Efficacy of ultrasound-guided microwave ablation for vascular malformations in children

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ABSTRACT

Objective: The aim of this study was to report our center's experience in treating pediatric vascular malformations using ultrasound-guided microwave ablation.

Methods: Twenty-two symptomatic children with vascular malformations underwent ultrasound-guided microwave ablation. All patients received ultrasound follow-up after microwave ablation, whereas magnetic resonance imaging follow-up was conducted depending on the disease's condition. The Visual Analog Scale and the PedsQL4.0 Chinese Version was utilized to assess the changes in pain severity, limb motion evaluation, and quality of life before and after treatment.

Results: The study included 22 cases, comprising four arteriovenous malformations, nine venous malformations, two diffuse microcystic lymphatic malformations, two cases of Klippel-Trenaunay syndrome, and five cases of fibro adipose vascular anomaly. All children presented with pain at the affected site (22 cases; 100%). The malformations were located in the limbs in 17 cases (77%), subcutaneous and intramuscular tissues of the buttocks in one case (4.5%), subcutaneous tissue of the abdominal wall in one case (4.5%), and retroperitoneal in three cases (14%). All 22 patients (100%) experienced pain. Additionally, 20 cases (91%) exhibited swelling at the affected site or developed swelling after physical activity. Limb hypertrophy was observed in five cases (23%), whereas another five cases (23%) showed signs of limb atrophy. Joint mobility restrictions were present in four cases (18%). Among these 22 patients, 17 cases (77.3%) experienced complete resolution of pain and local lesion appearance changes, whereas four cases (18.2%) reported pain relief. However, in one case (4.5%) of Klippel-Trenaunay syndrome, postoperative improvement was observed at the treatment site, but a new centripetal malformation developed within the treated region. This patient subsequently underwent surgical intervention, resulting in an improvement in clinical symptoms. The pre-treatment malformation volume was 209.85 ± 343.17 cm^3, which reduced to 32.95 ± 66.04 cm^3 1 year after ablation. The volume reduction was statistically significant ($t = 2.374$; $P = .026$; $P < .05$), with an average volume reduction rate of 85.51%. No major complications were found, such as nerve damage or skin burns.

Conclusions: Ultrasound-guided microwave ablation is a relatively safe and effective technique for treating pediatric vascular malformations. Further multicenter studies are recommended to validate these findings. (J Vasc Surg Venous Lymphat Disord 2025;13:102240.)

Keywords: Arteriovenous malformation; Microwave ablation; Pediatric vascular malformations; Ultrasound; Venous malformation (VM)

Vascular malformations are congenital anomalies of vascular morphogenesis that occur during embryonic development, with an overall prevalence of approximately 1.2% to 1.5%.[1,2] According to the classification system of the International Society for the Study of Vascular Anomalies (ISSVA),[3] vascular malformations are divided into slow-flow and high-flow lesions. The flow pattern plays a crucial role in treatment decisions, therapeutic approaches, and prognosis.[4,5] Slow-flow malformations are the most common type of vascular anomaly,[6] including venous malformations (VMs), lymphatic malformations (LMs), and capillary malformations, as well as some combined anomalies.[3] High-flow lesions mainly include arteriovenous malformations (AVMs) and

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arteriovenous fistulas. Fibro-adipose vascular anomaly (FAVA), which is unclassified under ISSVA, primarily manifests as a venous malformation and is also considered a slow-flow vascular anomaly.[4] The treatment of vascular malformations typically involves interventional radiology, surgical excision, or a combination of both.[7-9] Nonsurgical treatments, such as ethanol embolization, sclerotherapy, and oral targeted therapies (eg, sirolimus and others), are also commonly employed in managing vascular malformations.[1,10-12] However, some patients do not achieve symptom relief with these treatments and require alternative therapeutic options.

Ultrasound-guided microwave ablation has emerged as a minimally invasive treatment modality in recent years. The mechanism is when tissues are exposed to electromagnetic fields (typically 900-2500 MHz), polar molecules continuously rearrange, converting kinetic energy into thermal energy.[13] When the temperature reaches lethal levels, it triggers coagulative necrosis of the target lesion, which is subsequently absorbed and metabolized by the body, leading to local tissue remodeling and disease resolution. This technique has been widely utilized in treating various benign and malignant tumors across multiple organs, including thyroid nodules, breast tumors, hepatocellular carcinoma, pulmonary metastases, and renal tumors.[14-18] At our center, we have implemented ultrasound-guided microwave ablation for pediatric patients with vascular malformations who remained symptomatic despite previous treatments. Based on our experience, we present the following report.

ARTICLE HIGHLIGHTS

- **Type of Research:** Single-center retrospective observational study
- **Key Findings:** Twenty-two children with symptomatic vascular malformations underwent ultrasound-guided microwave ablation, resulting in an average volume reduction rate of 85.51%. All patients exhibited improvements in clinical symptoms, and no major complications occurred.
- **Take Home Message:** Ultrasound-guided microwave ablation is a safe and effective minimally invasive technique for treating symptomatic pediatric vascular malformations.

METHODS

Patients. Our study included pediatric patients who visited our hospital between January 1, 2022, and January 1, 2024. Inclusion criteria were: (1) clinically or pathologically diagnosed as symptomatic vascular malformations; (2) received ultrasound-guided microwave ablation treatment; (3) had previously undergone at least one treatment (including ethanol/polidocanol sclerotherapy, interventional embolization, or surgical excision). Exclusion criteria were: (1) diagnosed with capillary malformations or congenital arteriovenous fistulas; (2) lesions located within 1 cm of critical nerves; (3) presence of anesthesia or surgical contraindications. This study was approved by the Ethics Committee of our hospital in accordance with the Helsinki Declaration, and informed consent was obtained from all participants.

Vascular malformations were classified using the ISSVA classification system.[3] Clinical outcome parameters included the Visual Analogue Scale (VAS) and the PedsQL4.0 Chinese Version[19] to assess pain severity, limb motion, and quality of life before and after treatment. These data were collected by clinicians during pre-intervention and post-intervention patient visits. Complications occurring during interventional treatment were assessed using the Cardiovascular and Interventional Radiological Society of Europe (CIRSE) complication classification system.[20] Ultrasound examination was employed to calculate tumor volume. The following formulas were used to evaluate the efficacy: the nodule volume was calculated using the equation: $V = 0.523 \times (a \times b \times c)$ (V: volume, a: the maximum diameter, b and c: the other two perpendicular diameters); volume reduction rate ([preoperative volume − postoperative volume]/preoperative volume × 100%). Prior to the procedure, the interventional ultrasound physician, radiologist, and clinical clinicians carefully compared ultrasound, computed tomography, or magnetic resonance imaging (MRI) images to assess the relationship between the lesion and surrounding critical structures (Fig 1, *A-C*), formulating a detailed microwave ablation plan.

Equipment and microwave ablation technology. Ablation procedures were conducted with the MWA system (KY-2450A-1, Canyon Medical) and ultrasound machine (the Mindray M10) equipped with a linear ultrasound. We utilized a 16 G monopolar modified internal-cooling microwave electrode, with the tip positioned 3 mm from the microwave energy emission point and a total length of 8 cm (Kangyou). A peristaltic pump (Kangyou) continuously infused cooled saline (0 °C) into the inner cavity of electrode to maintain a low temperature, thereby preventing accidental burns at the puncture site and along the needle track. If critical adjacent structures, such as nerves, blood vessels, or the skin, required protection, a 20G puncture needle was used to inject a sufficient amount of saline between the lesion and these structures to create a hydrodissection barrier (Fig 1, *D-F*). If the saline was absorbed during treatment, additional saline was injected as needed. The effectiveness of vascular malformation ablation was determined by the presence of vaporization artifacts on real-time ultrasound imaging, with the typical energy setting ranging from 15 to 30 watts. Large vascular malformations were

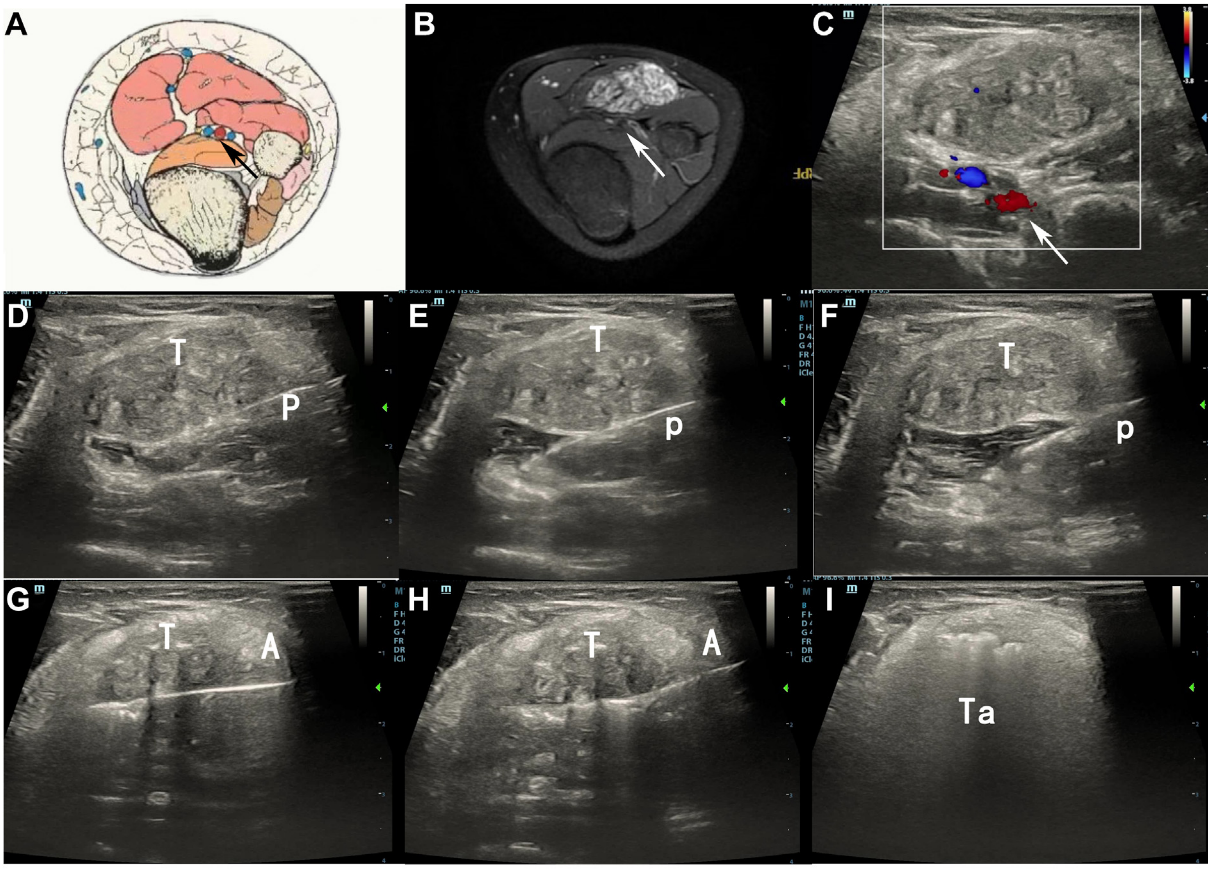

Fig 1. The ablation process of fibro adipose vascular anomaly (FAVA) in a 9-year and 5-month-old female patient, located near the popliteal fossa at the lateral head of the gastrocnemius muscle in the upper segment of the right lower leg. **(A)** Anatomical schematic diagram corresponding to the same imaging plane. **(B)** Magnetic resonance imaging (MRI) T2-weighted image of the FAVA lesion in the same plane. **(C)** Ultrasound image in the same plane, with *arrows* indicating important structures that require protection, including the tibial nerve, popliteal artery, and popliteal vein. **(D)** Initiation of hydrodissection under ultrasound guidance, with saline injected between the lateral head of the gastrocnemius and the soleus muscle. **(E)** Hydrodissection in progress under ultrasound monitoring. **(F)** Ultrasound image showing a satisfactory state of hydrodissection. **(G)** Initiation of ablation. **(H)** Ablation in progress along the first needle path. **(I)** Ultrasound image near the completion of ablation after shifting the first ultrasound plane. *A*, 16G microwave ablation electrode; *P*, 20G puncture needle; *S*, isolation saline; *T*, vascular malformation lesion; *Ta*, ablated vascular malformation lesion (aerosolized shadow overlying the original vascular malformation lesion).

treated using a continuous mode with moving ablation, whereas smaller vascular malformations underwent fixed ablation. For large-volume vascular malformations, the electrode tip was initially placed at the deepest part of the lesion under ultrasound guidance (Fig 1, *G*). The appropriate energy output was selected based on the appearance of vaporization artifacts during ablation and recorded accordingly. Once the first ablation site exhibited vaporization artifacts (Fig 1, *G*), the electrode was held in place for 0.5 to 1 second before advancing. The electrode tip was not allowed to extend beyond the previous ablation point's vaporization artifact, and the withdrawal speed was adjusted in real time based on ultrasound monitoring to ensure adequate coverage of the tumor by gas shadows before further electrode retraction (Fig 1, *H*). After completing the first puncture path, a second parallel puncture was made in a more superficial direction, followed by sequential moving ablation. This approach was designed to prevent gas formation due to thermal denaturation, which could degrade image quality, obscure the ultrasound field, and potentially compromise the procedure. After completing the ablation of one ultrasound plane (Fig 1, *I*), the electrode was moved parallel to the adjacent ultrasound plane, and the same ablation technique was applied. This process was repeated until the entire lesion was completely ablated and covered by vaporization artifacts (Supplementary Video 1, online only). For smaller lesions, punctures were made into the central area of the lesion for fixed ablation. General anesthesia was utilized only for uncooperative younger patients, whereas older children received the procedure under local anesthesia.

Table. Baseline characteristics of patients

Characterizations	All patients (n = 22)
Demographics	
Age, years	6.83 (2.42–14.33)
Female sex	13 (59%)
Classification of deformities	
AVM	4 (18%)
VM	9 (41 %)
FAVA	5 (23%)
Diffuse microcystic lymphangioma	2 (9%)
KT syndrome	2 (9%)
Lesion site	
Subcutaneous/intramuscular in the buttocks	1 (4.5%)
Extremities	17 (77%)
Subcutaneously of the abdominal wall	1 (4.5%)
Retroperitoneal	3 (14%)
Symptoms before treatment	
Pain	22 (100%)
Swelling	20 (91%)
Hypermobility of joints	4 (18%)
Atrophy of the affected limb	5 (23%)
Hypertrophy of the affected limb	5 (23%)
Impact on appearance	10 (45%)
VAS	6 (3–10)
Previous treatment	22 (100%)
Polidocanol	8 (36%)
Ethanol	6 (27%)
Embolism/surgery	2 (9%)
Ethanol + embolism	4 (18%)
Polidocanol + ethanol	2 (9%)
Duration of clinical follow-up, weeks	57.5 (15–115)
Follow-up	
Ultrasound follow-up	22 (100%)
MRI	6 (27%)
Volume reduction, %	85.51 (48.72%–100%)
Major complications	0 (0%)
Clinical change	
Asymptomatic	17 (77.3%)
Improvement	4 (18.2%)
Worse	1 (4.5%)
VAS	0 (0–1)

AVM, Arteriovenous malformations; *FAVA,* fibro adipose vascular anomaly; *KT,* Klippel-Trenaunay; *MRI,* magnetic resonance imaging; *VAS,* visual analogue scale; *VM,* venous malformations.
Data are presented as number percent or mean (range).

Statistical analyses. Normally distributed continuous variables are presented as mean ± standard deviation. Non-normally distributed continuous variables are presented as median and range. Statistical analyses were performed using SPSS version 23 (IBM Software), and $P < .05$ was considered statistically significant.

RESULTS

Patients. A total of 22 patients were included in the study, comprising nine males (41%) and 13 females (59%). The median age was 6 years and 10 months, with an age range of 2 years and 5 months to 14 years and 4 months. Patients presented with various types of vascular malformations, including four cases (18%) of AVM (1 case of Cho IIIa: numerous delicate shunts between arterioles and venules; 3 cases of Cho IIIb: numerous dilated shunts between arterioles and venules),[21] nine cases (41%) of VM (1 case of Puig II: drains into normal veins, 4 cases of Puig III: drains into dilated veins, and 4 cases of Puig IV: represents dysplastic venous ectasia),[22] two cases (9%) of diffuse microcystic LM, two cases (9%) of K-T syndrome, and five cases (23%) of FAVA The malformations were located in the limbs in 17 cases (77%), in the subcutaneous and intramuscular tissues of the buttocks in one case (4.5%), in the subcutaneous tissue of the abdominal wall in one case (4.5%), and in the retroperitoneal space in three cases (14%). All 22 patients (100%) exhibited clinical symptoms, primarily presenting as pain (either at rest or post-exercise). Swelling was observed in 20 cases (91%), either localized at the affected site or occurring post-exercise. Limb hypertrophy at rest was documented in five cases (23%), whereas an equivalent proportion (23%) demonstrated atrophy of the affected limb. Joint mobility impairment was identified in four cases (18%). Radical treatment was performed in 16 cases, whereas palliative treatment was administered in six cases (including 3 cases of Puig IV VM, 1 case of K-T syndrome, and 1 case of diffuse retroperitoneal LM). The median follow-up duration was 73.5 weeks (range, 52-98 weeks) (Table).

Outcomes and complications. Clinical improvement was observed in all 22 pediatric patients following treatment, with 17 cases (77.3%) achieving complete symptom resolution and four cases (18.2%) experiencing symptom improvement with only minor residual pain that did not affect their quality of life. The median VAS score for pain significantly decreased from an average of 6 (range, 3-10) at admission to an average of 0 (range, 0-1) at follow-up. At follow-up, all patients were able to engage in normal activities without any residual motor impairment. Unfortunately, in one case of a lymphatic vascular malformation associated with K-T syndrome, although the treated area remained stable post-treatment, a new lesion developed at the proximal end. Due to the parents' anxiety, surgical excision was ultimately performed.

All patients underwent ultrasound examinations to assess the extent of volume reduction of the malformations; 22 patients (100%) received ultrasound evaluations, and six patients (27%) underwent additional MRI. The volume of the malformations before treatment was measured at 209.85 ± 343.17 cm^3, whereas the volume at 1 year post-ablation was 32.95 ± 66.04 cm^3. The difference in volume before and after treatment was statistically significant ($t = 2.374$; $P = .026$; $P < .05$), with an average volume reduction rate of 85.51% (range, 48.72%-100%). No surgical complications, such as nerve damage or skin burns, were observed. There were no deviations from the expected post-treatment course (according to the CIRSE complication classification system).[20]

Among the four cases of AVMs, three showed complete disappearance on imaging after ablation, whereas one case exhibited a volume reduction rate of 48.72% at 1 year post-ablation; however, blood supply was not observed in the imaging area, suggesting the presence of residual fibrotic tissue. All positive symptoms resolved postoperatively. The average volume reduction rate for the nine VMs at 1 year post-ablation was 90.59% (range, 63.84%-100%), with three cases achieving complete absorption. MRI is the most crucial follow-up examination for assessing VM, as they appear hypervascular in contrast-enhanced MRI (Fig 2, *A-D*). Contrast-enhanced MRI demonstrated absorption of the original lesion or absence of blood supply post-ablation, whereas T2-weighted imaging exhibited the disappearance of abnormal signals from the lesion tissue (Fig 2, *E-H*) or signal reversal (with originally strong signals from the lesion turning to low or no signals).

Five patients diagnosed with FAVA also achieved a satisfactory rate of symptom control, characterized by the absence and alleviation of pain, alongside a reduction in contracture symptoms, all of which did not impact their quality of life. Notably, during follow-up, the tumors exhibited significant shrinkage, with an average volume reduction rate of 81.62% (range, 55.56%-100%) 1 year post-ablation. FAVA lesions typically exhibit hypervascular abnormal signals on contrast-enhanced MRI (Fig 3, *A-D*). Following effective ablation treatment, the lesion volume decreases and is replaced by avascular tissue (Fig 3, *E-H*).

Two cases of diffuse microcystic LMs demonstrated favorable treatment outcomes. We have reported a case of diffuse lymphangioma in the foot and ankle with treatment outcomes.[23] A case of bilateral diffuse microcystic lymphangioma in the feet and ankles underwent surgical excision of the lesions in the left foot and ankle at approximately 10 months of age, with scar healing postoperatively (Fig 4, *A*). At 12 years and 4 months of age, the patient underwent ultrasound-guided microwave ablation for lesions in the right foot and ankle at our hospital (Fig 4, *B*; Supplementary Video 2, online only). Although there was a mild complication of lymphatic fluid leakage within 3 weeks post-procedure, satisfactory recovery was achieved after applying compression bandaging and establishing collateral lymphatic circulation, resulting in a normal appearance (Fig 4, *C*). In contrast, another case involved a retroperitoneal diffuse LM, which exhibited significant vascular involvement, including the abdominal aorta, vena cava, and celiac trunk. Only partial ablation of the malformation was performed in safe areas. One year post-treatment, the tumor volume reduction rate was 52.20%, and the ablation volume closely matched the volume reduction rate, indicating a favorable outcome despite its palliative nature. Following ablation treatment, symptoms such as abdominal distention and pain, as well as postprandial discomfort, nearly resolved.

DISCUSSION

The vascular structure, location, and hemodynamic changes associated with vascular malformations can vary significantly. Consequently, individualized and multidisciplinary treatment approaches are often necessary. VMs, being the most common slow-flow vascular anomalies, can be treated through various methods, including ethanol embolization, sclerotherapy, coil embolization, or tissue adhesive embolization.[24-26] However, these techniques have certain limitations; for instance, ethanol injection may lead to ectopic embolization, resulting in soft tissue necrosis and nerve paralysis. In contrast, ultrasound-guided microwave ablation induces immediate thermal destruction of tissue without causing collateral damage to distant structures, avoiding irregular ectopic or remote necrotic areas.

Moreover, the radiation exposure associated with embolization and sclerotherapy under digital subtraction angiography is a significant concern for pediatric patients,[27] whereas ultrasound-guided microwave ablation eliminates this risk due to the absence of radiation. Aside from the above differences, percutaneous ultrasound-guided microwave ablation differs from other embolization techniques in that its mechanism of action is thermal injury to the abnormal vessels, leaving no residual materials such as coils or tissue adhesives. Post-ablation, the absorption of necrotic tissue facilitates optimal remodeling, resulting in a greater proportion of patients experiencing clinical improvement in local appearance. Our preliminary treatment experience indicates that the average volume reduction rate for VMs 1 year post-ablation was 90.59% (range, 63.84%-100%), with significant improvement in clinical symptoms across all patients (77.3% were asymptomatic, and 18.2% experienced symptom improvement), demonstrating a favorable safety profile.

The latest ISSVA classification system includes unclassified FAVA. These anomalies typically present in children or adolescents as solid masses accompanied by persistent severe pain and/or progressive contracture.[3] Histopathologic examinations typically reveal venous dilation, increased venous components, and fibrofatty

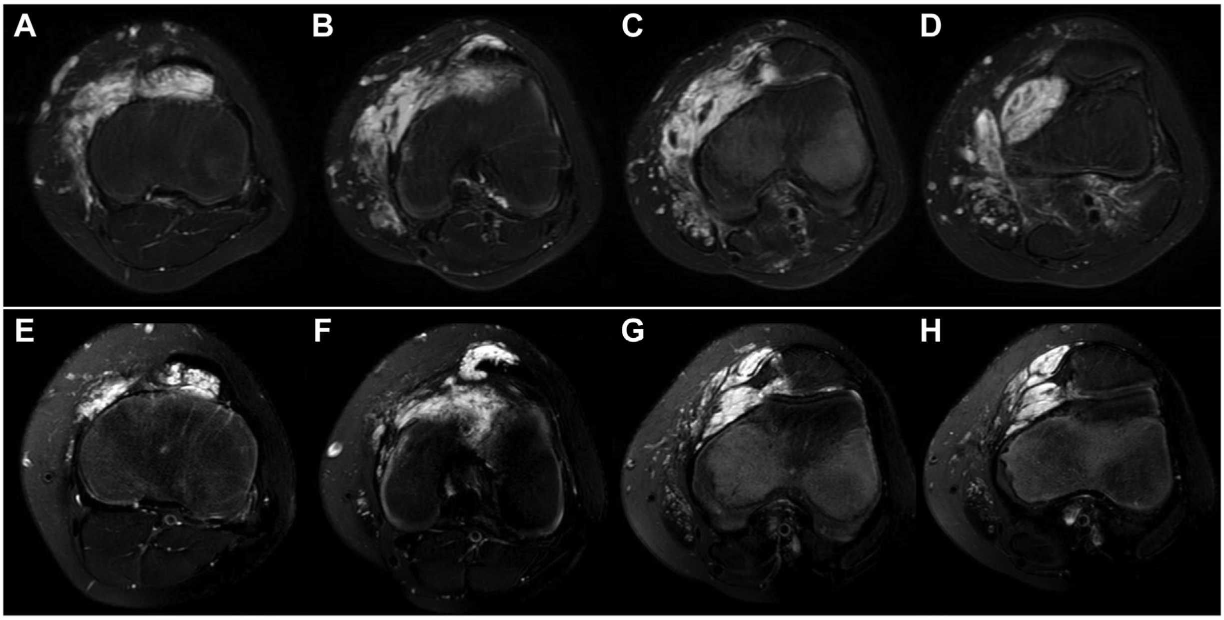

Fig 2. A magnetic resonance imaging (MRI) comparison before and after ablation of a venous malformation (VM) in the lateral aspect of the left knee joint in a 12-year and 11-month-old patient. The VM in the lateral knee joint was the designated ablation area. However, due to the potential risk of joint effusion, patellar ligament injury, and joint instability, ablation was not performed around the patella. **(A-D)** Preoperative T2-weighted images show the lesion as a hyperintense signal. **(E-H)** T2-weighted images obtained 9 months after ablation reveal the disappearance of abnormal signals in the treated tumor region, indicating successful treatment.

tissue infiltrating and replacing normal muscle fibers. Fibrofatty infiltration and compression from abnormal blood vessels lead to muscle atrophy. Exercise-induced pain reduces patients' willingness to move the affected limb, leading to disuse muscular atrophy.[28] Ultrasonography revealed heterogeneous, hypervascular, solid space-occupying echogenic lesions. MRI shows heterogeneous high signals within the muscle, accompanied

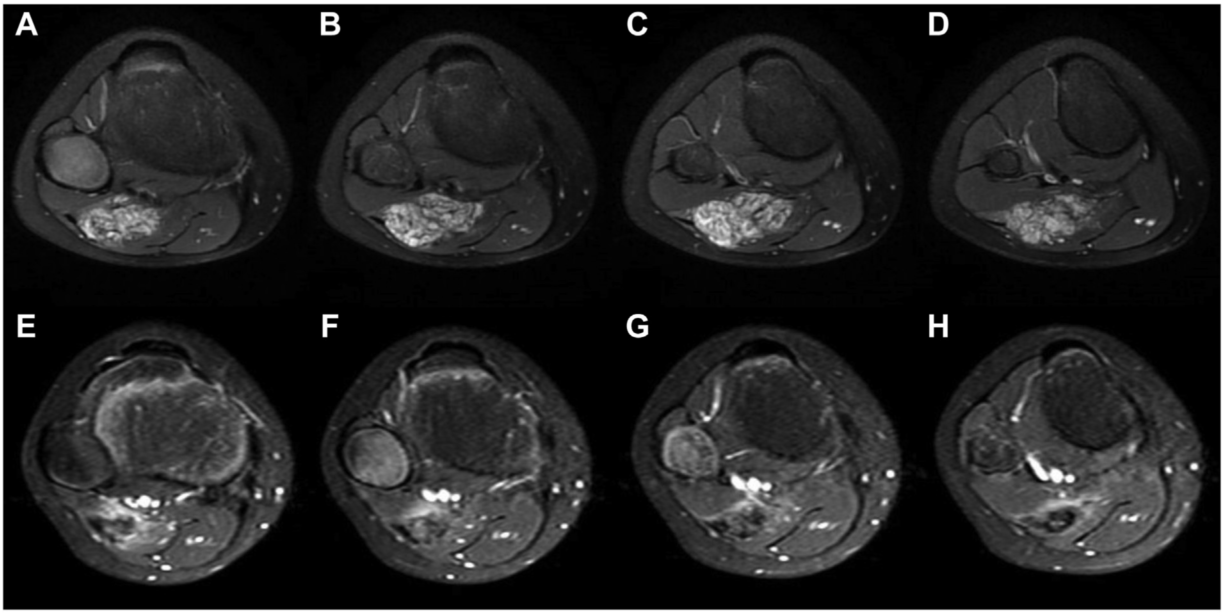

Fig 3. A magnetic resonance imaging (MRI) comparison before and nine months after ablation of an intramuscular fibro adipose vascular anomaly (FAVA) lesion in the lateral gastrocnemius of the upper right lower leg in a 9-year and 5-month-old patient. **(A-D)** Preoperative T2-weighted images (fat-suppressed) show the lesion as a hyperintense T2 signal. **(E-H)** Contrast-enhanced MRI (T1 fat-suppressed) obtained 9 months after ablation demonstrates the absence of blood supply in the ablated tumor region.

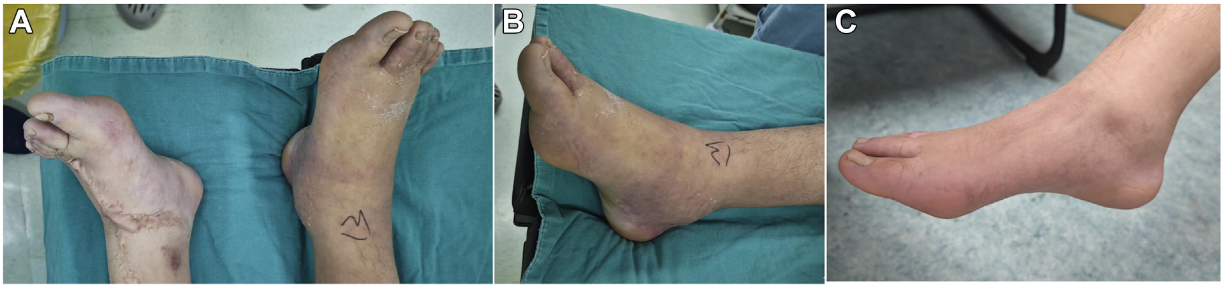

Fig 4. The pre- and post-procedural appearance of a diffuse microcystic lymphangioma in the right foot and ankle of a 12-year and 4-month-old patient treated with microwave ablation. **(A)** Preoperative appearance of bilateral feet; the left foot underwent surgery at 10 months of age, leading to scar contracture. **(B)** Preoperative appearance of the right foot before microwave ablation. **(C)** Appearance of the right foot and ankle 6 months after microwave ablation.

by venous expansion. Treatment options include endovascular therapy and surgical intervention; however, sclerotherapy often yields suboptimal results. It has been established that the venous components of the malformation are as crucial to address as the fibroadipose components responsible for contracture and pain, suggesting that ablation may serve as a viable alternative treatment. We treated five pediatric patients diagnosed with FAVA, who not only exhibited typical clinical manifestations but also had biopsy results excluding other tumor pathologies. The tumors demonstrated an average reduction rate of 81.62% (range, 55.56%-100%) 1 year post-ablation. Although this reduction was less pronounced than that achieved through surgical excision, the residual tissue consisted of avascular tissue, with symptom improvement being comparable. Given that ultrasound-guided microwave ablation offers rapid recovery, enhanced aesthetic outcomes (without incisions), and does not require wound care, nor does it typically present complications such as fluid accumulation beneath surgical sites, it stands as a promising alternative treatment modality.

Symptomatic large cystic LMs can be effectively treated with percutaneous sclerotherapy, demonstrating good safety profile.[28] However, for LMs, the efficacy of percutaneous sclerotherapy may be limited, necessitating the use of alternative sclerosing agents such as bleomycin.[29] We attempted ultrasound-guided percutaneous microwave ablation on two cases of diffuse microcystic LMs, with one patient's early outcomes documented in a published summary.[30] The prognosis of diffuse microcystic LMs in both feet and ankles varied markedly with different treatment approaches. A surgical scar on the left foot from a procedure performed 10 years ago resulted in contracture, whereas the right foot, treated with ultrasound-guided microwave therapy, achieved an aesthetically pleasing appearance. Postoperatively, only a transient complication of lymphatic fluid leakage occurred at the ablation needle puncture site, which fully resolved following the application of compression bandaging. In contrast, the left foot experienced delayed wound healing and lymphatic fluid leakage following surgery performed 11 years prior. Remarkably, the patient was able to ambulate the day after treatment, with no impact on quality of life. More than a year of follow-up has shown a satisfactory appearance, with no recurrence of the lesion.

Another pediatric patient presented with a diffuse microcystic LM encasing major vessels such as the celiac trunk in the retroperitoneum. Microwave ablation targeted only a portion of the tumor, with ultrasound contrast revealing that the ablation volume accounted for approximately 50% to 60% of the tumor's total volume. Prior to ablation, the lesion measured 579.90 cm^3, and 1 year post-ablation, it reduced to 277.19 cm^3, yielding a volume reduction rate of 52.20%, alongside improvement in abdominal pain and distension symptoms. It seems to suggest that microwave ablation may be a good alternative to injection therapies for microcystic LMs capable of establishing collateral circulation.

Thermal ablation operates on the principle of inducing coagulative necrosis in diseased tissues through heating, encompassing both radiofrequency and microwave ablation. The temperature in the central zone of radiofrequency ablation electrodes ranges from 80 to 100 degrees Celsius, whereas microwave ablation electrodes achieve higher temperatures and do not exhibit impedance or thermal sink effects, making their thermal efficacy superior. Conductive heat can inadvertently damage surrounding tissues, particularly in sensitive organs. The water isolation technique, commonly referenced in thyroid thermal ablation, involves the injection of saline into the tracheoesophageal groove to protect the recurrent laryngeal nerve and cervical vessels. Similarly, water isolation can be utilized during the ablation of peripheral soft tissue lesions to increase the safety distance between the ablation target and vital organs and tissues, thereby protecting them.

Laurence Verhaeghe reported on four cases of radiofrequency ablation for VMs.[31] Although the results were notable, the study did not mention the use of water isolation techniques to protect critical structures. In the first case of our article, a female patient had a tumor located within the right peroneus muscle, adjacent to the tibial nerve and posterior tibial vessels, with less than a 1 cm distance, which may have contributed to her muscle weakness and partial loss of strength occurring within 6 months post-ablation. Adequate water isolation during her procedure might have prevented or mitigated this complication. In our study involving vascular malformations in similar locations, we successfully utilized water isolation techniques to avoid nerve injury complications. Lu Wang et al[32] reported on the efficacy and safety of microwave ablation with water separation for treating vascular malformations. Their report indicated that in 35 cases of VMs, water isolation techniques were successfully used to protect the surrounding normal tissues, including peripheral nerves, thereby preventing the occurrence of nerve injury complications.

Although there have been some reports on microwave ablation for cases of vascular malformations, the numerous classifications of vascular malformations and the variability in the affected areas prompt us to further enrich the existing research on microwave ablation for vascular malformations in children. Our team believes the keys to successful ultrasound-guided microwave ablation of vascular malformations are: (1) Performing a one-to-one anatomical restoration based on preoperative imaging and ultrasound images; (2) Developing a comprehensive protective plan for surrounding critical tissues, effectively employing water isolation techniques; and (3) Mastering precise ultrasound puncture techniques.

Additionally, compared with adult patients, pediatric patients often undergo surgery under general anesthesia due to non-cooperation, which makes it impossible to perform neurofeedback in a conscious state. Performing ablation surgery under peripheral nerve electrophysiological monitoring during general anesthesia is a safer approach, but it is only feasible in hospitals with the necessary conditions. For older or more cooperative children, local anesthesia can be used, and in the conscious state, the neurologic examination and observation of the child's limb movement controlled by the nerves can help determine whether there is nerve damage. This is the most economical and practical approach.

Although we have attempted and successfully treated 22 cases of pediatric vascular malformations using percutaneous ultrasound-guided microwave ablation, our study suggests that this method may be a minimally invasive, effective, and safe treatment option for these vascular malformations. However, the limitations of this study include a relatively short follow-up period for this cohort, and continuous vigilance is required regarding symptom control and disease recurrence. There are few reports on microwave ablation for pediatric vascular malformations. Although our study has a slightly larger sample size compared with most previous studies, it remains limited, and we hope for multicenter expansion.

CONCLUSIONS

Ultrasound-guided percutaneous microwave ablation may be a minimally invasive, effective, and safe treatment method for pediatric vascular malformations and intramuscular FAVA. It is recommended that this approach can be promoted across multiple centers and diseases to gather more reliable evidence.

AUTHOR CONTRIBUTIONS

Conception and design: XK
Analysis and interpretation: SH, FX, HZ, JC, XK
Data collection: SH, FX, XL, ZZ, JZ, LP, XK
Writing the article: SH, FX, XL, HZ, JC, XK
Critical revision of the article: SH, FX, ZZ, JZ, LP, XK
Final approval of the article: SH, FX, XL, JZ, JC, ZZ, JZ, LP, XK
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SH and FX contributed equally to this article and share co-first authorship.

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