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High-intensity focused ultrasound in the multimodal treatment of colorectal cancer liver metastases: A case report

YUANHONG YANG[1*], HAO ZHANG[2*], YIFAN SHEN[2*], FAN YANG[3], DAN ZHAO[2], YUJIE LIN[2] and GUOHUA HUANG[2]

[1]Department of Proctology, Suining Central Hospital, Suining, Sichuan 629000, P.R. China; [2]High-Intensity Focused Ultrasound Treatment Center, Suining Central Hospital, Suining, Sichuan 629000, P.R. China; [3]Department of Oncology, Suining Central Hospital, Suining, Sichuan 629000, P.R. China

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Abstract. Colorectal liver metastasis (CRLM) is typically associated with a poor prognosis. However, adopting multiple comprehensive treatment methods can significantly improve patients' long-term survival rates. High-intensity focused ultrasound (HIFU) is an emerging therapeutic technique that presents new treatment possibilities for patients. The present study reports the case of a patient who was diagnosed with liver metastasis following laparoscopic rectal cancer surgery. After unsuccessful tumor control with classical chemotherapy, radiofrequency ablation and interventional embolization therapy, the patient underwent HIFU treatment, which resulted in complete tumor remission and >10 years of tumor-free survival. In this case, HIFU treatment significantly improved tumor control without causing additional trauma. This case highlights a successful multimodal treatment approach for CRLM and provides valuable insights for similar cases, underscoring the importance of personalized treatment that integrates multiple therapeutic modalities. As a non-invasive and innovative technique, HIFU demonstrates significant potential in providing a new avenue for the future treatment of CRLM.

Introduction

Colorectal cancer is a common malignancy of the digestive system, and the liver is its most frequent site of distant metastasis (1). The relatively high incidence of colorectal liver metastasis (CRLM) can be attributed in part to the liver's unique anatomical and physiological environment. Specifically, ~70% of the liver's blood supply is delivered via the portal venous system, which carries a rich and slowly circulating volume of blood from the gastrointestinal tract. Combined with the liver's inherent immune-tolerant properties, these factors create a conducive milieu for metastatic colonization (2). Additionally, alterations in the tumor microenvironment, such as the suppression of local immune responses and the influence of liver-specific factors, play a significant role in promoting the growth and survival of metastatic tumor cells (3). Furthermore, the expression of certain molecular markers has been associated with an increased risk of liver metastasis. For example, the upregulation of CD44, CD133, epithelial cell adhesion molecule, Nanog and Sox2 enhances tumor cell self-renewal, proliferation and tumorigenicity, thereby fostering the cells invasive and metastatic potential (4).

The management of CRLM, encompassing both systemic and local therapies, is tailored to the patient's overall condition and the number, size and location of the liver lesions. Systemic treatments primarily comprise chemotherapy, targeted therapy and immunotherapy, while local therapies mainly include surgical resection, transarterial embolization/transarterial chemoembolization (TAE/TACE), radiofrequency ablation (RFA), microwave ablation (MWA), selective internal radiation therapy, stereotactic body radiation therapy and HIFU. Surgical resection remains the primary treatment for CRLM, aiming to completely remove all visible tumors and offering potential curative prospects (5). However, only 10-20% of patients with CRLM are eligible for resection, with a 5-year postoperative survival rate of only 30% (3).

Systemic chemotherapy is the standard treatment for patients with unresectable or widespread liver metastases. Common regimens include FOLFOX and FOLFIRI, often combined with targeted agents. Notably, the FOLFOXIRI plus bevacizumab regimen has demonstrated significant survival benefits, albeit with a higher incidence of adverse events (6). Emerging immunotherapies, such as those utilizing lipopolysaccharide-targeted fusion proteins and nanoparticle systems, show potential for enhanced efficacy but require further validation regarding their safety profiles (7). TAE/TACE is a local control approach for metastatic liver cancer that improves both response and survival rates (8). Other local treatments include

Correspondence to: Dr Guohua Huang, High-Intensity Focused Ultrasound Treatment Center, Suining Central Hospital, 127 West Desheng Road, Chuanshan, Suining, Sichuan 629000, P.R. China
E-mail: hghyyh@hotmail.com

*Contributed equally

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RFA and MWA, which can decrease tumor size, alleviate pain and improve survival rates. However, their effectiveness is limited by tumor size and location; larger tumors or those near major hepatic vessels are not suitable for RFA or MWA therapy (9).

HIFU has emerged as a powerful, non-invasive and non-ionizing technique for the targeted ablation of tumors. Guided by ultrasound or magnetic resonance imaging (MRI), HIFU enables precise ablation of lesions, including those adjacent to major hepatic vessels, without causing harm to them (10). The most extensively studied therapeutic application of HIFU is thermal tissue ablation, which has demonstrated both palliative and curative potential (11). Over the past two decades, a growing body of preclinical and clinical literature has emerged in support of the capacity of HIFU to enhance nascent antitumor immune responses and to potentiate the effects of cancer immunotherapies (for example, checkpoint inhibitors) through mechanisms such as immune modulation and drug delivery (12-14).

Case report

A 78-year-old woman was admitted to Suining Central Hospital (Suining, China) in June 2013 presenting with repeated bloody stools for >1 month that had worsened 1 day prior to admission. An abdominal CT scan upon admission revealed wall thickening at the rectosigmoid junction and enlargement of the perirectal and bilateral inguinal lymph nodes, raising suspicion of a malignant tumor (Fig. 1A and B). The medical team recommended a colonoscopy for further diagnostic clarification. After being informed of the risks and benefits of the procedure, the patient declined colonoscopy and requested direct surgical intervention. Following a multidisciplinary team discussion, it was concluded that the probability of colon cancer was high and that proceeding directly to surgical exploration was appropriate given the patient's refusal of a colonoscopy. The patient underwent laparoscopic radical surgery for rectal cancer under general anesthesia 2 days after admission. Tissues were fixed in 10% neutral buffered formalin at 15-25˚C for 12-24 h and then sectioned to 4-μm thick. Hematoxylin and eosin staining was used at 15-25˚C for 45 min, and the results were assessed under an Olympus BX43 optical microscope (Olympus Corporation). The postoperative pathological diagnosis confirmed a moderately to well-differentiated ulcerative adenocarcinoma (Fig. 1C), but the patient subsequently declined adjuvant chemotherapy. A follow-up abdominal CT scan 3 months after surgery demonstrated multiple liver nodules, suggesting the presence of metastatic tumors (Fig. 2).

As a standard approach for multiple small lesions, systemic chemotherapy was initiated 3 months after surgery, using the FOLFOX regimen (100 mg oxaliplatin by intravenous infusion on day 1; 200 mg calcium folinate by intravenous infusion on days 1-2; 500 mg fluorouracil by intravenous bolus on day 1, followed by 1,500 mg via continuous intravenous infusion over 44 h). However, the treatment was discontinued due to poor patient tolerance. A multidisciplinary consultation then recommended the use of RFA. However, the pre-procedural assessment identified the following notable challenges for RFA: The lesion beneath the liver capsule in the right lobe of the liver was relatively superficial, which could potentially lead to incomplete coverage by the radiofrequency probe and impact treatment efficacy; the lesion adjacent to the right portal vein posed a heightened risk for RFA due to its proximity to major blood vessels; and the lesion at the apex of the right lobe was too deep for adequate radiofrequency coverage.

A total of 5 days after the initial chemotherapy treatment, the patient was admitted to the in the Department of Hepatobiliary Surgery and underwent RFA with a concurrent biopsy of the left hepatic lobe lesion. The postoperative pathology, performed as aforementioned, confirmed liver metastasis of colorectal cancer. The cells were arranged in irregular glandular structures with infiltrative growth, and the nuclei were enlarged, with prominent nucleoli (Fig. 3A). The patient developed abdominal pain and a fever following the operation. A CT scan 1 week after RFA revealed signs of infection (Fig. 3B and C), which recovered after antibiotic treatment. In October 2013, the chemotherapy regimen was switched to XELOX (1,500 mg capecitabine orally twice daily on days 1-14; 180 mg oxaliplatin by intravenous infusion on day 1), followed by TACE 8 days later, targeting the metastatic lesions in the right hepatic lobe. A contrast-enhanced CT scan conducted 10 days post-TACE showed no significant reduction in the size of the three lesions in the right hepatic lobe compared with the size in the images taken before the procedure, with persistent mild enhancement (Fig. 4).

Due to the presence of multiple residual lesions in the right lobe of the liver, particularly one adjacent to the portal vein and the surrounding major blood vessels, RFA therapy was deemed inappropriate. Furthermore, the patient declined further RFA treatment due to the infection that occurred following the previous RFA procedure. Therefore, in November 2013, the patient underwent HIFU ablation for the residual lesions in the right lobe of the liver. This was followed by three cycles of the XELOX regimen, starting 8 days later. A follow-up CT scan conducted at 1 month post-HIFU showed complete resolution of the lesions beneath the liver capsule and adjacent to the portal vein in the right lobe, with no enhancement observed in the lesion at the apex of the right lobe (Fig. 5).

After the patient completed a total of six cycles of XELOX chemotherapy, a CT scan at the end of January 2014 confirmed the disappearance of the lesion at the apex of the right lobe (Fig. 6). A cluster of low-density masses was observed in the left lobe, with partial enhancement of some lesions (Fig. 7A). Approximately 1 month later, HIFU treatment was performed under general anesthesia for the lesion in the left lobe (the lesion that had previously been treated with RFA). A subsequent CT scan performed at the end of May 2014 showed the clustered low-density mass in the left lobe with no evident enhancement (Fig. 7B).

Tumor marker levels, including carcinoembryonic antigen (CEA), α-fetoprotein (AFP), carbohydrate antigen (CA)12-5, CA15-3, and CA19-9, were monitored every 1-3 months from June 2013 to February 2014, and every 6-12 months thereafter until July 2015. An analysis of the timeline of changes in the patient's CEA levels, alongside

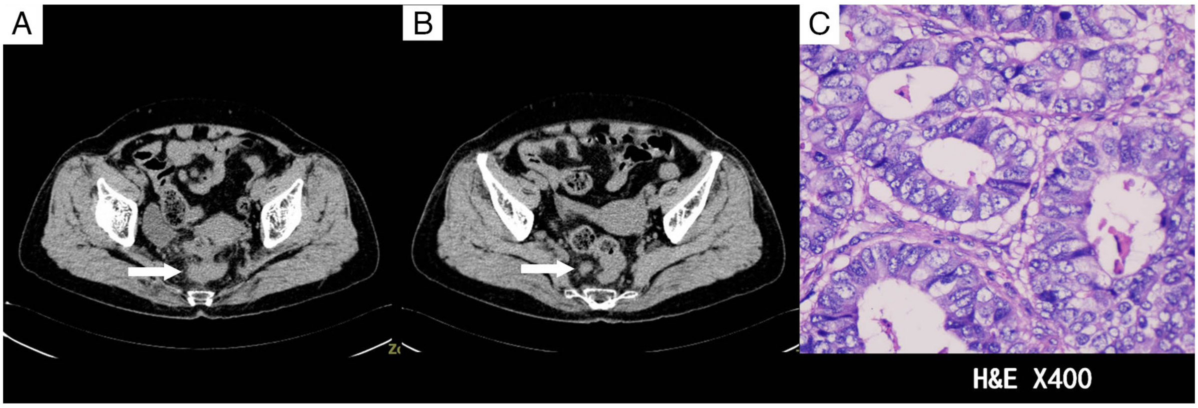

Figure 1. Preoperative computed tomography scan and postoperative pathological. (A) Thickening of the intestinal wall at the junction of the sigmoid colon and rectum (arrow). (B) Enlarged perirectal lymph nodes (arrow). (C) Postoperative pathology reveals moderately to well-differentiated ulcerative adenocarcinoma (H&E staining; x400 magnification). H&E, hematoxylin and eosin.

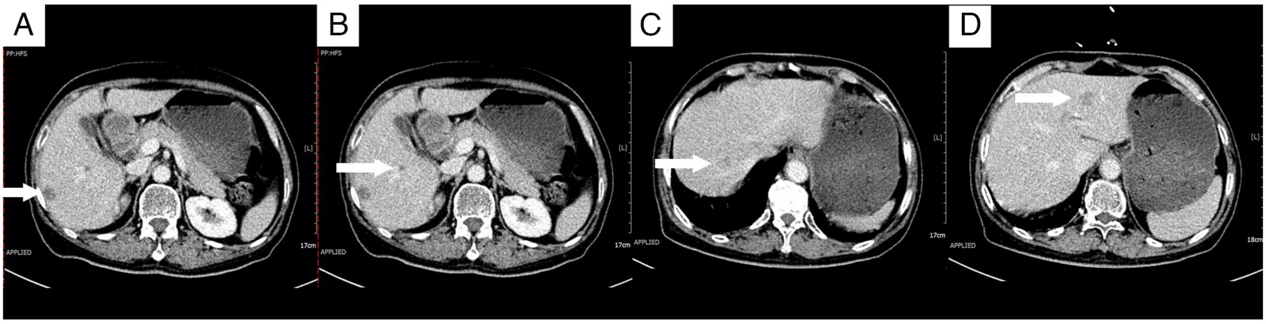

Figure 2. Enhanced computed tomography scans 3 months after surgery. (A) A 14x11-mm lesion beneath the liver capsule in the right lobe (arrow). (B) An 8x7-mm lesion adjacent to the right portal vein (arrow). (C) A 17x14-mm lesion at the apex of the right lobe (arrow). (D) A 15x15-mm lesion in the left lobe (arrow).

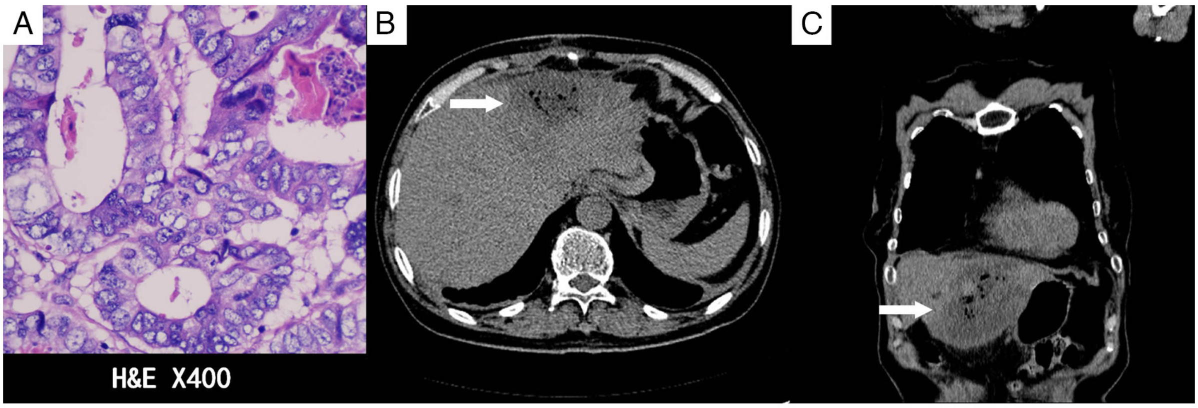

Figure 3. Pathological and computed tomography imaging in the left lobe of the liver following radiofrequency ablation. (A) Histopathology of the lesion in the left lobe of the liver reveals that the cells are arranged in irregular glandular structures with infiltrative growth. The nuclei are enlarged and nucleoli are prominent. The pathological diagnosis is metastatic colorectal carcinoma to the liver. (B and C) A clustered heterogeneous density shadow can be seen in the left lobe of the liver, with gas density shadows within it (arrow). The adjacent greater omentum is thickened. The results suggest infection.

the diagnosis and treatment of rectal cancer liver metastases, revealed that the main lesion was located in the left lobe of the liver. Before HIFU treatment for the left liver lesion, CEA levels remained elevated above the normal range. However, following HIFU treatment, CEA levels returned to a normal level (Fig. 8). AFP, CA12-5, CA15-3 and CA19-9 levels remained within the normal range throughout the disease course. Contrast-enhanced CT scans over the 2 years following HIFU therapy showed no evidence of tumor recurrence (Fig. 9). Beginning in the sixth year after surgery, annual contrast-enhanced MRI examinations were performed, facilitated by upgrades in the hospital's imaging equipment. These MRI studies confirmed the absence of tumor recurrence in the right hepatic lobe. In the left hepatic

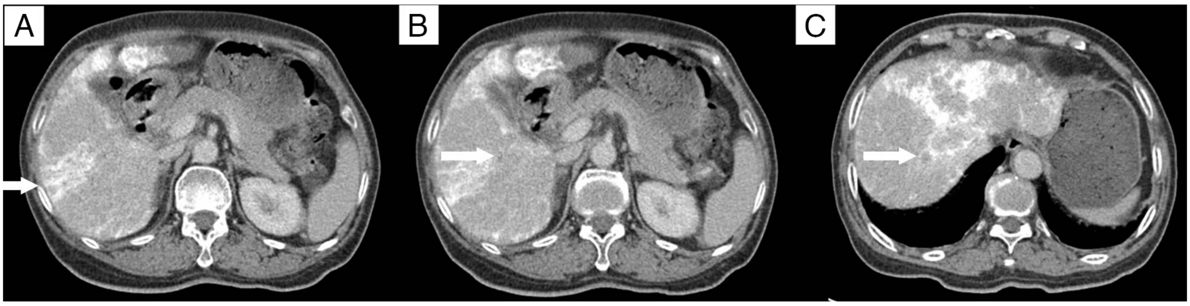

Figure 4. Enhanced computed tomography scans following transarterial chemoembolization. (A) The lesion beneath the liver capsule in the right lobe shows no significant reduction in size compared with before, with mild enhancement (arrow). (B) The lesion adjacent to the portal vein in the right lobe still shows mild enhancement (arrow). (C) The lesion at the apex of the right lobe of the liver shows no significant reduction in size compared with before, with mild enhancement (arrow).

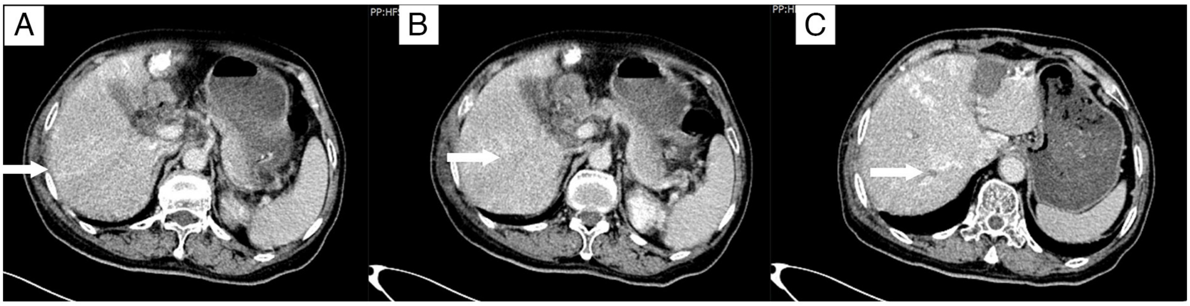

Figure 5. Enhanced computed tomography scans 3 weeks after high-intensity focused ultrasound combined with chemotherapy. (A) The lesion beneath the liver capsule in the right lobe disappeared (arrow). (B) The lesion adjacent to the portal vein in the right lobe disappeared (arrow). (C) No evident enhancement can be observed in the lesion at the apex of the right lobe (arrow).

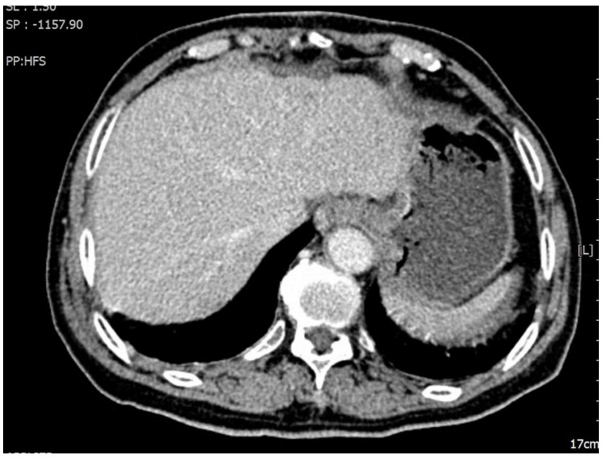

Figure 6. Enhanced computed tomography scan after chemotherapy on day 2. No evidence of the lesion at the apex of the right lobe of the liver can be observed.

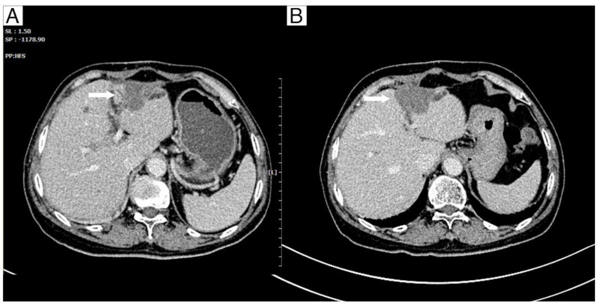

Figure 7. Left liver lesion: Pre- vs. post-HIFU comparison. (A) Pre-HIFU enhanced computed tomography scan demonstrating a clustered low-density mass with streaky low-density components in the left lobe of the liver, showing mild enhancement and attenuation in the venous phase (arrow). (B) At 3 months post-HIFU, a low-density mass can be observed in the left lobe of the liver, without evident enhancement (arrow). HIFU, high-intensity focused ultrasound.

lobe, only residual scar tissue was observed, with no signs of tumor recurrence (Fig. 10).

When reviewing the patient's entire treatment course (Fig. 11), liver metastases were detected during the 3-month postoperative follow-up after colorectal cancer surgery. An integrated approach combining systemic therapy and local treatment was adopted. Early interventions such as RFA and TACE failed to effectively control the local lesions. Subsequently, focused ultrasound ablation achieved excellent local therapeutic outcomes. Over a long-term follow-up period of 10 years, with annual re-examinations, no tumor recurrence was observed, indicating a complete cure.

Discussion

Compared with other types of metastatic liver cancer, CRLM usually presents with a more favorable prognosis, justifying the exploration of more intensive treatment strategies. HIFU treatment can improve the penetration of chemotherapy drugs into tumor tissues by enhancing the local blood supply through

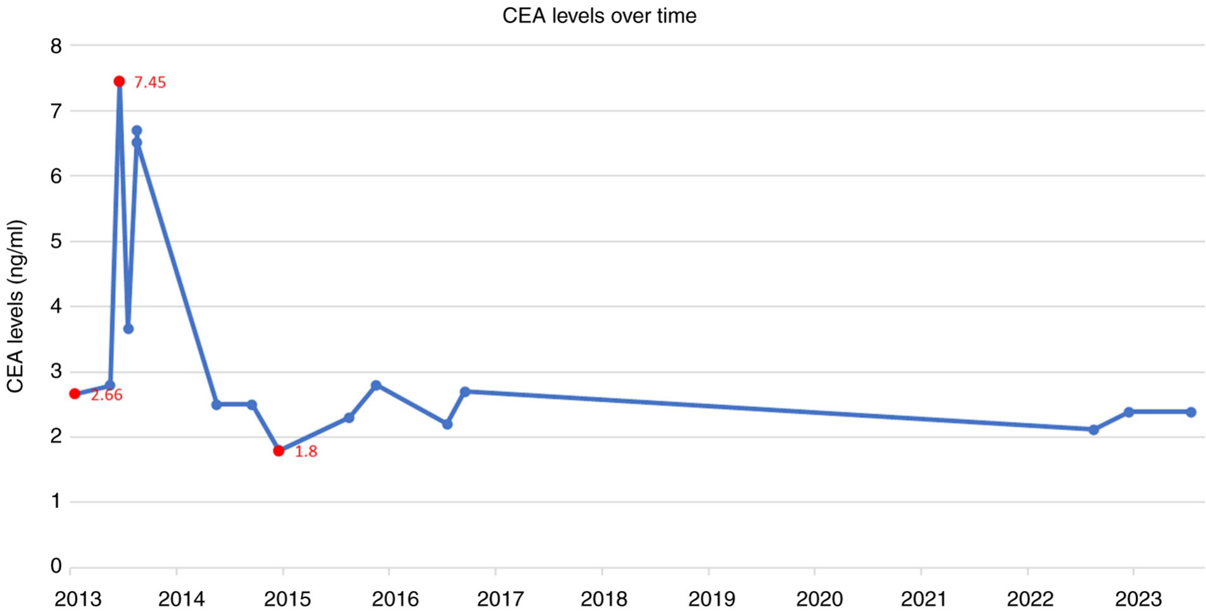

Figure 8. Timeline of changes in CEA levels (normal range, 0-5 ng/ml). The CEA level was 2.66 ng/ml before radiofrequency ablation and chemotherapy, peaked at 7.45 ng/ml during treatment, decreased to 1.8 ng/ml after combined therapy, and then remained within the normal range for an extended period. CEA, carcinoembryonic antigen.

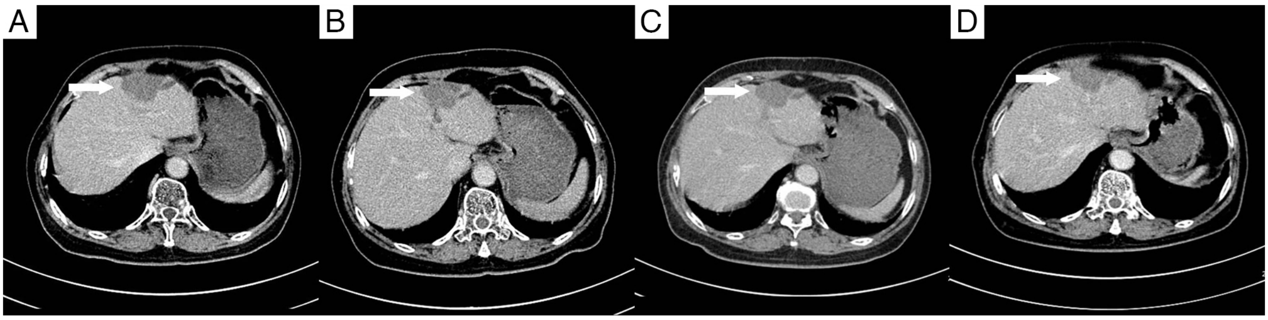

Figure 9. Enhanced computed tomography scan of the lesion in the left lobe of the liver post-HIFU. (A) The lesion measured 38x33 mm at 3 months post-HIFU (arrow). (B) The lesion measured 37x33 mm at 6 months post-HIFU (arrow). (C) The lesion measured 35x32 mm at 18 months post-HIFU (arrow). (D) The lesion measured 33x30 mm at 2 years post-HIFU (arrow). HIFU, high-intensity focused ultrasound.

local thermal effects, thereby increasing chemosensitivity. In a previous single-center retrospective study (15), a total of 523 patients with unresectable pancreatic ductal adenocarcinoma (PDAC) were recruited. Of these patients, 347 received HIFU combined with gemcitabine (GEM), which was administered through either regional arterial chemotherapy or systemic chemotherapy. The remaining patients received GEM alone. The median overall survival time for the patients receiving HIFU combined with GEM therapy was 7.4 months, compared with 6.0 months for those receiving GEM alone (P=0.002). The 6-month, 10-month, 1-year and 2-year survival rates for the HIFU + GEM and GEM alone groups were 66.3 vs. 47.5% (P<0.0001), 31.12 vs. 15.9% (P<0.0001), 21.32 vs. 13.64% (P=0.033) and 2.89 vs. 2.27% (P=0.78), respectively. These findings suggested that the combination of HIFU and GEM improves overall survival compared with standard chemotherapy alone in patients with PDAC (15). However, the efficacy of tumor therapy can be hindered by the tumor-specific hypoxic microenvironment, high osmotic pressure and vascular dysfunction. The hypoxic environment not only promotes tumor formation and progression, but also contributes to chemoresistance (16,17). Considering the unique hypoxic environment inside tumors, a novel bio-targeted synergistic system comprising genetically engineered bacteria and multifunctional nanoparticles can overcome the limitations of HIFU in terms of targeting ability and single-image monitoring mode. This synergistic approach has shown promise in improving the efficacy and safety of focused ultrasound ablation surgery (18). Other studies have highlighted that local ablation may stimulate immune responses, which will contribute to tumor control (19,20). It has been proposed that, by identifying tumor antigen exposure, thermal ablation of tumors may trigger an '*in vivo* vaccination', thereby stimulating the production of antibodies and promoting the eradication of the local tumor and control of distant metastasis while establishing antitumor immune memory, a phenomenon referred to as 'antitumor induced immunity' (21). HIFU can be combined with other interventional treatment methods, such as TACE, to achieve a synergistic effect. While TACE aims to devascularize tumors by embolizing their feeding arteries,

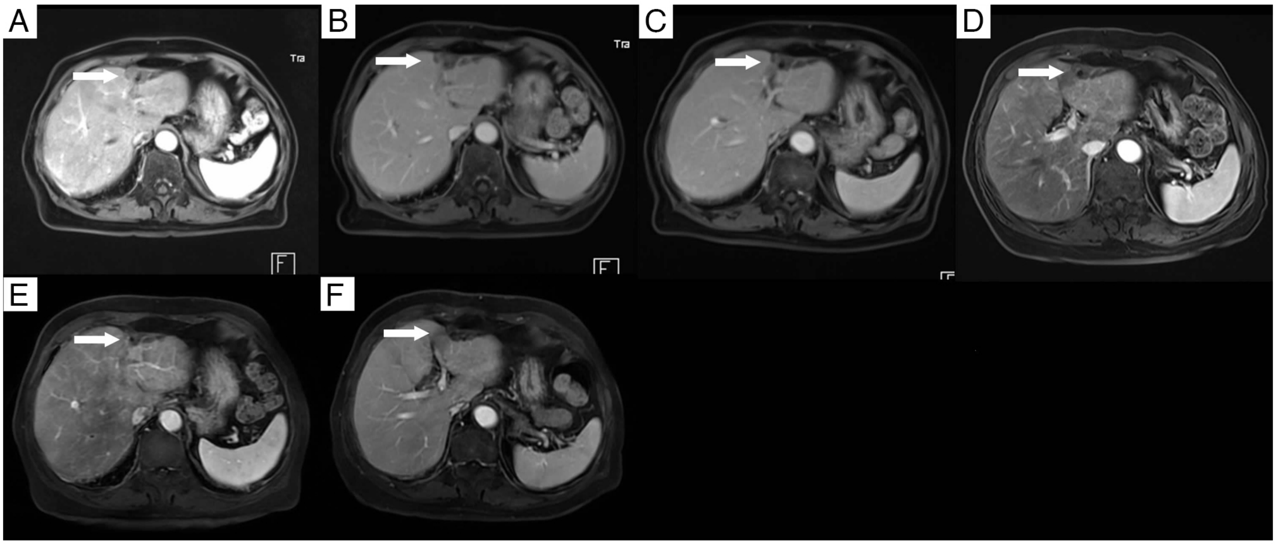

Figure 10. Follow-up by enhanced magnetic resonance imaging. (A) The lesion measured 30x19 mm at 6 years post-HIFU. At (B) 7, (C) 8, (D) 9, (E) 10 and (F) 11 years post-high-intensity focused ultrasound, the left hepatic lobe shows stable residual scar tissue without signs of recurrence.

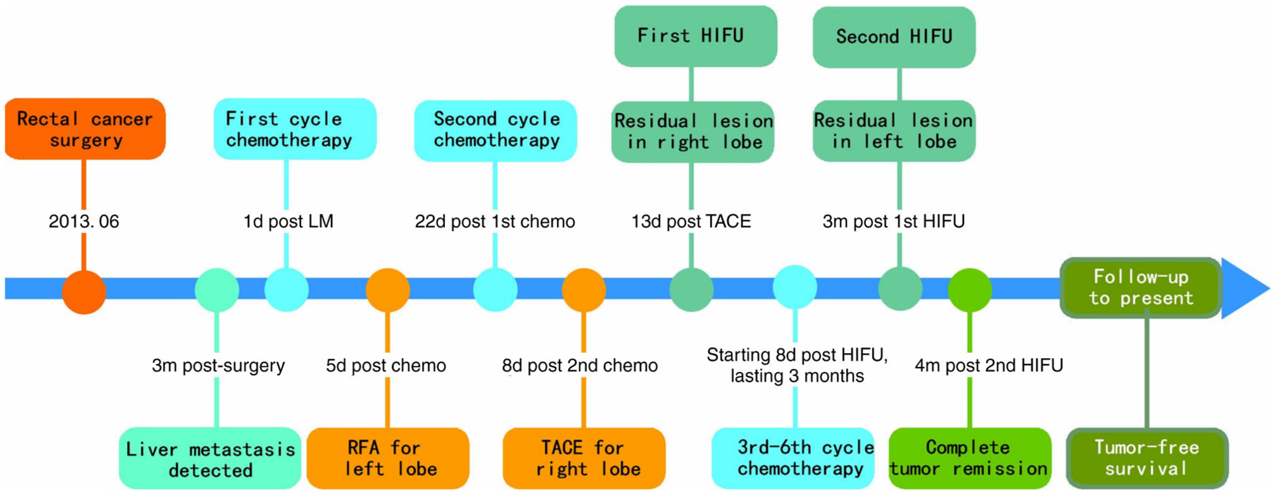

Figure 11. Timeline of the patient's clinical course. d, days; m, months; LM, liver metastasis; chemo, chemotherapy; TACE, transarterial chemoembolization; HIFU, high-intensity focused ultrasound; RFA, radiofrequency ablation.

its efficacy can be limited by alternate blood supplies or the formation of collateral circulation, often leading to incomplete necrosis. In such cases, subsequent HIFU ablation can target these residual lesions, achieving local tumor control and improving treatment efficacy (22).

The most common pathological type of colon cancer is adenocarcinoma, accounting for >90% of all cases. Adenocarcinomas can be further classified into various subtypes, including well-differentiated, moderately differentiated and poorly differentiated adenocarcinomas, among which the well-differentiated type generally carries the most favorable prognosis (23). In the treatment of colon cancer, systemic chemotherapy is crucial in addition to surgery. In the present case, although the pathological type of the patient's colon cancer was well-differentiated adenocarcinoma, the patient declined chemotherapy after surgery, which led to the rapid development of liver metastases. The initial treatment involved RFA for lesions in the left hepatic lobe and TACE for lesions in the right hepatic lobe, combined with two cycles of chemotherapy. However, following these treatments, the patient failed to achieve complete tumor remission and experienced complications. Subsequently, the patient underwent HIFU as a local therapy while maintaining chemotherapy treatment, which ultimately resulted in complete tumor remission. It is notable that throughout the treatment course, the patient received a total of six cycles of XELOX chemotherapy, which played a crucial role in achieving the favorable final outcome. This also suggests that the combination of HIFU with chemotherapy may produce synergistic effects, thereby enhancing the efficacy of the chemotherapy. For irregularly shaped tumors, HIFU enables three-dimensional conformal complete ablation, offering advantages over local ablation methods such as RFA or MWA, while also demonstrating a superior safety profile. In treating multiple small tumors, HIFU allows for greater precision under real-time monitoring. For lesions adjacent to the diaphragm or major blood vessels, HIFU can achieve complete tumor ablation without damaging these critical structures (24). With the application of new technologies and AI assistance, HIFU treatment will become even more precise and efficient in the future (25,26). The absence of tumor recurrence during the long-term follow-up in the present case suggests that HIFU may contribute to stimulating a systemic antitumor immune response. The successful outcome of this integrated treatment strategy provides new insights and directions for future cancer therapy. Nevertheless, more rigorous, prospective and comparative studies are needed to definitively establish the role of HIFU in the management of CRLM.

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Availability of data and materials

The data generated in the present study are included in the figures and/or tables of this article.

Authors' contributions

YY, HZ and YS contributed equally to this work. YY designed the study, provided recommendations for patient treatment plans, and wrote the paper. HZ acquired patient imaging and pathological images, and was responsible for data collection, organization, and analysis, as well as contributing to the paper writing. YS performed the HIFU treatment and follow-up of patients, and participated in paper writing. FY conducted the chemotherapy and follow-up of patients. DZ and YL assisted in the HIFU treatment and follow-up of patients. GH is the corresponding author and was responsible for designing the study, providing recommendations for patient treatment plans, performing HIFU treatment for patients, contributing to paper writing and overseeing the overall work of the research team. All authors have read and approved the final manuscript. YY, HZ, YS, FY, DZ, YL and GH confirm the authenticity of all the raw data.

Ethics approval and consent to participate

This case report is retrospective in nature does not harm the interests of the patients and ensures no disclosure of patient information. The requirement for ethical approval was waived by the Ethics Committee of Suining Central Hospital (Suining, China).

Patient consent for publication

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (Ethics Committee of Suining Central Hospital) and with the Helsinki Declaration. Written informed consent was obtained from the patient for being included in the study and for the publication of this case report and any accompanying images.

Competing interests

The authors declare that they have no competing interests.

Use of artificial intelligence tools

During the preparation of this work, AI tools were used to improve the readability and language of the manuscript or to generate images, and subsequently, the authors revised and edited the content produced by the AI tools as necessary, taking full responsibility for the ultimate content of the present manuscript.

References

1. Engstrand J, Nilsson H, Stromberg C, Jonas E and Freedman J: Colorectal cancer liver metastases - a population-based study on incidence, management and survival. BMC Cancer 18: 78, 2018.
2. Wang Y, Zhong X, He X, Hu Z, Huang H, Chen J, Chen K, Zhao S, Wei P and Li D: Liver metastasis from colorectal cancer: Pathogenetic development, immune landscape of the tumour microenvironment and therapeutic approaches. J Exp Clin Cancer Res 42: 177, 2023.
3. Sathe A, Mason K, Grimes SM, Zhou Z, Lau BT, Bai X, Su A, Tan X, Lee H, Suarez CJ, *et al*: Colorectal cancer metastases in the liver establish immunosuppressive spatial networking between tumor-associated SPP1+ macrophages and fibroblasts. Clin Cancer Res 29: 244-260, 2023.
4. Walcher L, Kistenmacher AK, Suo H, Kitte R, Dluczek S, Strauß A, Blaudszun AR, Yevsa T, Fricke S and Kossatz-Boehlert U: Cancer stem cells-origins and biomarkers: Perspectives for targeted personalized therapies. Front Immunol 11: 1280, 2020.
5. Chinese College of Surgeons; Section of Gastrointestinal Surgery, Branch of Surgery, Chinese Medical Association; Section of Colorectal Surgery, Branch of Surgery, Chinese Medical Association; Colorectal Cancer Professional Committee, Chinese Anti-Cancer Association; Colorectal Cancer Professional Committee, *et al*: China guideline for diagnosis and comprehensive treatment of colorectal liver metastases (version 2023). Zhonghua Wei Chang Wai Ke Za Zhi 26: 1-15, 2023 (In Chinese).
6. Cremolini C, Antoniotti C, Stein A, Bendell J, Gruenberger T, Rossini D, Masi G, Ongaro E, Hurwitz H, Falcone A, *et al*: Individual patient data meta-analysis of FOLFOXIRI plus bevacizumab versus doublets plus bevacizumab as initial therapy of unresectable metastatic colorectal cancer. J Clin Oncol: Aug 20, 2020 (Epub ahead of print).
7. Song W, Tiruthani K, Wang Y, Shen L, Hu M, Dorosheva O, Qiu K, Kinghorn KA, Liu R and Huang L: Trapping of lipopolysaccharide to promote immunotherapy against colorectal cancer and attenuate liver metastasis. Adv Mater 30: e1805007, 2018.
8. Weber M, Lam M, Chiesa C, Konijnenberg M, Cremonesi M, Flamen P, Gnesin S, Bodei L, Kracmerova T, Luster M, *et al*: EANM procedure guideline for the treatment of liver cancer and liver metastases with intra-arterial radioactive compounds. Eur J Nucl Med Mol Imaging 49: 1682-1699, 2022.
9. Mimmo A, Pegoraro F, Rhaiem R, Montalti R, Donadieu A, Tashkandi A, Al-Sadairi AR, Kianmanesh R and Piardi T: Microwave ablation for colorectal liver metastases: A systematic review and pooled oncological analyses. Cancers (Basel) 14: 1305, 2022.
10. Orsi F and Varano G: Minimal invasive treatments for liver malignancies. Ultrason Sonochem 27: 659-667, 2015.
11. De Maio A, Alfieri G, Mattone M, Ghanouni P and Napoli A: High-Intensity focused ultrasound surgery for tumor ablation: A review of current applications. Radiol Imaging Cancer 6: e230074, 2024.
12. Padilla F, Foley J, Timbie K, Bullock TNJ and Sheybani ND: Guidelines for immunological analyses following focused ultrasound treatment. J Immunother Cancer 11: e007455, 2023.

13. Sheybani ND, Batts AJ, Mathew AS, Thim EA and Price RJ: Focused ultrasound hyperthermia augments release of glioma-derived extracellular vesicles with differential immunomodulatory capacity. Theranostics 10: 7436-7447, 2020.
14. Ashar H, Singh A, Kishore D, Neel T, More S, Liu C, Dugat D and Ranjan A: Enabling chemo-immunotherapy with HIFU in canine cancer patients. Ann Biomed Eng 52: 1859-1872, 2024.
15. Ning Z, Xie J, Chen Q, Zhang C, Xu L, Song L and Meng Z: HIFU is safe, effective, and feasible in pancreatic cancer patients: A monocentric retrospective study among 523 patients. Onco Targets Ther 12: 1021-1029, 2019.
16. Li K, Gong Y, Qiu D, Tang H, Zhang J, Yuan Z, Huang Y, Qin Y, Ye L and Yang Y: Hyperbaric oxygen facilitates teniposide-induced cGAS-STING activation to enhance the antitumor efficacy of PD-1 antibody in HCC. J Immunother Cancer 10: e004006, 2022.
17. Zhu XH, Du JX, Zhu D, Ren SZ, Chen K and Zhu HL: Recent research on methods to improve tumor hypoxia environment. Oxid Med Cell Longev 2020: 5721258, 2020.
18. Wang Y, Tang Y, Du Y, Lin L, Zhang Z, Ou X, Chen S, Wang Q and Zou J: Genetically engineered bacteria-mediated multi-functional nanoparticles for synergistic tumor-targeting therapy. Acta Biomater 150: 337-352, 2022.
19. Mauri G, Nicosia L, Xu Z, Di Pietro S, Monfardini L, Bonomo G, Varano GM, Prada F, Della Vigna P and Orsi F: Focused ultrasound: tumour ablation and its potential to enhance immunological therapy to cancer. Br J Radiol 91: 20170641, 2018.
20. Ran LF, Xie XP, Xia JZ, Xie FL, Fan YM and Wu F: Specific antitumour immunity of HIFU-activated cytotoxic T lymphocytes after adoptive transfusion in tumour-bearing mice. Int J Hyperthermia 32: 204-210, 2016.
21. Mauri G, Orsi F and Sconfienza LM: Systemic effects of local tumor ablation: Oncogenesis and antitumor induced immunity. Radiology 283: 923, 2017.
22. You Y, Wang Z, Ran H, Zheng Y, Wang D, Xu J, Wang Z, Chen Y and Li P: Nanoparticle-enhanced synergistic HIFU ablation and transarterial chemoembolization for efficient cancer therapy. Nanoscale 8: 4324-4339, 2016.
23. Su F, Li J, Zhao X, Wang B, Hu Y, Sun Y and Ji J: Interpretable tumor differentiation grade and microsatellite instability recognition in gastric cancer using deep learning. Lab Invest 102: 641-649, 2022.
24. Zhang X, Landgraf L, Bailis N, Unger M, Jochimsen TH and Melzer A: Image-guided high-intensity focused ultrasound, a novel application for interventional nuclear medicine? J Nucl Med 62: 1181-1188, 2021.
25. Luan S, Ji Y, Liu Y, Zhu L, Zhao H, Zhou H, Li K, Zhu W and Zhu B: AI-powered ultrasonic thermometry for HIFU therapy in deep organ. Ultrason Sonochem 111: 107154, 2024.
26. Yang K, Li Q, Xu J, Tang MX, Wang Z, Tsui PH and Zhou X: Frequency-domain robust PCA for real-time monitoring of HIFU treatment. IEEE Trans Med Imaging 43: 3001-3012, 2024.