Received: 24 August 2025 / Accepted: 30 November 2025 / Published online: 30 December 2025

DOI 10.34689/SH.2025.27.6.020

UDC 618.14-006.36-073.756.8

MAGNETIC RESONANCE-GUIDED FOCUSED ULTRASOUND IN GYNECOLOGY: FUNDAMENTALS AND SAFETY, POTENTIAL IMPACT ON FERTILITY AND PREGNANCY OUTCOMES. LITERATURE REVIEW

Malika M. Meirmanova[1], https://orcid.org/0000-0002-0435-4389
Aizhan A. Abiltayeva[2], https://orcid.org/0000-0002-0172-9202
Askar M. Abiltayev[3], https://orcid.org/0000-0003-4127-2347
Ayan O. Myssaev[4], https://orcid.org/0000-0001-7332-4856;
Gaukhar M. Myssayeva[5], https://orcid.org/0000-0002-0839-8581;
Yernar K. Kairkhanov[3], https://orcid.org/0000-0001-7289-3272
Rustem S. Kazangapov[3], https://orcid.org/0000-0003-1513-7432
Zuhra S. Siyazbekova[2], https://orcid.org/0000-0001-9244-7085

[1] East Kazakhstan Multidisciplinary Center of Oncology and Surgery, Ust-Kamenogorsk, Semey;
[2] NCJSC "Semey Medical University", Semey, Republic of Kazakhstan;
[3] NCJSC "Semey Medical University", Pavlodar Branch, Pavlodar, Republic of Kazakhstan;
[4] NCJSC "Astana Medical University", Astana, Republic of Kazakhstan;
[5] LPP "MedcenterUltraline", Astana, Republic of Kazakhstan.

Abstract

Background and Objective. Uterine fibroids are the most common benign tumor in women of reproductive age (20-40%). Given the trend toward delayed childbearing and the high frequency of hysterectomies, organ-preserving, minimally invasive methods such as Magnetic Resonance-Guided Focused Ultrasound (MRgFUS) ablation are becoming highly relevant. The objective of this review is to study and systematize publications on the use of MRgFUS technology, focusing on its impact on fertility and reproductive outcomes.

Methods. A comprehensive and systematic search of scientific literature from the last 10-20 years was conducted in databases (PubMed, Medline, Google Scholar, etc.) using keywords including "MRgFUS," "uterine fibroids," "fertility," and "HIFU." Out of 1247 identified studies, 46 of the most relevant publications meeting strict criteria were included in the final review.

Results. MRgFUS ablation is a safe and effective method based on the thermal coagulative necrosis of myoma tissue. Efficacy depends on the histological structure of the fibroid (hypointense on T2WI is preferred) and careful patient selection. Live birth rates after MRgFUS are encouraging, ranging from 41% to over 70%. The miscarriage rate (8-28%) is comparable to that following other conservative interventions and is lower than after Uterine Artery Embolization. MRgFUS preserves uterine integrity and does not increase the risk of uterine rupture or placental abnormalities. However, the reintervention rate may be higher than after myomectomy.

Conclusions. MRgFUS is a promising, minimally invasive option for fertility preservation in women with uterine fibroids. Reproductive outcomes are comparable to other conservative methods. Treatment success critically depends on strict patient selection and technical aspects. Large prospective randomized studies are necessary to clarify long-term reproductive outcomes and optimize protocols, especially in combination with Assisted Reproductive Technology.

Keywords: *radiological diagnostics, focused ultrasound, MRI, ablation, uterine fibroids, uterine adenomyosis, fertility, pregnancy.*

For citation:

Meirmanova M.M., Abiltayeva A.A., Abiltayev A.M., Myssaev A.O., Myssayeva G.M., Kairkhanov Ye.K., Kazangapov R.S., Siyazbekova Z.S. Magnetic resonance-guided focused ultrasound in gynecology: fundamentals and safety, potential impact on fertility and pregnancy outcomes. Literature review // *Nauka i Zdravookhranenie* [Science & Healthcare]. 2025. Vol.27 (6), pp. 185-192. *doi 10.34689/SH.2025.27.6.020*

Резюме

ПРИМЕНЕНИЕ ФОКУСИРОВАННОГО УЛЬТРАЗВУКА ПОД КОНТРОЛЕМ МАГНИТНО-РЕЗОНАНСНОЙ ТОМОГРАФИИ В ГИНЕКОЛОГИИ: ОСНОВЫ И БЕЗОПАСНОСТЬ, ПОТЕНЦИАЛЬНОЕ ВЛИЯНИЕ НА ФЕРТИЛЬНОСТЬ И ИСХОД БЕРЕМЕННОСТИ. ОБЗОР ЛИТЕРАТУРЫ

Малика М. Мейрманова[1], https://orcid.org/0000-0002-0435-4389
Айжан А. Абильтаева[2], https://orcid.org/0000-0002-0172-9202
Аскар М. Абильтаев[3], https://orcid.org/0000-0003-4127-2347
Аян О. Мысаев[4], https://orcid.org/0000-0001-7332-4856;
Гаухар М. Мысаева[5], https://orcid.org/0000-0002-0839-8581
Ернар К. Каирханов[3], https://orcid.org/0000-0001-7289-3272
Рустем С. Казангапов[3], https://orcid.org/0000-0003-1513-7432
Зухра С. Сиязбекова[2], https://orcid.org/0000-0001-9244-7085

[1] ВКО КГП на ПХВ «Многопрофильный центр онкологии и хирургии», Республика Казахстан;
[2] НАО «Медицинский Университет города Семей» г. Семей, Республика Казахстан;
[3] НАО «Медицинский Университет города Семей» Павлодарский Филиал, Республика Казахстан;
[4] НАО «Медицинский Университет города Астана», г. Астана, Республика Казахстан;
[5] ТОО «Медцентр Ultraline», г. Астана, Республика Казахстан.

Цель исследования. Миома матки - наиболее распространенная доброкачественная опухоль у женщин репродуктивного возраста (20-40%). Учитывая тенденцию к откладыванию деторождения и высокую частоту гистерэктомий, особую актуальность приобретают органосохраняющие, малоинвазивные методы, такие как абляция фокусированным ультразвуком под контролем МРТ (ФУЗ МРТ). Цель обзора - изучить и систематизировать публикации об использовании технологии ФУЗ МРТ, сфокусировавшись на ее влиянии на фертильность и репродуктивные результаты.

Методы. Проведен комплексный и систематический поиск научной литературы за последние 10-20 лет в базах данных (PubMed, Medline, Google Scholar и др.) с использованием ключевых слов, включая “MRgFUS”, “uterine fibroids”, “fertility”, и «ФУЗ МРТ». Из 1247 идентифицированных работ в финальный обзор были включены 46 наиболее релевантных публикаций, соответствующих строгим критериям.

Результаты. ФУЗ МРТ -абляция является безопасным и эффективным методом, основанным на термическом коагуляционном некрозе миоматозной ткани. Эффективность зависит от гистологической структуры миомы (предпочтительны гипоинтенсивные на T2WI) и тщательному отбору пациентов. Показатели живорожденияпосле MRgFUS обнадеживают, варьируясь от 41% до более 70%. Частота выкидышей (8-28%) сопоставима с таковой после других консервативных вмешательств и ниже, чем после эмболизации маточных артерий. ФУЗ МРТ сохраняет целостность матки и не повышает риск разрыва матки или аномалий плацентации. Однако, частота повторных вмешательств может быть выше, чем после миомэктомии.

Выводы. ФУЗ МРТ является перспективной, минимально инвазивной опцией для сохранения фертильности у женщин с миомой матки. Репродуктивные исходы сопоставимы с другими консервативными методами. Успех лечения критически зависит от строгого отбора пациентов и технических аспектов. Необходимы крупные проспективные рандомизированные исследования для уточнения долгосрочных репродуктивных результатов и оптимизации протоколов, особенно в сочетании с вспомогательными репродуктивными технологиями (ВРТ).

Ключевые слова: *лучевая диагностика, фокусированный ультразвук, МРТ, абляция, миома матки, аденомиоз матки, фертильность, беременность.*

Для цитирования:

Мейрманова М.М., Абильтаева А.А., Абильтаев А.М., Мысаев А.О., Мысаева Г.М., Каирханов Е.К., Казангапов Р.С., Сиязбекова З.С. Применение фокусированного ультразвука под контролем магнитно-резонансной томографии в гинекологии: основы и безопасность, потенциальное влияние на фертильность и исход беременности. Обзор литературы // Наука и Здравоохранение. 2025. Vol.27 (6), С.185-192. *doi 10.34689/SH.2025.27.6.020*

Түйіндеме

ГИНЕКОЛОГИЯДА МАГНИТТІ-РЕЗОНАНСТЫ ТОМОГРАФИЯ БАҚЫЛАУЫМЕН ФОКУСТЕЛГЕН УЛЬТРАДЫБЫСТЫ ҚОЛДАНУ: НЕГІЗДЕРІ МЕН ҚАУІПСІЗДІГІ, ФЕРТИЛЬДІККЕ ЖӘНЕ ЖҮКТІЛІК НӘТИЖЕЛЕРІНЕ ӘСЕРІ. ӘДЕБИЕТТІК ШОЛУ.

Малика М. Мейрманова[1], https://orcid.org/0000-0002-0435-4389
Айжан А. Абильтаева[2], https://orcid.org/0000-0002-0172-9202
Аскар М. Абильтаев[3], https://orcid.org/0000-0003-4127-2347
Аян О. Мысаев[4], https://orcid.org/0000-0001-7332-4856;
Гаухар М. Мысаева[5], https://orcid.org/0000-0002-0839-8581
Ернар К. Каирханов[3], https://orcid.org/0000-0001-7289-3272
Рустем С. Казангапов[3], https://orcid.org/0000-0003-1513-7432
Зухра С. Сиязбекова[2], https://orcid.org/0000-0001-9244-7085

[1] Шығыс Қазақстан облыстық онкология және хирургиялық көпсалалы орталығы, Өскемен, Қазақстан Республикасы;
[2] КеАҚ «Семей медицина университеті», Семей қ., Қазақстан Республикасы;
[3] КеАҚ «Семей медицина университеті» Павлодар филиалы, Қазақстан Республикасы;
[4] КеАҚ «Астана медицина университеті», Астана қ., Қазақстан Республикасы;
[5] ЖШС «Медцентр Ultraline», Астана қ., Қазақстан Республикасы.

Өзектілігі мен мақсаты. Жатыр миомасы - репродуктивті жастағы әйелдер арасында жиі кездесетін қатерсіз ісіктердің ең кең таралған түрі (20-40%). Репродуктивті функцияны кейінге қалдыру үрдісін және гистерэктомияның жоғары жиілігін ескере отырып, ағзаны сақтауға бағытталған, минималды инвазивті әдістердің, соның ішінде магниттік-резонанстық томография (МРТ) бақылауымен фокустелген ультрадыбыстық абляцияның (МРТ-БФУ) клиникалық маңыздылығы артып отыр.

Шолудың мақсаты - МРТ-БФУ технологиясын қолдану жөніндегі заманауи ғылыми жарияланымдарды талдау және жүйелеу, оның фертильдікке және репродуктивті нәтижелерге ықпалын бағалау.

Әдістері. Соңғы 10-20 жыл аралығында жарық көрген ғылыми дереккөздерінде (PubMed, Medline, Google Scholar және т.б.) «MRgFUS», «uterine fibroids», «fertility» және «ФУЗ МРТ» сөздері бойынша жүйелі және кешенді әдеби іздеу жүргізілді. Анықталған 1247 мақаланың ішінен іріктеу критерийлеріне сәйкес келетін 46 зерттеу талдауға енгізілді.

Нәтижелері. МРТ-БФУ - миоматозды тінге бағытталған жоғары қарқынды ультрадыбыстық энергияның әсерінен термокоагуляциялық деструкция туындататын қауіпсіз әрі тиімді репродуктивті ағзаны сақтау әдісі. Әдістің нәтижелілігі миоманың морфологиялы құрылымына (T2WI кескіндерінде гипоинтенсивті сигналдың басым болуы) және пациентті дұрыс таңдау тактикасына тәуелді.

МРТ-БФУ-дан кейін тірі босану жиілігі оң нәтижелер көрсетеді - 41%-дан 70%-ға дейін. Түсік тастау жиілігі (8-28%) басқа консервативті араласулардан кейінгі көрсеткіштермен салыстырмалы және жатыр артериясының эмболизациясынан қарағанда төмен.

МРТ-БФУ жатырдың анатомиялық және функционалдық тұтастығын сақтайды, миометрийдің перфорациясы мен плацентарлық имплантация ақауларының даму қаупін арттырмайды. Дегенмен, қайталама араласу қажеттілігі миомэктомиядан қарағанда жоғары болуы мүмкін.

Қорытындылар. МРТ-БФУ - жатыр миомасы бар әйелдерде репродуктивті функцияны сақтау тұрғысынан перспективті, минималды инвазивті емдеу әдісі. Репродуктивті нәтижелер тиімділігі бойынша басқа репродуктивті ағзаны сақтау тәсілдерімен салыстырмалы. Емнің тиімділігі пациентті дұрыс іріктеуге және процедураның техникалық параметрлеріне тікелей байланысты.

Ұзақ мерзімді репродуктивті нәтижелерді нақтылау және емдеу хаттамаларын, әсіресе көмекші репродуктивті технологиялармен (КРТ) үйлестіруді оңтайландыру үшін ірі проспективті рандомизацияланған зерттеулер қажет.

Түйінді сөздер: *сәулелік диагностика, фокустелген ультрадыбыс, МРТ, абляция, жатыр миомасы, аденомиоз, фертильдік, жүктілік.*

Дәйексөз үшін:

Мейрманова М.М., Абильтаева А.А., Абильтаев А.М., Мысаев А.О., Мысаева Г.М., Каирханов Е.К., Казангапов Р.С., Сиязбекова З.С. Гинекологияда магнитті-резонансты томография бақылауымен фокустелген ультрадыбысты қолдану: негіздері мен қауіпсіздігі, фертильдікке және жүктілік нәтижелеріне әсері. Әдебиеттік шолу // Ғылым және Денсаулық сақтау. 2025. Vol.27 (6), Б. 185-192. *doi 10.34689/SH.2025.27.6.020*

Introduction

Uterine fibroids are the most prevalent benign tumors of the female reproductive tract, affecting between 20% and 40% of women during their reproductive years [31,39]. The incidence peaks in women over 35, with an overall prevalence reaching 90% in the 25-45 age group. In recent decades, there has been a noticeable trend toward detecting fibroids in women nearing the end of their childbearing potential. This phenomenon is largely attributed to social factors, particularly the decision by many to postpone childbearing until later in their reproductive period. Consequently, the proportion of surgical procedures for uterine fibroids in gynecological hospitals ranges from 41% to 74% [17].

The management of patients with uterine fibroids necessitates a differentiated approach, which is determined by a complex interplay of factors: the patient's age, clinical presentation, size and characteristics of the myomatous nodules, tumor growth rate, and the extent of the fibroid's impact on reproductive function.

The problem of uterine fibroid treatment remains a central focus in both national and global gynecology. While the necessity of radical surgical intervention is undisputed in cases involving acutely severe symptoms or giant nodules, there are persistent concerns regarding the high rate of hysterectomies and the optimal management strategy for asymptomatic fibroids. Given that approximately one in four women undergoing fibroid-related surgery is under the age of 40, the primary goal of surgical treatment, following myomectomy, is unequivocally the preservation of reproductive function. This underscores the increasing importance of organ-sparing and minimally invasive treatment modalities for young women.

One such relatively new technique that has entered clinical practice in recent years is Magnetic Resonance-Guided Focused Ultrasound (MRgFUS) ablation for uterine fibroids.

The MRgFUS technology is based on the remote delivery of high-intensity focused ultrasound energy. Using precise MRI navigation, the ultrasound beam is focused onto the pathological target area inside the body. Within a few seconds, the tissue at the focal point is heated to a temperature sufficient for thermal necrosis (ablation), while the surrounding healthy tissues remain unaffected (intact). This method achieves a non-invasive, strictly localized destruction of tumor cells, effectively meeting the criteria for an ideal surgical tool [45].

MRgFUS represents a non-invasive, organ-sparing treatment for uterine fibroids and adenomyosis, increasingly considered for women desiring fertility preservation. Current literature suggests that MRgFUS does not significantly impair fertility and is associated with encouraging pregnancy outcomes, including high live birth rates and a low incidence of severe complications. A number of studies and meta-analyses report that pregnancy and live birth rates after MRgFUS are comparable to those following other conservative treatments, with miscarriage rates similar to the general population or other interventions [10, 16, 18, 25, 28, 29, 37]. However, the evidence base is limited by a lack of large prospective trials, and some authors point to a higher rate of repeat interventions (reinterventions) compared to surgical options like myomectomy or Uterine Artery Embolization (UAE) [10,25,41]. Overall, MRgFUS appears to be a safe and effective fertility-preserving option, yet careful patient selection and further research are warranted to clarify long-term reproductive outcomes and optimize protocols [10, 16, 18, 25, 28, 29].

The aim of this study is to examine and systematize publications on the use of MRgFUS ablation technology for the subsequent refinement of this treatment method, specifically to investigate the impact of MRgFUS on female fertility and reproductive outcomes.

Methods

To achieve the stated objective-investigating the impact of MRgFUS ablation on fertility and reproductive outcomes-a comprehensive and systematic search of the scientific literature spanning the past 20 years was conducted. The key search terms used across both Russian- and English-language databases (PubMed, Medline, Cinahl, Embase, e-library, Cochrane, Health star, Google Scholar, and Consensus) included: “uterine fibroids”, “MRI for uterine fibroids”, “radiological diagnostics of uterine fibroids”, “pregnancy”, “MRgFUS for uterine fibroids”, “fertility”, “MRgFUS”, “HIFU” and “pregnancy outcomes”.

Inclusion Criteria:

The analysis included publications that met the following criteria:

- Publications available in both Russian and English languages.
- Articles addressing the application of MRgFUS for uterine fibroids and its influence on reproductive function predominantly published within the last 20 years (with the potential inclusion of older works deemed to hold significant scientific or historical value).
- Studies containing clearly formulated and statistically substantiated conclusions.
- Full-text articles retrieved from the aforementioned scientific databases.

Exclusion Criteria: The following were excluded from the review: meeting abstracts, newspaper articles, and personal communications.

The initial search, based on the key queries, encompassed over 100,000 scientific articles, which led to the identification of 1,247 potentially relevant works. Following a preliminary screening, 196 of the most relevant articles were selected for subsequent in-depth analysis (**Figure 1**).

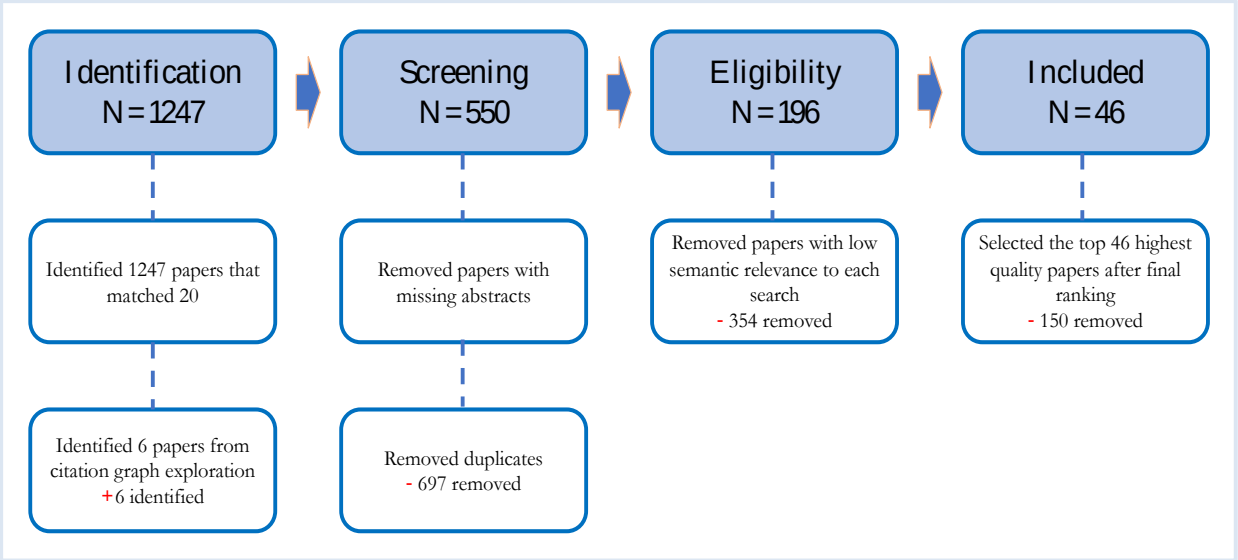

Figure 1: Flow diagram of the literature search and selection process. Four unique search strategies were used, combining terms for MRgFUS, fertility, pregnancy, and comparative treatments.

As a result of thorough screening and criterion assessment, 46 publications-representing the most authoritative and relevant studies-were ultimately included in this final review and served as its foundation.

Given the substantial volume and fragmented nature of the information available on this topic, particular emphasis within this review will be placed on the patient selection criteria, the technical principles of MRgFUS ablation, and its direct impact on fertility and reproductive outcomes.

Results

Physico-Biological Principles and Mechanism of MRgFUS Action

The continuous development of therapeutic options for treating uterine fibroids remains highly relevant [21]. Among the organ-sparing techniques, non-invasive focused ultrasound ablation (FUS) guided by Magnetic Resonance Imaging (MRI) holds a special place, as it often allows patients to avoid hospitalization [3, 11, 42].

The primary physiological effect of MRgFUS is thermal ablation. The temperature increase within the target tissue causes protein denaturation and irreversible cell damage, leading to coagulative necrosis, tumor growth arrest, and subsequent regression. The extent of thermal injury is dependent on the exposure time and the temperature reached [3, 7, 8, 35].

An important secondary mechanism is the occlusion of vessels supplying the tumor. This is achieved through the thermal closure of microvessels, the collapse of vessels due to the destruction of surrounding tissue followed by fibrosis, and the activation of thrombotic processes resulting from endothelial reaction or mechanical vessel damage by acoustic waves [7, 46].

Furthermore, focused ultrasound is capable of modulating the immune response and potentially suppressing carcinogenesis. This occurs through the antigenic properties of damaged tumor proteins, local inflammatory reactions generating effector cells, the release of heat shock proteins, and a reduction in immunosuppressive cytokines [20, 46]. Although these immunological effects may be insufficient for independent tumor growth control [43, 44], they contribute to the overall therapeutic efficacy.

The Role of MRI Guidance and Thermometry

The integration of therapeutic ultrasound with MRI visualization has established MRgFUS as one of the fastest-growing therapeutic technologies. MRI visualization enables precise localization of the target tumor and its margins, as well as clear visualization of the surrounding anatomy. A key feature of MRI is its ability to monitor temperature changes in real-time, thereby creating a closed-loop control system [8, 14, 32].

MR thermometry is based on the temperature-dependent shift in the resonance frequency of water protons, which makes it highly suitable for thermometry [15, 24]. Crucially, this temperature sensitivity is independent of the tissue type and the process of thermocoagulation, rendering MRI a reliable technology for non-invasive monitoring of FUS ablation [19, 26, 36]. The main limitations of the method include susceptibility to patient motion and inaccuracies in fatty tissues.

Overall Efficacy and Methodological Predictors

The treatment process, known as sonication, involves the pulsed delivery of FUS energy, with treatment duration varying from a few seconds up to 20 seconds, depending on the desired coagulation temperature [1, 23]. The software provides automatic configuration of the treatment zone, aiming for a sub-millimeter boundary between healthy and target tissue [5, 27, 30, 40]. MRI thermography allows for closed-loop control of energy deposition with high spatial and temporal resolution [6, 12, 38].

Numerous publications have confirmed the safety and efficacy of MRgFUS [1; 2; 5; 9; 14; 15; 19; 20; 23; 24; 26; 27; 30; 32; 36; 40; 43; 44; 46]. Clinical efficacy assessment has shown an increase in the Non-Perfused Volume (NPV) and a significant reduction in fibroid symptoms, as measured by the Symptom Severity Score (SSS) and Quality of Life (UFS-QOL) scale [38]. An increase in NPV strongly correlates with fibroid size reduction and a lower frequency of repeat interventions [3,24].

A meta-analysis of 10 studies reported that the overall improvement in SSS six months post-MRgFUS averaged 31.0 (95% CI 23.9-38.2), indicating substantial symptomatic relief.

Influence of Location and T2WI Signal Intensity

MRgFUS efficacy can be influenced by fibroid characteristics:

Location: Studies have shown that MRgFUS can treat fibroids of various locations, including submucosal fibroids and pedunculated subserosal fibroids [7,40]. For example, treatment of submucosal fibroids showed an average NPV of 80% and a size reduction of 90.1% at 24 months, though its superiority over hysteroscopic myomectomy has not been definitively proven yet [5].

T2WI Signal Intensity: MRI T2-weighted imaging is used for planning, as signal intensity correlates with vascularity and response to therapy. Hypointense fibroids on T2WI have been found to yield a higher average NPV (86.3%) and better long-term outcomes compared to hyperintense fibroids (67.6%) [3,9,38,45]. Slightly homogeneous hyperintense fibroids pose a particular challenge, with an average NPV of only 55.8%, potentially making them an exclusion criterion or requiring more meticulous selection [3,34,45].

Impact of MRgFUS on Fertility and Pregnancy Outcomes

Initially, MRgFUS was not offered to women planning future pregnancies, but current data have prompted multicenter studies in this group. Numerous studies confirm that women can successfully conceive and give birth after MRgFUS. Live birth rates are reported to range from 41% to over 70% across various cohorts [16, 18, 25, 28, 29, 37]. The mean time to conception following MRgFUS is 8 months [33]. A series described 54 pregnancies in 51 patients after MRgFUS [33], with 41% (22 patients) successfully carrying to term.

Pregnancy Complications and Comparative Efficacy

The rate of spontaneous abortions (miscarriages) after MRgFUS is generally between 8%-28%, which is comparable to rates in the general population or following other conservative interventions, and notably lower than after UAE [10,16,18,25,28,37]. Most studies show no significant increase in adverse pregnancy outcomes, such as preterm birth, placental abnormalities, or uterine rupture, compared to other treatments [10, 18, 25, 28, 29].

Efficacy Comparison: Compared to myomectomy, MRgFUS may result in a slightly lower overall pregnancy rate, but shows comparable rates of miscarriage and complications. Compared to UAE, MRgFUS is associated with a lower risk of miscarriage and abnormal placentation [10, 25, 37, 41]. MRgFUS preserves the structural integrity and function of the uterus, making it a favorable choice for women wishing to avoid surgery [10, 18, 25, 28, 29].

Reinterventions and Patient Selection

A controversial aspect is the rate of repeat interventions (reinterventions): some authors note that this rate may be higher after MRgFUS compared to surgical methods like myomectomy or UAE [10, 25, 41]. Consequently, meticulous patient selection and technical expertise are crucial for optimizing reproductive outcomes [3, 9, 34, 38, 45]. Pregnancy success after MRgFUS depends on factors such as patient age, history of infertility, and fibroid characteristics (size, location, vascularization) [14,18].

Discussion

The discussion of MRgFUS ablation efficacy begins with an understanding of its pathogenetic mechanism. The crucial finding is that the connective tissue within myomatous nodules acts as the primary absorber of focused ultrasound energy. This active energy absorption leads to intense heating of the stroma, while the destruction of myocytes occurs secondarily. Consequently, the treatment outcome is directly dependent on the histological structure and moisture content of the connective tissue: a drier connective tissue has higher FUS absorption, which paradoxically minimizes the destructive volume of myocytes and vascular elements [12].

MRgFUS induces a histological transformation of the fibroid tissue (myocytes and stroma convert into a state of wet coagulative necrosis), which leads to the arrest of nodule growth and symptom regression. For maximum efficacy, fibroids characterized by a parenchyma 1/stroma 3 structure (stroma-dominant) with minimal or no edema are preferred. In cases of significant edema or pronounced destructive changes (less than 30% viable tissue), the substrate available to absorb FUS energy is insufficient, thereby reducing procedural effectiveness [3, 22]. Inadequate connective tissue prevents the temperature (55-85°C) from being sustained long enough to induce coagulative necrosis in the myocytes, which inherently do not absorb FUS well. This explains the lower efficacy observed in the proliferative or atypical hyperplasia parenchyma 2/stroma 1 histotype.

MRgFUS is generally considered a highly safe procedure. However, like any medical intervention, it carries potential side effects. Common side effects that do not require medication include pelvic pain, nausea, vomiting, and fatty edema of the upper abdomen [3, 4, 34, 45].

Despite the overall high safety profile, rare but serious complications have been reported. The frequency of adverse events ranges between 0.003% and 0.088% of all treated cases. Severe complications include skin burns, bone destruction (successfully managed conservatively), and extremely rare cases of intestinal damage and acute renal failure (due to lysis of necrotic tumor masses) [3, 4, 34, 45]. Strict adherence to established protocols and the use of auxiliary measures are critically important to minimize these risks.

The accumulated data unequivocally suggest that MRgFUS is a promising, minimally invasive method for women with uterine fibroids who seek to preserve their fertility. Pregnancy and live birth rates after MRgFUS are encouraging, and the risk of serious obstetric complications, such as uterine rupture or placenta accreta, remains low [10,16,18,25,28,29,37]. Compared to UAE, MRgFUS is associated with a lower risk of miscarriage and abnormal placentation [10, 25, 28, 37, 41]. While myomectomy remains the "gold standard" for maximizing the chances of pregnancy, MRgFUS offers a less invasive alternative.

A major issue limiting the widespread adoption of MRgFUS in reproductive practice is the lack of large, prospective, randomized studies and the relatively short

follow-up periods in most published works [10, 13, 25, 28, 41].

Furthermore, several critical factors influence the success of the procedure and reproductive outcomes: Patient Age: The mean age of patients in earlier successful studies was around 43 years. Conversely, younger women (of prime reproductive age) more frequently present with hyperintense fibroids, which are more resistant to MRgFUS, complicating treatment in this key demographic. Technical Aspects: Success is closely linked to meticulous patient selection (including assessment based on T2WI signal intensity), technical expertise, and fibroid characteristics [10, 14, 18]. Assisted Reproductive Technology (ART): Data on Intrauterine Insemination (IUI) or In Vitro Fertilization (IVF) after MRgFUS remain limited. The optimal timing for pursuing ART post-treatment has also not been established.

Despite the encouraging current data on 35 live births following MRgFUS, the heterogeneity of these case series and the low enrollment levels in past clinical trials preclude definitive conclusions regarding rare and serious outcomes.

Conclusion

MRgFUS is a safe and effective organ-sparing method for the treatment of uterine fibroids. It provides clinical improvement and symptom regression through thermal ablation and coagulative necrosis, with a low risk of severe complications when protocols are strictly followed. Ultrasound ablation does not pose an obstacle to subsequent pregnancy. Pregnancy and live birth rates after MRgFUS are comparable to those of other conservative treatments, and the risk of spontaneous abortion and placental abnormalities is lower than after UAE. The success of treatment critically depends on careful patient selection, which includes evaluating age, history of infertility, and fibroid characteristics (predominantly hypointense fibroids on T2WI). MRgFUS represents a promising, minimally invasive option for fertility preservation in women with uterine fibroids. Further high-quality research is necessary to fully define its role in reproductive medicine, standardize treatment protocols, and refine patient selection criteria.

Acknowledgments: *None.*

Conflict of Interest: *The authors declare no conflicts of interest.*

Author Contributions: *All authors contributed equally to the preparation of this material.*

Publication Information: *This material has not previously been submitted for publication elsewhere and is not under consideration by other publishers.*

Funding: *This study was not funded.*

Literature:

1. Aamir T. Khan. Uterine fibroids: current perspectives. International Journal of Women's Health. 2014. Т. 6. С. 95-114.

2. Alberta Cappelli. Uterine Artery Embolization for the Treatment of Symptomatic Uterine Fibroids of Different Sizes: A Single Center Experience. Journal of Personalized Medicine. 2023. Т. 13. № 6. - С. 906-906.

3. Alessandro Napoli. Primary pain palliation and local tumor control in bone metastases treated with magnetic resonance-guided focused ultrasound. Investigative Radiology. 2013. Т. 48. № 6. - С. 351-358.

4. Anna Maria Ierardi. Uterine Myomas: Extravascular Treatment. Seminars in Ultrasound Ct and Mri. 2020. Т. 42. № 1. - С. 56-74.

5. Aymara Mas. Updated approaches for management of uterine fibroids. International Journal of Women's Health. 2017. Т. 9. - С. 607-617.

6. Clemens Koesters. Uterine artery embolization in single symptomatic leiomyoma: do anatomical imaging criteria predict clinical presentation and long-term outcome? Acta Radiologica. 2014. Т. 55. № 4. - С. 441-449.

7. *Elizabeth A.* Stewart. Clinical practice. Uterine fibroids. The New England Journal of Medicine. 2015. Т. 372. № 17. - С. 1646-1655.

8. Emma Giuliani. Epidemiology and management of uterine fibroids. International Journal of Gynecology & Obstetrics. 2020. Т. 149. № 1. - С. 3-9.

9. Erin Gomez. MRI-based pictorial review of the FIGO classification system for uterine fibroids. Abdominal Radiology. 2021. Т. 46. № 5. - С. 2146-2155.

10. Fang Li. HIFU as an alternative modality for patients with uterine fibroids who require fertility-sparing treatment. International Journal of Hyperthermia. 2023. Т. 40. № 1.

11. Gaylene Pron. Magnetic Resonance-Guided High-Intensity Focused Ultrasound (MRgHIFU) Treatment of Symptomatic Uterine Fibroids: An Evidence-Based Analysis / Gaylene Pron, G. Pron. 2015. Т. 15. № 4. - С. 1-86.

12. George A. Vilos. The Management of Uterine Leiomyomas. Journal of obstetrics and gynaecology Canada. 2015. Т. 37. № 2. - С. 157-178.

13. Inez M Verpalen. Magnetic resonance-high intensity focused ultrasound (MR-HIFU) therapy of symptomatic uterine fibroids with unrestrictive treatment protocols: A systematic review and meta-analysis. European Journal of Radiology. 2019. Т. 120. - С. 108700.

14. Irene Mindjuk. MRI predictors of clinical success in MR-guided focused ultrasound (MRgFUS) treatments of uterine fibroids: results from a single centre. European Radiology. 2015. Т. 25. № 5. - С. 1317-1328.

15. James E. Silberzweig. Management of Uterine Fibroids: A Focus on Uterine-sparing Interventional Techniques // Radiology. 2016. Т. 280. № 3. - С. 675-692.

16. Jaron Rabinovici. Pregnancy outcome after magnetic resonance-guided focused ultrasound surgery (MRgFUS) for conservative treatment of uterine fibroids. Fertility and Sterility. 2010. Т. 93. № 1. - С. 199-209.

17. Joo, B. pain palliation in patients with bone metastases using magnetic resonance guided focused ultrasound with conformal bone system a preliminary report. Yonsei medical journal. 2015.

18. Jun shu Li. Pregnancy outcomes in nulliparous women after ultrasound ablation of uterine fibroids: A single-central retrospective study. Scientific Reports. 2017. Т. 7. № 1. - С. 3977-3977.

19. K.J. Neis. Hysterectomy for Benign Uterine Disease. Deutsches Arzteblatt International. 2016. Т. 113. № 14. - С. 242-249.

20. Kamilla Karlsen. Fertility after uterine artery embolization of fibroids: a systematic review. Archives of Gynecology and Obstetrics. 2018. Т. 297. № 1. С. 13-25.

21. Kristiina Pynnä. Cost-effectiveness of hysterectomy for benign gynecological conditions: a systematic review. Acta Obstetricia et Gynecologica Scandinavica. 2014. T. 93. № 3. C. 225-232.

22. Krisztina Fischer. Potential of minimally invasive procedures in the treatment of uterine fibroids: a focus on magnetic resonance-guided focused ultrasound therapy. International Journal of Women's Health. 2015. T.7. C. 901-912.

23. Kuznetsova M. Familial Predisposition to Leiomyomata: Searching for Protective Genetic Factors. Biomedicines. 2022. T. 10. № 2. - C. 508-508.

24. Lutfi Kurban. Uterine Artery Embolization of Uterine Leiomyomas: Predictive MRI Features of Volumetric Response. American Journal of Roentgenology. 2021. T. 216. № 4. - C. 967-974.

25. Luz Angela Torres-de la Roche. Should Ultrasound-Guided High Frequency Focused Ultrasound Be Considered as an Alternative Non-Surgical Treatment of Uterine Fibroids in Non-Asiatic Countries? An Opinion Paper. Journal of Clinical Medicine. 2022. T. 11. № 3. C. 839-839.

26. Mahesh Fuldeore. Healthcare utilization and costs among women diagnosed with uterine fibroids: a longitudinal evaluation for 5 years pre- and post-diagnosis. Current Medical Research and Opinion. 2015. T. 31. № 9. - C. 1719-1731.

27. Maria V. Vargas. Feasibility, Safety, and Prediction of Complications for Minimally Invasive Myomectomy in Women With Large and Numerous Myomata. Journal of Minimally Invasive Gynecology. 2017. T. 24. № 2. - C. 315-322.

28. Michael K. Bohlmann. High-Intensity Focused Ultrasound Ablation of Uterine Fibroids - Potential Impact on Fertility and Pregnancy Outcome. Geburtshilfe Und Frauenheilkunde. 2014. T. 74. № 2. - C. 139-145.

29. Min Zhao. Evaluating pregnancy outcomes in women with uterine fibroids treated with high-intensity focused ultrasound: insights from a single-institution study. Reproductive Health. 2024.

30. M.S. Ghant. Beyond the physical: A qualitative assessment of the burden of symptomatic uterine fibroids on women's emotional and psychosocial health. Journal of Psychosomatic Research. 2015. T. 78. № 5. - C. 499-503.

31. Muhammad O. Awiwi. Review of uterine fibroids: imaging of typical and atypical features, variants, and mimics with emphasis on workup and FIGO classification. Abdominal Imaging. 2022.

32. Natasha D. Sheybani. Perspectives on Recent Progress in Focused Ultrasound Immunotherapy. Theranostics. 2019. T. 9. № 25. - C. 7749-7758.

33. Nguyen Minh Duc. Magnetic Resonance-Guided Focused Ultrasound Surgery for Leiomyoma and Adenomyosis: An Alternative Nonvascular Approach. / Nguyen Minh Duc, M.D. Nguyen - Gynecology and Minimally Invasive Therapy. 2019. T. 8. № 4. C. 196-198.

34. Nguyen Minh Duc. Adverse events of focused ultrasound surgery for uterine fibroids and adenomyosis. Reports in Medical Imaging. 2018. T. 11.

35. Parker E. Ludwig. Pregnancy success and outcomes after uterine fibroid embolization: updated review of published literature. // British Journal of Radiology. 2020. T. 93. № 1105. - C. 20190551-20190551.

36. Piotr Czuczwar. Predicting the results of uterine artery embolization: correlation between initial intramural fibroid volume and percentage volume decrease. Przeglad Menopauzalny. 2014. T. 13. № 4.

37. Rachel M. Whynott. The Effect of Uterine Fibroids on Infertility: A Systematic Review. Seminars in Reproductive Medicine. 2017. T. 35. № 6. C. 523-532.

38. Rita Golfieri. Focal lesions in the cirrhotic liver: their pivotal role in gadoxetic acid-enhanced MRI and recognition by the Western guidelines. Digestive Diseases. 2014. T. 32. № 6. - C. 696-704.

39. Sara M. Drayer. Prevalence, morbidity, and current medical management of uterine leiomyomas. International Journal of Gynecology & Obstetrics. 2015. T. 131. № 2. C. 117-122.

40. Serdar E. Bulun, Longo D.L. Mechanisms of disease: Uterine fibroids - The New England Journal of Medicine. 2013. T. 369. № 14. - C. 1344-1355.

41. Shannon K. Laughlin-Tommaso. FIRSTT study: randomized controlled trial of uterine artery embolization vs focused ultrasound surgery. American Journal of Obstetrics and Gynecology. 2019. T. 220. № 2.

42. Stephen D. Quinn. Safety and five-year re-intervention following magnetic resonance-guided focused ultrasound (MRgFUS) for uterine fibroids. European Journal of Obstetrics & Gynecology and Reproductive Biology. 2014. T. 182. - C. 247-251.

43. Tetsuya Katsumori. Insufficient Leiomyoma Infarction in Uterine Artery Embolization: Relationship with Tumor Location. // Journal of Vascular and Interventional Radiology. 2019. T. 30. № 5. - C. 668.

44. Thomas Kröncke. Uterine Artery Embolization (UAE) for Fibroid Treatment - Results of the 7th Radiological Gynecological Expert Meeting. Rofo-fortschritte Auf Dem Gebiet Der Rontgenstrahlen Und Der Bildgebenden Verfahren. 2019. T. 191. № 7. - C. 630-634.

45. Wenzhuang Chin. MR-guided focused ultrasound for the treatment of adenomyosis: current insights. 2015. T. 4. - C. 1-8.

46. Zahra Allameh. Evaluation of the Efficacy and Complications of Uterine Artery Embolization in Comparison with Laparotomy-Myomectomy in the Treatment of Uterine Myomas: A Randomized Clinical Trial. Medical journal of the Islamic Republic of Iran. 2022. T. 36. C. 87-87.

Corresponding author:
Abiltayeva A.A., PhD, NCJSC «Semey Medical University», Pavlodar Branch, Pavlodar, Republic of Kazakhstan.
Postal code: 140000, NCJSC "Semey Medical University", Pavlodar Branch, Pavlodar, Republic of Kazakhstan;
Address: Pavlodar city, street Tolstogo L. 107/5
Phone: 8(702)107 21 25
E-mail: ai_samina@mail.ru