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ΔΙΠΛΩΜΑΤΙΚΗ ΕΡΓΑΣΙΑ

« Preoperative Embolization in the Management of Solitary Fibrous Tumors of the CNS »

ΟΝΟΜΑ – ΕΠΩΝΥΜΟ

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ΠΡΑΚΤΙΚΟ ΚΡΙΣΕΩΣ

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Τα Μέλη της Εξεταστικής Επιτροπής

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PREFACE

Preoperative embolization has emerged as an adjunctive technique in the management of central nervous system (CNS) tumors, offering neurosurgeons a valuable tool to enhance surgical outcomes and mitigate perioperative risks. CNS tumors encompass a diverse array of neoplasms, ranging from benign meningiomas to highly malignant glioblastomas, each presenting unique challenges in surgical management. One common characteristic among many CNS tumors is their high vascularity, with robust blood supplies often posing significant intraoperative challenges such as excessive bleeding and compromised visualization. In this context, preoperative embolization stands as a cornerstone strategy aimed at reducing tumor vascularity, thereby facilitating safer and more effective surgical interventions.

The importance of preoperative embolization in CNS tumor management is underscored by its ability to minimize intraoperative hemorrhage, a critical factor strongly associated with surgical morbidity and mortality. By selectively occluding tumor-feeding vessels, embolization diminishes the risk of intraoperative bleeding, affording neurosurgeons improved surgical access and enhanced precision during tumor resection. Moreover, reduced blood loss translates into fewer transfusion requirements, minimizing the associated risks of transfusion-related complications and improving postoperative recovery trajectories for patients.

Beyond its hemostatic benefits, preoperative embolization contributes to optimizing surgical outcomes by facilitating maximal safe tumor resection. By devascularizing the tumor preoperatively, embolization enables neurosurgeons to navigate complex anatomical regions with greater ease, reducing the likelihood of inadvertent damage to adjacent eloquent structures. This not only enhances the completeness of tumor resection but also minimizes the risk of neurological deficits, ultimately promoting better functional outcomes for patients.

Furthermore, preoperative embolization plays a pivotal role in the management of CNS tumors with a propensity for rapid growth or extensive vascularity, such as meningiomas, hemangioblastomas and hypervascular metastases. In such cases, embolization serves as a valuable adjunct to traditional surgical approaches, allowing for effective tumor debulking and cytoreduction while mitigating the risk of intraoperative complications.

Considering all of the above in conjunction with the fact that I work in a hospital that uses endovascular techniques in regular basis and also with the fact that Solitary Fibrous Tumors (Hemangiopericytomas) represent an hypervacular tumour that have not yet been sufficiently reviewed I decided to do a systematic literature review regarding preoperative Embolization in the Management of Solitary Fibrous Tumors of the CNS.

AKNOWLEDGMENTS

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ABSTRACT

Ελληνικά

Υλικό: Οι Μονήρεις Ινώδεις Όγκοι (SFTs) στο Κεντρικό Νευρικό Σύστημα (ΚΝΣ) αποτελούν σπάνιο τύπο ινώδους νεόπλασμα που παρουσιάζει σημαντικές διαγνωστικές και θεραπευτικές προκλήσεις. Αυτοί οι όγκοι αποτελούν λιγότερο από το 1% όλων των SFTs, προέρχονται συνήθως από τα μήνιγγες, τον νωτιαίο μυελό και τα κρανιακά νεύρα. Είναι ιδιαιτέρως αγγειοβριθείς όγκοι που εμφανίζονται σε ποικίλες και συχνά περίπλοκες τοποθεσίες εντός του ΚΝΣ, καθιστώντας συχνά την πλήρη χειρουργική αφαίρεση τους ανέφικτη. Η ποικίλη αγγειοβρίθεια των SFTs επηρεάζει σημαντικά τις συμπληρωματικές δυνατές επιλογές θεραπείας, ιδιαίτερα αυτή του προεγχειρητικού εμβολισμού. Αυτή η τεχνική, χρησιμοποιείται συχνά για αγγειοβριθείς όγκους και λειτουργεί ως συμπληρωματική της χειρουργικής. Στοχεύει στη μείωση της αιματικής παροχής του όγκου, διευκολύνοντας έτσι την χειρουργική αφαίρεση. Αυτό μπορεί να οδηγήσει σε μειωμένη αιμορραγία, μικρότερη διάρκεια χειρουργείου και μείωση της θνησιμότητας και της θνητότητας που σχετίζεται με τη χειρουργική διαχείριση του νευρικού και αγγειακού ιστού.

Μέθοδοι: Διεξήχθη μια εστιασμένη ανασκόπηση βάσει PRISMA και χρησιμοποιώντας την PubMed, επιλέγοντας μελέτες των τελευταίων 11 ετών που αναλύουν τον προεγχειρητικό εμβολισμό για SFTs του ΚΝΣ. Άρθρα που συζητούσαν μη σχετικές διαδικασίες ή άλλους τύπους όγκων αποκλείστηκαν. Οι επιλεγμένες μελέτες κατηγοριοποιήθηκαν περαιτέρω σε τρεις ομάδες βάσει των περιοχών του ΚΝΣ που εμπλέκονται, αντανακλώντας τις διακριτές ιδιότητές τους και τις αντίστοιχες τεχνικές εμβολισμού που χρησιμοποιήθηκαν (Ενδογκεφαλικά/Σπονδυλικά/Κογχικά).

Αποτελέσματα: Ο προεγχειρητικός εμβολισμός, χρησιμοποιώντας κυρίως παράγοντες όπως το Onyx, φαίνεται να έχει δυνατότητα μείωσης των περιεγχειρητικών κινδύνων μαλακώνοντας τους

όγκους και μειώνοντας την αγγειοποίηση. Ωστόσο, η αποτελεσματικότητα διαφέρει αρκετά ανάλογα με το μέγεθος, τη θέση και την αγγειακή πολυπλοκότητα του όγκου. Η ατελής αφαίρεση της αγγείωσης του όγκου, οι όγκοι με κυρίαρχη τροφοδότηση από τις αρτηρίες την έσω καρωτίδα και την σπονδυλοβασική και τα πολλαπλά μικρά σύνθετα τροφοφόρα παρουσίασαν μόνο περιθωριακά αποτελέσματα ενώ συνοδεύονταν επίσης από αυξημένο κίνδυνο επιπλοκών. Οι τροποποιημένες τεχνικές προστασίας με μπαλόνι και ο διακρανιακός ή διαμυελικός εμβολισμός αντίστοιχα στα υβριδικά χειρουργικά δωμάτια έχουν τη δυνατότητα να μειώσουν αυτόν τον κίνδυνο, αλλά απαιτούνται μελέτες με μεγαλύτερα δείγματα.

Συμπεράσματα: Ο προεγχειρητικός εμβολισμός φαίνεται υποσχόμενος για τη βελτίωση των χειρουργικών αποτελεσμάτων στα SFTs του ΚΝΣ αλλά απαιτεί μια προσαρμοσμένη και εξατομικευμένη προσέγγιση για την αντιμετώπιση των μοναδικών χαρακτηριστικών κάθε περίπτωσης. Επιπλέον έρευνα είναι απαραίτητη για τη βελτίωση των τεχνικών εμβολισμού και την καθιέρωση εξατομικευμένων πρωτοκόλλων που επικεντρώνονται κυρίως στο μέγεθος και τη θέση του όγκου, ενσωματώνοντας μια λεπτομερή αγγειογραφική αξιολόγηση των διακριτών αγγειακών μοτίβων για την ενίσχυση της μακροχρόνιας επιτυχίας αυτής της στρατηγικής θεραπείας.

English

Background: Solitary Fibrous Tumors (SFTs) in the Central Nervous System (CNS) are a rare type of fibroblastic neoplasm that present significant diagnostic and therapeutic challenges. These tumors, accounting for less than 1% of all SFTs, typically arise from the meninges, spinal cord, and cranial nerves. They are highly vascular tumors appearing in diverse and often complex locations within the CNS often making complete surgical excision not feasible. The variable vascularity of SFTs significantly influences complementary possible treatment options,

particularly preoperative embolization. This technique, commonly used for hypervascular tumors, serves as an adjunct to surgery. It aims to decrease the tumor's blood supply, thus facilitating safer surgical resections. This can lead to reduced bleeding, shorter surgery time, and lower morbidity and mortality associated with the surgical management of neural tissue and vascular structures.

Methods: We conducted a focused review using PubMed, selecting studies from the last 11 years that discussed preoperative embolization for CNS SFTs. Articles discussing unrelated procedures or other tumor types were excluded. The selected studies were further categorized into three groups based on the CNS regions involved, reflecting their distinct properties and the corresponding embolization techniques used(Intracranial/Spinal/Orbital).

Results: Preoperative embolization, primarily using agents like Onyx, shows potential in reducing perioperative risks by softening tumors and decreasing vascularity. However, effectiveness varies a lot with the tumor's size, location and vascular complexity. Incomplete devascularasation of the tumor, ICA/VB-dominant SFTs and multiple small complex feeders presented to yield only marginal results while also carried an increased risk of complications. Modified Balloon Protection Techniques and intra-operative transcranial or transpedicular embolization respectively in the hybrid operating rooms are able to minimize that risk but studies with bigger samples are needed.

Conclusion: Preoperative embolization shows promising results for improving surgical outcomes in CNS SFTs but demands a customized and tailored approach to address the unique characteristics of each case. Additional research is essential to refine embolization techniques and establish individualized protocols that primarily focus on tumor size and location, integrating a comprehensive angiographic examination of distinct vascular patterns to enhance the long-term success of this treatment strategy.

CONTENTS

FIGURES

ABBREVIATIONS

Abbreviation	Meaning	Page
AVM	Arteriovenous malformation	18, 21
DSA	Digital subtraction angiography	21
EBRT	External beam radiation therapy	34
ECA	External carotid artery	35, 36, 40, 41, 43
HN	Head and Neck	24
HPC	Hemangiopericytoma	35
ICA	Internal carotid artery	35, 36, 40, 41, 42, 43
MMA	Middle meningeal artery	41, 43
MRI	Magnetic resonance imaging	19, 23
NBCA	N-butyl-2 cyanoacrylate	38, 40
PGWS	Permanent guiding wire	36, 42
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-analysis Protocols	27
PVA	Polyvinyl Alcohol	21
STA	Superficial temporal artery	41, 43
TAGM	Tris-acryl gelatin microspheres	38, 39, 40

Abbreviation	Meaning	Page
VB	Vertebrobasilar	35, 36, 40, 41, 43
WHO	World health organisation	22, 34

Table 1: List of abbreviations present in text with meaning and location

1. INTRODUCTION AND SCOPE

1.1. Embolization as a Medical Procedure

Embolization is a medical procedure used to block blood vessels and treat various health conditions. It is a minimally invasive method carried out by interventional radiologists and sometimes neurosurgeons who use imaging techniques to guide a small catheter through the blood vessels to the target site. Once in place, materials like beads, coils, or gels are released to stop blood flow. This technique is useful for shrinking tumors by cutting off their blood supply, controlling bleeding, managing aneurysms, and treating abnormal connections between blood vessels. Compared to traditional surgery, embolization offers advantages such as shorter recovery times and fewer complications, making it an important option in the treatment of various medical conditions (Hartnell, 1993).

1.2. Evolution of Embolic Materials

The evolution of embolization has seen significant developments, beginning with Charles Dotter in the 1960s, who initially used embolization to manage bleeding in gastrointestinal cases. This laid the groundwork for its broader clinical use (Payne, 2001). Initially, simple materials like autologous clots were employed. Over the years, this progressed to more sophisticated materials. By the late 1970s, the introduction of Gianturco coils marked a significant improvement, allowing for more targeted and reliable vessel occlusion (Rose, 2009). Advances continued with the introduction of polyvinyl alcohol particles and gelatin sponges, which became standard in embolotherapy. More recently, the development of drug-eluting beads and biocompatible

materials has improved treatment effectiveness and reduced complications (Osuga, et al., 2012) (Coldwell, et al., 1994).

1.3. Advancements in Embolization Techniques

The techniques for embolization have undergone significant improvements beyond the foundational use of fluoroscopy. Innovations such as digital imaging technology have replaced older methods, offering clearer, more detailed visualizations of vascular structures. This technological shift has enabled real-time monitoring during procedures, significantly increasing the accuracy and safety of embolizations. These advancements not only enhance the procedural efficiency but also play a crucial role in minimizing the risks associated with embolization, leading to better patient outcomes and reduced recovery times (Chatziioannou, et al., 2012).

1.4. Diverse Applications of Embolization

Initially focused on acute cases such as hemorrhages, the scope of embolization has broadened dramatically over the decades. A pivotal development occurred in the 1990s when Jacques Ravina pioneered the use of Uterine Fibroid Embolization (UFE). This technique provided a groundbreaking non-surgical alternative for the treatment of uterine fibroids, significantly reducing the need for invasive surgical procedures (Edwards, et al., 2007). Following this, embolization found new applications in oncology, especially in the treatment of liver tumors as well as in other types. This adaptation showcased the technique's flexibility and effectiveness in managing a diverse array of medical conditions, thereby expanding its clinical utility across various subspecialties of medicine (Salman, et al., 2002).

1.5. Expansion into Neurosurgery and Other Fields

In the realm of neurosurgery, embolization techniques have become indispensable tools. They are primarily used in the management of complex conditions such as arteriovenous malformations (AVMs) and aneurysms. This application has revolutionized neurosurgical approaches by offering minimally invasive alternatives to traditional surgery. The ability to close off problematic blood vessels or reduce the risk of bleeding without opening the skull has significantly enhanced patient safety and recovery times. These advances have not only improved clinical outcomes but have also broadened therapeutic possibilities within neurosurgery and other related fields, making embolization a critical component of modern medical practice (Deshmukh, et al., 2005).

1.6. Future Prospects and Innovations

The future of embolization includes potential innovations like robotic-assisted navigation, which could improve the precision of catheter placement in complex vascular structures (Schwein, et al., 2018). Research is also ongoing into new bioresorbable materials that can deliver drugs directly to pathology sites, potentially expanding the applications of embolization further (Poursaid, et al., 2016).

1.7. Detailed Analysis of a Typical Embolization Procedure

1. **Patient Evaluation and Planning**: Before an embolization procedure, a comprehensive patient evaluation is necessary to determine the suitability of the treatment. This includes reviewing the patient's medical history, current health status, and specific condition needing treatment. Diagnostic imaging, such as CT scans, MRI, or ultrasounds, plays a crucial role in planning the procedure (Keller, et al., 1981).
2. **Access and Catheter Insertion**: The procedure typically begins with the insertion of a catheter into a blood vessel, usually through a small incision in the groin or wrist. This step is performed

under local anesthesia to minimize discomfort. The catheter is then carefully guided through the vascular system to the target area using real-time imaging techniques such as fluoroscopy (Skaf, et al., 2007).

3. **Delivery of Embolic Agents**: Once the catheter is in place, embolic agents are delivered through it to the target site. These agents can vary depending on the specific condition being treated and may include materials such as microspheres, coils, or specialized drugs. The choice of embolic material is crucial and is based on the desired outcome, whether it is to reduce blood flow to a tumor or to block an aneurysm (Hu, et al., 2021).
4. **Monitoring and Adjustments**: Throughout the procedure, continuous monitoring is necessary to assess the progress and effectiveness of the embolization. Adjustments may be made in real-time to ensure that the embolic agents are adequately blocking the blood flow without affecting neighboring structures (Hur, et al., 2014).
5. **Post-Procedure Care**: After the embolic agents have been successfully deployed, the catheter is removed, and the incision site is closed. Post-procedure care involves monitoring the patient for any immediate complications, such as bleeding at the catheter insertion site or reactions to the embolic material. Patients typically remain under observation for several hours before being allowed to go home (Hemingway & Allison, 1988).
6. **Follow-Up and Long-Term Monitoring**: Follow-up appointments are crucial to monitor the long-term effectiveness of the embolization and to detect any late-onset complications. Additional imaging tests may be conducted in the weeks or months after the procedure to ensure that the embolic agents are still correctly positioned and that the desired therapeutic outcome has been maintained (van der Linden, et al., 2009).

7. **Evaluation of Procedure Success and Potential Retreatment**: In some cases, further treatment may be necessary if the initial embolization does not achieve the desired result or if the condition recurs. The decision for retreatment is based on follow-up evaluations and ongoing patient symptoms (Srinivasan, et al., 2022).

1.8. Embolization Practice in Neurosurgery

Embolization has significantly evolved since its initial application in the 1970s for treating arteriovenous malformations (AVMs), advancing to a critical adjunct in neurosurgical procedures for complex vascular lesions. This progression is marked by substantial developments in embolic materials and technologies. Originally employing simple materials such as autologous clots, as mentioned above, embolization technology advanced by the late 1980s with the introduction of innovations like liquid embolic agents (e.g., Onyx) and detachable coils, crucial for enhancing control and efficacy in neurosurgical settings (Bristol, et al., 2006). The precision of embolization further improved with the adoption of digital subtraction angiography (DSA) in the 1990s, which provided detailed, real-time vascular imaging essential for planning and executing interventions (Reilley, et al., 1983). As embolization technology matured, its applications broadened to include preoperative treatments of tumors and aneurysms, demonstrating significant benefits such as reduced surgical time and minimized intraoperative bleeding (Griessenauer, et al., 2016). Embolization is now routinely employed as an adjunct to neurosurgery, particularly for managing highly vascular lesions. This method facilitates surgical procedures by reducing the vascularity of tumors preoperatively, thereby easing their resection and diminishing intraoperative blood loss. The synergy between embolization and surgery simplifies complex surgical procedures and enhances patient safety and outcomes, as highlighted in various studies (Kendall & Moseley,

1977) (Lefkowitz, et al., 1998). Embolization utilizes a variety of embolic agents specifically tailored to the neurovascular lesion's characteristics. Coils, made from platinum or stainless steel, induce blood clotting and are commonly used in treating aneurysms (Brassel & Meila, 2015). Particles such as polyvinyl alcohol (PVA) or embospheres are chosen based on the vessel size and desired occlusion level to block or reduce blood flow (Kaufman, 1979). For targeted occlusions of small vessels or complex lesions, liquid embolic agents like cyanoacrylate glue or ethylene-vinyl alcohol copolymer (Onyx) are preferred, solidifying within vessels to create permanent blockages (Nguyen, et al., 2016).

These agents are integral in preoperative or adjuvant embolization for CNS tumors, especially highly vascularized tumors such as meningiomas, hemangioblastomas, and solitary fibrous tumors (SFTs), or those situated in critical regions. This strategic targeting of tumor-supplying vessels to decrease vascularity and facilitate surgical resection is well articulated in various studies. By reducing intraoperative bleeding, embolization enhances surgical safety and is pivotal in optimizing treatment outcomes, as explored in numerous research (Texakalidis, et al., 2019), (Gellad, et al., 1990). This transformative technique underscores the collaboration between neurosurgery and interventional radiology, reshaping neurosurgical practices for complex CNS tumors (Nelson, et al., 1994). However, the specific utility of preoperative embolization in CNS SFT management remains under-researched due to the tumors' rarity, a concern raised in recent studies (Mashaly, et al., 2017). This highlights the ongoing need for research to fully understand and harness embolization's potential in treating such rare conditions.

1.9. Solitary Fibrous Tumors (SFTs) and CNS Challenges

Solitary Fibrous Tumors (SFTs), also historically known as hemangiopericytomas, are now categorized under a unified classification as a single entity in the 2021 WHO Classification of

Tumors of the Central Nervous System (WHO Classification of Tumors Editorial Board, 2021), due to their shared genetic and pathogenetic characteristics. These tumors originate from fibroblastic or fibroblast-like cells and are a relatively rare form of tumor that can occur in various locations, including but not limited to the central nervous system (CNS), pleura, and mediastinum. The unification of these tumors under one category is based on significant genetic similarities, specifically the presence of the NAB2-STAT6 gene fusion, which is a hallmark of this tumor type (Shin, et al., 2021). Solitary Fibrous Tumors in the CNS are particularly rare, accounting for less than 1% of all SFTs. They predominantly affect adults and show a slight female predominance. Within the CNS, SFTs typically arise from structures such as the meninges, cranial nerves, or spinal cord, manifesting as slowly enlarging masses that can complicate diagnostic and therapeutic approaches. The rarity and diverse locations of CNS SFTs pose significant challenges in both diagnosis and treatment (Jiang, et al., 2017). Histopathologically, CNS SFTs are characterized by a distinctive patternless arrangement of spindle-shaped cells embedded in a collagen-rich stroma. They often display features reminiscent of the old classification of hemangiopericytoma, including alternating areas of cell density and branching, thin-walled blood vessels. Immunohistochemical staining is crucial for diagnosing these tumors, with markers such as CD34, CD99, and Bcl-2 typically showing positivity. This staining helps distinguish SFTs from other CNS tumors (Westra, et al., 1994). Imaging techniques such as MRI or CT scans reveal that CNS SFTs often exhibit heterogeneous characteristics, which can complicate the preoperative diagnosis. Their variable vascularity also affects the planning and efficacy of treatments such as preoperative embolization, a technique used to decrease tumor blood supply and facilitate safer surgical resection. However, the utility of embolization in CNS SFTs is not well-established due to their rarity and the limited clinical data available (Arai, et al., 2023). The primary treatment for CNS SFTs typically involves

surgical resection, aimed at complete removal of the tumor. This approach is often curative for localized tumors and provides long-term control. However, achieving complete resection can be challenging, particularly when tumors are located in critical or hard-to-reach areas of the CNS. In some cases, complete removal is not feasible, which necessitates considering other therapeutic strategies to manage the disease effectively (Jiang, et al., 2017). This comprehensive understanding and approach to treating CNS SFTs underscore the importance of interdisciplinary collaboration between neurosurgery and interventional radiology. By combining advanced diagnostic imaging, histopathological analysis, and tailored surgical and interventional techniques, medical professionals can optimize treatment outcomes and minimize complications for patients with this challenging and rare tumor type. Such collaborative efforts continue to reshape the landscape of neurosurgical practice and highlight the critical role of integrated medical strategies in managing complex CNS tumors.

1.10. Challenges and Management of CNS SFTs

The management of solitary fibrous tumors (SFTs) in the central nervous system (CNS) typically prioritizes surgical resection as the primary treatment strategy, with the goal of complete tumor removal when feasible. Achieving complete resection is often curative for localized tumors, offering long-term control. However, the feasibility of complete removal can be limited, particularly when tumors are situated in critical or hard-to-reach areas of the CNS. Challenges in surgical treatment for CNS SFTs arise from several factors:

1. **Tumor HN**: CNS SFTs may appear in diverse and often complex locations within the brain and spinal cord, including near vital structures like blood vessels and nerves or in areas that control essential functions. These locations may necessitate sophisticated surgical approaches

to ensure complete resection while minimizing potential damage to critical surrounding structures (Bisceglia, et al., 2011).

2. **Tumor Size and Vascularity**: Large and highly vascularized CNS SFTs pose increased risks of intraoperative bleeding, complicating surgical excision. Preoperative or adjuvant embolization can be employed to diminish tumor vascularity by obstructing blood flow, potentially easing surgical procedures by reducing bleeding risks. Nonetheless, the effectiveness of embolization varies based on the tumor's vascularity and the success of the embolization technique itself (Ladner, et al., 2014).
3. **Risk of Incomplete Resection**: Despite advances in surgical and adjuvant therapies, achieving a complete resection of CNS SFTs may not always be possible, especially for tumors in eloquent or critical regions. In such cases, residual tumor tissue might be intentionally left to avoid significant neurological deficits, increasing the risk of tumor recurrence and potentially necessitating further adjuvant treatments (Swaminathan, et al., 2022).
4. **Adverse Effects of Embolization**: While embolization serves as a valuable adjunct to surgical resection, it carries its own risks, including vascular injury, ischemic damage to surrounding tissues, or unintended embolization of nearby vessels, which can lead to adverse neurological outcomes. The balance between the potential benefits and risks of embolization requires meticulous consideration and expertise from interventional radiology specialists (Tanaka, et al., 2018).
5. **Lack of Standardized Protocols**: There is a noticeable absence of standardized protocols for the timing, techniques, and patient selection for adjuvant embolization in managing CNS SFTs. The limited high-quality evidence available results in variability in clinical practice among

healthcare providers and institutions, highlighting the need for established guidelines to optimize treatment outcomes and minimize complications (Kim, et al., 2018).

In summary, the management of surgical treatment options for CNS SFTs is complicated by various factors, including the tumor's location, size, vascularity, risk of incomplete resection, and the challenges associated with adjuvant embolization. These issues underscore the importance of a multidisciplinary approach involving neurosurgeons, interventional radiologists, neuro-oncologists, and other relevant healthcare professionals to devise personalized treatment plans. In scenarios where complete resection is unachievable or if the tumor recurs post-operatively, alternative adjuvant treatments such as radiation therapy or chemotherapy might be considered, though their efficacy in CNS SFT management remains underexplored and not well-established.

1.11. Purpose of this literature review

This review was conducted in order to create a comprehensive, evidence-based summary of the current state of knowledge in this specific area of medical practice, which can serve as a valuable resource for healthcare professionals, researchers, and decision-makers involved in the management of SFTs, to provide a comprehensive overview of the current evidence on the use of embolization as a preoperative treatment, as well as to identify any existing gaps in knowledge.

This systematic literature review aims in assessing recent trends on Preoperative Embolization in the Management of Solitary Fibrous Tumors of the CNS. Specific research questions that do not fall under the purview of this paper, but can by analysed in future studies include the following:

1. What are the new methods, materials and intravascular techniques utilised in the research procedure?

2. What are the specific benefits/outcomes in reducing tumor vascularity and blood loss, making surgical resection easier and safer and providing additional benefits when dealing with inaccessible CNS regions?
3. Are there any different individualized approaches concerning unique regions of the CNS?

2. MATERIALS AND METHODS

2.1. Protocol Development

Our research protocol stands as a testament to the meticulous planning and methodological rigor underpinning our investigation. Drafted in adherence to the Preferred Reporting Items for Systematic Reviews and Meta-analysis Protocols (PRISMA) guidelines, it underwent rigorous scrutiny and refinement.

2.2. Eligibility Criteria

The delineation of our review's scope was underpinned by the establishment of stringent inclusion criteria aimed at guaranteeing the relevance and specificity of our findings. Papers elucidating medical interventions conducted on human subjects were included, ensuring a comprehensive examination of the available literature. With a notable emphasis on the Preoperative Embolization in the Management of Solitary Fibrous Tumors of the Central Nervous System (CNS) procedure, studies detailing interventions performed specifically in this context were prioritized. Moreover, we imposed a temporal constraint, restricting our selection to papers published exclusively in the English language between the years 2013 and 2024. Following this initial screening, a meticulous review process ensued. Additionally, to further refine the focus of the present study, publications addressing nasal and oral solitary fibrous tumors were subsequently removed from consideration. Publications not directly pertinent to CNS solitary fibrous tumors were systematically eliminated.

2.3. Information Sources

A cornerstone of the present methodology lay in the comprehensive exploration of existing literature. To this end, exhaustive searches were conducted across electronic bibliographic databases, with PubMed serving as our primary source of inquiry. Leveraging the wealth of resources available, our searches were meticulously executed, culminating in a final exploration

on March 13, 2024. Prior to execution, our search strategy underwent rigorous peer review by an esteemed expert, ensuring its methodological soundness and comprehensiveness. Following retrieval, the acquired results were meticulously curated, with duplicate entries systematically expunged to maintain the integrity of our dataset.

2.4. Search Strategy

Central to the investigative process was the formulation of a robust search strategy tailored to the nuances of our research domain. Employing a judicious combination of relevant keywords and Boolean operators, our query aimed to cast a wide net while maintaining precision. Crucially, filters were set to encompass results published within the past decade, aligning with our commitment to capturing the most contemporary advancements in the field.

More specifically: the Pubmed advanced builder tool for the present research was utilized. In the query box, the following keywords were entered: "Solitary fibrous tumors OR Hemangiopericytoma AND Preoperative AND Embolization OR Endovascular." The focus was placed on the Title/Abstract field to narrow the search to articles where these keywords appeared prominently. This approach was chosen to ensure that the articles we included primarily addressed preoperative embolization for solitary fibrous tumors, rather than mentioning it only as a secondary topic.

Next, search criteria were refined by specifying articles published within the past 11 years, starting from 2013, and limited our focus to studies involving adult human subjects aged over 15 years.

Further refinement was undertaken by excluding articles that discussed anatomical areas outside the central nervous system (CNS), such as the pleura or mediastinum. Additionally, studies related to the nasal cavity, oral cavity, and external auditory canal were omitted. Articles discussing non-

relevant procedures, such as separation surgeries or radiotherapy, as well as those pertaining to other tumor types or congenital malformations were excluded.

These stringent criteria allowed the acquisition of a more focused and relevant pool of articles for our study, enhancing the precision and applicability of our findings.

2.5. Results

The culmination of the search efforts yielded a trove of potential sources, totaling 66 results. However, recognizing the imperative of quality over quantity, a stringent process of critical appraisal ensued. Through meticulous evaluation, this initial pool was judiciously distilled to a refined selection of 24 publications deemed most pertinent to our research objectives. Each identified result underwent thorough scrutiny by an expert researcher to ascertain its relevance, validity, and methodological robustness.

2.6. Selection of Sources of Evidence

Integral to the integrity of our review process was the establishment of a systematic approach to source selection. To mitigate bias and ensure consistency, a methodical screening process took place involving two independent investigators (M.K, the thesis author and the thesis supervisor, T.K), wherein titles and abstracts were sequentially evaluated against predefined criteria took place. Any discordance or ambiguity in selection was addressed through collegial deliberation including a third investigator (committee member G.S), with consensus reached among team members. Additionally, the involvement of expert oversight provided further assurance of the fidelity and rigor of our selection process.

In summation, the research protocol exemplifies a comprehensive and meticulous approach to scientific inquiry. From the formulation of the search strategy to the curation of our final dataset,

every facet of our methodology reflects a commitment to excellence and transparency in pursuit of knowledge. The relevant diagram representing our approach can be found below:

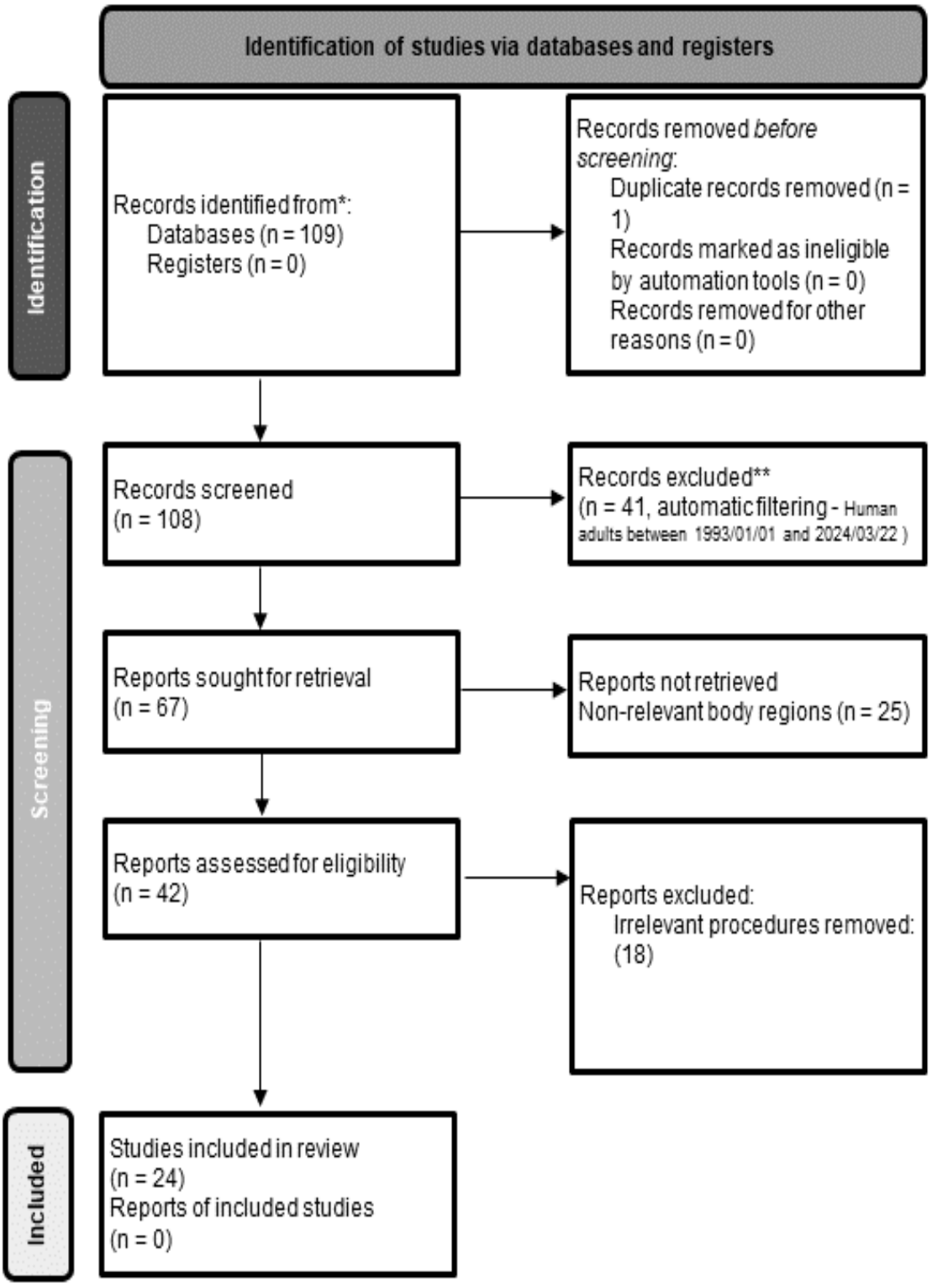

Figure 0-1: PRISMA 2020 flow diagram for our systematic review which included searches of the PubMed database.

3. RESULTS

Utilizing the PubMed advanced builder tool, the present search was tailored to specific keywords: "*Solitary fibrous tumors OR Hemangiopericytoma AND Preoperative AND Embolization OR Endovascular*" within the Title/Abstract field. Our search criteria were further refined by limiting articles to those published within the past 11 years, starting from 2013, and involving adult human subjects aged over 19 years.

3.1. Stages of research

The research process using the PubMed advanced builder tool unfolded in four distinct stages:

Stage 1: Initial Search

109 articles were initially identified as potentially relevant to our research objectives using the PubMed advanced builder tool. The next aim was to distill a vast body of literature into concise and relevant insights, laying the groundwork for scholarly inquiry. Recognizing the necessity for precision and scholarly integrity, a process of refinement was initiated, scrutinizing each article against predefined criteria to determine its alignment with the research aims.

Stage 2: Refinement

66 articles remained under consideration for further analysis after this initial curation. To maintain focus and relevance, articles deviating from the core subject matter were excluded from the study. This meticulous selection process ensured that the research scope remained clear and well-defined.

Stage 3: Thorough Evaluation

26 articles were meticulously curated as the final set for in-depth examination. Each article underwent thorough evaluation, prioritizing its potential contribution to the research discourse, with a focus on relevance and depth of insight. Following this curation, further refinement

excluded articles discussing anatomical areas outside the central nervous system (CNS), such as the pleura or mediastinum. Additionally, studies related to the nasal cavity, oral cavity, and external auditory canal were omitted, alongside non-relevant procedures like separation surgeries or radiotherapy. Moreover, articles pertaining to other tumor types (Hemangioblastoma, osteosarcoma etc.) or congenital malformations were excluded to ensure a concentrated focus on preoperative embolization for solitary fibrous tumors. This meticulous approach enhanced the relevance and specificity of our research findings. Furthermore, two duplicate articles were identified and subsequently removed from the dataset to maintain the integrity of the research results.

Stage 4: Final Selection

24 articles comprised the ultimate curated collection, each presenting unique perspectives and valuable insights relevant to the research inquiry. These articles form the foundation upon which the subsequent phases of the research will be built, offering a solid framework for further analysis and exploration in the field.

3.2. Grouping

Considering the increased diversity and distinctive properties of various central nervous system (CNS) regions, we have further categorized the **24 final articles into three distinct groups**. This subdivision was prompted by two primary observations. Firstly, recurring patterns and techniques, such as the use of embolic agents, within similar CNS regions could be identified. Secondly, an additional aim of the study was the safety and accuracy of the findings by acknowledging the unique characteristics inherent to each group, thus treating them as separate categories.

The three delineated groups are as follows (Table 2):

Id	Paper	SFT location	Publication Type	No of patients with SFTs	Embolic agent	Direct / Intra-arterial embolization
1	Fusco, et al., 2016	Intracranial	Case Series	1 (out of 5)	Onyx	Intra-arterial
2	Li, et al., 2021	Intracranial	Case Series	3 (out of 13)	-	Intra-arterial
3	Arai, et al., 2023	Intracranial	Case Report	1	-	Intra-arterial
4	Iampreechakul, et al., 2016	Intracranial	Review	6 (out of 37)	-	Intra-arterial
5	Almefty, et al., 2017	Intracranial	Case Series	1 (out of 2)	Onyx	Intra-arterial
6	Hanak, et al., 2015	Intracranial	Case Series	15	Onyx	Intra-arterial
7	Ding, et al., 2013	Intracranial	Case Report	1	Onyx	Direct
8	Tobias, et al., 2021	Intracranial	Review	43	-	Intra-arterial
9	Yammine, et al., 2018	Intracranial	Case Report	1	PVA	Intra-arterial
10	Moscote-Salazar, et al., 2014	Intracranial	Review	-	Mixed (Gelfoam, Coils, PVA)	Intra-arterial
11	Hayakawa, et al., 2015	Intracranial	Case Series	1 (out of 2)	PVA	Intra-arterial
12	Lavrador, et al., 2015	Spinal	Case Report	1	-	Intra-arterial
13	Kvaščevičius, et al., 2022	Spinal	Case Report	1	Onyx	Intra-arterial
14	Yamada, et al., 2020	Spinal	Case Series	2	Gelfoam	Intra-arterial
15	Onoki, et al., 2017	Spinal	Case Report	2	-	Intra-arterial
16	Mashaly, et al., 2017	Spinal	Case Report	1	Onyx	Direct
17	Menaker, et al., 2023	Spinal	Case Report	1	Mixed (Coils, Gelfoam)	Intra-arterial
18	Yazıcı, et al., 2022	Orbital	Case Report	1	-	Intra-arterial
19	Vijitha, et al., 2020	Orbital	Case Report	1	Onyx	Direct
20	Demura, et al., 2019	Orbital	Case Report	1	Mixed (NBCA, Coils)	Intra-arterial
21	Wang, et al., 2021	Orbital	Case Report	1	Onyx	Intra-arterial
22	Wallace, et al., 2014	Orbital	Case Report	1	NBCA	Intra-arterial
23	Kishimoto, et al., 2014	Orbital	Case Report	1	-	Intra-arterial
24	Mian & Gilliland, 2019	Orbital	Case Report	1	Coils	Intra-arterial

Table 2: Summary table of data examined.

Group 1: Intracranial solitary fibrous tumors

The group contains **11 articles**:

1. Preoperative Embolization of Extra-axial Hypervascular Tumors with Onyx. (Fusco, et al., 2016). In this study five patients were treated with one diagnosed with SFT and the other four having hypervascular meningiomas. Each patient underwent embolization within 24 hours prior to their surgical procedure and all procedures were completed without any complications. Onyx was used as the embolic agent in all cases supporting existing evidence of its safety and effectiveness for preoperative tumor embolization. The study underscores the benefit of achieving significant devascularization via a single supplying pedicle typically involving the MMA and STA as the primary feeding arteries this paper is a case series.
2. Microsurgical intracranial hypervascular tumor resection immediately after endovascular embolization in a hybrid operative suite: A single-center experience. (Li, et al., 2021). This paper investigates 13 patients with hypervascular tumors, including three with SFTs. Each patient underwent preoperative embolization, and only one experienced a catheterization-related bleeding complication. Gross total resection was achieved in 12 of the 13 cases. The average blood loss during microsurgical resection was significantly reduced to around 703.8 ± 886.8 mL. Postoperative outcomes revealed that symptoms improved in three patients and remained stable in six. The study demonstrates that one-stage hybrid embolization prior to intracranial hypervascular tumor resection is both safe and effective for minimizing intraoperative blood loss. This approach prevents or quickly addresses embolization-related complications, reducing the need for multiple surgeries. Preoperative embolization significantly decreases blood loss, can be done in a single stage, allows immediate management of complications, and enhances overall surgical safety. This study is a case series.

3. Surgical treatment for extremely rare solitary fibrous tumors of the central nervous system originating from cranial nerve VIII: new clinicopathological findings. Illustrative case. (Arai, et al., 2023). This article states that confirming the diagnosis is crucial because immediate and complete removal of the tumor is ideal for SFTs. In this case, preoperative embolization was performed only on the tumor's external carotid artery system, leaving the vertebrobasilar system feeder, which led to unexpected bleeding. The diagnosis of a neurogenic SFT of the CNS was made based on intraoperative and pathological findings. Neurogenic SFTs of the CNS require careful treatment due to the high likelihood of incomplete resection, diagnostic challenges, strong adhesion to surrounding nerves, and difficulties in hemorrhage control. A prompt full-body examination is recommended when diagnosing intracranial SFTs. This article is a case report.
4. Pre-operative Embolization of Intracranial and Extracranial Tumors: A Review of 37 Cases. (Iampreechakul, et al., 2016). In this research among 37 patients with hypervascular intracranial tumours six were diagnosed with SFTs it was found that pre-operative embolization of intra- and extracranial tumors is in general a safe procedure however only extensive or complete angiographic devascularization effectively minimized intra-operative blood loss this study outlines specific indications for pre-operative embolization such as a history of significant bleeding in previous surgeries presence of hypervascular tumors like SFT, hemangioblastoma and paraganglioma multiple flow voids seen on mri hypervascular tumors of the skull the scalp and deep-seated tumors including those of the cranial base or intraventricular locations where early surgical access to primary feeding vessels is difficult and tumors with intratumoral aneurysms this article is a review.

5. Hybrid Surgery Management of Giant Hypervascular Tumors: Intraoperative Endovascular Embolization with Microsurgical Resection. (Almefty, et al., 2017). In the present paper, out of the two patients, 1 had an SFT. Intraoperative embolization facilitates the safe resection of giant hypervascular tumors and mitigates the consequences of potential tumor infarction, hemorrhage, or swelling from embolization. These cases exemplify the benefits of combining expertise in endovascular and microsurgical techniques within modern hybrid operating rooms, allowing for their simultaneous application. Giant hypervascular intracranial tumors represent a formidable challenge due to their size, which limits surgical control of the blood supply, and the risk of critical blood loss during debulking. While embolization aids in resection, it carries the risk of life-threatening tumor infarction, hemorrhage, or swelling if performed preoperatively. Endovascular intraoperative embolization avoids these fatal risks and allows the surgeon to address any complications instantly. The primary embolic agent used in these cases was onyx. This article is a case series.
6. Preoperative embolization of intracranial hemangiopericytomas: case series and introduction of the transtumoral embolization technique. (Hanak, et al., 2015). In this paper 15 cases of SFTs who underwent preoperative embolization were reviewed . In larger SFTs, preoperative embolization did not significantly reduce operative blood loss, highlighting the potential hazards associated with direct ICA circulation embolization approaches. A careful review of the pre-embolization angiogram, combined with an understanding of angiographically silent ECA–ICA anastomoses, is critical to minimizing the risk of ECA embolization complications such as blindness and cranial nerve palsies. It was found that HPCs with an ECA-dominant blood supply were more completely embolized compared to ICA/VB-dominant tumors. While ECA-dominant tumors can be well embolized with particles, ICA/VB-dominant HPCs

represent a challenging endovascular dilemma. However, using a novel transtumoral technique with Onyx, near-total embolization was achieved in ICA/VB-dominant tumors while avoiding the risks associated with embolizing directly from the pial vessels. This article is a case series.

7. Onyx embolization of an intracranial hemangiopericytoma by direct transcranial puncture. (Ding, et al., 2013). This article presents the first reported case of an intracranial HPC treated with direct transcranial presurgical puncture using the embolic agent Onyx. This novel technique has been demonstrated to be both safe and effective. It is recommended as an alternative to traditional intraarterial embolization in situations where the conventional method is either impractical or poses a significant risk of complications. The case report details the procedural steps, outcomes, and potential benefits of this innovative approach, providing valuable insights into its application for highly vascular intracranial tumors. This article is a case report.
8. Skull base hemangiopericytomas. (Tobias, et al., 2021). A total of 43 patients with SFTs were analyzed, including 6 from a case series and 37 from a literature review. This study demonstrates that radical resection of HPC is achievable even in the complex anatomical conditions of skull base surgery. Pre-operative arterial embolization helps maintain a clear visual field and reduces excessive blood loss. Additionally, the findings suggest that EBRT can be beneficial for local growth control and as a palliative measure for skull base HPCs. This study is a review.
9. Salvage preoperative embolization of an infratemporal solitary fibrous tumor: A case report with review of the literature. (Yammine, et al., 2018). This article explores the impact of preoperative embolization on surgical outcomes particularly how it led to necrosis and softening of the tumor making the resection markedly easier this specific case used pva

microspheres 100-300μm as the embolization agent of choice the findings highlight the effectiveness of using pva microspheres in preoperative embolization showing that they significantly enhance both the ease and success of tumor removal surgeries. This article is a case report.

10. [Endovascular management of skull base tumors. A practical review on literature]. (Moscote-Salazar, et al., 2014). This article is a literature review examining the benefits of preoperative embolization in the management of skull base tumors. Key advantages include reduced intraoperative bleeding, shortened surgery duration, decreased postoperative hospital stays, and a diminished need for blood transfusions. The review also highlights a decrease in morbidity and mortality associated with the surgical management of neural tissue and vascular structures. Various embolization agents are discussed, including Onyx, PVA (150μm), gel foam, ethanol, and coils. This comprehensive review underscores the effectiveness of these embolization techniques in enhancing surgical outcomes and minimizing complications. This study provides an in-depth analysis of the benefits and options available for preoperative embolization.
11. Modified Balloon Protection Technique for Preoperative Embolization of Feeder Arteries from Internal Carotid Artery Branches to Skull-Base Tumor: Technical Note. (Hayakawa, et al., 2015). In this article, two patients with hypervascular tumors were studied, one of whom had an SFT. The microcatheter could not be threaded into the ICA feeder arteries, so particulate embolic material was injected near the ICA branch while maintaining ICA balloon protection with the PGWS at the orifice of the ophthalmic artery. After embolization, an aspiration catheter removed the remaining embolic material in the ICA. Both cases had no post-embolization complications or high-intensity areas in the diffusion-weighted MRI, allowing

the tumorectomy to proceed as scheduled. This article was a case series using PVA as the primary embolic agent. This article is a case series.

Group 2: Spinal solitary fibrous tumors

This group contains **6 articles:**

1. Dumbbell-shaped spinal solitary fibrous tumor: Combined approach and a review of the literature. (Lavrador, et al., 2015). This report describes a unique case of a dumbbell-shaped SFT marking the first instance where preoperative embolization was part of the surgical planning. This highly vascular tumor benefits from an integrated neuroradiology-neurosurgical intervention to achieve total resection of the tumor which remains on of the the primary goals in the management of SFTs. This article is a case report
2. A Case Report of Rare Sacral Solitary Fibrous Tumor. (Kvaščevičius, et al., 2022). This report describes a unique case of a large primary epidural SFT in the sacrum. Preoperative endovascular tumor embolization was preformed. A two-staged piecemeal tumor resection using a combined anterior and posterior approach may be more radical and safer than a single-staged surgery, providing better control of the tumor and surrounding structures. This combined approach can preserve normal neurological function and maintain a good quality of life for the patient. To date, the patient shows no signs of tumor recurrence despite refusing adjuvant radiotherapy. This article is a case report.
3. Combination therapy with preoperative embolization and en block laminectomy using thread saw for spinous process solitary fibrous tumor: A case report. (Yamada, et al., 2020). This report describes two cases of primary SFTs. In the first case, gel foam was used, while the second case did not mention the embolic material. In conclusion, the combination of preoperative embolization and en bloc laminectomy using a thread saw was found to be

effective for spinous process SFTs. This strategy is believed to be useful for controlling intraoperative bleeding and achieving gross tumor resection in spinous process SFTs. This study was a case series.

4. Recurrent primary osseous hemangiopericytoma in the thoracic spine: a case report and literature review. (Onoki, et al., 2017). This report details a case in which preoperative embolization of spinal SFT at the level of T5-T7 was carried out to prevent uncontrollable bleeding during surgery. The patient underwent a total spondylectomy and spinal reconstruction with instrumentation, indicating that this technique may be effective for safely and adequately excising recurrent HPC of the spine. However, it is essential for patients to be closely monitored for local recurrence and potential malignant degeneration of the tumor post-surgery. This study is a case report.
5. Intraoperative Transpedicular Onyx Injection to Reduce Vascularity of a Thoracic Hemangiopericytoma After Unsuccessful Preoperative Endovascular Embolization: a Technical Report. (Mashaly, et al., 2017). This study describes a case where a T12 hemangiopericytoma was treated using a two-stage surgical resection, which included a direct intraoperative transpedicular injection of the embolic agent Onyx. Preoperative endovascular embolization may not always be possible due to the location of segmental or radiculomedullary arteries relative to tumor feeders or the small size of these arterial feeders. In such scenarios, percutaneous Onyx injection can be an alternative. This case report demonstrates that direct intraoperative injection via the transpedicular route is a safe and effective method for decreasing lesion vascularity and managing intraoperative blood loss. This study is documented as a case report.

6. Intracranial solitary fibrous tumor with delayed symptomatic metastasis to the lumbar spine: illustrative case. (Menaker, et al., 2023). This paper describes an extremely rare case of an intracranial SFT that metastasized to the spine six years after the initial treatment, specifically targeting the L4 vertebral body. This metastasis caused central canal stenosis, leading to the patient experiencing low back pain and radiculopathy of the lower extremitie. The treatment included successful preoperative embolization using a combination of particles, coils, and gelfoam, followed by spinal decompression and posterolateral instrumented fusion. This study is a case report.

Group 3: Orbital solitary fibrous tumors

This group contains **7 articles:**

1. Preoperative Endovascular Embolization of Orbital Solitary Fibrous Tumor With 500-700 Micron Tris-Acryl Gelatin Microspheres. (Yazıcı, et al., 2022). This report describes an exceedingly rare case where endovascular tumor embolization was performed using 500-700 μm tris-acryl gelatin microspheres (TAGM). Two days later, the tumor was entirely removed with minimal bleeding. There were no embolization- or surgery-related complications, and no tumor recurrence or metastasis was observed during the 42-month postoperative follow-up. This study is presented as a case report.
2. Preoperative embolisation of orbital solitary fibrous tumour. (Vijitha, et al., 2020). This article describes a rare case involving a patient whose initial surgical excision was halted due to significant intraoperative bleeding. Diagnosed with a hypervascular orbital solitary fibrous tumor (SFT), the patient ultimately achieved a successful outcome through a combination of preoperative percutaneous embolization with Onyx under fluoroscopic guidance, followed by surgical resection and adjuvant radiotherapy. Onyx, a non-adhesive liquid embolic agent,

solidifies upon contact with the vessel wall, causing vascular occlusion. This preoperative embolization technique effectively reduced the vascularity of the orbital SFT, facilitating easier dissection and complete surgical excision with minimal blood loss. This study is a case report.

3. Intraorbital Solitary Fibrous Tumor Requiring Preoperative Embolization of Feeding Artery. (Demura, et al., 2019) . This report describes a rare case of a patient with a hypervascular orbital solitary fibrous tumor (SFT) supplied by multiple feeders. To control intraoperative blood loss, the patient first underwent preoperative embolization using a combination of coils and n-butyl-2-cyanoacrylate (NBCA). This was followed by complete surgical excision using a combination of endoscopic endonasal approach and craniotomy. This dual technique minimized blind spots and prevented severe bleeding. The patient's postoperative recovery was uneventful, with preoperative diplopia being the only remaining issue. This study is a case report.
4. Preoperative transarterial embolization of a recurrent orbital solitary fibrous tumor with significant hypervascularity: a case report. (Wang, et al., 2021). This report presents a patient with a history of resected solitary fibrous tumor (SFT) who experienced a recurrence, resulting in proptosis and vision loss. Due to the lesions not being visible, preoperative transarterial embolization with Onyx (instead of direct embolization) was used instead of percutaneous embolization. Following this, ocular enucleation was performed to enhance exposure for complete tumor removal. Embolization of the distal branch of the right internal maxillary artery and the right ophthalmic artery significantly reduced the blood supply, allowing for enucleation and tumor resection with minimal blood loss and no further complications. This study is a case report.

5. Endovascular preoperative embolization of orbital hemangiopericytoma with n-butyl cyanoacrylate glue. (Wallace, et al., 2014). This report describes a unique case of a hypervascular orbital tumor with multiple feeder vessels arising from the third segment of the left ophthalmic artery and the nasofrontal branch of the internal maxillary artery, as demonstrated by a diagnostic cerebral angiogram. Due to the extensive vascularity, the patient underwent preoperative embolization with n-butyl cyanoacrylate for the surgical resection of the large orbital SFT. The estimated intraoperative blood loss was minimal, and the patient was discharged the next day in good condition. This article is a case report.
6. [A case of intraorbital solitary fibrous tumor resected successfully with preoperative arterial embolization]. (Kishimoto, et al., 2014). This article details a rare case of an orbital solitary fibrous tumor (SFT) treated with preoperative endovascular embolization. MRI and CT scans revealed an intraorbital lesion, and a biopsy confirmed the SFT diagnosis by identifying spindle cells. The infraorbital artery was embolized, enabling the tumor's excision through a lower rim orbital incision with minimal bleeding. The tumor's close proximity to the lacrimal canaliculus suggested its origin from the lacrimal apparatus. The patient experienced no recurrence during the three-month follow-up period. This study is a case report.
7. Managing a long-recurring primary orbital hemangiopericytoma. (Mian & Gilliland, 2019). This case involves a patient with a recurrent benign left medial orbital SFT, who had undergone six surgical procedures over 22 years. Preoperative embolization was performed to achieve vascular control. The left internal carotid artery was stented, and bead and coil embolization of the left ophthalmic and internal maxillary arteries resulted in expected blindness of the left eye. The tumor was surgically resected the next morning. Initial surgeries had managed mild to

moderate proptosis and preserved vision, allowing several years of good visual function. This article is a case report.

4. DISCUSSION

The solitary fibrous tumor (SFT) is a rare spindle cell neoplasm derived from mesenchymal cells. It is known to recur clinically and is classified as a tumor of 'intermediate malignancy' under the World Health Organization (WHO) classification of soft tissue tumors (WHO Classification of Tumours Editorial Board, 2020). SFTs of the central nervous system (CNS) demonstrate higher rates of local recurrence (61%–76%) and metastasis (23%–64%) (Arai, et al., 2023). Despite aggressive multimodality management, the five-year recurrence-free survival rate reported in a modern series was 60% (Ding, et al., 2013). The average survival following gross total resection combined with external beam radiation therapy (EBRT) was 83.6 months (Tobias, et al., 2021). Accurate diagnosis is crucial for SFTs because immediate and complete tumor removal is ideal.

Although the role of preoperative embolization is not yet well-defined as the gold standard before the resection of CNS solitary fibrous tumors (SFTs), significant advancements have been made in the preoperative embolization management of these tumors. Considering all factors, the total resection of every CNS solitary fibrous tumor should always be the primary goal, whenever feasible, regardless of its location (intracranial, spinal, or orbital) due to the increased likelihood of local recurrence.

The present review identified recent trends in the preoperative embolization of SFTs based on the findings of studies grouped into 3 different categories discussed below. Most identified studies concerned intracranial SFTs.

Intracranial solitary fibrous tumors

In the studies included and analyzed in this review, 120 patients underwent preoperative embolization of a hypervascular CNS tumor; 73 of these tumors were SFTs. The embolic agent

most commonly used was Onyx. The management of intracranial HPCs involves aggressive microsurgical resection, aiming for total resection whenever feasible. In cases of subtotal resection, such as with gigantic tumors, areas that are difficult to access, neurogenic SFTs, or in instances of recurrence, management includes radiation with or without chemotherapy (Ding, et al., 2013). While pre-operative embolization of intra- and extracranial tumors was safe, only extensive or complete angiographic devascularization proved effective in reducing intra-operative blood loss (Iampreechakul, et al., 2016). However, in larger tumors, preoperative embolization did not significantly reduce operative blood loss (Arai, et al., 2023), (Iampreechakul, et al., 2016), (Hanak, et al., 2015). Technical and practical challenges, along with potential risks associated with pre-operative embolization of SFTs, may occur, particularly when embolizing feeders from the internal carotid artery or the vertebrobasilar system. A careful review of pre-embolization angiograms, combined with an understanding of angiographically silent external carotid artery (ECA)–internal carotid artery (ICA) anastomoses, is critical to minimizing the risk of complications such as blindness and cranial nerve palsies (Hanak, et al., 2015). SFTs with an ECA-dominant blood supply were more completely embolized than ICA/vertebrobasilar (VB)-dominant tumors (Hanak, et al., 2015). While ECA-dominant tumors are effectively embolized using particles, ICA/VB-dominant HPCs present a complex endovascular challenge. Embolization of feeders from the internal carotid artery and vertebrobasilar system branches often leads to complications, and these particular feeder arteries are typically avoided, resulting in unexpected bleeding (Hanak, et al., 2015). By using a novel transtumoral technique with Onyx, near-total embolization in ICA/VB-dominant tumors can be achieved while avoiding the risks associated with embolizing directly from pial vessels (Hanak, et al., 2015). In one study particulate embolic material was injected near the ICA branch with ICA balloon protection by the permanent guiding wire system (PGWS) at the

orifice of the ophthalmic artery. Post-embolization, the remaining embolic material in the ICA was removed using an aspiration catheter (Hayakawa, et al., 2015). There were no post-embolization complications, no high-intensity areas on diffusion-weighted magnetic resonance images, and tumorectomy proceeded as scheduled (Fusco, et al., 2016), (Iampreechakul, et al., 2016), (Almefty, et al., 2017), (Hayakawa, et al., 2015).

Embolization of giant SFTs represents a formidable challenge because their size limits surgical control of the blood supply, and debulking poses the risk of critical blood loss (Almefty, et al., 2017). Embolization facilitates resection but carries the risk of life-threatening tumor infarction, hemorrhage, or swelling if performed preoperatively (Almefty, et al., 2017). Endovascular intraoperative embolization mitigates these risks and allows the surgeon to respond immediately if complications occur (Almefty, et al., 2017). Intraoperative embolization facilitates the safe resection of giant hypervascular tumors, exemplifying the benefits of combining endovascular and microsurgical techniques in modern hybrid operating rooms. One-stage hybrid embolization before intracranial hypervascular tumor resection is a safe and effective procedure to decrease intraoperative blood loss and manage embolization-related complications timely, avoiding the risks associated with multiple surgical interventions. The direct transcranial puncture route for intratumoral delivery of embolic agents is a safe and effective method and should be considered for highly vascular intracranial lesions where endovascular embolization is technically challenging or carries an unacceptably high complication risk (Almefty, et al., 2017), (Ding, et al., 2013).

Spinal solitary fibrous tumors

Spinal and sacral solitary fibrous tumors (SFTs) are indolently growing and typically asymptomatic in the early stages (Kvaščevičius, et al., 2022). However, they may cause compression symptoms ranging from radicular symptoms and lower back pain to paresis, and less

commonly, bowel and bladder incontinence. Surgery is the fundamental treatment for these tumors, and even benign SFTs should be treated with wide surgical resection when possible. Depending on the exact location of the tumor, different surgical approaches have been performed. These range from combined anterior and posterior approaches—which can be radical enough and safer than single-stage surgeries, providing good control of the tumor and the internal organs with surrounding structures—to en bloc laminectomy using a thread saw, total spondylectomy—spinal reconstruction with instrumentation (Lavrador, et al., 2015), (Kvaščevičius, et al., 2022), (Yamada, et al., 2020), (Onoki, et al., 2017). Before surgical removal, endovascular tumor embolization should always be considered, as these tumors are usually hypervascular, and thus it may help to prevent massive intraoperative bleeding (Demura, et al., 2019), (Onoki, et al., 2017). Preoperative endovascular embolization is not feasible in some cases due to the location of the segmental or radiculomedullary arteries in relation to tumor feeders, and, rarely, due to the small size of these arterial feeders (Menaker, et al., 2023). Percutaneous injection of Onyx is an alternative option. In one case report, direct intraoperative injection via a transpedicular approach was an effective method for decreasing the vascularity of some lesions and improving intraoperative blood loss (Menaker, et al., 2023). Local recurrence rates after gross total resection have been reported as high as 51.4%, and metastatic disease is observed in nearly one-third of patients (Menaker, et al., 2023). Metastasis of intracranial solitary fibrous tumors to the vertebral bones is exceedingly rare. Treatment options for metastatic disease to the spine include surgery and radiation therapy, with some evidence suggesting that combined modalities yield improved outcomes (Lavrador, et al., 2015), (Mashaly, et al., 2017).

Orbital solitary fibrous tumors

Solitary fibrous tumors (SFTs) constitute 1-3% of all orbital masses, with surgical resection being the primary treatment. If not completely removed, SFTs may recur and potentially undergo malignant transformation. These complications have been reported in up to 37% for recurrence and 12% for malignant transformation in orbital cases, respectively, and can manifest years later. Preoperative embolization is a rarely utilized technique for solid tumors in the orbit, with a recent review indicating that only 3 out of 275 patients with orbital SFT in the literature were managed with this approach (Yazıcı, et al., 2022) (Kishimoto, et al., 2014).

Complete surgical resection is the curative treatment for orbital solitary fibrous tumors. Incomplete resection is a known risk factor for recurrence and malignant transformation. Preoperative computed tomography angiography (CTA) can assess the blood supply to the lesion. Embolization can effectively reduce the vascularity of orbital SFTs and minimize intraoperative hemorrhage, making them more amenable to easier dissection and complete surgical excision. Factors such as the size and location of the tumor, patient visual function, and patient preferences should be considered when deciding the surgical approach, such as orbitotomy or craniectomy. A combined transcranial and transnasal approach can provide advantages for tumor removal and helps to significantly reduce blind spots during surgery (Yazıcı, et al., 2022) (Demura, et al., 2019) (Wang, et al., 2021).

Regarding the embolic agents used in the studies, a variety of agents were employed, including TAGM, polyvinyl alcohol, coils, Onyx (eV3-Covidien, Irvine, CA), NBCA, and particulate embospheres (150–300 μm), each aimed at facilitating complete resection and each with its unique features. TAGM may be preferred over polyvinyl alcohol as it adheres to the vascular endothelium and can remain for up to four weeks without causing severe inflammation or degeneration (Yazıcı,

et al., 2022). However, due to potential revascularization, surgical procedures should ideally be performed within a few days following embolization. It is also noteworthy that embolizing microspheres may cause allergic reactions due to their porcine gelatin content. TAGM is available in six different size ranges (40-120 µm to 900-1200 µm), and particle sizing is critical for efficacy and minimizing complications. This material may be particularly suitable for endovascular embolization in orbital solid tumors (Yazıcı, et al., 2022), (Vijitha, et al., 2020), (Wallace, et al., 2014) .

5. CONCLUSIONS

Preoperative embolization of CNS solitary fibrous tumors (SFTs) is a widely accepted procedure in neurosurgery due to its potential to minimize intraoperative blood loss and facilitate the plan for total microsurgical resection when adequate angiographic devascularization is achieved. Although generally safe, this procedure sometimes presents varying challenges depending on the vascular feeders. SFTs fed primarily by the ECA (MMA/STA), are generally easier and safer to embolize, often resulting in successful outcomes. In contrast. SFTs with complex vascular structures such as multiple feeders or those supplied by the ICA/VB or smaller segmental arteries tend to only achieve partial devascularization, which is less effective in reducing intra-operative blood loss. For high-risk cases, including those with extensive vascular networks or where traditional approaches pose significant risks, advanced techniques like one-stage hybrid intraoperative embolization in hybrid operating rooms have been utilized. In the studies reviewed, the liquid embolic agent Onyx emerged as the most commonly utilized option by a significant margin.

Suggestions for further research

Looking ahead, there is a pressing need to define the role of embolization more clearly in neurosurgical resections and to explore the long-term outcomes such as tumor recurrence, patient survival, and post-operative quality of life. Continued research into the technical aspects of embolization, including the selection and timing of embolic materials, is essential. Future efforts should aim to develop standardized protocols that are adaptable to the unique features of each SFT, supported by expanded research initiatives, potentially through multicenter collaborations. This would provide the robust data needed to enhance the safety and effectiveness of embolization procedures. The ongoing refinement of these techniques and a growing body of research will

undoubtedly improve the neurosurgical community's capability to manage these challenging tumors more effectively.

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