRODUCTION

High intensity focused ultrasound (HIFU), also known as focused ultrasound ablation surgery (FUAS) or focused ultrasound surgery (FUS), is a non-invasive therapeutic technique. This technique is based on the excellent penetrability of ultrasonic waves in the human body and the ability to focus those waves on the targeted lesions. The temperature of the treated area is raised to approximately 65-100 resulting in coagulative necrosis as the mechanical effect of the ultrasounic waves is converted into heat. The possibility that HIFU might be developed as a result of controlling local heating phenomena was introduced by Lynn et al in the 1940s [1], but the technique was not developed at that time because there was no adequate targeting method available. In the 1980s, with the development of diagnostic imaging, HIFU has received considerable attention again. Zhibiao Wang from Chongqing Medical University began his HIFU project in China in 1988, and proposed a new conception of the 'biological focal field' [2]. After 10 years of basic research, ultrasound-guided HIFU (USgHIFU) was first used in clinic to treat a patient with osteosarcoma in 1997. Over the last two decades, many studies have indicated that HIFU ablation is a safe and effective treatment for different types of solid tumors and some benign diseases in different organs [3-5]. This article reviews the current applications, clinical efficacy, and future directions of HIFU.

2. CURRENT APPLICATIONS

Figure 1. Ultrasound guided focused ultrasound tumor therapeutic system (Model-JC300, Chongqing Haifu Medical Technology Co., Ltd.)

Currently, both USgHIFU [Figure 1] and magnetic resonance imaging guided focused ultrasound surgery (MRgFUS) or MRgHIFU [Figure 2] are used in clinical practice.

For guiding and monitoring HIFU ablation, MRI offers excellent anatomic resolution and temperature monitoring [6, 7]. Early work by Huber and Hynynen confirmed the feasibility of MRgFUS treatment in the breast [8, 9].

Although the feasibility and effectiveness of MRgFUS are being tested in several other clinical applications, which include the ablation of uterine fibroids, breast cancer, bone metastasis, and locally confined prostate cancer [10-13]. However, up until now, MRgFUS is not considered as a routine treatment in clinical practice. Recently, third-generation transcranial focused ultrasound made it possible to use thermocoagulation and create intracranial lesions measuring 2 to 6 mm and it is also possible to produce MR images which relay information of temperature changes in real time, enabling a shift from reversible test heating to irreversible therapeutic heating. This promising development demonstrated the possibility of a noninvasive treatment with outcomes similar to those of conventional brain surgery [14,15].

In comparison with MRI, ultrasound (US) has its own advantages over other imaging modalities. Firstly, MRI could offer excellent anatomic resolution, but it couldn't offer real-time anatomic background imaging for temperature mapping and with a big noise during the procedure. In contrast, ultrasound provides clear real-time monitoring imaging without making big noise. Secondly, it will be very difficult to monitor the temperature changes of the tissue when the movement occurs during the procedure of MRgFUS. Although ultrasound could not offer temperature monitoring, but many studies have indicated that US grey-scale change is reliable for monitoring the response to HIFU treatment [16,17]. Thirdly, since the bore size of MRI is relatively small, it is difficult to position patient, for example, when tumor locates at right lobe of the liver. In addition, this small bore size has also limited the size of transducer, which leads to a low acoustic power of the transducer. Therefore, USgHIFU has a much wider applications than that of MRgFUS. USgHIFU has been widely used in the treatment of liver cancer, pancreatic cancer, bone tumors, soft tissue tumors, breast cancer, breast fibroadenoma, uterine fibroids, adenomyosis, and other indications [5, 16, 17].

Figure 2. Magnetic resonance imaging guided focused ultrasound tumor therapeutic system (Model-JM, Chongqing Haifu Medical Technology Co., Ltd.)

3. CLINICAL EFFICACY

As a non-invasive technique, HIFU has a particular value for patients who are not indicated for surgical operation. In addition to having the potential for curative treatment and extending life expectancy, HIFU has also been shown to reduce or eliminate tumor related pain and thus improving the quality of life for patients with cancers at the advanced stage.

3.1. Liver cancer

The liver has been a target for HIFU since the early days of animal experimentation [18]. Although primary liver cancer and liver metastases require completely separate analysis, the technological approach of HIFU treatments is similar.

In 2001, Wu et al. reported the pathological changes of hepatocellular carcinoma (HCC) after extracorporeal ablation with USgHIFU) [19]. From November 1998 to May 2000, a total of 50 consecutive patients with HCC at stage IV a were treated with transcatheter arterial chemoembolization (TACE) or TACE followed by USgHIFU [20]. Among them, 26 patients were treated with TACE along, and 24 patients were treated by TACE followed by USgHIFU. The mean diameter of tumors was 10.5 cm. The median survival time was 11.3 months in patients treated with TACE followed by HIFU and it was 4.0 months in patients treated with TACE alone (P =0.004). The 1-year survival rate was 42.9% in the group of patients treated with TACE followed by HIFU and 0% in the group of patients treated with TACE alone (P < 0.01).

In Oxford, UK, 22 patients with liver metastases were treated using USgHIFU. The results showed that the adverse event profile was favorable when compared to open or minimally invasive techniques [21].

Unlike microwave, radiofrequency ablation and other puncture ablation techniques, HIFU has its unique advantages in ablating lesions located in difficult locations of the liver. The difficult locations were defined as tumor adjacent to main blood vessels, the heart, the gallbladder and bile duct, bowel or the stomach. Zhang et al. [22] reported that HIFU can achieve complete tumor necrosis even when the lesion is located adjacent to the major hepatic blood vessels. Indeed, there is no discernible damage to the major vessels, even though the adjacent tumor has been completely ablated. From November 2007 to April 2009, Orsi et al treated 17 patients with 24 liver metastases at difficult locations. After one session of HIFU treatment, PET-CT and/or MDCT at day 1 showed complete response in 22/24 liver metastases. No side effects were observed during a median of 12 months of follow-up [23].

Other teams have taken advantage of MRI to monitor liver tumor treatments [24, 25]. Nevertheless, the ultrasound (US)-guided JC model remains to date the only system with a significant clinical track record in liver and a regulatory approval for liver applications (CE mark and Chinese CFDA) [25]

3.2. Pancreatic cancer

Pancreatic cancer is a malignant tumor with extremely poor prognosis. The poor prognosis associated with this disease is attributable to its early systemic spread and aggressive local growth [26]. Surgical outcomes have improved over the last two decades, but the median 5-year survival after surgery is still around 20%. For patients with locally advanced or metastatic pancreatic cancer, several trials have showed systemic chemotherapy improves overall survival, but the median survival time is only 5-8 months [27]. Therefore, it is important to explore the novel treatment strategies to extend the life expectancy and improve the quality of life of patients with pancreatic cancer.

The first prospective trial was conducted between December 2000 and September 2002 in Chongqing [28]. Eight patients with advanced pancreatic cancer who were considered unsuitable for surgical operation were enrolled. Three patients had stage III and 5 patients had stage IV disease and all complained abdominal pain. Among them, 6 patients completed HIFU in one session and 2 patients had two sessions of HIFU treatment. The pain associated with the pancreatic lesion relieved in all patients during the follow up period. Reduction of tumor volume was observed in all patients, ranging from 20%-70%. The median survival time was 11.25 months. Serum amylase and bilirubin remained at normal levels and no complications were reported. Orsi et al. [23] treated 7 patients with USgHIFU between November 2007 and June 2009. All of the seven patients were almost completely palliated in symptoms by 24 hours after treatment. The median survival time was 11 months. MDCT or MRI at 24 hours after treatment did not detect any injury of the surrounding structures. PET-CT at one month after HIFU showed good response to HIFU. At the beginning of this study, all patients were cautiously observed in hospital for at least three days after HIFU. Portal vein thrombosis was observed in one patient who was discharged 7 days later. The amylase level showed no elevation over baseline in the 3 days after treatment.

Since then, many centers started to use this technique to treat patients with unresectable pancreatic cancer. Marinova et al. performed a prospective interventional study addresses the clinical effectiveness of USgHIFU treatment for patients with advanced-stage pancreatic cancer. Their results showed that significant early relief of cancer-induced abdominal pain was achieved by HIFU in 84 % of patients. Tumor volume reduction was 37.8 ± 18.1 % after 6 weeks. In this study, 21 % of HIFU-treated patients had local tumor progression with a median time of 14.4 months from HIFU. The median overall survival and progression-free survival were 16.2 and 16.9 months from diagnosis and 8.3 and 6.8 months from intervention [29]. Recently, Zhu et al. retrospectively analyzed 83 patients with unresectable pancreatic cancer treated using USgHIFU and the results showed that complete response rate was 3.6% (3/83) and partial response rate was 79.5% (66/83). After HIFU treatment, pain relief was observed in 74 patients, and the total relief rate was 97.6% (74/76). The median survival time was 9.9 months from HIFU, and the overall survival rate in 1 and 2 years was 41.5% and 9.6%, respectively [30]. Another study also showed the similar results with pain relief in 98.2% of the patients, and the overall median survival time was 12.1 months. No major postoperative complications were observed [31]. Recently, Marinova et al. performed a study to evaluate the quality of life of patients with pancreatic cancer using USgHIFU. Compared to baseline, global health significantly improved 3 and 6 months after HIFU treatment. Functional subscales including physical, emotional, and social functioning were considerably improved at 6 months, as were leading symptom pain, fatigue, and appetite loss. Moreover, pain intensity measured by NRS revealed effective and strong pain relief at any time points [32]. Therefore, we concluded that HIFU is an alternative treatment option for patients with pancreatic cancer.

3.3. Malignant bone tumors

There has been a general consensus that due to the attenuation of ultrasound energy by bones, ultrasound energy cannot enter the bones with sufficient intensity for therapeutic ablation. However, the penetration of ultrasound into bone tissue is related to the ultrasound frequency. Animal experiments have shown that focused ultrasound can achieve transcranial thermal injury. In addition, when the tumor causes partial or complete cortical destruction, ultrasound waves can easily enter the medullary space and focus on the lesion, leading to complete necrosis of tumors [33]. Both MRgFUS and USgHIFU can be used in the treatment of bone tumors.

In 1997, the first patient with osteosarcoma was successfully treated with USgHIFU. Later, Chen et al. performed a preliminary study of HIFU treatment for malignant bone tumors. 99mTc MDP bone scan showed reduced osteogenesis in the treatment area. All patients experienced pain relief as well as improvement in the range of motion of the affected joints. Histopathology confirmed that treatment has reached the target area [34, 35].

Following the early success, Chen et al. continued to treat patients who were not suitable for surgery or refused surgery using USgHIFU [36]. The long-term follow-up results of USgHIFU ablation for patients with primary bone malignancies were published [37]. Between December 1997 and November 2004, 80 patients with primary bone malignancy (Enneking staging: 60 patients in stage IIb and 20 patients in stage III) were treated using USgHIFU. Among them, 62 patients with osteosarcoma, 1 with periosteal osteosarcoma and 3 with Ewing's sarcoma received HIFU and chemotherapy. The remaining 14 patients with chondrosarcoma, malignant giant cell tumor of bone, sarcoma of the periosteum or unknown histology, received HIFU alone. MRI or CT, and single photon emission CT (SPECT) were used to assess tumor response. Follow-up images demonstrated completely ablated malignant bone tumors in 69 patients and greater than 50% tumor ablation in the remaining 11 patients. Overall survival rates at 1, 2, 3, 4, and 5 years were 89.8%, 72.3%, 60.5%, 50.5%, and 50.5%, respectively. In the patients with stage IIb cancer, survival rates at 1, 2, 3, 4, and 5 years were 93.3%, 82.4%, 75.0%, 63.7%, and 63.7%, respectively. In those with stage III disease, survival rates at 1, 2, 3, 4, and 5 years were 79.2%, 42.2%, 21.1%, 15.8%, and 15.8%, respectively. Among the patients with stage IIb disease, long-term survival rates were substantially improved in the 30 patients who received the full treatment (complete high-intensity focused ultrasound and full cycles of chemotherapy) compared with the survival rates for the 24 patients who did not finish the chemotherapy cycles and the six patients who underwent partial ablation only. Only five (7%) of the 69 patients who underwent complete ablation had local cancer recurrence during the follow-up period.

Bone metastases are common and can be caused by most types of malignancies. As cancer treatment prolongs the overall survival of patients, the number of patients with bone metastases is expected to increase further. MRgFUS has been approved for pain palliation in patients with bone metastases by the U.S. FDA. A study showed that MRgFUS relieved pain in 60–100% of patients; pain relief occurred rapidly and lasted for more than 3 months [38]. HIFU is recommended as a second line treatment for pain relief in bone metastases after radiotherapy failure. Treatable lesions should be visualized on the image and restricted to the non-articular areas of the limbs, ribs, sternum, pelvis, shoulders, and posterior sacrum.

Multiple studies have shown that the clinical response rate after MRgFUS for bone metastases ranged from 64% to 76% [39-41]. In a randomized controlled study, the response rate of patients in MRgFUS group was better than that of the placebo group (64% vs. 20%, p<0.001) [42]. The most common complication during MRgFUS treatment occurred in 32% of patients. Third degree skin burns or fractures were seen in 3% of patients. In addition, a paired design study compared the efficacy of MRgFUS and conventional radiotherapy as first-line local treatments, with MRgFUS showing a higher response rate (71% vs. 26%, p=0.0009) one week after treatment [43].

Certainly, HIFU therapeutic ablation of malignant bone tumors is feasible and effective, and may eventually become part of a regimen of limb-sparing techniques in patients with malignant bone tumors. The patients with bone metastases could also benefit from HIFU and have better quality of life [Figure 3].

Figure 3. CT images obtained from a patient with iliac metastasis from multiple myeloma. He had severe pain and no response to chemotherapy and radiotherapy. The pain significantly relieved 1 day after HIFU treatment. (A) Pre-HIFU CT image showed a lesion located in the right iliac (arrow). The size of the lesion was 11cm in diameter; (B) one month post-HIFU CT image showed the volume of the tumor significantly reduced (arrow); (C) four months post-HIFU image showed the size of the treated tumor further reduced (arrow). Courtesy of Dr. Franco Orsi from the European Institute of Oncology, Milan, Italy.

3.4. Breast tumors

Both MRgFUS and USgHIFU can be used in the treatment of breast fibroadenoma and breast cancer. In 2001, Huber et al. treated one patient with HIFU followed by lumpectomy 5 days later. MR imaging following treatment and histological examination following excision revealed lethal and sub lethal damage to the tumor [8]. Hynynen et al. treated 11 fibroadenomas in nine patients under local anaesthesia. The treatment efficacy was evaluated by MRI, and the follow results showed the treated fibroadenomas were getting smaller [9]. Recently, Liang et al. performed a study aimed to assess the efficacy, safety and follow-up outcomes of USgHIFU in the treatment of breast fibroadenoma. The median localization time for all fibroadenomas was 3 min, and the median treatment time was 9 min. Under local anesthesia, all the patients tolerated the treatment well. No serious adverse event occurred in any of the patients. Based on contrast-enhanced ultrasound (CEUS) or contrast enhanced MRI evaluation, the median NPV ratio was 100%. The shrinkage rates were 26.77 ± 50.05%, 50.22 ± 42.01% and 72.74 ± 35.39% at 3-6 months, 6-12 months and over 12 months, respectively [44]. Another study was performed to compare the quality of life, cosmesis and cost-utility of open surgery, vacuum-assisted breast biopsy and HIFU for fibroadenoma. The results showed that open surgery, vacuum-assisted breast biopsy and HIFU were all effective and safe for fibroadenoma, but HIFU had the best quality of life improvement, breast cosmesis and cost-effectiveness [45].

The first randomized controlled clinical trial for breast cancer was conducted by Wu et al. [46]. In this study, patients were treated with either modified radical mastectomy (n=25) or HIFU followed by modified radical mastectomy within 1-2 weeks (n=23). The HIFU-treated area included the tumor and 1.5-2.0 cm of surrounding normal tissue. Pathological results showed that coagulative necrosis occurred in the cancerous tissue and the safety margin [46]. They also noted that the expression of PCNA, CD44v6 and MMP-9 was significantly higher in the untreated cancerous tissue than that in the untreated normal breast tissue. However, there was no expression in the HIFU-treated area. Additional histological analysis using NADH staining confirmed complete necrosis [47].

Wu et al. evaluated the long term results of USgHIFU in another study. These patients were enrolled if they were deemed unsuitable for surgery (n=6) or refused surgical resection (n=16). Among them, 4 patients were at stage I, 9 patients were at stage IIA, 8 patients were at stage IIIB and 1 patient was at stage IV. All patients received 6 cycles of adjuvant chemotherapy and radiotherapy after HIFU ablation [48, 49]. The absence of blood flow was observed in 19 of 22 tumors after HIFU treatment. As anticipated, all patients experienced a palpable breast lump following HIFU which extended to the whole treatment area (tumor and margin) and was therefore greater than the original tumor. After a median follow-up of 54.8 months, 1 patient died, 1 was lost to follow-up, and 20 were still alive. Five-year disease-free survival and recurrence-free survival were 95% and 89%, respectively. Although patients were advised of this noninvasive treatment in advance, it did give rise to anxiety, and 2 of the 21 patients elected to have mastectomy as a result. Local recurrence occurred in two patients at 18 and 22 months after HIFU ablation. Another clinical trial performed at the European Institute of Oncology (Milan, Italy) enrolled 12 patients with small breast cancer (<1.5 cm). After HIFU, all the patients underwent conservative surgery in order to obtain the standard breast cancer surgical treatment and an accurate histopathological assessment to confirm HIFU treatment results. The pathologic results have shown that the tumors have been ablated without major adverse effects. These studies have demonstrated that HIFU is a safe and effective treatment for patients with breast cancer. Therefore, HIFU can be used as a local treatment for patients with breast cancer who are indicated for surgery or do not want to undergo surgery.

3.5. Kidney cancer

Kidney cancer can also be treated with this non-invasive approach. Wu et al. [50] described a series of 13 patients with renal cell carcinoma. All 13 patients received HIFU treatment safely, including 10 patients underwent partial ablation and 3 patients underwent complete tumor ablation. Among the 8 patients with hematuria, 7 patients reported hematuria disappeared, and 9 of 10 patients with flank pain of presumed malignant origin disappeared. No side effects occurred after ablation using an experimental handheld device.

Later, Illing et al. treated eight patients with renal cancer in Oxford. After a single therapeutic HIFU session under general anaesthesia, the results were evaluated with either radiological images such as MRI or contrast ultrasound, or histological examinations. The results revealed that the adverse event profile was favorable when compared to open or minimally invasive techniques [21].

Some other patients in Oxford University received HIFU treatment outside of any trials. A patient with a 5cm renal cell carcinoma in a transplant kidney was treated twice with 90% ablation of the tumor. Transplanted kidneys seemed to be suitable for HIFU treatment because they are located in the groin area, so the ribs will not cause any problems. In addition, the perirenal fat that seems to affect treatment has been removed.

3.6. Benign uterine diseases

Among the indications for HIFU treatment, benign uterine diseases are the most common ones. Both MRgFUS and USgHIFU can be used for the treatment of benign uterine diseases, but USgHIFU has significantly higher treatment efficiency and better results.

In 2003, Stewart et al. and Tempany et al. have shown the safety and efficacy of MRgFUS for uterine fibroids [12,13]. Although the NPV achieved was only around 30% of the targeted fibroids, patients reported either significant or partial symptom relief. The shrinkage rate of the treated fibroids was 12% and 15% at 1 and 6 months, respectively [51]. The long-term follow-up results also demonstrated that patients underwent

MRgFUS had sustained symptom relief [52]. However, based on the mean NPV ratio immediately after treatment, subjects with higher NPV ratio have significantly greater improvement, with higher probability of intervention-free survival [52, 53]. Therefore, it is important to achieve a large NPV ratio of uterine fibroids for long-term success.

In earlier studies, a clear pathway from the anterior abdominal wall to the fibroid without passing through the bladder or the bowel was required, many patients were excluded from MRgFUS because bowel presence in acoustic pathway [12, 54]. Later, Zhang et al. showed that after the bowel was compressed with a degassed water balloon, MRgHIFU treatment is safe and feasible in ablating uterine fibroids in patients with bowel lies anterior to uterus [55]. In this study, Zhang et al have treated 21 patients with 23 fibroids, and the mean fibroid volume was 97.0±78.3 cm3. According to the treatment plan, an average of 75.0±11.4% of the fibroid volume was treated. The average non-perfused volume was 83.3±71.7 cm3, the average fractional ablation, which was defined as non-perfused volume divided by the fibroid volume immediately after HIFU treatment, was 76.9±18.7%. There were no statistically significant differences between the treatment volume and the non-perfused volume. Follow-up MRI at 3 months obtained in 12 patients, the fibroid volume decreased by 31.4±29.3% in average, with paired t-test showing a statistically significant reduction (p=0.002). The mean treatment time for ablating the average of 83.3 ±71.7 cm3 of fibroid volume was 2.5±1.4 hours, which was relatively short and acceptable to patient and physicians. Four patients experienced mild skin burn (two with skin redness, two with blisters), the skin burn subsided within 2 days. No other adverse events were observed [55].

In China, Wang et al. have reported their preliminary results of USgHIFU treatment for symptomatic uterine fibroids in 2002 [56]. Between July 2001 and January 2003, He et al. treated 23 patients with HIFU at one center. Patients were enrolled if they refused hysterectomy. The fibroids were between 4 and 8 cm in diameter and located at the anterior wall of the uterus. The average volume of menstruation and uterine volume decreased throughout the follow-up period and the average size of uterine fibroids reduced in 17 patients with a mean reduction of 78.9%. One patient had myomectomy because of the persistent menorrhagia and the histopathological results from this patient showed that normal tissues around the treated area were undamaged. Unfortunately, four patients had temporary numbness on the lower limbs because of damage to the sciatic nerve which is now avoided by changing the treatment protocol [57].

Over the last 10 years, this JC model HIFU system has been modified and thus led to a very low level of adverse effects. Currently, this technique has been clinically considered as an alternative treatment for patients with uterine fibroids in China. Many studies have shown the safety and effectiveness of HIFU for uterine fibroids [58, 59]. A prospective study with 2411 subjects from 20 centers compared HIFU treatment with myomectomy and hysterectomy and the results showed that patients treated with HIFU had a similar long-term therapeutic outcome and a lower postoperative morbidity compared with patients treated with surgery [8]. A systematically review of minimally invasive approaches to uterine fibroid treatment for improving quality of life and fibroid-associated symptoms showed that HIFU significantly reduced uterine fibroids related symptoms and improved the quality of life (UFS QoL) of patients [9].

Recently, multiple studies have shown that achievement of NPV ratio higher than 70% has led to acceptable re-intervention rate during the follow-up period after USgHIFU [58,59]. Li et al. retrospectively reviewed 381patients with uterine fibroids underwent USgHIFU at the third Xiangya Hospital of Central South University from April 2012 to December 2014. During a mean of 70.0 ± 9.0 months of follow-up, 86.4% (329/381) of the patients reported symptomatic relief and the fibroids shrank after USgHIFU treatment. Seventy-nine patients received reintervention included myomectomy, a second session of HIFU, and hysterectomy. The overall reintervention rate was 20.7% (79/381) [58]. Wang et al. retrospectively reviewed 401 patients with a solitary uterine fibroid treated with HIFU. These patients were classified as extremely hypointense, hypointense, isointense and hyperintense fibroids based on signal intensity on T2 weighted imaging of MR. The average NPV ratio achieved in patients with extremely hypointense, hypointense, isointense and hyperintense fibroids was 75.2 ± 14.6%, 71.1 ± 15.6%, 68.2 ± 17.3% and

67.8 ± 16.6%, respectively; the re-intervention rates at 36 months after HIFU were 8.4%, 10.3%, 12.5% and 6.1%, respectively [60].

Myomectomy remains the preferred treatment for patients with uterine fibroids who wish to conceive. However, the incidence of uterine rupture after laparoscopic myomectomy is reported to be up to 1.2% [61]. In addition, strict contraception is often required for at least 1-2 years after the removal of uterine fibroids, depending on the number, size, and location of the lesions [62]. With changing attitudes towards marriage and childbirth, the number of pregnancies at advanced ages is increasing. HIFU is a good option for patients with fertility requirements, especially for older patients because HIFU can achieve precise ablation of fibroids without damaging the endometrium and adjacent myometrium around fibroids (Figure 4). Compared with myomectomy, it can significantly shorten the preparation time for pregnancy [63].

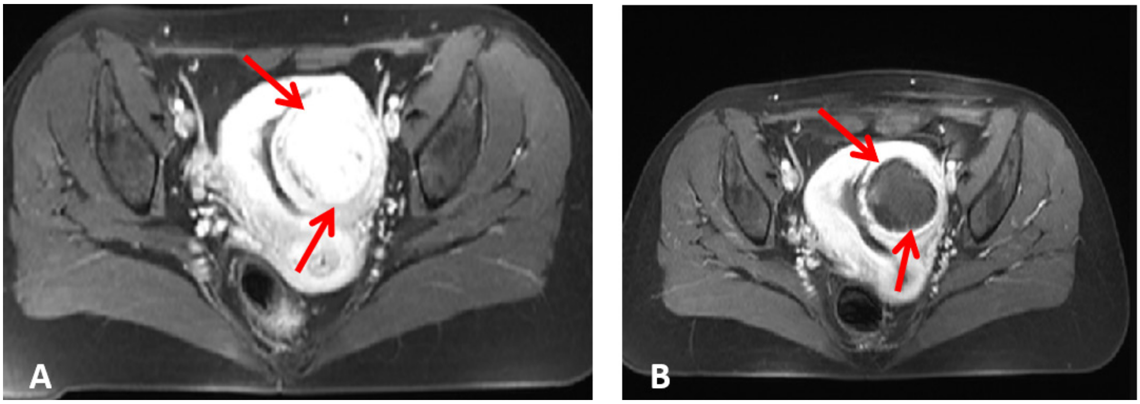

Figure 4. Contrast-enhanced MR images obtained from a 31 years old patient with uterine fibroid who wish to conceive. (A) Pre-HIFU MRI showed a submucosal fibroid (FIGO type II) located in the left lateral wall of the uterus. The size was 5.5 cm in diameter (arrow); (B) one day post-HIFU showed no perfusion in the uterine fibroid (arrow). The fibroid was completely ablated without damaging to the endometrium and adjacent myometrium.

The treatment of adenomyosis remains an intense challenge. In 2007, the first patient with adenomyosis was successfully treated with USgHIFU. Currently, many studies have demonstrated that HIFU is safe and effective in the treatment of adenomyosis [64, 65]. Multiple studies have shown that HIFU seems to have a beneficial effect on fertility of patients with adenomyosis [66, 67]. HIFU has also been used in the treatment of placenta accreta, cesarean scar pregnancy [68, 69]

4. OTHER INDICATIONS

USgHIFU has been used successfully for the treatment of soft tissue tumors [5, 70]. It has also been used in the treatment of abdominal wall endometriosis [71]. Several groups have used this technique in the management of recurrent ovary cancer, trophoblastic neoplasia with chemoresistance or recurrence [72, 73]. According to clinical needs, this technology is becoming increasingly widely used in clinical practice, solving many problems that current treatment methods cannot solve and providing new options for these patients. .

5. FUTURE DIRECTIONS

Cardiovascular diseases remain the leading cause of death globally. Recently, HIFU has been proven to be beneficial as an adjunct in the treatment of myocardial infarction and arrhythmias. It has also been investigated for in vivo treatment of resistant hypertension, symptomatic aortic valve stenosis, arterial stenosis, hypertrophic cardiomyopathy, and external cardiac pacing [74]. The emergence of therapeutic ultrasound-based therapies in cardiovascular disease management represents a promising innovative strategy beyond current established approaches.

MRgFUS allows for non-invasive treatment of intracranial lesions is another significant advancement in the field of therapeutic ultrasound. Although this is currently approved for surgical treatment of essential tremor and Parkinson's disease, advancements in imaging and ultrasound technology are allowing for the expansion of treatment indications to other intracranial diseases [75].

Histotripsy is a novel, cavitation effect of ultrasound-based ablative technique that was recently approved by the Food and Drug Administration for hepatic targets. In addition to the noninvasive ability to ablate lesions in the liver, histotripsy offers additional therapeutic potential. Although the effect of histotripsy on the oncologic therapeutic landscape remains uncertain, early data suggested a potential complementary therapeutic effect when combining histotripsy with existing immunologic therapies because of the technology's theoretical ability to sensitize tumors to adaptive immunity [76].

Recently, the Focused Ultrasound Foundation announced that focused ultrasound has been used for the treatment of over 170 diseases. At the same time, advances in engineering technology, including guidance techniques for the fusion of ultrasound and MRI, as well as optimization of transducer, are making HIFU treatments easier, safer, and more efficacious.

REFERENCES

[1] Lynn JG, Zwemer R L, and Chick A J. A new method for the generation and use of focused ultrasound in experiment biology. J Gen Physiol, 1942, 26: 179-193

[2] Wang ZB, Wu F, Wang ZL, Zhang Z, Zou JZ, Liu C, Liu YG, Cheng G, Du YH, He ZC, Gu ML, Wang ZG, Feng R. Targeted damage effects of high intensity focused ultrasound (HIFU) on liver tissues of Guizhou Province miniswine,1997, 4(2):181-2

[3] Hynynen K, Pomeroy O, Smith DN, Huber PE, McDannold NJ, Kettenbach J, Baum J, Singer S, Jolesz FA. MR imaging-guided focused ultrasound surgery of fibroadenomas in the breast: A feasibility study. Radiology, 2001; 219:176–185

[4] Wu F, Wang ZB, Zhu H, Chen WZ, Zou JZ, Bai J, Li KQ, Jin CB, Xie FL, Su HB. Feasibility of US-guided High-Intensity Focused Ultrasound Treatment in Patients with Advanced Pancreatic Cancer: Initial Experience. Radiology, 2005, 236:1034–1040

[5] Wu F, Wang ZB, Chen WZ, Wang W, Gui Y, Zhang M, Zheng G, Zhou Y, Xu G, Li M, Zhang C, Ye H, and Feng R. Extracorporeal high intensity focused ultrasound ablation in the treatment of 1038 patients with solid carcinomas in China: an overview. Ultrason Sonochem, 2004, 11:149-154

[6] Hynynen K, Damianou C, Darkazanli A, Unger E, Schenck JF. The feasibility of using MRI to monitor and guide noninvasive ultrasound surgery. Ultrasound Med Biol, 1993, 19:91-92

[7] Hynynen K, Vykhodtseva NI, Chung AH, Sorrentino V, Colucci V, Jolesz FA. Thermal effects of focused ultrasound on the brain: determination with MR imaging. Radiology, 1997, 204:247-253

[8] Huber PE, Jenne JW, Rastert R, Simiantonakis I, Sinn HP, Strittmatter HJ, von Fournier D, Wannenmacher MF, Debus J. A new noninvasive approach in breast cancer therapy using magnetic resonance imaging-guided focused ultrasound surgery. Cancer Res, 2001 Dec 1, 61(23):8441-7.

[9] Hynynen K, Pomeroy O, Smith DN, Huber PE, McDannold NJ, Kettenbach J, Baum J, Singer S, Jolesz FA. MR imaging-guided focused ultrasound surgery of fibroadenomas in the breast: a feasibility study. Radiology, 2001 Apr, 219(1):176-85

[10] Gedroyc WM. New clinical applications of magnetic resonance-guided focused ultrasound. Top. Magn. Reson. Imaging, 2006, 17(3):189–94

[11] Moonen CT, Quesson B, Salomir R, et al. Thermal therapies in interventional MR imaging. Focused ultrasound. Neuroimaging Clin. N. Am., 2001, 11(4):737–47

[12] Stewart EA, Gedroyc WM, Tempany CM. Focused ultrasound treatment of uterine fibroid tumors: safety and feasibility of a noninvasive thermoablative technique. Am J Obstet Gynecol, 2003, 189:48-54

[13] Tempany CM, Stewart EA, McDannold N, Quade BJ, Jolesz FA, Hynynen K. MR imaging-guided focused ultrasound surgery of uterine leiomyomas: a feasibility study. Radiology, 2003, 226:897-905

[14] Magara A, Bühler R, Moser D, Kowalski M, Pourtehrani P, Jeanmonod D: First experience with MR-guided focused ultrasound in the treatment of Parkinson's disease. J Ther Ultrasound 2: 11, 2014.

[15] Stavarache MA, Chazen JL, Kaplitt MG. Innovative Applications of MR-Guided Focused Ultrasound for Neurological Disorders. World Neurosurg. 2021 Jan;145:581-589.

[16] Zhang L, Zhu H, Jin C, Zhou K, Li K, Su H, Chen W, Bai J, Wang Z. High intensity focused ultra-

sound (HIFU):Effective and safe therapy for hepatocellular carcinoma adjacent to major hepatic veins. Eur Radiol, 2009, 19(2):437-45

[17] Orsi F, Zhang L, Arnone P, Bonomo G, Della Vigna P, Monfardini L, Zhou K, Chen WZ, Wang ZB, Veronesi U. High intensity focused ultrasound (HIFU) ablation: Effective and safe therapy for solid tumors at difficult locations. AJR Am J Roentgenol. 2010 Sep;195(3):W245-52.

[18] Taylor KJW, Connolly CC. Differing hepatic lesions caused by the same dose of ultrasound. J Pathol, 1969, 98:291–3

[19] Wu F, Wang Z, Chen W. Pathological study of extracorporeally ablated hepatocellular carcinoma with high-intensity focused ultrasound. Zhonghua Zhong Liu Za Zhi. 2001, 23(3):237-9

[20] Wu F, Wang ZB, Chen WZ, Zou JZ, Bai J, Zhu H, Li KQ, Jin CB, Xie FL, Su HB. Advanced hepatocellular carcinoma: treatment with high-intensity focused ultrasound ablation combined with transcatheter arterial embolization.Radiology, 2005, 235(2):659-67

[21] Illing RO, Kennedy JE, Wu F, ter Haar GR, Protheroe AS, Friend PJ, Gleeson FV, Cranston DW, Phillips RR, Middleton MR. The safety and feasibility of extracorporeal high-intensity focused ultrasound (HIFU) for the treatment of liver and kidney tumors in a western population. British Journal of Cancer, 2005, 93: 890 – 895

[22] Zhang L, Zhu H, Jin C, Zhou K, Li K, Su H, Chen W, Bai J, Wang Z. High intensity focused ultrasound (HIFU):Effective and safe therapy for hepatocellular carcinoma adjacent to major hepatic veins. Eur Radiol, 2009, 19(2):437-45

[23] Orsi F, Zhang L, Arnone P, Bonomo G, Della Vigna P, Monfardini L, Zhou K, Chen WZ, Wang ZB, Veronesi U. High intensity focused ultrasound (HIFU) ablation: Effective and safe therapy for solid tumors at difficult locations. AJR American Journal of Roentgenology, (accepted)

[24] Okada A, Murakami T, Mikami K, Onishi H, Tanigawa N, Marukawa T, Nakamura H. A case of hepatocellular carcinoma treated by MR-guided focused ultrasound ablation with respiratory gating. Magn Reson Med Sci.2006; 5(3):167–71. 25. Kopelman D, Inbar Y, Hananel A, Freundlich D, Castel D, Perel A, Greenfeld A, Salamon T, Sareli M, Valeanu A, Papa M. Magnetic resonance-guided focused ultrasound surgery (MRgFUS): ablation of liver tissue in a porcine model. Eur J Radiol. 2006; 59:157–62

[25] Aubry JF, Pauly KB, Moonen C, Haar GT, Ries M, Salomir R, Sokka S, Sekins KM, Shapira Y, Ye F, Huff-Simonin H, Eames M, Hananel A, Kassell N, Napoli A, Hwang JH, Wu F, Zhang L, Melzer A, Kim YS, Gedroyc WM. The road to clinical use of high-intensity focused ultrasound for liver cancer: technical and clinical consensus. J Ther Ultrasound. 2013 Aug 1;1:13..

[26] National Cancer Institute. Surveillance, Epidemiology and End Results Program. 2020.

[27] Von Hoff DD, Ervin T, Arena FP, et al. Increased survival inpancreatic cancer with nab-paclitaxel plus gemcitabine. N EnglJ Med. 2013;369(18):1691–1703.

[28] Wu F, Wang ZB, Zhu H, Chen WZ, Zou JZ, Bai J, Li KQ, Jin CB, Xie FL, Su HB. Feasibility of US-guided high-intensity focused ultrasound treatment in patients with advanced pancreatic cancer: initial experience. Radiology, 2005, 236(3):1034-40

[29] Marinova M, Huxold HC, Henseler J, Mücke M, Conrad R, Rolke R, Ahmadzadehfar H, Rauch M, Fimmers R, Luechters G, Cuhls H, Radbruch L, Schild HH, Strunk H. Clinical Effectiveness and Potential Survival Benefit of US-Guided High-Intensity Focused Ultrasound Therapy in Patients with Advanced-Stage Pancreatic Cancer. Ultraschall Med. 2019 Oct;40(5):625-637.

[30] Zhu B, Li J, Diao L, Ma K, Fan Y, Yang W. High-intensity focused ultrasound ablation for advanced pancreatic cancer.J Cancer Res Ther. 2019;15(4):831-835.

[31] Qian C, Wan L, Wu Y. Analysis of the results of high-intensity focused ultrasound for patients with advanced pancreatic cancer. Int J Hyperthermia. 2023;40(1):2250586

[32] Marinova M, Feradova H, Gonzalez-Carmona MA, Conrad R, Tonguc T, Thudium M, Becher MU, Kun Z, Gorchev G, Tomov S, Strassburg CP, Attenberger U, Schild HH, Dimitrov D, Strunk HM. Improving quality of life in pancreatic cancer patients following high-intensity focused ultrasound (HIFU) in two European centers. Eur Radiol. 2021 Aug;31(8):5818-5829

[33] Wu F, Chen WZ, Bai J, Zou JZ, Wang ZL, Zhu H, Wang ZB. Pathological changes in human malignant carcinoma treated with high-intensity focused ultrasound. Ultrasound Med Biol, 2001 Aug, 27(8):1099-106

[34] Chen W, Wang Z, Wu F, Zhu H, Zou J, Bai J, Li K, Xie F. High intensity focused ultrasound in the treatment of primary malignant bone tumor. Zhonghua Zhong Liu Za Zhi, 2002, 24(6):612-5 (in Chinese)

[35] Chen WZ, Zhou K. High-intensity focused ultrasound ablation: a new strategy to manage primary bone tumors. Current Opinion in Orthopedics, 2005, 16(6):494-500

[36] Chen W, Wang Z, Wu F, Zhu H, Zou J, Bai J, Li K, Xie F. High intensity focused ultrasound in the treatment of primary malignant bone tumor. Zhonghua Zhong Liu Za Zhi, 2002, 24(6):612-5

(in Chinese)

[37] Chen WZ, Zhu H, Zhang L, Li KQ, Su HB, Jin CB, Zhou K, Bai J, Wu F, Wang ZB. High intensity focused ultrasound ablation: effective treatment for patients with primary bone malignancy. Radiology. 2010 Jun;255(3):967-78.

[38] Hurwitz, M.D.; Ghanouni, P.; Kanaev, S.V.; Iozeffi, D.; Gianfelice, D.; Fennessy, F.M.; Kuten, A.; Meyer, J.E.; LeBlang, S.D.; Roberts, A.; et al. Magnetic resonance-guided focused ultrasound for patients with painful bone metastases: Phase III trial results. J. Natl. Cancer Inst. 2014, 106, dju082

[39] Liberman, B.; Gianfelice, D.; Inbar, Y.; Beck, A.; Rabin, T.; Shabshin, N.; Chander, G.; Hengst, S.; Pfeffer, R.; Chechick, A.; et al. Pain palliation in patients with bone metastases using MR-guided focused ultrasound surgery: A multicenter study. Ann. Surg. Oncol. 2009, 16, 140–146.

[40] Napoli, A.; Anzidei, M.; Marincola, B.C.; Brachetti, G.; Ciolina, F.; Cartocci, G.; Marsecano, C.; Zaccagna, F.; Marchetti, L.; Cortesi, E.; et al. Primary pain palliation and local tumor control in bone metastases treated with magnetic resonance-guided focused ultrasound. Investig. Radiol. 2013, 48, 351–358.

[41] Lee, H.-L.; Kuo, C.-C.; Tsai, J.-T.; Chen, C.-Y.; Wu, M.-H.; Chiou, J.-F. Magnetic resonance-guided focused ultrasound versus conventional radiation therapy for painful bone metastasis: A matched-pair study. J. Bone Jt. Surg. Am. 2017, 99, 1572–1578.

[42] Hurwitz, M.D.; Ghanouni, P.; Kanaev, S.V.; Iozeffi, D.; Gianfelice, D.; Fennessy, F.M.; Kuten, A.; Meyer, J.E.; LeBlang, S.D.; Roberts, A.; et al. Magnetic resonance-guided focused ultrasound for patients with painful bone metastases: Phase III trial results. J. Natl.Cancer Inst. 2014, 106, dju082.

[43] Lee, H.-L.; Kuo, C.-C.; Tsai, J.-T.; Chen, C.-Y.; Wu, M.-H.; Chiou, J.-F. Magnetic resonance-guided focused ultrasound versus conventional radiation therapy for painful bone metastasis: A matched-pair study. J. Bone Jt. Surg. Am. 2017, 99, 1572–1578.

[44] Liang M, Zhang Z, Zhang C, Chen R, Xiao Y, Li Z, Li T, Liu Y, Ling L, Xie H, Chen L, Liu X, Wang S, Xia T. Feasibility and efficacy of ultrasound-guided high-intensity focused ultrasound of breast fibroadenoma. Int J Hyperthermia. 2023;40(1):2240548.

[45] Li Z, Yue X, Pan F, Yang L, Xiao Y, Mu D, Liu H, Chen M, Yin H, Huang H, Wang Z, Zhang C.A Comparison of Quality of Life, Cosmesis and Cost-Utility of Open Surgery, Vacuum-Assisted Breast Biopsy and High Intensity Focused Ultrasound for Breast Fibroadenoma. Acad Radiol. 2024 Oct;31(10):3900-3909.

[46] Wu F, Wang ZB, Cao YD, Chen WZ, Bai J, Zou JZ, Zhu H. A randomised clinical trial of high-intensity focused ultrasound ablation for the treatment of patients with localised breast cancer. Br J Cancer, 2003, 89(12): 2227-33

[47] Wu F, Wang ZB, Cao YD, Chen WZ, Zou JZ, Bai J, Zhu H, Li KQ, Jin CB, Xie FL, Su HB, Gao GW. Changes in biologic characteristics of breast cancer treated with high-intensity focused ultrasound. Ultrasound Med Biol, 2003, 29(10):1487-92

[48] Wu F, Wang ZB, Cao YD, Xu ZL, Zhou Q, Zhu H, Chen WZ. Heat fixation of cancer cells ablated with high-intensity-focused ultrasound in patients with breast cancer. Am J Surg, 2006, 192 (2):179-84

[49] Wu F, Wang ZB, Zhu H, Chen WZ, Zou JZ, Bai J, Li KQ, Jin CB, Xie FL, Su HB. Extracorporeal high intensity focused ultrasound treatment for patients with breast cancer. Breast Cancer Res Treat, 2005, 92(1):51-60

[50] Wu F, Wang ZB, Chen WZ, Bai J, Zhu H, Qiao TY. Preliminary experience using high intensity focused ultrasound for the treatment of patients with advanced stage renal malignancy. J Urol, 2003,170(6 Pt 1):2237-40

[51] Rabinovici J, Inbar Y, Revel A, Zalel Y. Gomori JM. Itzchak Y,. Schiff E, Yagel S. Clinical improvement and shrinkage of uterine fibroids after thermal ablation by magnetic resonance-guided focused ultrasound surgery. Ultrasound Obstet Gynecol, 2007, 30:771-777

[52] Stewart EA, Gostout B, Rabinovici J, Kim HS, Regan L, Tempany CM. Sustained relief of leiomyoma symptoms by using focused ultrasound surgery. Obstet Gynecol, 2007,110:279-287

[53] Fennessy FM, Tempany CM, McDannold NJ, So MJ, Hesley G, Gostout B, Kim HS, Holland GA, Sarti DA, Hynynen K, Jolesz FA, Stewart EA. Uterine leiomyomas: MR imaging-guided focused ultrasound surgery--results of different treatment protocols. Radiology, 2007, 243:885-893

[54] Hindley J, Gedroyc WM, Regan L, Stewart E, Tempany C, Hynyen K, Mcdannold N, Inbar Y, Itzchak Y, Rabinovici J, Kim HS, Geschwind JF, Hesley G, Gostout B, Ehrenstein T, Hengst S, Sklair-Levy M, Shushan A, Jolesz F. MRI guidance of focused ultrasound therapy of uterine fibroids: early results. AJR Am J Roentgenol, 2004, 183:1713-1719

[55] Zhang L, Chen WZ, Liu YJ, Hu X, Zhou K, Chen L, Zhu H, Zou HL, Bai J, Wang ZB. Feasibility of magnetic resonance imaging–guided high intensity focused ultrasound therapy for ablating uterine fibroids in patients with bowel lies anterior to uterus. Eur J Radiol, 2010 Feb, 73(2):396-403

[56] Wang W, Liu WY, Zhou JM, Xu JM, Gai LH, Huang CJ. High-intensity focused ultrasound treatment for symptomatic uterine fibroids: Preliminary results. Chinese Journal of ultrasonography, 2002, 11(3): 161-163 (in Chinese)

[57] He H, Lu L, Zhou Y, Nie Y. Clinical study of curing uterine leiomyoma with high intensity focused ultrasound. Zhongguo Xian Dai Yi Xue Za Zhi, 2004, 14(19): 9 (in Chinese)

[58] Li W, Jiang Z, Deng X, Xu D. Long-term follow-up outcome and reintervention analysis of ultrasound-guided high intensity focused ultrasound treatment for uterine fibroids. Int J Hyperthermia. 2020;37(1):1046-1051.

[59] Liu Y, Wu X, Wu A, Gong C, Wang Z, Zhang L. Ultrasound-guided high intensity focused ultrasound ablation for uterine fibroids: long-term outcomes and factors affecting local recurrence. Int J Hyperthermia. 2021;38(1):1341-1348.

[60] Wang Y, Gong C, He M, Lin Z, Xu F, Peng S, Zhang L.Therapeutic dose and long-term efficacy of high-intensity focused ultrasound ablation for different types of uterine fibroids based on signal intensity on T2-weighted MR images. Int J Hyperthermia. 2023;40(1):2194594.

[61] Claeys J, Hellendoorn I, Hamerlynck T, et al. The risk of uterine rupture after myomectomy: a systematic review of the literature and meta-analysis. GynecolSurg. 2014�11:197–206.

[62] Zou M, Chen L, Wu C, Hu C, Xiong Y. Pregnancy outcomes in patients with uterine fibroids treated with ultrasound-guided high-intensity focused ultrasound. BJOG. 2017 Aug;124 Suppl 3:30-35.

[63] Jiang Z, Li Q, Li W, Zhu X, Jiang J, Chen L, He S, Xue M, Ye M, Li X. A comparative analysis of pregnancy outcomes of patients with uterine fibroids after high intensity focused ultrasound ablation and laparoscopic myomectomy: a retrospective study. Int J Hyperthermia. 2021;38(1):79-84.

[64] Zhang X, Li K, Xie B, He M, He J, Zhang L. Effective ablation therapy of adenomyosis with ultrasound-guided high-intensity focused ultrasound. Int J Gynaecol Obstet. 2014 Mar;124(3):207-11.

[65] Shui L, Mao S, Wu Q, Huang G, Wang J, Zhang R, Li K, He J, Zhang L. High-intensity focused ultrasound (HIFU) for adenomyosis: Two-year follow-up results. Ultrason Sonochem. 2015 Nov;27:677-681.

[66] Ma R, Briones DAB, Zou M, Xiong Y, Bai J, Zhang L Analysis of factors affecting pregnancy outcomes in patients with adenomyosis after high intensity focused ultrasound ablation: a retrospective study. Int J Hyperthermia. 2024;41(1):2390124.

[67] Wei J, Wang L, Tao H, Wang X, Zheng F, He P, Zhou L, Fan L, Chen J, Zhong H, Huang W, Zeng D, Li J. Comparison of pregnancy outcomes in infertile patients with different types of adenomyosis treated with high-intensity focused ultrasound. Int J Hyperthermia. 2023;40(1):2238140.

[68] Lin Z, Gong C, Huang Q, Zhang Z, Wang D, Yuan L, Wang X, An Q, Chen D, Liu S, Zou X, Setzen R, Yang B, Zhang L.A comparison of results following the treatment of placenta accreta and placenta increta using high-intensity focused ultrasound followed by hysteroscopic resection. Int J Hyperthermia. 2021;38(1):576-581),

[69] Peng Y, Dai Y, Wen C, Yu G, Jin P. Clinical efficacy and safety of high-intensity focused ultrasound combined with ultrasound-guided suction curettage at different time intervals for Cesarean scar pregnancy: a retrospective study. Int J Hyperthermia. 2024;41(1):2388653.

[70] Zhang R, Chen JY, Zhang L, Li KQ, Xiao ZB, Mo SJ, Chen L, Chen WZ. The safety and ablation efficacy of ultrasound-guided high-intensity focused ultrasound ablation for desmoid tumors. Int J Hyperthermia. 2021 Sep;38(2):89-95.

[71] Zhu X, Chen L, Deng X, Xiao S, Ye M, Xue M. A comparison between high-intensity focused ultrasound and surgical treatment for the management of abdominal wall endometriosis. BJOG. 2017 Aug;124 Suppl 3:53-58.

[72] Lei T, Guo X, Gong C, Chen X, Ran F, He Y, Shi Q, He J. High-intensity focused ultrasound ablation in the treatment of recurrent ovary cancer and metastatic pelvic tumors: a feasibility study. Int J Hyperthermia. 2021;38(1):282-287.

[73] She C, Li S, Wang X, Lu X, Liang H, Liu X. High-intensity focused ultrasound ablation as an adjuvant surgical salvage procedure in gestational trophoblastic neoplasia chemotherapy with chemoresistance or recurrence: two case reports. Int J Hyperthermia. 2021;38(1):1584-1589.

[74] Bansal A, Bulwer B, von Krüchten R, Singh J, Rehan R, Doost A. Role of Ultrasound-Based Therapies in Cardiovascular Diseases. Struct Heart. 2024 Jul 16;9(2):100349.

[75] Binder DK, Shah BB, Elias WJ. Focused ultrasound and other lesioning in the treatment of tremor. J Neurol Sci. 2022 Apr 15;435:120193.

[76] Sandilos G, Butchy MV, Koneru M, Gongalla S, Sensenig R, Hong YK. Histotripsy - hype or hope? Review of innovation and future implications. J Gastrointest Surg. 2024 Aug;28(8):1370-1375.