Implications of Glomus Tumor Pathology and Pain Mechanism for Surgical Treatment

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Glomus tumor is a rare, benign vascular neoplasm arising from the glomus body, most frequently located in subungual and fingertip regions. Despite its small size, it often causes severe paroxysmal pain and cold sensitivity, posing diagnostic and therapeutic challenges. This review summarizes current understanding of its pathological characteristics, pain mechanisms, immunohistochemical features, and surgical management. The pain arising from glomus tumors is associated with an abundance of unmyelinated nerve fibers and bioactive substances such as substance P, histamine, and cyclooxygenase-2 (COX-2), which mediate neurogenic inflammation and mechanical stimulation. Immunohistochemical analyses of the glomus tumor typically reveal positive expression of alpha-smooth muscle actin (α-SMA), muscle-specific actin (MSA), high-molecular-weight caldesmon (h-caldesmon), and vimentin, which support smooth muscle differentiation, while genetic alterations such as neurogenic locus notch homolog protein 2 (*NOTCH2*) fusion and alpha-thalassemia mental retardation syndrome X-linked (*ATRX*) deletion have been linked to tumorigenesis and malignant transformation. Microscope-assisted excision remains the gold-standard approach for treatment, achieving precise tumor removal with low recurrence and minimal postoperative nail deformity. Radiofrequency ablation emerges as a minimally invasive alternative with satisfactory long-term control for patients with high surgical risk or recurrence. In conclusion, integrating molecular insights with minimally invasive technologies holds significant promise for optimizing individualized management and advancing patient outcomes.

Keywords: glomus tumor; pain mechanism; microscope-assisted surgery; radiofrequency ablation

Introduction

Glomus tumor is a relatively rare, benign vascular tumor that usually originates from the glomus of arteriolar anastomosis. Most solitary glomus tumors occur in people aged 20 to 40 years and only account for 1.6% of all soft tissue tumors and about 1% to 5% of all hand tumors [1]. The glomus is a contractile neuromuscular arterial structure present in the reticular dermis [2]. Glomus tumor was first discovered by Pierre Masson in 1924 [3]. The confirmed lesion has a unique entity. The lesion is small in size but can cause severe pain that is disproportionate to its size [4]. In 1972, based on the detailed histological characteristics, Smith and Barnard confirmed that the lesion originates from the glomus [5]. The glomus consists of afferent arterioles, anastomotic vessels, primary collecting veins, and the intraglomerular reticular and capsule. Abnormal proliferation of any part of glomus may precipitate the formation of glomus tumor [6]. Glomus tumor can occur in any area of the human body. The most common location is the distal phalanges of human fingers, especially the subungual area. Of note, the incidence rate of finger glomus tumor is higher in women than in men [7,8]. In men, glomus tumors typically occur in other parts of the body [8,9]. Glomus tumors can be classified as solitary and multiple glomus tumors; solitary glomus tumors are characterized by a higher incidence rate, while multiple glomus tumors rarely occur in the fingers [10,11]. The three general clinical manifestations of glomus tumors are spontaneous intermittent severe pain, trigger line pain, and cold pain [12]. Although these symptoms may not occur simultaneously, they can severely impair the patient's quality of life. For patients with glomus tumor, early surgical resection represents a better therapeutic option.

This article reviews the pathological characteristics and pain mechanism of glomus tumors, providing critical insights into optimizing surgical treatment plans. By integrating the latest evidence of pain mechanisms in the context of glomus tumors, this paper highlights the implications of the advances in surgical techniques for improving diagnosis accuracy and postoperative outcomes.

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Pain Mechanisms of Glomus Tumors

Pain is a major symptom of glomus tumors. Patients with glomus tumors often experience severe paroxysmal pain due to low temperatures and pressure exerted on the hands. The pain associated with glomus tumor is typically severe, localized, and unbearable [13]. The pain mechanisms of glomus tumors remain unclear, but several widely accepted hypotheses have been proposed.

Glomus tumors contain a high density of active mast cells. When stimulated, mast cells will rapidly undergo degranulation reactions, releasing a variety of active substances including heparin, 5-hydroxytryptamine, and histamine [14]. The synergistic effect of these bioactive substances is the main contributor to the abnormal pain sensation [15,16]. By detecting substance P and neurofilament protein-H (NFH) in the glomus tumor specimens, Wu *et al*. [17] found that their expression levels were correlated with the degree of pain. The experimental results showed that substance P is the main afferent pain transmitter in the chronic pain process of hemangioma, and NFH plays an important role in pain transmission. In an immunohistochemical staining analysis, Yanai *et al*. [18] detected positive expression for S100 protein and cyclooxygenase-2 (COX-2) in isolated glomus tumor specimens obtained from eight patients, with five samples demonstrating positive expression for substance P, a vasoactive peptide 4 related to pain. Through the study, the authors proposed a possible mechanism underlying the pain development in patients with glomus tumor: Substance P and inflammatory mediators, such as COX-2 and prostaglandins, cause significant dilation and increased permeability of tumor blood vessels, leading to increased pressure in the tumor capsule. Subsequently, the increased intracapsular pressure mechanically stimulates or directly compresses the unmyelinated nerve fibers that are abundant in the tumor, ultimately leading to abnormal discharge and causing characteristic paroxysmal pain.

Although several mechanisms have been proposed, the supporting evidence varies in strength. The involvement of substance P and COX-2 has been repeatedly confirmed in immunohistochemical and clinical studies, suggesting a relatively robust basis, whereas the cold sensitivity mechanism remains less extensively validated. The cold-sensitive pain experienced by patients with glomus tumors is related to the tissue composition of the glomus. Many experiments have shown that glomus tumors are densely distributed with unmyelinated nerve fibers. When exposed to cold, the myofilaments within glomus cells contract, increasing intracapsular pressure and stimulating the surrounding nerve fibers, which contributes to pain generation [19,20].

Overall, the pain associated with glomus tumors appears to be multifactorial, involving both biochemical and mechanical pathways. Neuroactive substances such as substance P, COX-2, and histamine contribute to neurogenic inflammation and heightened pain sensitivity, while increased intracapsular pressure and mechanical compression of unmyelinated nerve fibers further amplify paroxysmal pain. Together, these mechanisms account for the characteristic triad of glomus tumor symptoms—localized tenderness, cold sensitivity, and spontaneous, severe pain.

Pathological and Molecular Mechanisms of Glomus Tumors

To better understand the underlying mechanism of pain in glomus tumors, it is necessary to explore their pathological and molecular characteristics, as the structural and genetic alterations form the biological basis for their unique clinical manifestations. The connective tissue capsule surrounding glomus tumors contains bundles of myelinated and unmyelinated nerve fibers, while the cytoplasm of glomus cells contains myofilaments similar to those of smooth muscle cells [19,20]. The glomus body itself plays a role in regulating local blood flow through the arteriovenous shunt. During temperature changes, vasodilation occurs to maintain thermal balance, thereby altering intracapsular pressure in the tumor and exacerbating the pain symptoms [21,22].

Glomus tumors are a type of benign vascular tumor derived from modified smooth muscle cells. Typical solitary lesions are often found at the fingertips or under the nails, usually less than 1 cm in diameter, and appear as red or bluish-red nodules. These lesions can result in a bulging, deformed, and discolored nail plate. In comparison, multiple glomus tumor lesions are smaller (0.1–0.3 cm), but in some cases they may exceed 3 cm, often with unclear boundaries and soft texture [23–26]. Glomus tumors are histologically characterized by a combination of vascular components, glomus cells, and smooth muscle cells. Depending on the predominance of these components, they are characterized as solid type (approximately 75%), vascular type (20%), or glomangiomyoma type (5%), with the solid type being the most common form [20]. Painful lesions are often associated with a high density of glomus cells, covered by a wide network of myelinated nerve fibers, suggesting the pain mechanism may be related to nerve fiber wrapping.

Immunohistochemistry is a crucial approach to the diagnosis of glomus tumors. Generally, glomus tumors exhibit highly expression of smooth muscle-related markers, including alpha-smooth muscle actin (α-SMA), muscle-specific actin (MSA), high-molecular-weight caldesmon (h-caldesmon), vimentin, and type IV collagen. Study reports that these markers are positively expressed in over 80%–90% of cases, indicating that the tumor exhibits stable smooth muscle–like differentiation [27]. Despite showing positivity in some cases, the extent of cluster of differentiation 34 (CD34) expression varies from case to case (about 30%–70%); therefore, it is not established as a specific marker for glomus tumor [28]. This variability may be related to the variations in tumor subtype, degree of differentiation, and stromal composition, which are accountable for the inconsistent CD34 expression among samples.

Such instability reduces its diagnostic specificity and limits its value as a reliable immunohistochemical marker in clinical practice. At the molecular level, recent studies have revealed that glomus tumors also exhibit distinct genetic features. Study of molecular and genetic has shown that familial glomus tumors are associated with abnormalities in chromosomal regions such as 1p21-22 and 11q, showing a clear genetic tendency [29]. Neurogenic locus notch homolog protein 2 (*NOTCH2*) gene alterations—particularly cardiac mesoderm enhancer-associated non-coding RNA (*CARMN*)::*NOTCH2* fusion and structural rearrangements—are regarded as key oncogenic drivers, with high detection rates in both benign and malignant forms. Moreover, alpha-thalassemia mental retardation syndrome X-linked (*ATRX*) gene deletion has been frequently observed in malignant glomus tumors and may correlate with tumor grade and biological aggressiveness [30].

Implications for Diagnosis and Surgical Treatment

The study of the pathology and pain mechanism of glomus tumors not only provides an important basis for the basic understanding of the disease, but also directly influences the development of accurate diagnostic strategies and the selection of surgical techniques. At present, diagnosing glomus tumors requires the recognition of the classic clinical triad—namely, localized tenderness, cold sensitivity, and spontaneous, severe pain—to enable their early identification. By applying a combination of several diagnostic methods, such as Love's pin test, Hildreth test, and cold sensitivity test, clinicians can successfully diagnose glomus tumors during preliminary screening with high sensitivity and specificity [31]. However, most evidence supporting these bedside tests are derived from single-center series and diagnostic cohorts; in addition, high-quality prospective studies comparing their sensitivity and specificity across anatomical sites are lacking, limiting their generalizability. The pathological basis of pain—namely, local vascular dilation, pressure buildup, and neurofiber compression—explains why these physical tests can effectively reproduce patients' pain responses, thereby improving diagnostic accuracy. Glomus tumors in other locations outside the hands and feet, similar to gastric glomus tumors and glomus jugulare tumors, are extremely rare. Compared with subungual or digital glomus tumors, visceral forms such as gastric or spinal glomus tumors often display thicker vessel walls, less prominent neural components, and distinct immunophenotypic features, which may account for their different clinical behavior and type of treatments received.

Combining clinical pathological features with imaging examinations has become the core of the diagnostic process. Patel *et al*. [32] reported that among all the imaging tools, magnetic resonance imaging (MRI) demonstrates the highest sensitivity for glomus tumors, typically showing isointense to high signal lesions on T2-weighted and STIR images. A "salt-and-pepper" appearance, reflecting the coexistence of slow-flow and fast-flow vascular components, is often observed and regarded as a typical imaging sign of glomus tumors. These MRI features correspond to the tumor's rich vascularity and smooth muscle, like structure, which aid in defining the lesion's location, size, and extent prior to surgery. High-frequency ultrasound also provides valuable complementary information. de Almeida *et al*. [33] found that in cases with bone remodeling and vascular proliferation, well-defined hypoechoic nodules with prominent internal blood flow signals on Doppler imaging serve as a characteristic reflection of the underlying pathological changes. Therefore, MRI is primarily used for localization and extent evaluation, while high-frequency ultrasound aids in assessing vascularity and nail bed involvement. By linking clinical presentation with surgical planning, these imaging modalities provide the anatomical and functional insights that guide treatment decisions. It should be noted that most imaging evidence is largely derived from retrospective case series and small cohorts. Comparative accuracy data across modalities (MRI, ultrasound, and others) are limited and heterogeneous, leaving current imaging algorithms grounded primarily in expert consensus rather than level-I evidence.

Currently, there are no standard guidelines for the diagnosis and treatment of glomus tumors. However, previous literature shows that mechanical compression of nerve fibers and vasoactive inflammatory mediators account for the pain experienced by patients with glomus tumors, explaining the failure of conservative or drug treatments in achieving pain relief. Broadly supported by observational outcome data, surgical resection is the primary, radical treatment method that provides rapid symptom relief and long-term cure in most cases [34]. However, randomized or comparative prospective trials evaluating surgery versus conservative or interventional alternatives remain scarce.

In terms of specific surgical strategies, incision design and exposure method are key to determining efficacy and complication risk. Owing to the pathological characteristics of glomus tumors, such as small lesion size, encapsulation, and proximity to nerve fibers and microvessels, incisions are required to allow full visualization to facilitate complete resection and ensure preservation of nail bed integrity. For the surgical treatment of subungual glomus tumors, the most commonly used method is transungual resection. The core procedure of this approach is to carefully peel and extract the nail plate, and then make a longitudinal incision at the nail bed to fully expose the tumor lesion [35]. Because it allows more direct visualization of the tumor during surgery, this approach is widely regarded as one of the classic methods for achieving complete resection and minimizing recurrence rate. In clinical practice, this method is the primary choice of most surgeons when dealing with glomus tumors located in the subungual area. One of its advantages is the ability to achieve complete resection of the lesion, thereby significantly reducing the incidence of postoperative recurrence [36]. Successful outcomes of using this approach hinge on a clear understanding of the lesion's encapsulated structure and the density of surrounding neurovascular structures. For glomus tumors located in the proximal subungual area, some scholars have reported using a lateral subperiosteal approach as an alternative. The main feature of this method is to avoid direct and large-scale destruction of the nail bed but to access the lesion area through subperiosteal dissection on the side or proximal end of the nail, thereby minimizing invasiveness during the resection operation. However, this approach comes with several shortcomings. A limited exposure to the surgical field may render clear delineation of the tumor boundary highly challenging. Therefore, the adoption of the lateral subperiosteal approach may lead to incomplete tumor resection and increased risk of postoperative recurrence in some cases [37]. In comparison, the transungual approach provides a better surgical field of view and remains the preferred choice by most surgeons. However, its disadvantages cannot be ignored. The transungual approach may result in postoperative nail bed damage after incision of the nail bed. Since the nail bed is crucial for the nail plate formation and nail growth, its damage may lead to nail deformity during the healing process [20]. To address these shortcomings, some scholars have proposed the use of a nail-preserving approach in recent years. These approaches involve complete tumor resection while preserving the integrity of the nail bed and nail plate as much as possible. This can effectively prevent the adhesion of the matrix and nail epithelium during the healing process of the nail bed, thereby significantly reducing the incidence of postoperative nail deformity [20]. Elhefnawy *et al*. [38] reported that the recurrence rate in patients receiving the nail-preserving surgical approaches ranged from 4% to 15.7%, whereas Kransdorf *et al*. [39] found that those treated with the transungual approach had a relatively lower recurrence rate, measuring 2%–5%. However, according to Roan *et al*. [40], patients treated with nail-preserving approaches had a markedly lower incidence of postoperative nail deformities (24.1%) compared with those who underwent the transungual approach. These findings suggest that while the transungual approach may allow for more tumor exposure and excision, it carries a higher postoperative risk of cosmetic and functional complications. In contrast, nail-preserving approaches better maintain nail integrity and appearance but may be associated with a slightly higher recurrence rate due to limited tumor exposure. Therefore, the choice of surgical approach must be tailored to each patient, balancing the goal of complete tumor removal with aesthetic and functional outcomes, taking into account lesion location, size, and surgeon's expertise. Available comparative data are primarily retrospective and sometimes conflicting, with reported trade-offs between recurrence and cosmetic outcomes. Thus, surgical approach selection should be individualized and, ideally, guided by prospective registry data to more accurately quantify these trade-offs.

The application of microsurgery has greatly improved surgical precision. Microsurgical magnification helps identify the wide networks of microvessels and nerve fibers covering glomus tumors, thereby minimizing damage and recurrence risk. Microscope-assisted surgery enables clear differentiation between tumor tissue and the surrounding nail unit while preserving neurovascular integrity, with the magnification typically set at 10× to 12.5× [41]. Several case series reports have shown that microscope-assisted resection can significantly reduce the recurrence rate and the incidence of postoperative nail deformity and paresthesia in the fingertips and subungual lesions that have been excised. In a clinical study of 22 patients with glomus tumors, microscope-assisted surgical resection was found to enable more precise identification of the lesions, thereby achieving complete surgical resection and minimizing damage to the nail unit, including the nail bed, matrix, and epithelium [42]. The results also showed no recurrence cases during the postoperative follow-up period and reduced incidence of nail bed deformity, with recovered flat state in nail plate and preserved aesthetic appearance of the nails observed in most of the patients. In a study consisting of a larger sample, measuring 61 patients with glomus tumors, Zhong *et al*. [35] validated the clinical feasibility and efficacy of microsurgery, with a focus on the rational selection of surgical approaches and the refinement of the operation. In this study, more than 80% of the selected patients showed good recovery of the nail bed and a low incidence of nail deformity during postoperative follow-up. The overall recurrence rate of patients was only 4.3%. This clinical evidence attests to the importance of understanding tumor microanatomy in the selection of appropriate surgical visualization methods. Nevertheless, the current line of evidence for the superiority of microscope-assisted approaches is largely based on nonrandomized series with variable periods of follow-up; therefore, more well-designed comparative studies that address cost concerns, learning curve, and functional outcomes are warranted to validate the efficacy of microsurgery in minimizing recurrence and deformity.

In recent years, with the development of minimally invasive technologies, radiofrequency ablation (RFA) has gained increasing attention as an emerging interventional therapy for glomus tumors [43]. RFA achieves pain relief by destroying small vessels and nerve endings through thermal coagulation. While traditional surgical resection remains the preferred treatment of glomus tumors, it may not be the optimal solution in certain situations. For example, surgical incision of tumors in specific regions may result in significant functional or aesthetic impairment, severe comorbidities or poor surgical tolerance, and heightened risk of trauma and postoperative complications, particularly in cases where traditional open or transungual resection has been performed. In this context, RFA, as a minimally invasive interventional procedure, can achieve coagulation and necrosis of tumor tissue through local thermal ablation, thereby achieving pain relief and lesion control [44]. Previous studies have reported that RFA can achieve effective local lesion control in diseases such as osteoid osteoma, gastric glomus tumors, and spinal tumors, and can also benefit some recurrent or metastatic cases [45–47]. Becce *et al*. [48] successfully treated a patient with a primary intraosseous spinal glomus tumor using computed tomography (CT)-guided RFA, with the tip temperature maintained at 80 °C for two cycles, each lasting three minutes. Compared with surgical resection, RFA offers several advantages, including minimal invasiveness, faster recovery, and a lower risk of postoperative complications. In most reported cases, the total ablation energy used in RFA ranged from 14 Gy to 36 Gy. Utilization of the RFA approach may minimize nail bed destruction, alleviate postoperative pain, and reduce the risk of recurrence. Therefore, for patients who are not suitable for surgery or recurrent and refractory cases, RFA can be used as a promising treatment method. Recent evidence also supports the long-term efficacy of RFA. Sallabanda *et al*. [49] conducted a mean follow-up of 4.2 years and reported a 97% overall survival and tumor control rate, with no statistically significant risk factors identified for reduced tumor control. These findings suggest that RFA can achieve durable tumor control and pain relief in selected patients, further reinforcing its role as a valuable complementary or alternative option to surgical resection. Ramos *et al*. [50] found that a patient suffering from a hand hemangioma treated by RFA underwent desirable recovery, highlighting the potential of RFA in preventing postoperative nail deformity to some extent. However, RFA is still not widely adopted because the procedure requires maintaining a safe margin from nearby neurovascular structures to minimize the risk of iatrogenic thermal injury. Consequently, RFA is limited to the application in high-risk or recurrent cases. Most of the literature concerning RFA application in glomus tumors is in the form of case reports and small series, but the level of evidence substantially supporting its efficacy remains limited (due to the absence of controlled comparison in existing reports), and the long-term oncologic and functional outcomes in patients treated with RFA remain incompletely characterized. Thus, RFA is considered a salvage therapy, or a method under constant research, in most centers. This necessitates a series of prospective comparative studies to define indications, technical parameters, and outcome benchmarks related to this therapeutic method.

The treatment of special cases also deserves attention. Despite their rarity, clustered glomus tumors are extremely difficult to diagnose and cure. The tendency of clustered glomus tumors to present as multifocal lesions is consistent with the genetic and molecular heterogeneity previously discussed. Such multifocal lesions can be detected with preoperative MRI. Whether to perform a one-time resection or staged treatment in the case of multifocal lesions is dependent on lesion distribution [51]. Nevertheless, making such a decision is difficult given the limited literature on the specific quantitative criteria, such as the maximum lesion diameter or the number of nodules, and their unproven clinical applicability and reproducibility. For lesions with unclear boundaries, intraoperative pathological frozen sections can help define appropriate resection margins and reduce the risk of residual tumors [52]. In addition, by bridging our understanding of the disease based on fundamental research and clinical practice, molecular testing provides additional insights into distinguishing benign tumors from malignant transformation and contributes to guiding adjuvant therapy decisions. In atypical cases or suspected malignant transformation, further evaluation should involve genetic testing, such as for *NOTCH2* fusion or *ATRX* mutation [30], to guide more reasonable surgical or adjuvant treatment. However, the clinical application of such genetic assays is currently limited by cost, accessibility, and the lack of standardized testing platforms across institutions. Furthermore, the clinical utility of routine molecular profiling remains unproven in the context of glomus tumors because of the mostly descriptive data from research with small sample sizes and the absence of established guidelines to decide when to perform such testing. Future multicenter studies are needed to determine whether molecular markers reliably predict aggressive behavior or guide adjuvant therapy decisions in a cost-effective manner.

Postoperative rehabilitation and follow-up are also an integral part of the treatment process. It is anticipated that the completion of surgical resection is followed by either complete or gradual relief of pain experienced by the patients. However, recurrence is inevitable in certain patients at a rate ranging from 2% to 24%, mainly attributed to incomplete tumor excision due to microscopic nerve infiltration and clustered lesions [53,54]. A study reported that most patients demonstrated long-term improvements in quality of life following treatment [55]. It is recommended that such patients should be followed up for 3–6 months after surgery to monitor the progress of pain relief and nail bed function recovery; if symptoms persist or recur, another imaging assessment is required [56]. From a pathophysiological perspective, because glomus tumors originate from perivascular smooth muscle-like cells, postoperative recovery should also focus on maintaining local microcirculation and preventing fibrotic compression that could reproduce pain. Long-term follow-up (2–3 years) should be considered, including imaging and functional assessments, pain scoring, nail aesthetics preservation, as well as rehabilitation measures for ensuring fingertip protection and nail bed hygiene [57]. While the available follow-up recommendations are pragmatic, they are largely consensus-based. At present, evidence guiding optimal follow-up intervals, imaging strategies, and outcome metrics—particularly for high-risk or atypical lesions—is insufficient, highlighting the need for standardized, prospective evaluation. More frequent follow-up should be indicated for high-risk patients—such as those with recurrent or histologically atypical lesions—particularly within the first year postoperatively, incorporating enhanced imaging assessment and pain monitoring to enable early detection of recurrence or malignant transformation.

In summary, from surgical design and the application of microsurgical techniques to complication prevention and recurrence management, the clinical pathway for treating glomus tumors has become well established. Advancing research on the pathology and pain mechanisms of glomus tumors has generated a growing evidence base that now informs scientifically grounded clinical guidance aimed at improving diagnostic accuracy, surgical precision, and postoperative management. The persistent advancements in molecular pathology, intraoperative navigation, and minimally invasive technologies such as RFA will also lend further support to enhancing the precision and personalization of existing diagnostic and therapeutic approaches for glomus tumors. We are hopeful that these progresses will contribute to not only further reducing the recurrence rate of glomus tumors but also improving the patient's long-term quality of life while ensuring optimal functional and aesthetic results.

Conclusions

Glomus tumors are rare and benign, but their unique clinical manifestations and frequent occurrence in anatomically sensitive areas such as the subungual area and fingertips have posed significant challenges to their diagnosis and treatment. Studies on the pathology and pain mechanisms of glomus tumors have deepened our understanding of their biological behavior and provided a solid theoretical basis for treatment. The pain associated with glomus tumors reflects their extensive innervation and the presence of vasoactive mediators, such as substance P and COX-2, which provide a biological basis for the hallmark paroxysmal pain and cold sensitivity. Understanding these mechanisms could aid in more accurate clinical interpretation of the symptoms and determination of optimal timing for intervention.

From a therapeutic standpoint, surgical resection remains the most effective curative option. The advent of microscope-assisted techniques has introduced a paradigm shift toward more refined, function-preserving surgery, supporting superior surgical precision, reduced recurrence, and minimized postoperative nail deformities. For patients with recurrent, deep-seated, or surgically high-risk lesions, minimally invasive modalities such as RFA offer a more appropriate therapeutic adjunct or alternative. Through controlled thermal coagulation, RFA provides effective lesion control and pain relief with minimal trauma and faster recovery.

Looking forward, building on our current understanding of glomus tumor pathology and pain mechanisms, minimally invasive approaches promise a more standardized yet individualized treatment strategy. This progress is expected to enhance surgical safety, achieve better functional and aesthetic outcomes, and ultimately improve patients' overall quality of life.

Availability of Data and Materials

All data used in this study were obtained from publicly available databases, including PubMed and Web of Science.

Author Contributions

XFY and DW designed the research study and wrote the first draft. YDM and YCX performed the research. All authors have been involved in revising the manuscript critically for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

Not applicable.

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Conflict of Interest

The authors declare no conflict of interest.

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