Contemporary Management of Giant Cell Tumor of the Distal Femur: Role of Extended Curettage and Bone Cement Reconstruction

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Abstract

Background: Giant cell tumor of bone (GCTB) is a locally aggressive, osteolytic neoplasm that typically affects skeletally mature individuals, with a predilection for the epimetaphyseal region of long bones. The distal femur represents one of the most commonly involved sites and poses unique challenges due to its proximity to the knee joint, high functional demands, and risk of local recurrence. Historically, wide resection was advocated to minimize recurrence; however, this approach often compromises joint integrity and functional outcomes. Advances in surgical techniques and local adjuvant therapies have led to a paradigm shift toward limb- and joint-preserving strategies.

Aim: This review aims to critically evaluate the contemporary management of giant cell tumor of the distal femur, with a particular focus on extended intralesional curettage combined with polymethylmethacrylate (PMMA) bone cement reconstruction. The review analyzes oncologic control, functional outcomes, recurrence rates, complications, and the role of adjuvant therapies, integrating current evidence to guide clinical decision-making.

Methods and Content Overview: A comprehensive appraisal of the literature is undertaken, encompassing tumor biology, radiologic and histopathologic features, surgical principles of extended curettage, use of mechanical and chemical adjuvants, and biomechanical considerations of cement reconstruction in the distal femur. The review also discusses indications for curettage versus resection, the impact of subchondral bone involvement, and strategies to protect the articular surface. Emerging adjuncts, including systemic therapies and their influence on surgical planning, are addressed in the context of modern multidisciplinary care.

Conclusion: Extended curettage followed by PMMA bone cement reconstruction has emerged as a cornerstone in the management of distal femoral giant cell tumors, offering a balance between effective local tumor control and preservation of knee function. When meticulously performed with appropriate adjuvant measures, this approach achieves acceptable recurrence rates comparable to more radical procedures while maintaining superior functional outcomes. Careful patient selection, adherence to sound oncologic principles, and long-term surveillance remain essential to optimize results. This review underscores the role of curettage and cementation as a durable, evidence-based limb-salvage strategy in contemporary orthopedic oncology.

Keywords: *Giant Cell Tumor, Distal Femur, Extended Curettage and Bone Cement Reconstruction*

Introduction

Giant cell tumor of bone (GCTB) is a benign yet locally aggressive primary skeletal neoplasm characterized by extensive osteolysis, cortical destruction, and a marked tendency for local recurrence. It accounts for approximately 4–5% of all primary bone tumors and 15–20% of benign bone tumors, predominantly affecting skeletally mature individuals between the ages of 20 and 40 years. The distal femur is among the most commonly involved anatomical sites, reflecting the tumor's predilection for the epimetaphyseal region of long bones adjacent to major joints, where preservation of joint anatomy and function is of paramount importance [1,2].

Although histologically benign, GCTB demonstrates aggressive biological behavior, including progressive bone destruction, cortical breach, soft tissue extension, and, in rare cases, pulmonary metastasis. Local recurrence remains the principal clinical challenge, with reported rates varying widely according to surgical modality and use of adjuvant therapies. Early studies reported recurrence rates exceeding 40% following simple curettage, leading many surgeons to favor wide or en bloc resection to improve oncologic control, particularly in aggressive lesions of the distal femur [3].

The pursuit of improved functional outcomes, particularly in young and active patients, has driven a paradigm shift toward limb- and joint-preserving approaches. Extended intralesional curettage has emerged as the preferred surgical strategy for most distal femoral GCTBs, incorporating meticulous tumor removal using hand curettes and high-speed burrs to eradicate microscopic disease. This technique aims to balance local tumor control with preservation of native bone stock and articular integrity, thereby minimizing the morbidity associated with radical resection [4].

Reconstruction of the post-curettage cavity using polymethylmethacrylate (PMMA) bone cement has become an integral component of contemporary management. Cementation provides immediate structural stability, facilitates early weight-bearing, and enhances postoperative surveillance by allowing radiographic detection of recurrence at the cement–bone interface. Additionally, the exothermic polymerization of PMMA exerts a local cytotoxic effect, which may contribute to reduced recurrence rates compared with bone grafting alone [5].

Despite the widespread acceptance of curettage and cementation, several unresolved issues remain in the management of distal femoral GCTB. These include concerns regarding thermal injury to the subchondral bone and articular cartilage, the potential development of secondary osteoarthritis, optimal use of local adjuvants, and appropriate indications for alternative reconstructive strategies. Furthermore, the introduction of systemic therapies such as denosumab has expanded the therapeutic armamentarium but has also raised questions regarding long-term oncologic safety and integration with surgical treatment [6].

The aim of this review is to critically evaluate contemporary management strategies for giant cell tumor of the distal femur, with a focused emphasis on extended curettage and PMMA bone cement reconstruction. By synthesizing current evidence related to tumor biology, surgical principles, adjuvant modalities, oncologic outcomes, and functional results, this review seeks to clarify existing controversies and identify gaps in knowledge that warrant further investigation, thereby guiding evidence-based clinical decision-making [1–6].

Epidemiology and Molecular Pathobiology of Giant Cell Tumor of Bone

Giant cell tumor of bone demonstrates a distinct epidemiological profile, occurring almost exclusively after physeal closure and rarely before skeletal maturity. The peak incidence lies between the third and fourth decades of life, with a slight female predominance reported in several large series. Anatomically, GCTB shows a strong predilection for the epimetaphyseal region of long bones, particularly around the knee joint, with the distal femur representing one of the most frequently affected sites worldwide. This distribution underscores the clinical significance of distal femoral involvement due to its implications for joint preservation and long-term functional outcomes [7,8].

From a pathological standpoint, GCTB is composed of three principal cellular components: multinucleated osteoclast-like giant cells, mononuclear stromal cells, and monocyte/macrophage lineage cells. The neoplastic component is now recognized to be the mononuclear stromal cells, which orchestrate tumor behavior and drive osteolysis through complex cellular signaling pathways. These stromal cells express receptor activator of nuclear factor kappa-B ligand (RANKL), a key mediator in osteoclastogenesis, which promotes the recruitment and activation of osteoclast-like giant cells responsible for extensive bone resorption [9].

The RANK/RANKL/osteoprotegerin pathway plays a central role in the molecular pathobiology of GCTB. Overexpression of RANKL by stromal cells leads to unchecked osteoclast activation, resulting in aggressive local bone destruction characteristic of the disease. This molecular insight has not only enhanced understanding of tumor biology but has also provided a rational target for systemic therapy. In particular, inhibition of RANKL has emerged as a therapeutic strategy to reduce tumor burden, modulate disease progression, and facilitate surgical management in selected cases [10].

Genetic and cytogenetic studies have further elucidated the neoplastic nature of GCTB. Recurrent mutations in the H3F3A gene, encoding histone H3.3, have been identified as a defining molecular hallmark of conventional GCTB. These mutations are highly specific and help distinguish GCTB from other giant cell–rich lesions of bone, reinforcing the concept that the stromal cell population represents the true tumor driver. Importantly, these molecular features do not reliably predict clinical aggressiveness or recurrence, highlighting the multifactorial nature of disease behavior [11].

Despite its benign classification, GCTB demonstrates a spectrum of clinical aggressiveness. Factors such as cortical breach, soft tissue extension, pathological fracture, and high Campanacci grade have been associated with increased local recurrence risk, though their prognostic value remains debated. Notably, distal femoral lesions may exhibit more aggressive radiographic features due to delayed presentation and biomechanical stresses across the knee joint, emphasizing the importance of early diagnosis and appropriate surgical planning [12].

Understanding the epidemiological patterns and molecular mechanisms underlying GCTB is fundamental to optimizing management strategies. These insights support the rationale for intralesional surgical approaches combined with local and systemic adjuvants aimed at reducing recurrence while preserving joint function. As molecular-targeted therapies continue to evolve, their integration with established surgical techniques such as extended curettage and cement reconstruction remains an area of active investigation in orthopedic oncology [9–12].

Radiologic Evaluation and Classification of Distal Femoral Giant Cell Tumor

Radiologic assessment plays a pivotal role in the diagnosis, staging, surgical planning, and postoperative surveillance of giant cell tumor of the distal femur. Conventional plain radiography is typically the first-line imaging modality and often reveals a characteristic eccentric, expansile, lytic lesion involving the epimetaphyseal region, extending to the subchondral bone plate. The lesion usually lacks matrix mineralization and demonstrates a narrow zone of transition with non-sclerotic margins, although cortical thinning and breach may be evident in more advanced cases. These radiographic features are instrumental in differentiating GCTB from other lytic lesions around the knee [13].

Computed tomography (CT) provides superior delineation of cortical integrity, extent of bone destruction, and presence of subtle cortical breaches that may not be apparent on plain radiographs. In distal femoral GCTB, CT is particularly useful for preoperative planning, as it allows accurate assessment of subchondral bone thickness, intraosseous septations, and any extension into surrounding soft tissues. This information is critical in determining the feasibility of extended curettage and cement reconstruction versus more radical surgical options [14].

Magnetic resonance imaging (MRI) is the imaging modality of choice for evaluating the full extent of tumor involvement. MRI provides excellent soft tissue contrast and is essential for identifying intramedullary spread, soft tissue extension, joint involvement, and associated pathological fractures. Typical MRI findings include low to intermediate signal intensity on T1-weighted images and heterogeneous high signal intensity on T2-weighted images, often with fluid–fluid levels secondary to

secondary aneurysmal bone cyst changes. In distal femoral lesions, MRI is indispensable for assessing proximity to the articular cartilage and planning joint-preserving surgery [15].

Several classification systems have been proposed to stratify GCTB based on radiologic appearance and aggressiveness, with the Campanacci grading system being the most widely used. Campanacci grade I lesions are latent, well-marginated tumors confined within bone; grade II lesions are active tumors with cortical thinning and expansion; and grade III lesions are aggressive tumors with cortical destruction and soft tissue extension. This grading system remains clinically relevant, as it correlates with surgical complexity and recurrence risk, particularly in weight-bearing sites such as the distal femur [16].

Advanced imaging also contributes to postoperative monitoring and early detection of recurrence. Following curettage and cementation, radiographs and CT scans allow clear visualization of the cement–bone interface, where recurrent lesions typically manifest as progressive radiolucent zones. MRI may be limited by artifact from PMMA cement; however, newer metal artifact reduction sequences can enhance its utility in selected cases. Early identification of recurrence is essential to enable timely re-intervention and preserve joint function [17].

A comprehensive radiologic evaluation, integrating plain radiography, CT, and MRI, is fundamental to the contemporary management of distal femoral giant cell tumor. Accurate imaging not only facilitates diagnosis and classification but also directly influences surgical decision-making, choice of reconstruction, and long-term surveillance strategies. Radiologic findings must therefore be interpreted in conjunction with clinical and pathological data to optimize outcomes in patients undergoing extended curettage and bone cement reconstruction [13–17].

Principles of Surgical Management and Indications for Curettage in Distal Femoral Giant Cell Tumor

Surgical intervention remains the cornerstone of treatment for giant cell tumor of the distal femur, with the primary objectives being complete local tumor control, preservation of knee joint function, and minimization of recurrence. The choice between intralesional curettage and wide resection depends on multiple factors, including tumor size, Campanacci grade, cortical integrity, presence of soft tissue extension, and patient-related considerations such as age and functional demands. In contemporary practice, extended intralesional curettage has become the preferred approach for the majority of distal femoral GCTBs, particularly when the articular surface can be preserved and adequate mechanical stability can be achieved [18].

Extended curettage involves meticulous removal of all visible tumor tissue through a large cortical window, allowing direct visualization of the entire tumor cavity. This approach is augmented by the use of high-speed burrs to eliminate microscopic residual disease along the cavity walls, significantly reducing the risk of local recurrence compared with simple curettage alone. The distal femur, due to its wide metaphyseal region, often permits adequate exposure for thorough intralesional excision while maintaining sufficient bone stock for reconstruction [19].

The decision to pursue curettage rather than wide resection in distal femoral GCTB must be guided by oncologic safety. While wide resection offers lower recurrence rates, it is associated with higher morbidity, greater functional impairment, and increased complication rates related to endoprosthetic reconstruction. Multiple comparative studies have demonstrated that, when extended curettage is performed with appropriate adjuvants, local control rates approach those of wide resection, with superior functional outcomes and preservation of the native knee joint [20].

Pathological fracture at presentation, once considered a relative contraindication to curettage, is no longer an absolute indication for wide resection. Several studies have shown that extended curettage and cementation can be safely performed in selected cases of distal femoral GCTB with pathological fracture, provided that stable fixation can be achieved and soft tissue contamination is limited. This shift reflects a growing emphasis on individualized treatment planning rather than rigid adherence to historical surgical dogma [21].

Patient selection remains critical to the success of curettage-based management. Tumors with extensive soft tissue extension, massive cortical destruction precluding structural stability, or involvement of the

articular surface that cannot be reconstructed may still necessitate wide resection. However, advances in surgical technique, adjuvant use, and reconstructive options have progressively expanded the indications for intralesional surgery, even in high-grade lesions of the distal femur [22].

Ultimately, the principles guiding surgical management of distal femoral GCTB emphasize a balance between oncologic adequacy and functional preservation. Extended curettage, when carefully indicated and meticulously executed, provides a durable limb-salvage solution that aligns with contemporary orthopedic oncology practice. Ongoing refinement of surgical strategies and integration of adjunctive therapies continue to improve outcomes for patients with this challenging tumor [18–22].

Extended Curettage Techniques and Local Adjuvant Modalities

Extended intralesional curettage is a technically demanding procedure that aims to maximize local tumor eradication while preserving surrounding bone and joint structures. The procedure begins with creation of an adequately sized cortical window to allow complete visualization of the tumor cavity, which is particularly important in distal femoral lesions where residual tumor may be hidden beneath subchondral bone or within metaphyseal recesses. Thorough manual curettage using angled curettes remains the foundation of tumor removal, and inadequate exposure has been consistently associated with higher recurrence rates [23].

The use of a high-speed burr represents a critical component of extended curettage and has been shown to significantly reduce local recurrence compared with curettage alone. Burring allows removal of a thin margin of bone from the cavity walls, targeting microscopic residual tumor cells that are not visible to the naked eye. In the distal femur, careful burring of the subchondral region is essential to balance oncologic clearance with preservation of joint integrity, as excessive bone removal may predispose to articular collapse [24].

Local adjuvant therapies are frequently employed following mechanical tumor removal to further decrease recurrence risk. Chemical adjuvants such as phenol and hydrogen peroxide have been widely used due to their cytotoxic effects on residual tumor cells. Phenol causes protein denaturation and cellular necrosis, while hydrogen peroxide acts through oxidative damage and has the added benefit of mechanical cleansing through effervescence. Multiple clinical series have demonstrated reduced recurrence rates when these agents are used as adjuncts to extended curettage [25].

Thermal adjuvants represent another important category of local tumor control measures. Cryotherapy using liquid nitrogen induces cell death through ice crystal formation and vascular injury, resulting in deep tissue necrosis beyond the mechanically curetted margins. While effective, cryotherapy carries a higher risk of complications such as fracture, infection, and skin necrosis, particularly in weight-bearing bones like the distal femur. As a result, its use has declined in favor of less morbid adjuvant strategies [26].

Argon beam coagulation has emerged as a controlled thermal adjuvant that delivers superficial coagulative necrosis to the cavity walls. Its advantages include ease of use, predictable depth of penetration, and a favorable safety profile compared with cryotherapy. Several studies have reported low recurrence rates with argon beam coagulation when combined with high-speed burring and cementation, making it a valuable option in the modern surgical armamentarium [27].

The selection of adjuvant modalities should be individualized based on tumor extent, location, surgeon experience, and available resources. In distal femoral GCTB, the combination of meticulous mechanical curettage, high-speed burring, and judicious use of chemical or thermal adjuvants has been shown to achieve local control rates comparable to more aggressive resections. This multimodal approach underscores the importance of technique and attention to detail in optimizing outcomes following curettage-based management [23–27].

Bone Cement Reconstruction: Biomechanical and Oncologic Considerations

Polymethylmethacrylate (PMMA) bone cement has become a cornerstone in the reconstruction of defects following extended curettage of giant cell tumor of the distal femur. Its widespread use is attributed to its ability to provide immediate mechanical stability, allowing early weight-bearing and rapid functional recovery. In weight-bearing regions such as the distal femur, cement reconstruction

effectively restores structural integrity and reduces the risk of postoperative fracture compared with cancellous bone grafting alone [28].

From a biomechanical perspective, PMMA cement distributes load across the subchondral bone and surrounding cortex, particularly when combined with internal fixation in cases of extensive bone loss. The stiffness of cement exceeds that of cancellous bone, which contributes to its ability to support early mobilization. However, this mismatch in elastic modulus has raised concerns regarding stress shielding and potential degeneration of adjacent bone and cartilage. Despite these concerns, long-term studies have demonstrated satisfactory functional outcomes in patients treated with cementation of distal femoral GCTBs [29].

Beyond its mechanical role, PMMA cement exerts an important oncologic benefit through its exothermic polymerization process. During curing, temperatures within the cement can exceed 70°C, resulting in thermal necrosis of residual tumor cells at the bone–cement interface. This local cytotoxic effect has been proposed as a key factor in the reduced recurrence rates observed with cementation compared with bone grafting alone, particularly when used in conjunction with extended curettage and adjuvant therapies [30].

An additional advantage of cement reconstruction is facilitation of postoperative surveillance. The radiopaque nature of PMMA allows clear visualization of the bone–cement interface on follow-up radiographs and CT scans, enabling early detection of local recurrence, which typically presents as progressive radiolucency adjacent to the cement. Early identification of recurrence is critical in the distal femur, where timely re-intervention may preserve joint integrity and prevent the need for more extensive surgery [31].

Despite its benefits, the use of PMMA cement near the articular surface has raised concerns regarding thermal injury to the subchondral bone and overlying cartilage, potentially leading to secondary osteoarthritis. Several studies have suggested that preservation of a minimum thickness of subchondral bone or the interposition of a protective layer of cancellous bone or bone substitute can mitigate this risk. Careful surgical technique is therefore essential to balance oncologic control with long-term joint preservation in distal femoral lesions [32].

Overall, PMMA cement reconstruction offers a reliable and effective method for managing post-curettage defects in distal femoral giant cell tumors. When integrated with meticulous tumor excision and appropriate adjuvant use, cementation contributes to both mechanical stability and local tumor control, reinforcing its central role in contemporary limb-salvage strategies [28–32].

Subchondral Bone Preservation and Articular Surface Protection

Preservation of the subchondral bone and protection of the articular surface are critical considerations in the management of giant cell tumor of the distal femur, given the tumor's frequent proximity to the knee joint. Extensive subchondral involvement increases the risk of postoperative joint degeneration, collapse, and secondary osteoarthritis, which can significantly compromise long-term functional outcomes. Therefore, careful preoperative planning and intraoperative technique are essential to maintain joint integrity while achieving adequate oncologic clearance [33].

Several studies have emphasized the importance of maintaining a minimum thickness of subchondral bone to protect the overlying articular cartilage from thermal and mechanical injury associated with PMMA cementation. Although an exact threshold remains debated, preservation of at least 5–10 mm of subchondral bone has been suggested to reduce the risk of cartilage degeneration and joint surface collapse. When this layer is compromised by tumor extension, additional protective strategies are required to mitigate potential complications [34].

One commonly employed technique involves interposition of cancellous bone graft or bone substitute between the subchondral bone and PMMA cement. This "sandwich" or "layered" technique acts as a thermal insulator, reducing heat transfer to the articular cartilage during cement polymerization, while also providing biological support to the subchondral region. Clinical series have demonstrated satisfactory joint preservation and low rates of degenerative change when this approach is used in distal femoral GCTB with subchondral involvement [35].

Internal fixation may also play a role in protecting the articular surface in cases with extensive subchondral bone loss. The use of plates, screws, or intramedullary devices can offload stress from the reconstructed subchondral region and reduce the risk of postoperative fracture or collapse. In distal femoral lesions, supplemental fixation is particularly valuable when large cortical windows are created or when pathological fracture is present at diagnosis [36].

Long-term follow-up studies have shown that degenerative joint changes after curettage and cementation are multifactorial, influenced not only by cement proximity to cartilage but also by tumor aggressiveness, initial subchondral damage, and postoperative biomechanics. Importantly, radiographic evidence of osteoarthritic changes does not always correlate with poor clinical outcomes, as many patients maintain satisfactory knee function for years following joint-preserving surgery [37].

In summary, successful management of distal femoral GCTB requires meticulous attention to subchondral bone preservation and articular surface protection. By combining careful curettage, strategic use of interposed graft materials, and appropriate fixation when indicated, surgeons can minimize joint-related complications while maintaining the oncologic benefits of cement reconstruction. These considerations are integral to achieving durable, function-preserving outcomes in contemporary practice [33–37].

Local Recurrence: Risk Factors, Patterns, and Management

Local recurrence remains the most significant challenge in the management of giant cell tumor of the distal femur, even with contemporary surgical techniques. Recurrence rates following extended curettage and cementation have been reported to range from 10% to 25%, with most recurrences occurring within the first three years after surgery. The distal femur, due to its complex anatomy and frequent subchondral involvement, is particularly susceptible to residual microscopic disease if meticulous surgical technique is not employed [38].

Several tumor-related factors have been associated with an increased risk of local recurrence. Higher Campanacci grade, cortical breach, soft tissue extension, and presence of pathological fracture at presentation have all been implicated, although their individual prognostic significance remains debated. In distal femoral GCTB, lesions with extensive subchondral involvement may pose technical challenges during curettage, increasing the likelihood of residual tumor cells near the joint surface [39].

Surgical factors play a critical role in determining recurrence risk. Inadequate exposure, insufficient cortical window size, and omission of high-speed burring or adjuvant therapies have been consistently linked to higher recurrence rates. Studies comparing simple curettage with extended curettage have demonstrated significantly improved local control with the latter, underscoring the importance of aggressive intralesional excision in distal femoral lesions [40].

Patterns of recurrence following cementation are typically characterized by lytic changes at the bone–cement interface, most commonly at the margins of the original cavity. Early detection through vigilant radiographic surveillance is essential, as recurrent lesions are often amenable to repeat curettage and cementation if identified before extensive bone or joint destruction occurs. The radiographic clarity provided by PMMA cement facilitates early diagnosis and timely intervention [41].

Management of local recurrence depends on the extent of disease and the integrity of the surrounding bone and joint. Repeat extended curettage with adjuvants remains a viable option for most isolated recurrences and has been shown to yield acceptable control rates. However, multiple recurrences, extensive soft tissue involvement, or structural compromise of the distal femur may necessitate wide resection and endoprosthetic reconstruction to achieve durable disease control [42].

Understanding the multifactorial nature of local recurrence is essential for optimizing treatment outcomes in distal femoral GCTB. Careful patient selection, meticulous surgical technique, appropriate use of adjuvants, and structured follow-up protocols collectively contribute to minimizing recurrence risk. Ongoing research aimed at refining prognostic models and integrating systemic therapies may further improve local control in the future [38–42].

Functional Outcomes and Quality of Life After Curettage and Cementation

Functional outcome is a central determinant of treatment success in patients with giant cell tumor of the

distal femur, given the young age and high activity levels of most affected individuals. Extended curettage followed by PMMA cement reconstruction has consistently demonstrated favorable functional results, particularly when the native knee joint is preserved. Musculoskeletal Tumor Society (MSTS) and Toronto Extremity Salvage Score (TESS) assessments reported in multiple series indicate good to excellent function in the majority of patients treated with intralesional surgery, often exceeding outcomes observed after wide resection and endoprosthetic reconstruction [43].

Early mobilization and weight-bearing are key advantages of cement-based reconstruction and contribute significantly to functional recovery. PMMA cement provides immediate structural stability, allowing patients to commence rehabilitation soon after surgery without prolonged immobilization. In distal femoral lesions, this early return to activity is associated with preservation of muscle strength, joint range of motion, and overall limb function, which are critical determinants of long-term quality of life [44].

Comparative studies evaluating curettage and cementation versus wide resection have consistently demonstrated superior functional outcomes in the curettage group. While wide resection may reduce recurrence risk in selected aggressive cases, it is frequently associated with higher complication rates, including prosthetic loosening, infection, and mechanical failure. These complications can significantly impair function and necessitate revision surgery, particularly in younger patients with long life expectancy [45].

Pain relief is another important aspect of postoperative outcome. Most patients report substantial reduction in pain following tumor removal and defect reconstruction, with sustained improvement over time. Although radiographic evidence of degenerative joint changes may develop in some cases, particularly when cement is placed close to the articular surface, clinical symptoms do not always correlate with imaging findings. Many patients maintain satisfactory knee function and minimal pain for years following surgery [46].

Quality of life measures extend beyond physical function to include psychological well-being and social participation. Limb-salvage procedures such as curettage and cementation have been associated with improved patient satisfaction, body image, and ability to return to work or sport compared with more radical surgical options. Preservation of the native knee joint plays a pivotal role in these outcomes, reinforcing the value of joint-preserving strategies in distal femoral GCTB [47].

Overall, extended curettage with PMMA cement reconstruction offers an optimal balance between oncologic safety and functional preservation for most patients with distal femoral giant cell tumor. When performed with meticulous technique and appropriate patient selection, this approach yields durable functional outcomes and quality of life benefits that align with the goals of contemporary orthopedic oncology [43–47].

Role of Systemic Therapies and Denosumab in Distal Femoral Giant Cell Tumor

The introduction of systemic therapies has significantly influenced the contemporary management of giant cell tumor of bone, particularly in anatomically challenging locations such as the distal femur. Among these therapies, denosumab, a fully human monoclonal antibody targeting receptor activator of nuclear factor kappa-B ligand (RANKL), has emerged as the most impactful agent. By inhibiting RANKL-mediated osteoclastogenesis, denosumab effectively suppresses bone resorption and induces tumor consolidation, thereby altering the biological behavior of GCTB [48].

Clinical trials have demonstrated that denosumab leads to rapid reduction in tumor-related pain, decreased osteolytic activity, and radiologic evidence of peripheral sclerosis and intralesional bone formation. These effects can facilitate surgical management by improving structural stability, reducing intraoperative bleeding, and, in some cases, converting lesions previously considered unresectable into candidates for joint-preserving surgery. In distal femoral GCTB, denosumab has been particularly valuable in cases with extensive subchondral involvement or impending pathological fracture [49].

Despite these benefits, the integration of denosumab into surgical decision-making remains controversial. Several studies have raised concerns that preoperative denosumab may obscure tumor margins by inducing new bone formation, potentially increasing the risk of residual disease following

curettage. Histologically, denosumab-treated lesions demonstrate marked depletion of giant cells but persistence of neoplastic stromal cells, which may contribute to higher recurrence rates if intralesional surgery is performed without meticulous technique [50].

The timing and duration of denosumab therapy are therefore critical considerations. Short-term preoperative administration has been advocated by some authors to achieve structural consolidation while minimizing the risk of incomplete tumor removal. Conversely, prolonged therapy has been associated with rebound osteolysis and recurrence after discontinuation, underscoring the importance of close surveillance and clearly defined treatment endpoints. In distal femoral lesions, these factors are particularly relevant due to the biomechanical demands placed on the reconstructed joint [51].

Denosumab has also been employed as a primary treatment modality in patients who are poor surgical candidates or in whom surgery would result in unacceptable morbidity. While this approach may achieve disease control in the short term, long-term outcomes remain uncertain, and concerns regarding malignant transformation and atypical fractures have been reported, albeit rarely. As such, systemic therapy is generally regarded as an adjunct rather than a replacement for surgery in the management of resectable distal femoral GCTB [52].

In summary, denosumab represents a powerful adjunctive tool in the multidisciplinary management of giant cell tumor of the distal femur. When used judiciously and integrated with sound surgical principles, it may expand the indications for joint-preserving procedures such as extended curettage and cementation. However, careful patient selection, awareness of potential risks, and adherence to evidence-based protocols are essential to optimize outcomes and minimize recurrence [48–52].

Complications and Long-Term Surveillance After Curettage and Cementation

Although extended curettage and PMMA cement reconstruction are associated with favorable oncologic and functional outcomes, a range of complications may occur and must be carefully considered in the management of distal femoral giant cell tumor. Early postoperative complications include infection, hematoma formation, wound dehiscence, and postoperative fracture, particularly in cases with extensive cortical destruction or inadequate structural support. The distal femur, as a major weight-bearing site, is especially vulnerable to mechanical complications if stabilization is insufficient [53].

Thermal injury related to cement polymerization represents a unique complication of PMMA use. Excessive heat generation may damage adjacent subchondral bone and articular cartilage, potentially leading to cartilage degeneration and secondary osteoarthritis. While the clinical significance of this phenomenon varies, studies have shown that careful surgical technique, preservation of subchondral bone, and interposition of graft material can substantially reduce the risk of thermal-related joint damage [54].

Late complications primarily involve degenerative joint changes and local recurrence. Radiographic evidence of osteoarthritic changes has been reported in long-term follow-up studies, particularly when cement is placed in close proximity to the articular surface. However, these radiographic findings do not always correlate with clinical symptoms, and many patients maintain acceptable knee function despite imaging changes. The multifactorial nature of joint degeneration highlights the importance of individualized risk assessment and long-term follow-up [55].

Local recurrence remains a critical concern and necessitates structured surveillance protocols. Most recurrences occur within the first two to three years following surgery, emphasizing the need for frequent clinical and radiographic evaluation during this period. Standard follow-up typically includes serial plain radiographs of the distal femur, supplemented by CT or MRI when recurrence is suspected. Early detection allows for timely re-intervention, often preserving joint function [56].

Pulmonary metastasis, although rare, has been documented in patients with GCTB and may occur even in the absence of local recurrence. As a result, baseline and periodic chest imaging are recommended as part of long-term surveillance, particularly in patients with recurrent or aggressive disease. The clinical course of pulmonary metastases is often indolent, and surgical resection or observation may be appropriate depending on disease behavior [57].

Long-term surveillance following curettage and cementation should therefore be comprehensive and

individualized, incorporating assessment of local disease control, joint integrity, and systemic involvement. Patient education regarding symptom recognition and adherence to follow-up schedules is essential to optimize outcomes. Through vigilant monitoring and timely management of complications, extended curettage with cement reconstruction remains a safe and durable treatment strategy for distal femoral giant cell tumor [53–57].

Conclusion

Giant cell tumor of the distal femur presents a unique therapeutic challenge due to its locally aggressive behavior, proximity to the knee joint, and the high functional demands placed on this weight-bearing region. Over recent decades, advances in tumor biology, imaging, surgical technique, and adjuvant therapies have shifted management paradigms toward limb- and joint-preserving strategies that prioritize both oncologic control and functional outcome. Extended intralesional curettage has emerged as the cornerstone of treatment for most distal femoral lesions, provided that meticulous technique and appropriate patient selection are applied.

Reconstruction with polymethylmethacrylate bone cement plays a central role in contemporary management, offering immediate mechanical stability, facilitation of early rehabilitation, and an adjunctive oncologic effect through thermal cytotoxicity. When combined with high-speed burring and judicious use of local adjuvants, cementation achieves local control rates comparable to more radical procedures while preserving native knee anatomy. Attention to subchondral bone preservation and articular surface protection is essential to minimize long-term joint degeneration and maintain durable function.

The integration of systemic therapies, particularly denosumab, has expanded the therapeutic armamentarium and introduced new opportunities for surgical downstaging and joint preservation. However, their use must be carefully balanced against potential risks, including altered tumor morphology and recurrence patterns. As such, systemic agents are best employed as adjuncts within a multidisciplinary framework rather than as standalone treatments in resectable disease.

Local recurrence remains the principal determinant of long-term outcome and underscores the importance of meticulous surgical execution and structured postoperative surveillance. Early detection of recurrence allows for timely re-intervention and often preserves joint function. With appropriate follow-up and patient education, extended curettage and cement reconstruction provide a durable, function-preserving solution for the majority of patients.

In conclusion, extended curettage followed by bone cement reconstruction represents an evidence-based, effective, and functionally favorable approach to the management of giant cell tumor of the distal femur. Ongoing research into molecular pathways, optimized adjuvant strategies, and long-term outcomes will continue to refine treatment algorithms and further enhance patient-centered care in orthopedic oncology.

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