

Research Article

Super-Resolution Ultrasound Imaging of Oligodendroglioma: A Case Report and Literature Review

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Abstract

Oligodendroglioma is a type of diffusely infiltrating glioma, most common in adults between 25 and 45 years old. Neuroimaging constitutes an essential component of both diagnostic evaluation and surgical planning. While conventional imaging modalities effectively delineate tumor location and extent, they possess inherent limitations in detecting early pathological changes. Ultrasound imaging enjoys widespread clinical adoption owing to its excellent tissue penetration, lack of ionizing radiation, real-time imaging capacity, and equipment portability. Intraoperative ultrasound tools like contrast-enhanced ultrasound (CEUS) have become crucial for real-time tumor mapping. CEUS uses microbubble contrast agents to enhance tumor visualization by highlighting perfusion differences, improving boundary definition and residual tumor detection. Super-resolution ultrasound (SR-US) has emerged as an innovative imaging modality capable of high-resolution vascular mapping and functional assessment. Given these capabilities, this article presents a CEUS-guided surgical case, demonstrating its role in optimizing tumor resection while preserving brain function. A 33-year-old female patient was admitted to the hospital with a three-day history of an intracranial mass detected during a routine physical examination. MRI revealed a cysto-solid mass in the right frontal lobe, suggesting oligodendroglioma. The patient underwent a right frontal lobe resection, during which intraoperative ultrasound, CEUS, and SR-US imaging were performed. These imaging techniques revealed a cysto-solid mass with no blood vessels within the tumor and a rich microvascular structure in the surrounding brain tissue. The tumor was resected, and pathological examination confirmed the diagnosis of oligodendroglioma (WHO Grade II). MRI is the preferred diagnostic method, while CEUS and SR-US imaging have significant value in the diagnosis and treatment of brain tumors, improving diagnostic accuracy and surgical resection rates.

Keywords

Oligodendroglioma, Ultrasound, Microbubbles, Contrast, Super-Resolution Ultrasound Imaging

1. Introduction

Oligodendroglioma is a type of diffusely infiltrating glioma arising from oligodendrocytes, most common in adults

between 25 and 45 years old [1]. Accounting for 3-4% of primary brain neoplasms and about 7% of all glial tumors, its

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annual incidence is approximately 0.3 cases per 100,000 individuals. These tumors predominantly occur in the cerebral hemispheres, with preferential involvement of the frontal and temporal lobes. Less frequently, they may arise in atypical locations such as the cerebellum, brainstem, or ventricular system. Clinical manifestations typically include seizure activity and headaches secondary to elevated intracranial pressure, with focal neurological deficits varying according to tumor localization. The diagnosis and grading of brain tumors follows the World Health Organization (WHO) classification [2]. Neuroimaging constitutes an essential component of both diagnostic evaluation and surgical planning. For patients presenting with acute neurological symptoms, non-contrast cranial computed tomography (CT) serves as the initial imaging modality. On CT, oligodendrogliomas are hypodense or isodense masses, typically involving the cortex and subcortical white matter. Calcifications are seen in 34% to 80% of tumors [3]. Some tumors may demonstrate hemorrhagic components or cystic degeneration, while long-standing lesions can cause calvarial remodeling through chronic pressure effects. Contrast-enhanced CT can be helpful in detecting areas of blood-brain barrier (BBB) breakdown and defining the contrast-enhancing tumor border [4]. Magnetic resonance imaging (MRI) has become the preferred neuroimaging technique for brain tumor assessment. Standard MRI sequences provide valuable information regarding peritumoral edema, mass effect, cystic/necrotic components, hemorrhagic foci, and metastatic spread - features often associated with aggressive tumor behavior. These findings are often associated with aggressive tumors. However, the absence of or minimal peritumoral edema, absence of necrotic or hemorrhagic foci, lack of a mass effect, and no contrast enhancement is sometimes observed in high-grade tumors [5].

While conventional imaging modalities effectively delineate tumor location and extent, they possess inherent limitations in detecting early pathological changes due to restricted spatial resolution (typically on the millimeter scale) and limited detection sensitivity (generally in the millimolar concentration range) [6, 7]. Recent advances in optical imaging technologies, including near-infrared (NIR) fluorescence imaging and photoacoustic tomography [8, 9], have introduced new possibilities for neuroimaging research. These modalities offer distinct advantages such as enhanced spatial resolution, improved detection sensitivity, and reduced equipment costs [10, 11]. However, clinical implementation of optical techniques for neurological diagnosis remains constrained by technical challenges, particularly limited tissue penetration depth (<1 cm) and difficulties in quantitative analysis [12, 13]. This underscores the need for developing innovative imaging approaches that combine high sensitivity, superior resolution, and deeper tissue penetration capabilities to improve stroke diagnosis and management.

Unlike optical methods, ultrasound imaging enjoys widespread clinical adoption owing to its excellent tissue penetra-

tion, lack of ionizing radiation, real-time imaging capacity, and equipment portability [14, 15]. Intraoperative ultrasound tools like contrast-enhanced ultrasound (CEUS) have become crucial for real-time tumor mapping. CEUS uses microbubble contrast agents to enhance tumor visualization by highlighting perfusion differences, improving boundary definition and residual tumor detection. In recent years, super-resolution ultrasound (SR-US) has emerged as an innovative imaging modality capable of high-resolution vascular mapping and functional assessment [16, 17]. This technique employs ultrasound localization microscopy, which enables quantitative microvascular imaging through precise tracking and localization of individual microbubble contrast agents [18, 19]. Due to its exceptional resolution beyond the diffraction limit of conventional ultrasound, SR-US has been successfully implemented in early disease detection and treatment response monitoring across multiple clinical specialties. However, despite its growing applications, single-modality super-resolution ultrasound has not yet been explored for the diagnostic evaluation of oligodendrogliomas. Given these capabilities, this article presents a CEUS-guided surgical case, demonstrating its role in optimizing tumor resection while preserving brain function.

2. Case Report

A 33-year-old female patient was admitted to the hospital with a three-day history of an intracranial mass detected during a routine physical examination. Cranial MRI revealed a cysto-solid mass in the right frontal lobe, suggesting the possibility of oligodendroglioma (Figure 1). Under general anesthesia, the patient underwent a right frontal lobe resection. After marking the coronal incision on the forehead, disinfecting the area, and draping, the scalp was incised in layers to expose the skull. Four burr holes were drilled in the right frontal area, and a craniotomy was performed using a milling cutter. Intraoperative ultrasound was then conducted epidurally, revealing a cysto-solid mass in the right frontal lobe, predominantly cystic, with a nodular hyperechoic structure and acoustic shadowing on the deep cyst wall. Routine contrast-enhanced ultrasound (CEUS) and super-resolution ultrasound (SR-US) imaging were performed with an intravenous bolus injection of 2.4 mL of contrast agent (SonoVue; Bracco Imaging B.V., J20030117) using a VINNO G50 ultrasound system (VINNO Technology Co., Ltd., China) equipped with a probe frequency of 5-12 MHz.

CEUS reveals non-enhancement within the anechoic areas of the tumor, with heterogeneous enhancement observed in the surrounding brain parenchyma. SR-US imaging of the lesion shows no blood vessels within the tumor, while the surrounding brain tissue has a rich and dense microvascular structure. SR-US imaging shows the potential of non-invasively produce intracranial microvessel images with micron-scale resolution and accurate blood flow velocity.

Intraoperatively, a cortical fistula was created in the

middle frontal gyrus, and yellowish-brown fluid gushed out. After the cyst wall collapsed, the lesion was carefully dissected along the border of the surrounding normal tissue and completely resected. Tumor nodules were then exposed and resected after meticulous separation. Pathological examination confirmed the diagnosis of oligodendroglioma (WHO Grade II) in the right frontal lobe, characterized by gliosis with moderate density, clear cytoplasm, surrounding vascular proliferation, and hemorrhage. Psammoma bodies and calcification were also visible. Immunohistochemical staining results were positive for OLIG-2, GFAP, SOX-10, and Syn, while negative for EMA, IDH1, PTEN, NeuN, and BRAF. Ki-67 proliferation index was less than 3%, and CD34 was positive in blood vessels.

3. Discussion

Oligodendroglioma, originating from oligodendrocytes, accounts for 5% to 10% of gliomas and 1.3% to 4.4% of intracranial tumors. It has a male-to-female ratio of 2.13:1 and is most prevalent in adults. The tumor typically locates in the cerebral cortex or subcortex, grows slowly, and is most commonly found in the frontal lobe, followed by the parietal and temporal lobes. It lacks a capsule but has a clear boundary with normal brain tissue, primarily growing in an expansile manner. Calcification is common, occurring in 50% to 80% of cases, while hemorrhage and cystic degeneration are rare [20].

Imaging diagnostic techniques for oligodendroglioma mainly include computed tomography (CT) and MRI. CT scans reveal a tumor with mixed density, accompanied by calcification of various morphologies, a clear edge, and mild surrounding edema. Despite technological advancements, CT with intravenous contrast administration still demonstrates inferior soft tissue contrast resolution when compared to MRI. In neuroimaging practice, MRI has become the gold standard for brain tumor evaluation due to its superior tissue characterization capabilities. The standard diagnostic MRI protocol for intracranial neoplasms typically incorporates multiple essential sequences: T2-weighted imaging for anatomical delineation, fluid-attenuated inversion recovery (FLAIR) for edema detection, native T1-weighted imaging for baseline tissue assessment, and post-contrast T1-weighted imaging for blood-brain barrier integrity evaluation. MRI provides high-resolution images showing the tumor as a low-signal on T1 and a high-signal on T2, with uneven signals due to calcification, cystic degeneration, and blood products within the tumor. MRI also clearly demonstrates the relationship between the tumor and surrounding brain tissue, as well as the degree of tumor invasion [21, 22]. Enhanced scans may show no or mild enhancement. Despite its widespread clinical use, conventional MRI lacks pathological specificity, as different disease processes often exhibit similar imaging characteristics.

Tumor angiogenesis, a critical driver of neoplastic growth

and metastatic spread, cannot be adequately assessed using standard imaging techniques due to their limited resolution for microvascular evaluation [23]. Contrast-enhanced ultrasound (CEUS) has emerged as a valuable diagnostic tool in oncology, primarily due to the strong backscattering signals generated by microbubbles (MBs). These MBs can traverse tumor microvasculature unimpeded, enabling improved visualization of microcirculatory networks [24]. While CEUS provides real-time assessment of microvascular perfusion in tumor lesions, it remains unable to directly map the spatial distribution of microvessels within the tumor [25]. Consequently, developing non-invasive, sensitive methods for tumor lesion characterization continues to pose a major diagnostic challenge.

Meanwhile, ultrasound imaging technology has advanced considerably, with modern systems now available in diverse configurations, broadening their applicability across medical specialties. Ultrasound and CEUS have significant value in the diagnosis and treatment of brain tumors, particularly with the advent of SR-US imaging, which offers new avenues for precise diagnosis and treatment [26, 27]. Conventional ultrasound aids in lesion localization and tumor boundary determination during surgery, improving resection rates and reducing postoperative tumor recurrence risks. However, its clinical applications are limited by image contrast. CEUS enhances image contrast by exploiting differences in blood perfusion between lesional and normal tissues, providing more accurate and clear images for precise tumor boundary determination, blood perfusion understanding, and tumor residue assessment, thereby improving diagnostic accuracy and surgical resection rates. Furthermore, SR-US imaging techniques, such as ultrasound localization microscopy (ULM), achieve SR-US imaging of deep cerebral blood vessels, enabling clear observation of small-diameter blood vessels and deep structures, which has potential clinical value for assessing tumor resection margins and surgical risks [27].

Current limitations in super-resolution ultrasound imaging of superficial cerebral vasculature primarily stem from acoustic signal attenuation caused by cranial bone structures, resulting in reduced spatial resolution when compared to optical techniques. Most preclinical studies required removal of the bone (craniotomies) to create sufficient imaging windows [28], while Schwarz were able to use the fontanelle as an imaging window in neonatal patients, ULM is used to observe the human microvasculature undergoing treatment for life-threatening malformations forming direct connections between the cerebral arterial and venous systems. It is observed that neuroendovascular treatment of neonatal arteriovenous malformations causes remodeling and reorganization of the cerebral vasculature by also activating corticomedullary vascular connections. ULM enables us to follow microvascular changes in human neonates with high spatio-temporal resolution. ULM may provide a novel clinical translatable tool, particularly including cerebral imaging in

very young patients. [29]. Future technical advancements in volumetric acquisition protocols may further enhance the clinical utility of super-resolution ultrasound by enabling transcranial imaging with improved spatial resolution and comprehensive motion compensation capabilities.

4. Conclusions

In conclusion, the successful resection of the oligodendroglioma in this 33-year-old female patient was facilitated by a combination of conventional imaging, CEUS, and SR-US imaging techniques. The preoperative cranial MRI played a crucial role in identifying the location and characteristics of the tumor. Intraoperative CEUS and SR-US provided real-time, high-resolution images that enabled precise tumor boundary determination and assessment of blood perfusion, guiding the surgeon to achieve a complete resection. The pathological examination confirmed the diagnosis and provided further insights into the tumor's characteristics. The use of SR-US imaging, particularly for deep cerebral blood vessel visualization, underscores its potential to revolutionize intracranial tumor surgery by offering more precise assessment of tumor resection margins and reducing surgical risks.

Appendix

Overall, this case demonstrates the efficacy and advantages of incorporating advanced ultrasound imaging techniques into the diagnostic and therapeutic strategies for oligodendroglioma and other intracranial tumors.

Author Contributions

Xinyu Liu: Writing - original draft

Xue Song: Writing - review & editing

Cun Liu: Data curation

Yanling Zheng: Supervision

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Conflicts of Interest

The authors declare no conflicts of interest.

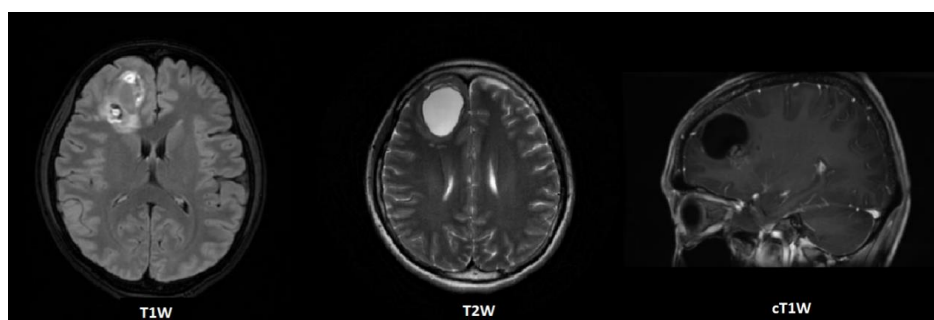


Figure 1. Transverse contrast-enhanced T1-weighted (T1W), T2-weighted (T2W), and contrast-enhanced T1-weighted (cT1W) images of the right frontal lobe oligodendroglioma.

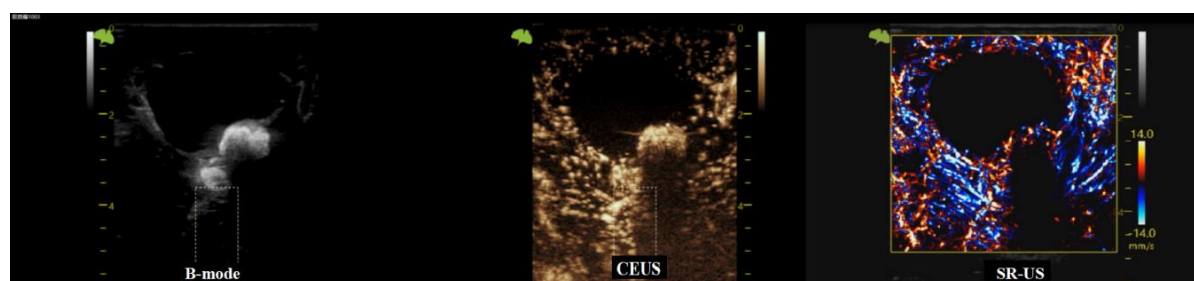


Figure 2. B-mode image showing a cysto-solid mass in the right frontal lobe, predominantly cystic, with a clear boundary and good internal acoustic transparency. A nodular hyperechoic structure with acoustic shadowing is observed on the deep cyst wall. CEUS reveals non-enhancement within the anechoic areas of the tumor, with heterogeneous enhancement observed in the surrounding brain parenchyma. SR-US imaging of the lesion demonstrates a well-circumscribed and dense microvasculature. The color bar represents blood flow direction, with red and blue indicating flow toward and away from the transducer, respectively.

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