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Custom 3D Implant for Hemiarthroplasty of the Third Metacarpal in a Giant Cell Tumor of bone: Functional Outcomes and Hand Stability

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ABSTRACT

Giant cell tumor (GCT) of the hand is a rare benign but locally aggressive bone tumor with high recurrence rates. It is commonly treated by curettage with cementation or bone grafting. However, reconstruction after en bloc resection of metacarpal GCT remains challenging, particularly in young patients. Conventional options such as allografts or standard prostheses are associated with notable complications and functional limitations. Custom-made 3D-printed implants have recently emerged as a potential alternative, although current evidence is limited.

We report the case of a 19-year-old woman with a recurrent GCT of the third metacarpal following initial curettage and cementation. After neoadjuvant denosumab therapy, an en bloc resection of the third metacarpal was performed. Reconstruction was achieved using a patient-specific 3D-printed titanium hemiarthroplasty featuring an intramedullary stem, screw fixation, porous surfaces for osseointegration, and dedicated structures for ligament reinsertion to ensure hand stability.

Early postoperative mobilization was allowed. At mid-term follow-up, the patient demonstrated excellent functional recovery, high total active motion, minimal pain, and no complications, implant instability, or tumor recurrence.

Custom-made metacarpal hemiarthroplasty appears particularly suitable for reconstruction of central rays, where transverse stability is supported by adjacent structures. This case supports patient-specific 3D-printed hemiarthroplasty as a promising reconstructive option, providing favorable early functional outcomes while preserving joint biomechanics. Further studies are needed to assess long-term durability.

Keywords: Giant cell tumor, 3D-printed implant, Metacarpal hemiarthroplasty, Patient-specific prosthesis, Hand function, En bloc resection.

INTRODUCTION

A giant cell tumor (GCT) of bone is a benign but locally aggressive tumor. It is rare in the hand, with approximately 2–4% of cases occurring in the metacarpals[7,21,26]. In this anatomical region, the literature reports a higher tendency for recurrence following conventional treatments, namely curettage and cementation. Some authors report recurrence rates of up to 90% after curettage[7,31]. This is particularly the case in patients presenting with aggressive Campanacci grade III lesions[16,31]. Although a stepwise surgical approach is often respected, grade III lesions frequently lead to en bloc resection[23]. Reconstruction using allografts or metacarpophalangeal (MCP) joint prostheses is, however, not without adverse effects and is associated with high complication rates[19,23].

With the growing development of custom-made 3D implants in orthopaedics, this approach has also emerged as a potentially valuable solution for the reconstruction of metacarpal defects[25].

The current literature on this topic remains limited. Most available data consist of case reports and one pilot study evaluating custom-made implants in the context of GCTs. As this technology has only recently been applied to this indication, long-term follow-up remains scarce. Nevertheless, the reported results appear promising. Overall patient satisfaction is high; however, total active motion (TAM) values are often moderate despite very satisfactory DASH, MSTS, or VAS scores[19].

We report a case of MCP hemiarthroplasty using a custom-made prosthesis in the setting of recurrent GCT.

CASE PRESENTATION

A 19-year-old woman presented with a painless swelling of the third metacarpal of the left hand, without associated functional impairment.

The swelling had appeared approximately six months prior to consultation, without associated complaints or limitation of motion. Clinical examination was therefore unremarkable.

Imaging revealed a lytic osseous lesion of the distal left third metacarpal (Figure 1) consistent with a diagnosis of GCT. Following discussion in a multidisciplinary setting of our sarcoma reference center, considering the patient's young age, intralesional curettage and cementation were initially proposed.

Postoperative follow-up, however, demonstrated early local recurrence with radiological changes after six months. Imaging revealed tumor regrowth surrounding the cementation, extending beyond the cortical bone with invasion of the surrounding soft tissues (Figure 2).

In this context, and in light of the particularly high recurrence rates—some authors reporting up to 90% recurrence for Campanacci grade III lesions—we opted for a neoadjuvant treatment with denosumab followed by an en bloc resection and reconstructive surgery[7,23,31].

Denosumab is a monoclonal antibody targeting the receptor activator of nuclear factor kappa-B ligand (RANKL). By binding to RANKL, it inhibits osteoclast activation and differentiation, resulting in a marked reduction in bone resorption. This mechanism is also associated with a significant reduction in multinucleated giant cells characteristic of GCTs, allowing progressive densification of the osseous lesion[2,14,27]. However, denosumab-induced peripheral and intralesional sclerosis has been reported to obscure tumor margins. Intra-lesional curettage after denosumab is therefore associated with an exceedingly high recurrence rate of local recurrence. Hence, there is a general consensus among orthopedic oncologists to avoid intra-lesional curettage and shift the surgical strategy toward en bloc resection in order to achieve adequate local control[5].

Several studies have shown that biological and radiological responses to denosumab generally occur within 3 to 6 months of treatment[2,14]. This therapeutic window allows local tumor control giving time for surgical planning design of a custom-made implant adapted to the bone defect.

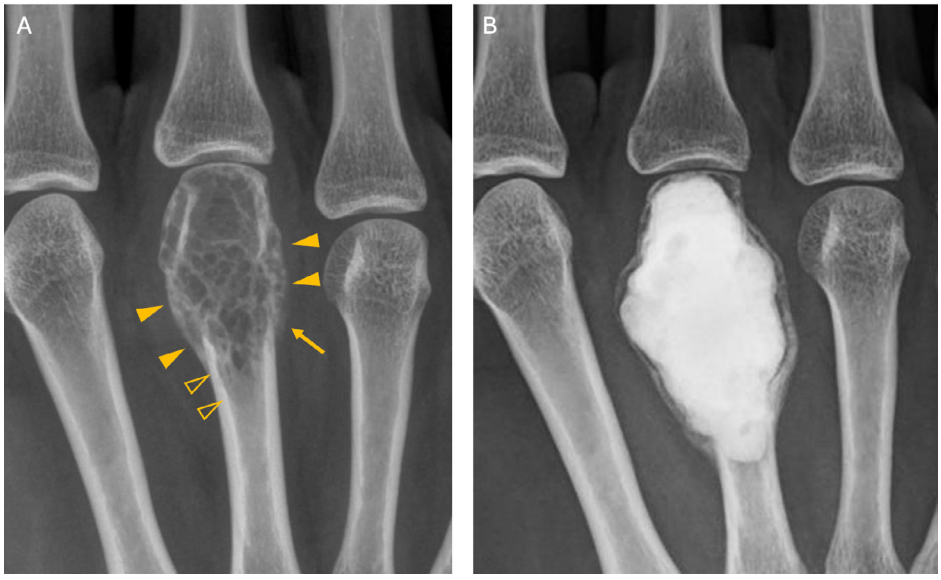

Fig. 1 — A: Expansive osteolytic lesion of the third metacarpal, involving the head and neck (metaphyso-epiphyseal region), surrounded by a peripheral bony shell representing periosteal reconstruction (solid arrowheads). The bone surface shows areas of focal ill-defined margins (arrows), indicating active behavior of the lesion or pathological fissure. Endosteal resorption of proximal cortex indicating endomedullary extension (open arrowheads). Note the characteristic internal septation commonly observed in giant cell tumor of bone.
B: Post-operative control after curettage and cementation.

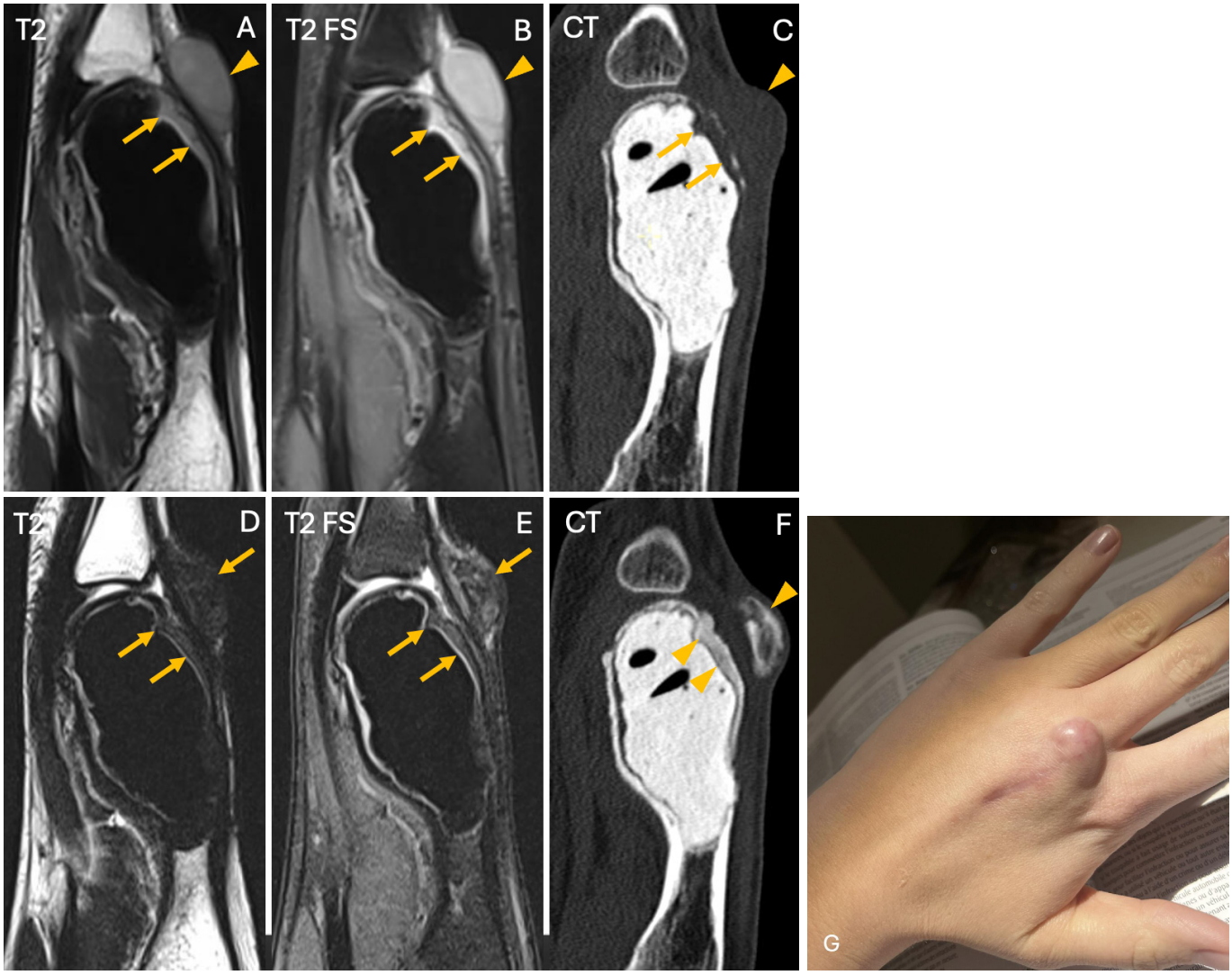

Fig. 2 — Sagittal view of the 3rd metacarpal at MRI (A, B) and CT (C) demonstrating nodular extraosseous recurrence along the dorsal aspect of the metacarpal (arrows) and at the periphery of the cement (arrowheads). Post-denosumab follow-up (D, E, F) shows a marked decrease in T2 signal at the sites of recurrence (D and E, arrows) corresponding to the appearance of mineralization (F, arrowheads). A slight reduction in the volume of the extraosseous nodule is also observed. G : illustrates the clinical visualization of the soft-tissue extension.

SURGICAL TECHNIQUE AND RECONSTRUCTION

For reconstruction, we collaborated with the company Implantcast for the design and manufacture of a patient-specific implant. A computed tomography scan of the contralateral hand was obtained to serve as an anatomical reference. Implant design was carried out in close collaboration with engineers, with dedicated orifices incorporated for ligament reinsertion. The implant was manufactured from a titanium alloy, with a porous proximal surface intended to promote osseointegration. A hemiarthroplasty was selected, combined with an intramedullary stem with additional screw fixation.

The proximal portion of the metacarpal, and consequently the carpometacarpal joint, was preserved, as it was not involved by the lesion, thereby avoiding reconstruction at a level associated with potentially disappointing functional outcomes[4,18].

Specific cutting guides were provided to secure the resection.

During surgery, the initial dorsal incision over the third metacarpal was reused. Complete resection of the subcutaneous tumor mass, which had become densified under denosumab treatment, was performed. The metacarpal diaphysis was then exposed to allow the use of personalized cutting guides. Particular attention was paid to identifying and preserving the intermetacarpal and metacarpophalangeal ligaments for subsequent reinsertion into the dedicated implant orifices. After preparation of the medullary canal, the implant was impacted using the dedicated instrumentation. A

second guide enabled complementary screw fixation. During this step, a drill bit fractured; however, this did not compromise final implant stability, which was deemed satisfactory (Figure 3).

Postoperative care and range of motion

In the immediate postoperative period, early mobilization according to pain tolerance was encouraged, allowing rapid tendon mobilization and preventing excessive stiffness due to scar formation[6]. No immobilizing splint was applied. Early postoperative assessment revealed a wide range of motion with very favorable TAM scores[33]. The VAS score demonstrated minimal pain, even in the immediate postoperative period. Results are shown in (Table I).

DISCUSSION

Several reconstructive options have been described for metacarpal resections, including vascularized or non-vascularized fibular grafts, metatarsal transfers, silicone implants, and prosthetic reconstruction[19].

We chose to perform a hemiarthroplasty using a custom-made prosthesis. We believe this represents an ideal indication for the central rays, specifically the third and fourth metacarpals. This approach requires several prerequisites: intact proximal cartilage of the first phalanx, respect for anatomical reconstruction, integration of ligament reconstruction, and maximal preservation of surrounding soft tissues. These rays are stabilized by adjacent metacarpals and reconstructed ligaments, particularly the deep transverse metacarpal ligament, a key stabilizer limiting separation of the metacarpal heads. This provides transverse stability, contributing to alignment and offering more predictable stability compared with the first and fifth rays[1].

Rigorous planning is essential to integrate ligament fixation zones and restore transverse stability. Longitudinal restoration is also achieved with engineering support based on contralateral hand CT imaging[30].

The improved stability of the central rays leads us to believe that this approach may provide superior durability and function. Although grip strength was not fully recovered compared with the contralateral side, the patient is right-handed, and when considering an expected 10% lower strength in the left hand, the measured value remains slightly below but still represents a very good functional outcome. A mild difference in hyperextension was observed compared with the adjacent fingers; however, no true extension deficit was present. Overall, the patient demonstrates an excellent functional recovery, as reflected by her total active motion (TAM) and by near-normal performance in daily activities, with an almost perfect DASH score.

At the 2-year follow-up, the patient demonstrated encouraging clinical and radiological outcomes. While we hope these results will be maintained over the long term, the current level of evidence remains limited and longer follow-up is necessary. Continued

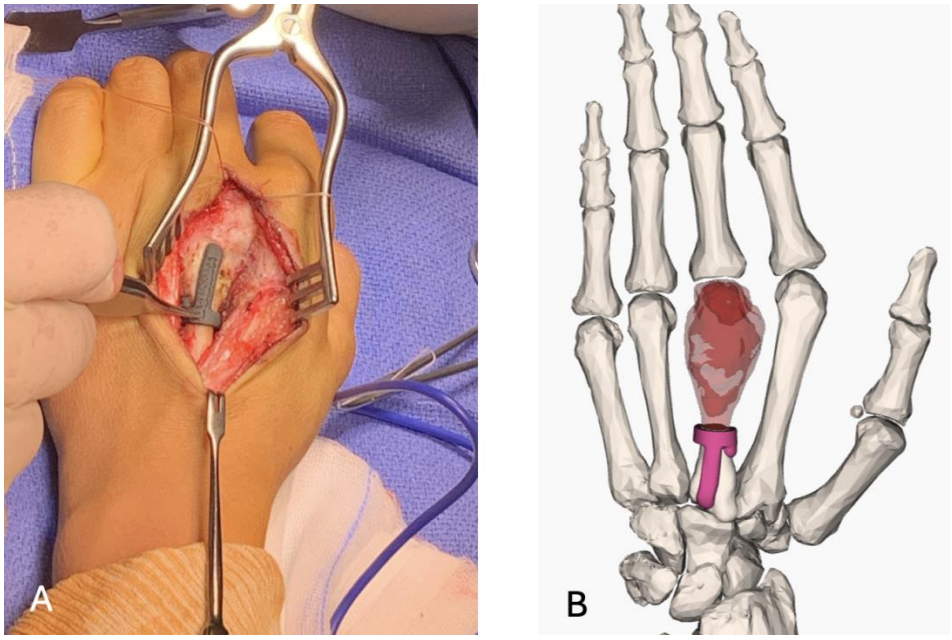

Fig. 3.1 — A: Preoperative 3D cutting guide (B) used for metacarpal osteotomy and corresponding intraoperative view (A).

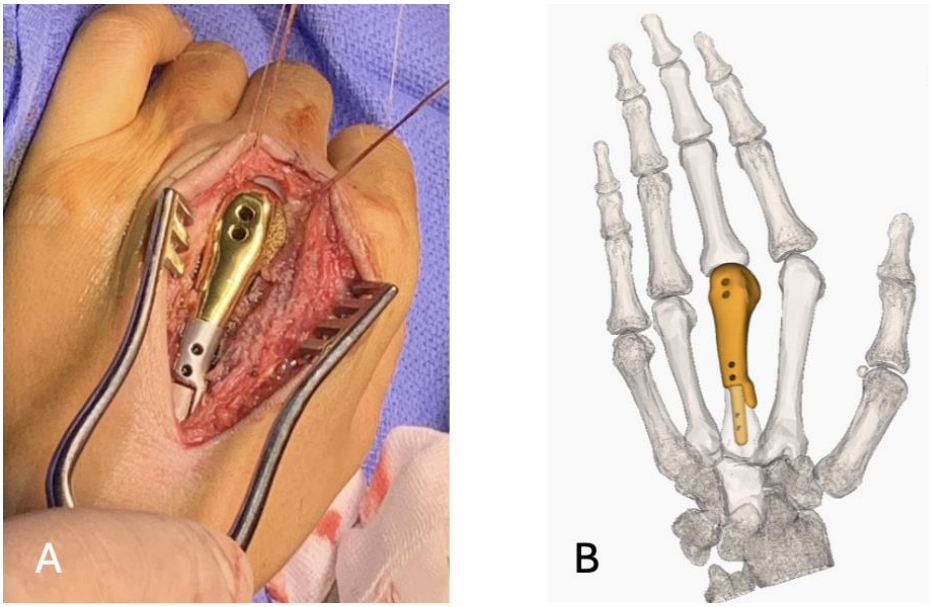

Fig. 3.2 — Preoperative 3D implant planning (B) with corresponding intraoperative surgical view (A).

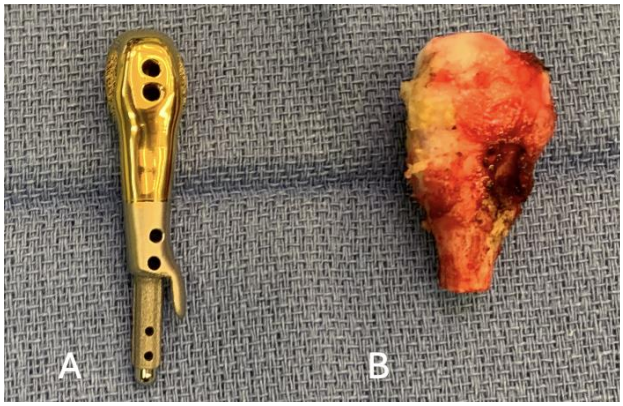

Fig. 3.3 — Photograph of the resected metacarpal specimen (B) and the corresponding custom-made prosthesis (A).

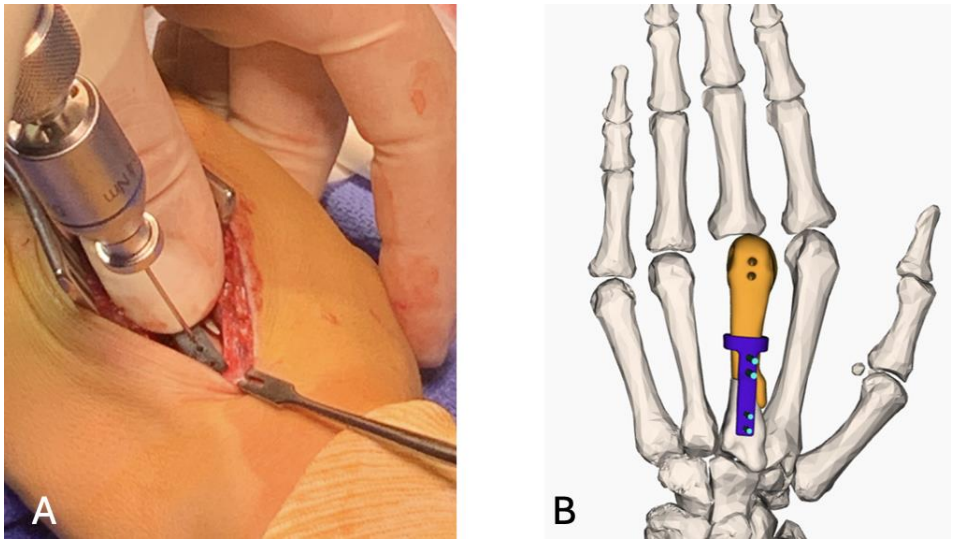

Fig. 3.4 — Preoperative planning (B) of the implant fixation guide and corresponding intraoperative view (A).

Table I. — This table summarizes the clinical data of our patient at nearly 18 months of postoperative follow-up. Clinical illustration showing fully recovered flexion (A) and a slight extension deficit (B) compared with the adjacent fingers, while still achieving full extension to 0°.

Follow-up	1.5 y
Extension	MCP : 0° PIP : 0° DIP : 0°
Flexion	MCP : 95° PIP : 100° DIP : 95°
TAM	290°
Grip strength	Operated : 20,3 kg Controlateral : 28.3 kg
Pinch (three-jaw chuck)	Operated : 5,3 kg Controlateral : 6,8 kg
VAS	0
DASH	3,3
Kapandji score	10/10

surveillance is therefore planned, consisting of semiannual hand radiographs during the first two years, followed by annual radiographs between years two and five, with MRI reserved for cases of clinical or radiographic concern. Beyond five years, follow-up will be primarily clinical, with imaging performed according to the presence of symptoms[11].

We deliberately selected hemiarthroplasty for several reasons. First, preserving bone stock was essential given the patient's young age. Second, this option was feasible due to the intact cartilage of the proximal phalanx. As demonstrated in the literature, unicompartmental reconstruction can provide satisfactory functional outcomes. Cartilage integrity is clearly a favorable prognostic factor for reconstruction durability[3].

Although literature on finger hemiarthroplasty remains limited, some studies report encouraging results. One study focusing on proximal interphalangeal joint hemiarthroplasty demonstrated a 72% survival rate at 10 years. This suggests that such solutions may offer satisfactory medium- to long-term outcomes[20].

We are nevertheless aware that revision rates can be variable and sometimes high in hemiarthroplasty, mainly due to progressive but premature wear of articular surfaces. However, MCP arthroplasties—particularly silicone implants or metallic implants—also show high revision rates and complications such as loosening, implant rupture, and loss of stability[15,19,28].

Although long-term implant survivorship remains unknown, failure of the reconstruction would not preclude further salvage procedures. In selected cases, salvage options may include conversion to a fusion-based reconstruction following metacarpal resection, as well as ray resection, both of which have been described in the oncological management of tumors of the hand[22,32]. In complex situations involving extensive disease, ray resection remains a viable oncological salvage option.(24) In addition, recent reports of patient-specific 3D-printed metacarpal prostheses—particularly in the more biomechanically demanding first ray—support the feasibility of customized reconstructions in oncologic settings[10].

Fixation methods remain debated, particularly in custom-made bone reconstructions. One group suggested a theoretical increased risk of periprosthetic fractures associated with intramedullary stems in metacarpal reconstructions[19]. However, this hypothesis is extrapolated from femoral implant literature, where biomechanical constraints differ substantially. No study has formally demonstrated this risk in metacarpal anatomy.

Conversely, some studies suggest a higher risk of stress risers in more rigid or extramedullary constructs. Excessive stiffness and discontinuity in elastic modulus are contributing factors. Intramedullary fixation may provide more homogeneous stress distribution, potentially reducing stress riser effects. These remain extrapolations and should be interpreted cautiously in the metacarpal context[12,13,17].

We opted for an intramedullary fixation based on extensive literature supporting this method in metacarpal fracture management. Several series report high union rates, low mechanical complication rates, and—most importantly—the possibility of

early mobilization, which is essential for preserving hand function. We therefore believe this feature to be favorable both for function and implant longevity[8,9,29].

CONCLUSION

This case supports patient-specific 3D-printed metacarpal hemiarthroplasty as a promising reconstructive option following en bloc resection of recurrent giant cell tumors of the hand. This approach allows preservation of bone stock, restoration of joint biomechanics, and early mobilization, resulting in encouraging functional outcomes with preserved range of motion, minimal pain, and satisfactory hand stability at mid-term follow-up. The use of an intramedullary stem with complementary screw fixation appears to provide sufficient primary stability, while the integration of ligament reinsertion may further contribute to joint stability and patient satisfaction. However, this technology has only recently been applied to this indication, and current evidence remains limited to small series and case reports. Long-term implant durability and oncological safety remain unknown, emphasizing the need for prolonged surveillance and larger studies with extended follow-up.

Limitations

This study has several limitations inherent to a single-case report. First, the follow-up remains relatively short, preventing definitive conclusions regarding long-term implant survival, wear, and loosening. Second, the absence of a control or comparative reconstruction technique limits the ability to draw conclusions on superiority. Third, patient-specific, custom-made implants may restrict reproducibility and generalizability due to cost, manufacturing time, and limited availability. Finally, the level of evidence remains low, emphasizing the need for larger series and longer follow-up to validate this reconstructive approach.

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Conflict of Interest: The authors reported no conflict of interest.

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