Journal of Orthopaedics 41 (2023) 47–56

Contents lists available at ScienceDirect

Journal of Orthopaedics

journal homepage: www.elsevier.com/locate/jor

Management of giant cell tumors of the distal radius

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A B S T R A C T

Background: The distal radius is the most common location for giant cell tumors (GCT) in the upper extremity. Treatment should balance the goals of maximizing function and minimizing recurrence and other complications. Given the complexity in surgical treatment, various techniques have been described without clear standards of treatment.

Objectives: The purpose of this review is to provide an overview of evaluation of patients presenting with GCT of the distal radius, discuss management, and provide an updated summary on outcomes of treatment options.

Conclusion: Surgical treatment should consider tumor Grade, involvement of the articular surface, and patient-specific factors. Options include intralesional curettage and en bloc resection with reconstruction. Within reconstruction techniques, radiocarpal joint preserving and sparing procedures can be considered. Campanacci Grade 1 tumors can be successfully treated with joint preserving procedures, whereas for Campanacci Grade 3 tumors consideration should be given to joint resection to prevent recurrence. Treatment of Campanacci Grade 2 tumors is debated in the literature. Intralesional curettage and adjuvants can successfully treat cases where the articular surface can be preserved, while en-bloc resection should be used in cases where the articular surface cannot undergo aggressive curettage. A variety of reconstructive techniques are used for cases needing resection, with no clear gold standard. Joint sparing procedures preserve motion at the wrist joint, whereas joint sacrificing procedures preserve grip strength. Choice of reconstructive procedure should be made based on patient-specific factors, considering relative functional outcomes, complications, and recurrence rates.

1. Introduction

Giant cell tumors (GCT) of bone are rare, benign yet locally destructive primary bone tumors that account for approximately 5% of benign primary bone tumors in adults.[1–4] GCT present challenges in management given high risk of recurrence, impact on function, and rare risk of metastatic disease.[1,3–6] The most common location of GCT in the upper extremity is the distal radius,[7] accounting for 10–12% of all cases.[8,9] Treatment of GCT of the distal radius requires several anatomic considerations. The kinematics of the wrist joint are complex,[10] and stability of the proximal carpal row is dependent on mechanics of surrounding articulations, including the radiocarpal articulation as well as surrounding ligaments, including the dorsal intercarpal ligament and dorsal radiocarpal ligament.[11] Given this complexity, resection of subchondral bone of the distal radius has been shown to lead to radiocarpal arthritis, joint collapse, and pain.[1,3,12] The purpose of this review is to provide an overview of evaluation of patients presenting with GCT of the distal radius, discuss management, and provide an updated summary on outcomes of treatment options.

2. Patient evaluation

2.1. Presentation

A detailed history and physical exam must be obtained when evaluating patients for GCT of the distal radius. Important aspects include pain onset and duration, prior treatments, range of motion, and function, which will both help identify the need for further evaluation and aid in surgical decision-making.[2,5] Patients will often present with tenderness, swelling, and limited motion of the wrist. Duration of symptoms may vary, though most present after experiencing pain for 3–6 months.[2] A comprehensive review of the patient's medical history and current state of health is also imperative as it will dictate treatment options.Patients that are not medically optimized for surgery may warrant conservative measures and nonoperative treatments. For those optimized, current functional status and future functional needs should be discussed with the patient when evaluating treatment options, as different surgical options result in varying functional outcomes.

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https://doi.org/10.1016/j.jor.2023.06.001
Received 15 April 2023; Received in revised form 24 May 2023; Accepted 1 June 2023
Available online 2 June 2023

2.2. Imaging

Plain film radiographs are the first imaging study of choice and will demonstrate an eccentric lytic lesion of the distal radial metaphysis extending into the epiphysis (Fig. 1).[2,13] The lesion may appear cystic and often well defined, expand the bone, thin the cortices to create a neocortex, elevate the periosteum, and invade the subchondral bone.[2,5] Advanced imaging can further characterize the lesion, and MRI will better delineate soft tissue and cystic components while CT will delineate involvement of the articular surface.[5] On MRI, the mass is hypointense on T1-weighted images, hyperintense on T2-weighted images, and peripheral enhancing on gadolinium-enhances images. Fluid-fluid levels demonstrating a secondary aneurysmal bone cyst (ABC) may also be seen on MRI. CT scan further characterizes osseous destruction and the neocortex and may elucidate a pathologic fracture.[2,14]

Imaging features such as thinning of the cortex, invasion of the subchondral bone, and ill-defined margins are of particular interest to the surgeon, as this would argue for joint resection procedures, whereas lack of these findings would suggest joint preserving procedures. Campanacci created a radiographic grading system for GCT which is helpful for this characterization and dictates surgical treatment of these lesions.[1,2] Grade 1 lesions are well-circumscribed with an intact cortex; Grade 2 lesions have well-defined borders with cortical thinning; and Grade 3 lesions demonstrate indistinct borders with cortical destruction.[1]

Beyond GCT, differential diagnosis of a lytic distal radius lesion includes an aneurysmal bone cyst, chondroblastoma, osteosarcoma, metastatic disease, and multiple myeloma. Aneurysmal bone cysts are also often eccentric, metaphyseal, cystic and benign in appearance though do not have cortical destruction and occur in younger age groups. Chondroblastoma is also a lytic lesion that may occur in the epiphysis with sclerotic margin but usually occurs in young patients and demonstrates significant surrounding edema on MRI. Osteosarcoma may be considered in an eccentric lytic lesion, especially as telangiectatic subtype may present with a secondary aneurysmal bone cyst. Lastly, in older patients, metastatic disease, multiple myeloma, and lymphoma must also be considered despite not often occurring in the distal radius.

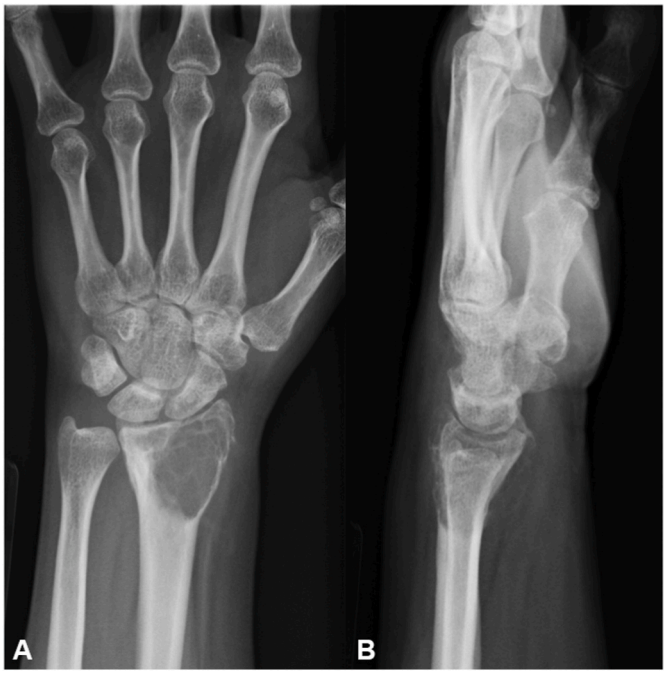

Fig. 1. Example of a Campanacci Grade 3 GCT of the distal radius. AP (A) and lateral (B) radiographs demonstrate classic eccentric, lytic lesion in the distal radial metaphysis and epiphysis with soap-bubble appearance, expansion of the bone, and thinning of the cortex with a volar soft-tissue mass.

2.3. Staging

Typically, classic Grade 1 lesions classic for GCT on radiographs and MRI do not require a biopsy prior to surgical intervention, though specimen should be sent for histopathologic confirmation intraoperatively after curettage prior to proceeding with the remaining procedure. A pre-operative biopsy is recommended however for aggressive lesions– typically Grade 2 and 3 – that could be other malignant or metastatic lesions.[13] This should be done after advanced imaging delineates the local extent of the tumor.[2] As with any musculoskeletal tumor, biopsy should be performed at the treating institution and be planned in conjunction with the treating surgeon.[15] Histopathology diagnostic of GCT includes multinucleated giant cells surrounded by mononuclear stromal cells whichmay vary in appearance including round, elongated, spindle, or polygonal.[13] The stromal cells, rather than the giant cells, are the neoplastic cell that leads to formation of these tumors from hematopoietic monocytes via the receptor activator nuclear factor-κB ligand (RANKL) pathway.[13,16] Gross pathology typically shows friable, hemorrhagic tissue, though histopathologic evaluation is often variable and may involve cystic degeneration, hemosiderin, mitotic figures, or increased spindle cell stroma.[17]

GCT has rare metastatic potential, occurring in 2–5% of all GCT cases, with benign metastases most commonly occurring in the lungs.[18] Campanacci Grade 3 tumors and lesions of the distal radius, however, have a higher rate of metastasis compared to other Grades and locations.[19,20] Because of this potential, staging includes chest imaging such as a chest radiograph or CT scan of the chest. The metastases are not aggressive, and patients with untreated pulmonary lesions still have good long-term prognosis and survival.[21] Nodules greater than 5 mm, however, warrant closer observation and consideration of treatment.[22]

3. Nonsurgical management

Nonoperative treatment of GCT is typically reserved for patients with lesions in difficult locations such as the spine or pelvis or with medical complexity preventing surgery. Given the surgical ease of access to the distal radius, solely nonoperative treatment is rare for symptomatic GCT. Nonsurgical modalities, however, include radiation, embolization, and denosumab.[2,5,13,23]

Radiation therapy for GCT is frequently used in unresectable lesions, and studies have shown local control in up to 80% of cases with radiation therapy alone.[24,25] Radiation therapy, however, has also been associated with secondary malignant transformation so should be weighed against the benefits of radiation for GCT.[26] Embolization has also been described for sacral and pelvic GCT, with a local control rate of 75%, but has not been described in surgically accessible locations.[27]

Denosumab is the only medical treatment approved for GCT, as it correlates with beneficial tumor response by limiting the RANK/RANKL pathway.[13,23] As a neoadjuvant, it aims to facilitate surgery by downstaging the tumor and in turn allowing for more conservative surgical options by creating a sclerotic rim around the lesion.[28] Studies have revealed disappearing of giant cell osteoclasts and increased fibrous tissue at final resection, suggesting downstaging of the tumor.[29] Timing in the literature has ranged from a 3–12 month course of denosumab prior to surgery, and administration has demonstrated a positive dose response between time course and degree of sclerotic perilesional bone formation.[28,29] This treatment, however, may increase the risk of local recurrence in patients treated with curettage.[13,23] Recurrence rates have been reported up to 60% in denosumab regimens lasting 6–12 months, but lower recurrence rates of 43% have been observed in regimens lasting 3 months.[29,30] Retrospective studies have revealed short courses are as effective as long courses, however, in terms of functional outcome scores, radiologic and histologic response, and recurrence-free survival.[31] Because of these recent discoveries, a short-term course of

denosumab is recommended when the chance of downstaging to perform a lesser morbid procedure outweighs potential chance of recurrence.[23,31]

4. Surgical management

Surgical management options are dictated by Campanacci Grade, involvement of the articular surface, and patient characteristics, with each option having distinct advantages and disadvantages (Table 1). Grade 1 lesions are contained within bone and are treated with joint preserving surgeries that conserve the native radiocarpal articulation.[32–34] Grade 3 lesions, which involve cortical disruption and a soft tissue component, are treated with en bloc resection that destroys the native radiocarpal articulation and requires reconstruction.[20,35–38] Joint reconstruction is classified into joint sacrificing and joint sparing procedures.[39] Grade 2 lesions that expand the cortex and encroach on the articular surface are managed surgically on a patient-specific basis given lack of consensus in the literature.[40]

4.1. Joint preserving options

The mainstay of joint preserving treatment for GCT of the distal radius is intralesional curettage combined with local adjuvant treatment of the cavity, filling of the cavity with bone graft or cement (Fig. 2). Intralesional curettage is indicated for Campanacci Grade 1 lesions and Campanacci Grade 2 lesions that do not compromise the subchondral bone. Curettage is coupled with mechanical, thermal, and chemical adjuvants such as burring, liquid nitrogen, electrocautery, argon beam, phenol, hydrogen peroxide, and anhydrous ethanol to decrease rate of local recurrence.[41,42] Filling of the cavity is then performed to provide structural support and prevent collapse of the joint surface. Options to fill the cavity include allograft, autograft, polymethylmethacrylate (PMMA), calcium sulfate, and calcium phosphate.[5,40] The preferred method of local adjuvant treatment and cavity filling remains controversial, with different rates of recurrence and complications between methods. In some studies, PMMA void filling was found to have a better recurrence free survival compared to bone graft.[43,44] Other studies, including a systematic review, have found that meticulous surgical technique and high speed burring, as opposed to specific chemical or thermal adjuvants or filling agents, was the most important factor in reducing local recurrence.[43] Fixation with a plate may be added to the construct if additional stability is required. Benefits of joint preserving procedures include maintained anatomic radiocarpal joint and preserved wrist function.[45] Intralesional curettage, however, does have higher rates of local recurrence compared to en bloc resection as well as radial collapse and radiocarpal degeneration.[46–48]

4.2. Joint sacrificing options

Joint sacrificing treatment for GCT of the distal radius involves en-bloc resection with reconstruction via arthrodesis. Resection is indicated for Campanacci Grade 2 lesions that threaten the radiocarpal joint and Campanacci Grade 3 lesions. Depending on the location and size of the tumor, resection can be performed through a dorsal or volar approach.

Reconstruction with radiocarpal arthrodesis can be performed via a variety of techniques and grafts. Total wrist arthrodesis options include distal ulnar procedures such as translocation, centralization, double barrel segmental reconstruction as well as bridging graft reconstruction.[49] The current authors prefer bridging plate reconstruction to optimize union through the use of structural grafts without sacrificing bone stock of the distal ulna (Fig. 3). Graft options for bridging plate reconstruction are structural allograft, vascularized fibula flaps or nonvascularized fibular allografts, and iliac crest autograft.[5,49,50] Dynamic compression plates are typically used for fixation of the graft, spanning from the radius to the second or third metacarpal for strength.[51] Partial wrist arthrodesis may also be performed utilizing a tibial cortical strut allograft or proximal fibula autograft.[5,49] Partial arthrodesis can be achieved by radio-lunate fusion, radio-scaphoid fusion, and radio-scapho-lunate fusion with structural grafts bridging the resected space.[5,49]

Benefits of arthrodesis include preservation of grip strength, prevention of wrist instability and degenerative changes, and decreased risk of complications and reoperation.[19,52] Arthrodesis is thus often indicated in laborers and in revision procedures after failed arthroplasty reconstruction or recurrence after curettage.[19,53] Arthrodesis has historically been thought to decrease function given lack of remaining wrist motion. Recent studies, however, have shown similar functional outcomes with lower complications and reoperation rates compared to both arthroplasty and intralesional curettage, arguing for higher utilization of arthrodesis for reconstruction of GCT of the distal radius.[40,54]

4.3. Joint sparing options

Joint sparing treatment for GCT of the distal radius also involves en-bloc resection, with reconstruction of the proximal radius. Resection, as above, is indicated for Campanacci Grade 2 lesions that threaten the radiocarpal joint and Campanacci Grade 3 lesions. Reconstruction with radiocarpal joint can be performed with osteoarticular allografts, proximal fibular autografts, and endoprosthesis. Advantages of joint sparing reconstructions include preserved wrist range of motion and theoretically higher function, though arthrodesis has been found to have at least similar if not higher functional outcomes in comparative studies.[38,49,52,54,55]

Osteoarticular allografts matched to patient-specific measurements may be utilized to reconstruct the radiocarpal joint. After resection of

Table 1
Summary of surgical options for GCT of the distal radius.

Surgical option	Procedure(s)	Indications	Advantages	Disadvantages
Joint preserving	Intralesional curettage	Campanacci Grade 1, 2 Lesions with no involvement of articular surface	Preserves native wrist motion	Higher rate of local recurrence Radiocarpal degeneration Radial collapse
Joint sacrificing	Radiocarpal arthrodesis	Campanacci Grade 2, 3 Lesions that threaten the articular surface	Better grip strength Fewer complications and reoperations	Limited wrist motion
Joint sparing	Osteoarticular allograft arthroplasty		Provides wrist motion	Allograft fracture Radiocarpal degeneration Nonunion Instability
	Proximal fibular autograft arthroplasty			Radiocarpal degeneration Instability
	Endoprosthetic arthroplasty			Loosening

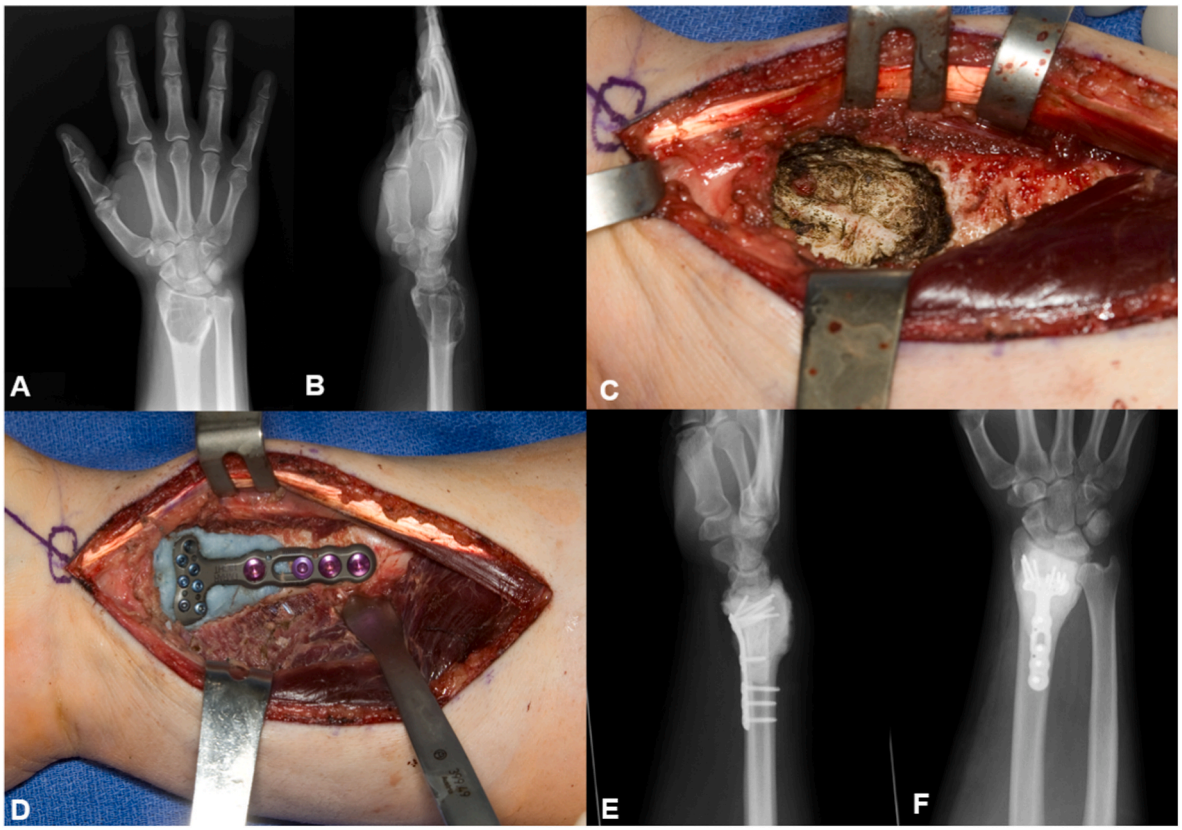

Fig. 2. Preoperative AP (A) and lateral (B) radiographs of a patient with a Campanacci Grade 2 GCT of right distal radius. Patient underwent curettage with hydrogen peroxide and argon beam adjuvants (C) followed by fixation with cement and volar plate (D). Post-operative radiographs show cement packing and stabilization of the right distal radius with supported articular surface (E, F).

the tumor, the allograft is modified to fit the donor defect and fixed with a compression or locking plate (Fig. 4). Risks associated with osteoarticular allografts include allograft fracture, revision to arthrodesis, and degeneration of the joint.[52,55,56]

Ipsilateral proximal fibular autografts may be used as a biologic arthroplasty given anatomic consistencies with the distal radius (Fig. 5).[49,57] The fibular head graft may be vascularized or non-vascularized, though vascularized autografts can provide improved union and prevention of collapse that may be associated with limited blood flow.[49,57,58] This method does, however, require expertise, time, and resources for microscopic reconstruction. Complications include instability and progressive degenerative changes due to non-anatomic reconstruction of the wrist joint.[49]

Endoprostheses can be used as a nonbiologic arthroplasty in either unipolar or total replacement designs. This may be preferred for patients concerned with donor site morbidity in proximal fibular autografts and limited bone bank resources for osteoarticular allografts. Prosthetic design often requires custom implants or 3D printed designs, and mid-term evaluation has shown acceptable outcomes in terms of range of motion and functional scores.[59] Complications are frequent, however, including subluxation and aseptic loosening.[49,59,60]

5. Outcomes

5.1. Functional outcomes

Intralesional curettage, when appropriately indicated, has consistently shown high functional outcomes (Table 2). Studies have reported grip strength up to 98% of the contralateral side, flexion-extension arc of 93–146°, and pronation/supination arc of 146–160°. Patient-reported outcomes (PROs) for curettage include disability of arm shoulder and hand (DASH) scores of 7–15, Musculoskeletal Tumor Society (MSTS) scores of 90–96%, and Toronto Extremity Salvage Scores (TESS) of 98%, even with long-term follow up to 13 years.[20,40,61] Intralesional curettage has resulted in significantly better patient reported outcomes compared to arthrodesis,[61] though these have been comparable in other studies.[20,40]

Regarding reconstruction after en-bloc resection, joint sacrificing procedures typically result in higher grip strength whereas joint sparing procedures result in greater range of motion (Table 2).[20,37–39] PROs are similar between joint sparing and joint sacrificing reconstructions, though disability scores have been reported as significantly higher in patients with preserved radiocarpal articulation compared to those with arthrodesis.[38–40,52]

Studies evaluating various joint sparing procedures have shown adequate functional outcomes and PROs after osteoarticular allograft, proximal fibular autograft, and endoprosthetic arthroplasties (Table 2). A comparative study by Wang et al. showed higher MSTS scores, Mayo wrist scores, grip strength, and flexion-extension motion in endoprosthetic reconstructions compared to osteoarticular allografts,[62] while other studies have shown comparable outcomes in terms of MSTS scores, grip strength, and motion.[38]

5.2. Complications

Rate of recurrence is an important consideration after treatment of GCT of the distal radius,as this location has historically shown a higher risk of local recurrence.[47,63] This may, however, be a result of the traditional way of treating GCT of the distal radius – intralesional curettage has generally been preferred over resection procedures given concern for affecting the complex function of the wrist. Several studies have shown an increase rate of local recurrence after intralesional

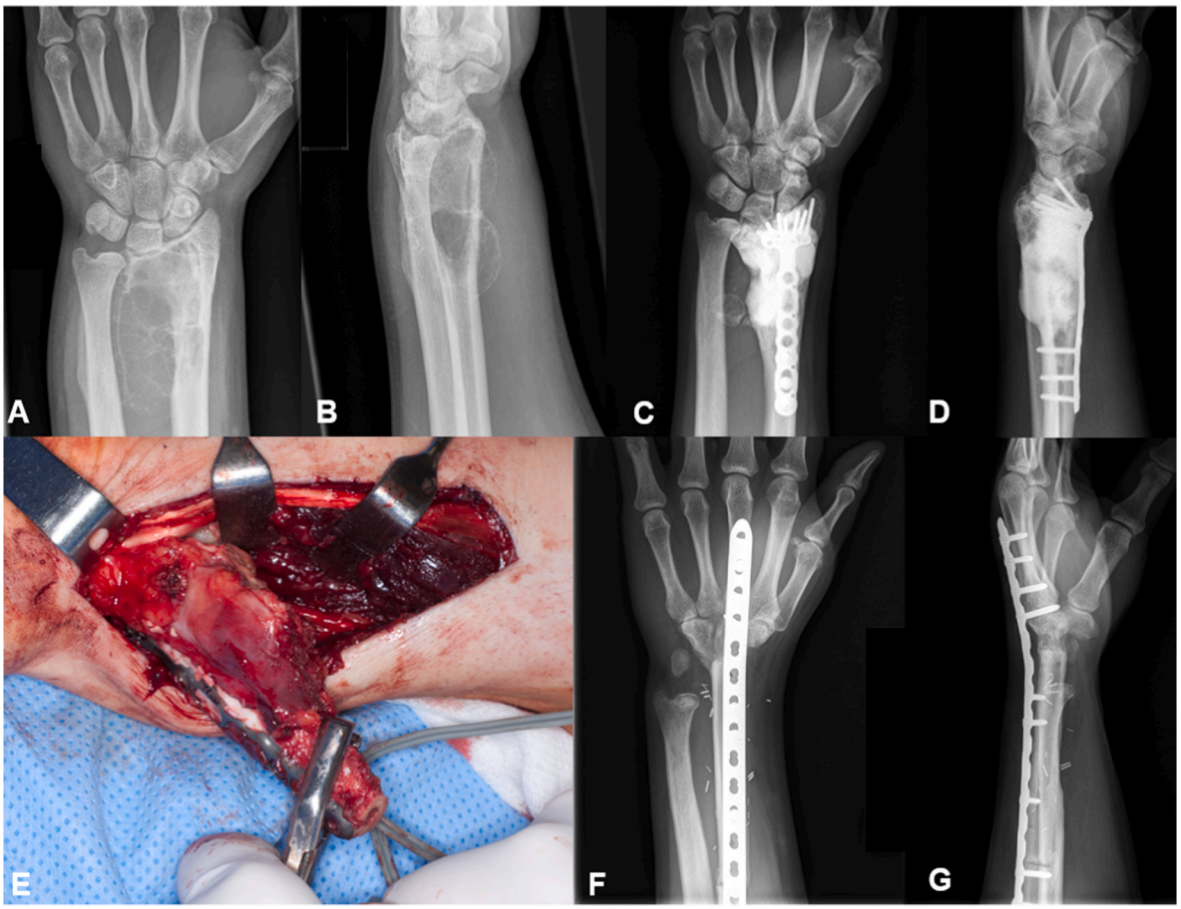

Fig. 3. AP (A) and lateral (B) radiographs of a Campanacci Grade 3 GCT which was treated at an outside facility and underwent 4 sperate curettage procedures over a 3-year time period secondary to recurrences which were treated with cement and plate fixation (C and D). He subsequently presented with additional recurrences and was treated with treated with resection (E) and radiocarpal arthrodesis with vascularized fibula autograft. Post-operative radiographs 6 months after the arthrodesis procedure show union of the fibular autograft, radius, and carpus (F, G).

treatment compared to en bloc resection. In a meta-analysis performed by Liu et al., relative risk of recurrence after intralesional treatment was found to be 2.8 (95% CI 1.17–6.71), with a 4.9 (95% CI 1.36–17.66) relative risk of recurrence when looking only at Campanacci Grade 3 GCT of the distal radius.[19] Odds of local recurrence are three times higher after intralesional curettage than resection and reconstruction procedures,[45] with local recurrence rates of 29–35% compared to 4–9%. The conversion rate of intralesional curettage to en bloc resection has been reported from 9 to 29%, most often for recurrence.[20,61]

Overall, a lower rate of major complications but higher rate of recurrence is seen with intralesional treatment.[19] The most common complication after intralesional curettage is arthritis of the preserved radiocarpal joint on imaging, reported in up to 45–63% of cases (Table 2).[20,40] A long-term study by Kuruoglu et al. further showed that preservation of the radiocarpal articulation often led to symptomatic osteoarthritis, with some requiring arthrodesis for pain control.[40] Radial collapse can also occur after curettage, detected by a change in ulnar variance after surgery.[48]

Complications after arthrodesis most commonly include nonunion and fracture (Table 2). Arthrodesis with vascularized fibula autografts, however, have shown a possibility of lower rates of nonunion.[64] Still, the most common reason for reoperation is proximal nonunions which eventually go onto union after a revision procedure.[40,64]

Osteoarticular allograft arthroplasties may be complicated by resorption, fracture, instability, arthritis, and nonunion with reoperation rates up to 18% (Table 2). The high revision rates for osteochondral allograft are primarily attributed to fracture.[52,55] A study by Wysocki et al. has reported 100% rate of degenerative arthritis of the reconstructed radiocarpal articulation, making this the most common complication in osteoarticular allografts. In a comparative series by Bianchi et al., the authors compared osteoarticular allografts to wrist arthrodesis and noted complications following reconstruction were specifically related to the type of reconstruction utilized, with a high rate of fracture in the osteoarticular allograft group, leading to arthrodesis for salvage.[52] Proximal fibular autograft reconstructions have high risk of instability and subluxation and reportedly up to 50% arthritis of the wrist articulation. Despite this, a recent systematic review observed high satisfaction rates with proximal fibular arthroplasty reconstruction at 87%.[38] Complications of custom endoprosthetic reconstructions also include instability, aseptic loosening, and infection.[65] Despite the advantage of no degenerative changes observed at early follow-up, studies have yet to evaluate long-term complications in custom endoprostheses.[62]

6. Summary

In this review, an updated summary of surgical treatment options for GCT of the distal radius was provided by characterizing procedures via outcome of the wrist joint, which has not been utilized in prior review literature. Surgical treatments of GCT of the distal radius were organized into three categories including joint preserving, joint sacrificing, and joint sparing procedures, creating a standardized working algorithm for considering indications, benefits, complications, and functional outcomes. Further, this review utilizes radiographic classification to dictate

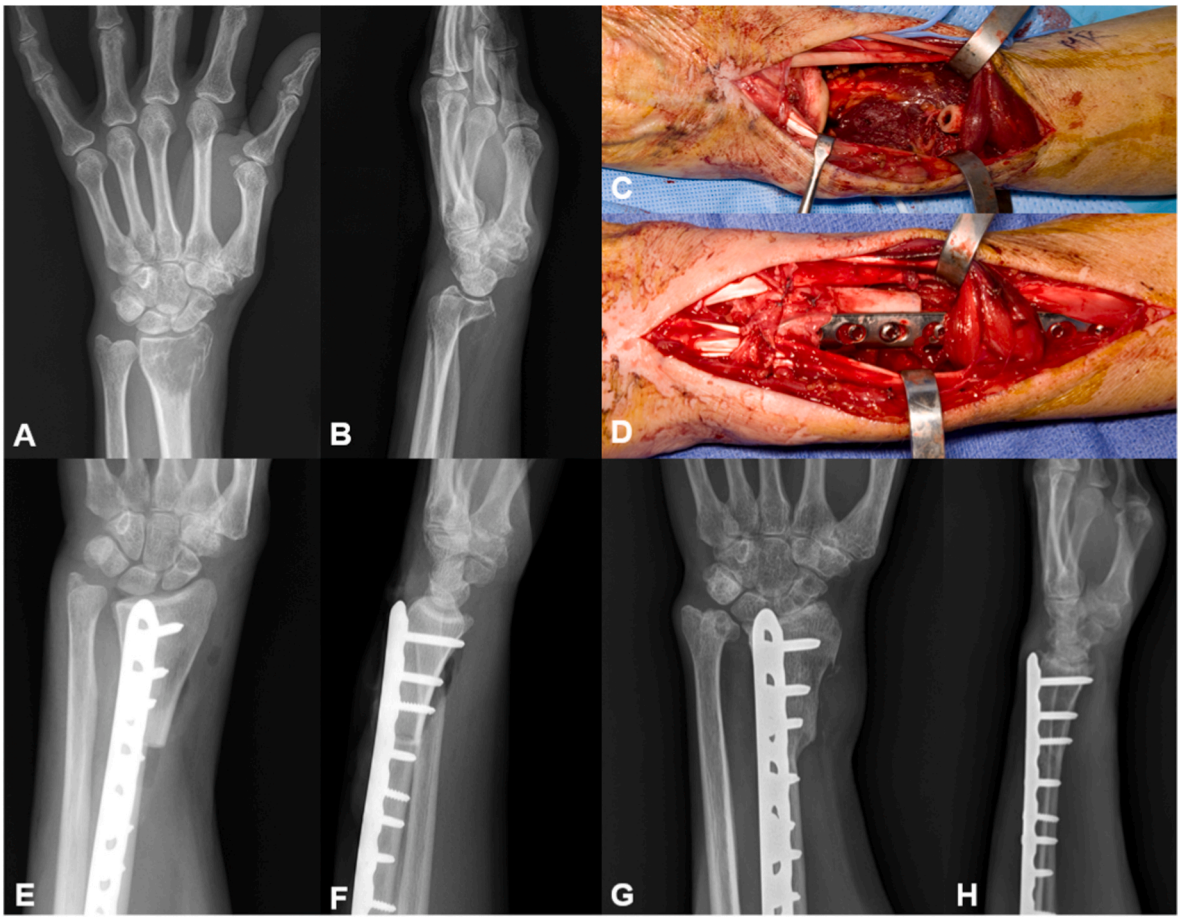

Fig. 4. AP (A) and lateral (B) radiographs of a Campanacci Grade 3 GCT which was treated with resection (C) and osteoarticular allograft reconstruction with compression plate fixation (D). Immediate post-operative radiographs show sparing and reconstruction of the radiocarpal joint (E, F). Four-year post-operative radiographs show solid fusion but also radiocarpal degenerative changes (G, H).

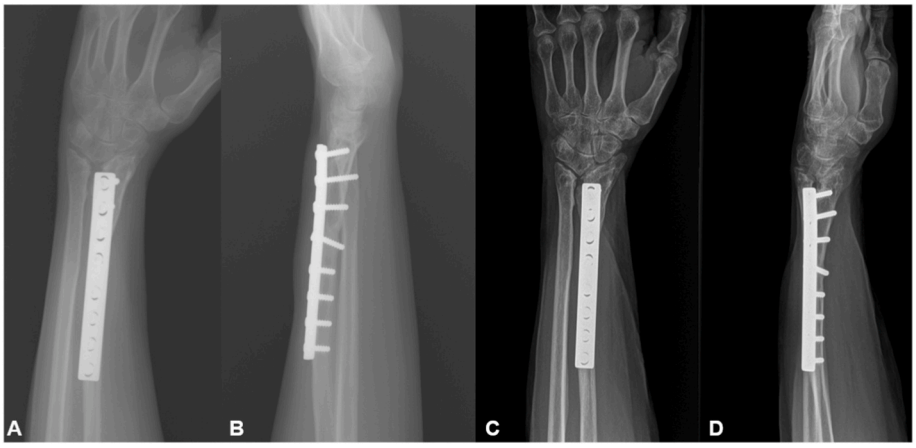

Fig. 5. Although not commonly utilized, following resection of the distal radius and proximal fibular autograft reconstruction can be utilized with the tibiofibular joint articular surface replacing the radiocarpal articulation (A, B). Twenty-four-year follow-up radiographs show retained proximal fibula autograft with moderate degenerative changes throughout the carpus (C, D).

surgical management, which will allow for standardization and optimization in treatment for GCT of the distal radius.

Surgical treatment of GCT of the distal radius is dictated by its Campanacci Grade, tumor location relative to the subchondral bone and articular surface, and patient specific factors. Extended intralesional curettage with the use of adjuvants and bone grafting or cement augmentation is the current standard treatment for patients with Campanacci Grade 1 tumors or Grade 2 tumors that do not threaten the articular surface of the distal radius. In the setting of Campanacci Grade 3 tumors and Grade 2 tumors that demonstrate articular destruction, however, en-bloc resection and reconstruction is recommended, though there is controversy on the ideal form of reconstruction.[39,52,61,66] Reconstruction of the distal radius following resection of GCT of bone can be classified as either joint sparing or joint sacrificing, with joint

Table 2
Outcomes of surgical treatments for GCT of the distal radius.

Technique	Author	Tumor	Cases	Follow-up (months)	Functional Outcomes	Complications	Local recurrence
Intralesional curettage	Abuhejleh et al.[49]	GCT Grades 2, 3	34	86	MSTS87: 33.5 TESS: 98%	0%	29%
Intralesional curettage	Kuruoglu et al.[31]	GCT Grades 2, 3	16	156	MSTS: 90% DASH: 15 Arc of motion P/S: 146°	63% arthritis Preserved RC articulation	31%
Intralesional curettage	Wysocki et al.[15]	GCT Grades 1, 2, 3	20	135	MSTS: 90% DASH: 7 Grip 98% Arc of motion F/E: 93° Arc of motion P/S: 160°	47% reoperation 45% arthritis	35%
Radiocarpal arthrodesis	Abuhejleh et al.[49]	GCT Grade 3	23	86	MSTS87: 27 TESS: 92%	4% malunion 4% non-union 4% fracture	4%
Radiocarpal arthrodesis	Bianchi et al.[62]	GCT Grade 3	20	94	MSTS93: 21 DASH: 40	10% fracture 5% nonunion 13% revision	–
Radiocarpal arthrodesis	Kuruoglu et al.[31]	GCT Grades 2, 3	5	156	MSTS: 86% DASH: 19 Arc of motion P/S: 134°	60% nonunion	13%
Radiocarpal arthrodesis	Wysocki et al.[15]	GCT Grades 1, 2, 3	15	135	MSTS: 90% DASH: 3 Grip 78% Arc of motion P/S: 157°	27% reoperation 20% nonunion	0%
Radiocarpal arthrodesis (partial)	Minami et al.[28]	GCT Grade 2	2	144	Enneking score: 87% Grip strength: 90% Arc of motion F/E: 70° Arc of motion P/S: 140°	1 revision 1 reoperation	1 recurrence
Radiocarpal arthrodesis	Zoccali et al.[29]	GCT Grades 2, 3	46	58	MSTS: 83% Grip strength: 55% Arc of motion P/S: 137°	0% Arthritis 0% instability 4% fracture 9% nonunion	7%
Radiocarpal arthrodesis	Lunn et al.[63]	GCT + other lesions	230	67	MSTS: 89% DASH: 17 Grip: 56% Arc of motion F/E: 26° Arc of motion P/S: 134°	32% reoperation 13% hardware failure 12% nonunion	–
Radiocarpal arthrodesis with vascularized fibula	Innocenti et al.[51]	GCT Grade 3 + post traumatic bone loss	11	94	DASH: 13 Grip: 59% Arc of motion P/S: 119°	0% nonunion	–
Joint sparing reconstructions	Lunn et al.[63]	GCT + other lesions	485	67	MSTS: 84% DASH: 13 Grip: 65% Arc of motion F/E: 78° Arc of motion P/S: 110°	20% reoperation 3% infection 13% hardware failure 7% nonunion	–
Osteoarticular allograft arthroplasty	Bianchi et al.[62]	GCT Grade 3	47	115	MSTS93: 21 DASH: 34	6% reabsorption 9% fracture 4% instability 9% arthritis 15% revision	–
Osteoarticular allograft arthroplasty	Zoccali et al.[29]	GCT Grades 2, 3	40	58	MSTS: 79% Grip strength: 56% Arc of motion F/E: 88° Arc of motion P/S: 139°	Arthritis 50% 25% instability 5% fracture 5% nonunion 3% resorption	7%
Osteoarticular allograft arthroplasty	Lans et al.[64]	GCT + other lesions	33	100	TESS: 96% DASH: 10	18% reoperation 39% fracture 12% nonunion 6% malunion	6%

(*continued on next page*)

Table 2 (*continued*)

Technique	Author	Tumor	Cases	Follow-up (months)	Functional Outcomes	Complications	Local recurrence
						58% degenerative changes	
Osteoarticular allograft arthroplasty	Wysocki et al.[15]	GCT Grades 1, 2, 3	4	135	MSTS: 87% DASH: 20 Grip 69% Arc of motion F/E: 108° Arc of motion P/S: 128°	0% reoperation 100% arthritis 25% nonunion	0%
Osteoarticular allograft arthroplasty	Wang et al.[50]	GCT Grade 3	15	34	MSTS: 71% Mayo wrist: 65 Grip strength: 55% Arc of motion F/E: 65° Arc of motion P/S: 107°	100% arthritis 7% resorption 27% instability	–
Proximal fibular autograft arthroplasty	Minami et al.[28]	GCT Grades 2, 3	2	174	Enneking score: 47% Grip strength: 65% Arc of motion F/E: 15° Arc of motion P/S: 60°	No complications	0%
Proximal fibular autograft arthroplasty	Barik et al.[40]	GCT Grade 3	11	32	MSTS: 21 Mayo Wrist: 66 Arc of motion F/E: 44° Arc of motion P/S: 121°	9% subluxation	9%
Proximal fibular autograft arthroplasty	Zoccali et al.[29]	GCT Grades 2, 3	108	58	MSTS: 87% Grip strength: 62% Arc of motion F/E: 82° Arc of motion P/S: 106°	50% Arthritis 19% instability 1% fracture 3% nonunion 1% resorption	7%
Custom prosthetic arthroplasty	Zhang et al.[52]	GCT Grades 2, 3	11	56	MSTS: 80% Grip strength: 71% Arc of motion F/E: 71° Arc of motion P/S: 85°	9% infection	9%
Custom prosthetic arthroplasty	Zoccali et al.[29]	GCT Grades 2, 3	32	58	MSTS: 82% Grip strength: 63% Arc of motion F/E: 75° Arc of motion P/S: 90°	3% aseptic loosening 16% instability	7%
Custom prosthetic arthroplasty	Wang et al.[50]	GCT Grade 3	15	31	MSTS: 82% Mayo wrist: 71 Grip strength: 64% Arc of motion F/E: 107° Arc of motion P/S: 115°	20% instability 0% arthritis	–

sparing procedures allowing for a greater range of motion while joint sacrificing procedures allow for greater grip strength and fewer complications.[52,55,61] The use of wrist arthrodesis, osteoarticular allografts, proximal fibular allografts, and endoprosthesis have become primary means of treatment, each with advantages and disadvantages.[39,52,66]

Reports of patient functional outcome have been conflicting, with some showing no difference between joint preserving, joint sacrificing, and joint salvage procedures[20,39] while others show improved functional outcomes with joint salvage.[61] In a long-term patient reported outcome study, however, Kuruoglu et al. noted a significant difference when examining DASH, with the arthrodesis patients having a lower disability score.[40] The lack of consensus in the literature may be due to the variety of functional outcome scores that have been utilized, making definitive conclusions regarding function difficult.[61,67,68]

GCT of the distal radius have historically shown a higher incidence of recurrence compared to other locations,[47,63] though this may be due to the traditional way they have been surgically treated. Recurrence after intralesional treatment is higher then en-bloc resection, but with less major complications.[19] With close proximity to the articular surface, curettage at the distal radius may be insufficient, leading to disease recurrences.[35,47] This, in conjunction with lower recurrence rates seen in joint resection and reconstruction procedures,[45] argues for aggressive treatment in all cases with concern for articular surface involvement.

The described evaluation and preferred treatments of GCT of the distal radius involves collaboration of radiologists, pathologists, medical oncologists, interventional oncologists, orthopedic oncologic surgeons, hand surgeons, and hand therapists. Medical oncologists and interventional oncologists, specifically, may aid in deciding surgical treatment options by assessing suitability for denosumab, radiation, or embolization as a neoadjuvant therapy. This multidisciplinary approach has proven to standardize treatments and optimize outcomes in both musculoskeletal oncology and hand surgery.[69–72] In the recent

proceedings for musculoskeletal oncologic interventions, standardization of techniques to improve consistency of outcomes was prioritized.[73] In this review, the current treatments and preferred techniques were described in terms of a multidisciplinary approach in order to optimize standardization and improve patient outcomes consistently in line with these recent priorities.

In summary, GCT of the distal radius can be successfully managed with intralesional curettage and adjuvants for cases where the articular surface can be preserved. In settings where the articular surface cannot be aggressively burred, joint sacrificing and joint sparing procedures should be utilized, which lead to acceptable functional outcomes despite complications. Choice of reconstructive procedure should be made based on patient-specific factors, considering relative functional outcomes, complications, and recurrence rates.

Funding

None.

Authors contribution

MHS contributed to conceptualization, methodology, writing, and editing. SHT contributed to writing and editing. MR and SLM contributed to conceptualization, resources, and writing. MTH contributed to conceptualization, methodology, writing, and supervision.

Declaration of competing interest

None.

Acknowledgements

None.

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