

RESEARCH



Complications, reoperations, and revisions after surgical treatment of humeral metastases with modular prosthesis, intramedullary nailing or plate fixation: a retrospective analysis

Konstantina Solou¹ · Filippo Tamburini¹ · Monica Cosentino² · Federica Zuccheri¹ · Barbara Dozza³ · Barbara Bordini² · Davide Maria Donati¹ · Costantino Errani¹

Received: 9 May 2026 / Accepted: 23 June 2026

© The Author(s), under exclusive licence to Springer-Verlag France SAS, part of Springer Nature 2026

Abstract

Purpose Modular prosthesis, intramedullary nailing and plate fixation are surgical options for humeral metastasis, but the optimal treatment for pathological or impending fractures remains controversial. This study evaluated complications, reoperations, and revisions in patients with humeral metastases treated with these surgical techniques.

Methods We retrospectively analyzed 115 patients with humeral metastases treated with modular prosthesis (n=33), intramedullary nailing (n=69) or plate fixation (n=13). We evaluated complications, reoperations without implant removal and revisions requiring implant removal. Cumulative incidence of complications and death was estimated using competing risk analysis.

Results In modular prosthesis group, 5/33 patients had complications (15.1%): three had subluxations or instability treated conservatively, one had local disease progression treated with embolization and radiotherapy, and one had deep infection who required revision. In intramedullary nailing group, 8/69 patients had complications (11.6%): seven had local disease progression and one had mechanical implant failure. Two patients required reoperation due to local disease progression, and none required revision. In plate fixation group, 4/13 patients had complications (30.7%): two had mechanical implant failure, one had local disease progression, and one had deep infection. Reoperation was required in one patient due to infection, while revision was required in two patients: one patient due to local disease progression and one patient due to mechanical implant failure.

Conclusion Modular prosthesis, intramedullary nailing and plate fixation were associated with distinct complication profiles. Modular prostheses were most commonly associated with instability, intramedullary nails with local disease progression, and plate fixation with a relatively high proportion of complications and revisions. Given the heterogeneity of anatomical location and treatment indications, these findings should be interpreted descriptively rather than as evidence of superiority of one technique over another.

Keywords Bone metastasis · Humeral metastasis · Surgical treatment · Complications · Reoperations · Revisions · Modular prosthesis · Intramedullary nailing · Plate fixation

Introduction

The metastasis of humerus is the second most common long bone site of metastatic disease [1]. Surgical treatment such as modular prosthesis, intramedullary nailing and plate fixation have been proposed among other techniques to provide

pain relief, restore function and enhance the quality of life [2–6].

A recent systematic review reported that there are heterogeneous data on complications, reoperations and implant revisions of patients with humeral metastases treated surgically, which were almost exclusively derived from small retrospective studies, many of which reported pooled

Extended author information available on the last page of the article

Published online: 29 June 2026

Springer

outcomes of patients with humeral metastases, due to limited sample sizes, thereby limiting the validity of subgroup comparisons [7]. Thus, we conducted a retrospective analysis of prospectively collected data including patients with humeral metastases treated with modular prosthesis, intramedullary nailing or plate fixation. The novelty of the present study lies in the detailed treatment-specific reporting of complications, reoperations and revisions in a relatively large single-center cohort while avoiding direct comparisons between fundamentally different anatomical locations and surgical indications.

Materials and methods

We performed a retrospective study of prospectively collected data including patients with humeral metastases treated with modular prosthesis, intramedullary nailing, or plate fixation at a single institution from 2014 to 2024. Ethical approval for this study was obtained from the Ethics Committee (Approval No. NCT03416959). Informed consent was obtained from all individual participants included in the study.

Between 2014 and 2024, we treated surgically 125 patients with humeral metastases. We included patients with humeral metastases who were treated with modular prosthesis, intramedullary nailing, or plate fixation. We excluded

patients with humeral metastases who underwent hemiarthroplasty ($n=4$), total humerus replacement ($n=4$), amputation ($n=1$), and patients who had no follow up ($n=1$), the excluded patient was a foreigner and continued treatment in his country. We analyzed the remaining 115 patients: 33 patients (28.7%) were treated with modular prosthesis, 69 patients (60%) were treated with intramedullary nailing, and 13 patients (11.3%) were treated with plate fixation.

Preoperatively, all patients were evaluated using plain radiographs and/or computed tomography or magnetic resonance imaging. Indications for surgery included pathological or impending fracture. An impending fracture was defined as a humeral lesion with circumferential cortical destruction exceeding 50%, or longitudinal cortical erosion greater than 3 cm [4]. The choice of surgical treatment was based on the size and location of the metastasis, according to the Capanna criteria [8], considering the patient's general status as assessed by the Karnofsky Performance Status scale and the estimated survival [9].

Out of 33 patients treated with modular prosthesis, 29 patients (88%) had proximal humeral metastases, three patients (9%) had diaphyseal humeral metastases, and one patient (3%) had distal humeral metastasis (Fig. 1). Out of 69 patients treated with intramedullary nailing, six patients (9%) had proximal humeral metastases, 62 patients (90%) had diaphyseal humeral metastases, and one patient (1%) had distal humeral metastasis. Out of 13 patients

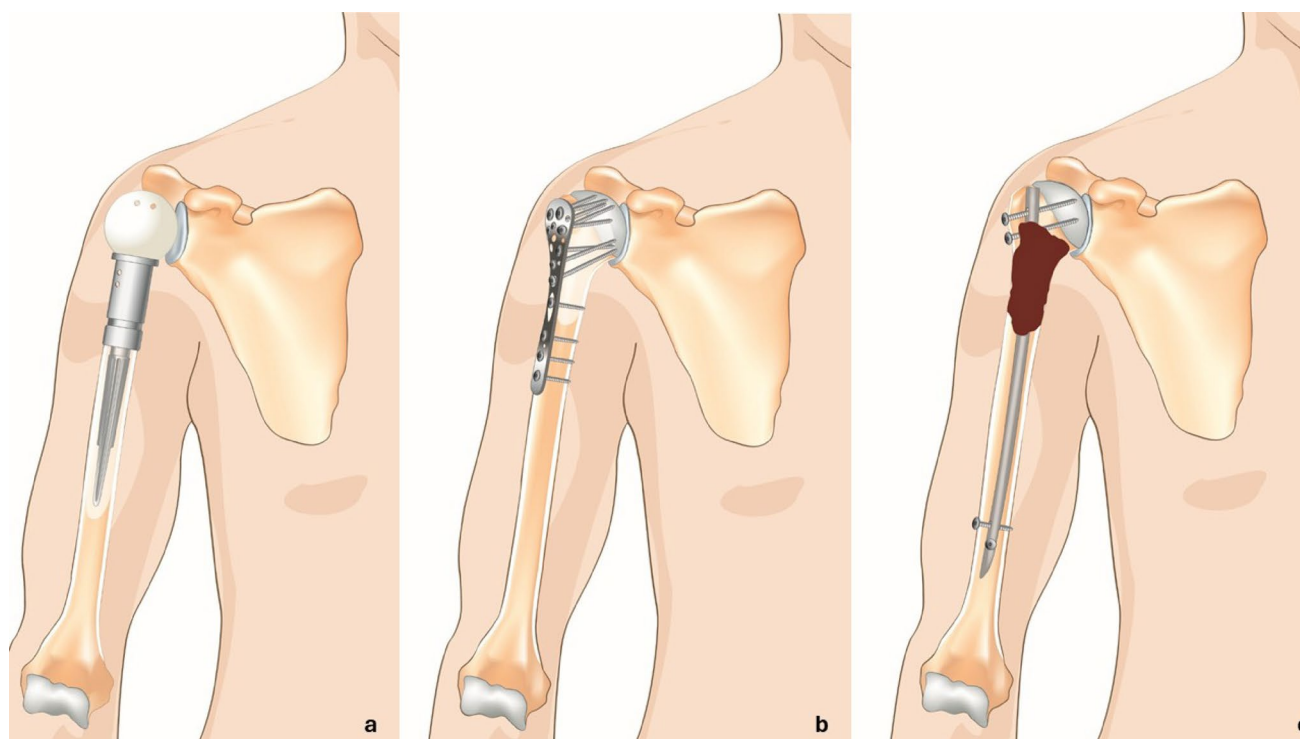


Fig. 1 **a** Design of modular prosthesis for treatment of proximal humerus metastasis. **b** Design of internal fixation with plate for treatment of proximal humerus metastasis. **c** Design of intramedullary nailing for treatment of proximal humerus metastasis

treated with plate fixation, two patients (15%) had proximal humeral metastases, six patients (46%) had diaphyseal humeral metastases and five patients (39%) had distal humeral metastasis. Postoperatively, the follow up consisted of physical examination and imaging assessments (anteroposterior and lateral radiographs of the humerus) every three months for the first two years, followed by every six months up to 5 years and annually thereafter.

Medical records were reviewed to collect demographic and clinical data, including patient's age and sex, primary tumor, time from diagnosis, number of bone metastases, presence of visceral metastases, lesion type (lytic, blastic, mixed), use of local adjuvant therapy, and administration of preoperative and postoperative radiotherapy. Surgical data included the implant type, the use of bone cement, and operative time. Laboratory parameters recorded were preoperative and postoperative hemoglobin, leukocyte count, alkaline phosphatase, C-reactive protein, estimated sedimentation rate. Postoperative complications were analyzed including the type of complications, the time from surgery to complication, and the need for reoperation or revision. Complications included local disease progression, infection, instability/dislocation, and mechanical implant failure (including screw pull-out, implant loosening, implant breakage, or peri-implant fracture). Reoperation was defined as any surgical treatment for complications with complete implant retention. Revision was defined as any surgical treatment for complications with implant removal.

Our primary study outcome was to record the incidence of complications during the follow up in patients with humeral metastasis treated with modular prosthesis, intramedullary nailing or plate fixation. Our secondary outcome was to analyze the proportion of reoperations and revisions.

The statistical analysis was performed using R (R Foundation for Statistical Computing; <https://www.R-project.org/>). The continuous variables were reported as mean and standard deviation (SD) or median and interquartile range (IQR); and the categorical variables were reported as percentages and frequencies. Each patient was followed until the date of last follow-up or date of death, which we define as the end of follow-up time. Overall survival was estimated using the Kaplan–Meier method and reported with 95% confidence intervals (CI). The cumulative incidence of the first postoperative complication was estimated using a competing risk model, considering death as a competing event. Because death precludes the subsequent occurrence of postoperative complications, it represents a competing event in patients with metastatic disease. Traditional Kaplan–Meier methods may overestimate complication incidence in the presence of high mortality. Therefore, cumulative incidence functions were used to provide a more accurate estimate of complication risk. The cumulative incidence was

calculated only in the subgroup of patients with proximal humerus metastasis treated with modular prosthesis and in the subgroup of patients with diaphyseal humerus metastasis treated with intramedullary nailing, due to the small sample size in the other subgroups.

Mean follow-up was 1.9 ± 2.10 years. Among patients treated with modular prosthesis, there were 11 females (33%) and 22 males (67%), with median follow up was 1.36 years [IQR 0.56, 2.65]. Among patients treated with intramedullary nailing, there were 39 females (57%) and 30 males (43%), with median follow up was 0.96 years [IQR 0.5, 1.86]. Among patients treated with plate fixation, there were seven females (54%) and six males (46%) with the median follow up was 2.15 years [IQR: 0.65, 4.98].

Pathologic fractures were found in 88 of 115 patients (77%); specifically, in 21 patients (63.6%) treated with modular prosthesis, in 55 patients (79.7%) treated with intramedullary nailing, and in 12 patients (92.3%) treated with plate fixation. Among patients treated with modular prosthesis, the most common primary bone tumor was kidney carcinoma (13 patients, 39.4%), followed by lung (7 patients, 21.2%), breast (3 patients, 9.1%), liver (3 patients, 9.1%), melanoma (1 patient, 3%), prostate (1 patient, 3%) and myeloma (1 patient, 3%), while four patients (12.1%) had other or unknown primary tumor. Among patients treated with intramedullary nailing, the most common primary bone tumor was kidney carcinoma (18 patients, 26.1%), followed by breast carcinoma (17 patients, 24.6%), myeloma (10 patients, 14.5%), lung (9 patients, 13%), liver (3 patients, 4.3%), thyroid (3 patients, 4.3%), prostate (3 patients, 4.3%) and gastric (1 patient, 1.4%), while five patients (5.24%) had other or unknown. Among patients treated with plate fixation, three patients (23.1%) had breast carcinoma, three patients (23.1%) had myeloma, three patients (23.1%) had kidney carcinoma, two patients (15.3%) had lung carcinoma, one patient (7.7%) had lymphoma, and one patient (7.7%) had prostate carcinoma. Multiple metastases were found in 17 patients (51.5%) treated with modular prosthesis, in 51 patients (73.9%) treated with intramedullary nailing and in nine patients (69.2%) treated with plate fixation (Table 1). Organ metastases were found in 15 patients (45.4%) treated with modular prosthesis, in 31 patients (44.9%) treated with intramedullary nailing and in five patients (38.4%) treated with plate fixation. The mean operative time was 107.41 ± 36.25 min in patients treated with modular prosthesis; 85.7 ± 29.28 min in patients treated with intramedullary nailing; and 117.58 ± 30.48 min in patients treated with plate fixation. Use of cement was needed in nine patients (69%) treated with plate fixation, but in none of the patients treated with intramedullary nailing (Table 2). Arterial embolization was used in five patients (15.1%) treated with modular prosthesis, three patients (4.3%) treated with

Table 1 Demographic data

Characteristic	Modular prosthesis (N=33)			Intramedullary nailing (N=69)			Plate Fixation (N=13)		
	Proximal Humerus N=29 ^a	Diaphy- seal Humerus N=3 ^a	Distal Humer- usN= ^a	Proximal Humerus N=6 ^a	Diaphy- seal Humerus N=62 ^a	Distal Humer- usN=1 ^a	Proximal Humerus N=2 ^a	Diaphy- seal Humerus N=6 ^a	Distal Humer- usN=5 ^a
Sex									
Female	11 (37.9)	0 (0.0)	0 (0.0)	5 (83.3)	33 (53.2)	1 (100.0)	2 (100.0)	3 (50.0)	2 (40.0)
Male	18 (62.1)	3 (100.0)	1 (100.0)	1 (16.7)	29 (46.8)	0 (0.0)	0 (0.0)	3 (50.0)	3 (60.0)
Age									
Median (Q1, Q3)	70.0 (59.0, 74.0)	62.0 (42.0, 70.0)	75.0 (75.0, 75.0)	60.0 (59.0, 81.0)	67.5 (61.0, 77.0)	83.0 (83.0, 83.0)	55.0 (43.0, 67.0)	72.0 (70.0, 77.0)	68.0 (65.0, 71.0)
Indication for surgery									
Complete fracture	17 (58.6)	3 (100.0)	1 (100.0)	5 (83.3)	49 (79.0)	1 (100.0)	1 (50.0)	6 (100.0)	5 (100.0)
Impending fracture	12 (41.4)	0 (0.0)	0 (0.0)	1 (16.7)	13 (21.0)	0 (0.0)	1 (50.0)	0 (0.0)	0 (0.0)
Primary Tumor									
Breast	3 (10.3)	0 (0.0)	0 (0.0)	2 (33.3)	14 (22.6)	1 (100.0)	1 (50.0)	2 (33.3)	0 (0.0)
Melanoma	1 (3.4)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Unknown	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (1.6)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Other	3 (10.3)	1 (33.3)	0 (0.0)	2 (33.3)	2 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Lung	6 (20.7)	1 (33.3)	0 (0.0)	0 (0.0)	9 (14.5)	0 (0.0)	0 (0.0)	1 (16.7)	1 (20.0)
Prostate	1 (3.4)	0 (0.0)	0 (0.0)	0 (0.0)	3 (4.8)	0 (0.0)	0 (0.0)	0 (0.0)	1 (20.0)
Kidney	13 (44.8)	0 (0.0)	0 (0.0)	1 (16.7)	17 (27.4)	0 (0.0)	0 (0.0)	2 (33.3)	1 (20.0)
Myeloma	0 (0.0)	0 (0.0)	1 (100.0)	1 (16.7)	9 (14.5)	0 (0.0)	1 (50.0)	0 (0.0)	2 (40.0)
Lymphoma	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (16.7)	0 (0.0)
Liver	2 (6.9)	1 (33.3)	0 (0.0)	0 (0.0)	3 (4.8)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Gastric	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (1.6)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Thyroid	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	3 (4.8)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Number of skeletal metastases									
Solitary	11 (42.3)	2 (66.7)	0 (0.0)	1 (20.0)	12 (20.3)	0 (NA)	0 (0.0)	3 (50.0)	1 (20.0)
Multiple	15 (57.7)	1 (33.3)	1 (100.0)	4 (80.0)	47 (79.7)	0 (NA)	2 (100.0)	3 (50.0)	4 (80.0)
Unknown	3	0	0	1	3	1	0	0	0
Organ Metastases									
Yes	13 (50.0)	2 (66.7)	0 (0.0)	2 (40.0)	29 (51.8)	0 (NA)	0 (0.0)	2 (33.3)	3 (60.0)
No	13 (50.0)	1 (33.3)	1 (100.0)	3 (60.0)	27 (48.2)	0 (NA)	2 (100.0)	4 (66.7)	2 (40.0)
Unknown	3	0	0	1	6	1	0	0	0
Type of lesion									
Lytic	24 (82.8)	2 (66.7)	1 (100.0)	6 (100.0)	55 (91.7)	0 (0.0)	2 (100.0)	5 (83.3)	5 (100.0)
Mixed	5 (17.2)	1 (33.3)	0 (0.0)	0 (0.0)	5 (8.3)	1 (100.0)	0 (0.0)	1 (16.7)	0 (0.0)
Unknown	0	0	0	0	2	0	0	0	0
Local Adjuvant Therapy									
No	25 (86.2)	3 (100.0)	0 (0.0)	5 (83.3)	48 (77.4)	1 (100.0)	1 (50.0)	5 (83.3)	5 (100.0)
Yes	4 (13.8)	0 (0.0)	1 (100.0)	1 (16.7)	14 (22.6)	0 (0.0)	1 (50.0)	1 (16.7)	0 (0.0)
Arterial Embolization	4 (13.8)	0 (0.0)	1 (100.0)	0 (0.0)	3 (4.8)	0 (0.0)	0 (0.0)	1 (16.7)	0 (0.0)
Electrochemotherapy	0 (0.0)	0 (0.0)	0 (0.0)	1 (16.7)	11 (17.7)	0 (0.0)	1 (50.0)	0 (0.0)	0 (0.0)
Preoperative Radiotherapy	9 (31.0)	0 (0.0)	0 (0.0)	1 (16.7)	4 (6.6)	0 (0.0)	1 (50.0)	1 (16.7)	1 (20.0)
Postoperative Radiotherapy	2 (6.9)	0 (0.0)	0 (0.0)	0 (0.0)	19 (31.1)	0 (0.0)	1 (50.0)	1 (16.7)	1 (20.0)
Karnofsky									
40	1 (3.8)	0 (0.0)	0 (0.0)	1 (16.7)	3 (5.2)	1 (100.0)	0 (0.0)	0 (0.0)	1 (20.0)
50	6 (23.1)	1 (33.3)	1 (100.0)	2 (33.3)	17 (29.3)	0 (0.0)	0 (0.0)	2 (40.0)	1 (20.0)
60	9 (34.6)	1 (33.3)	0 (0.0)	3 (50.0)	21 (36.2)	0 (0.0)	0 (0.0)	2 (40.0)	2 (40.0)
70	5 (19.2)	1 (33.3)	0 (0.0)	0 (0.0)	13 (22.4)	0 (0.0)	0 (0.0)	1 (20.0)	1 (20.0)
80	4 (15.4)	0 (0.0)	0 (0.0)	0 (0.0)	2 (3.4)	0 (0.0)	2 (100.0)	0 (0.0)	0 (0.0)
90	1 (3.8)	0 (0.0)	0 (0.0)	0 (0.0)	2 (3.4)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Unknown	3	0	0	0	4	0	0	1	0
Life status									

Table 1 (continued)

Characteristic	Modular prosthesis (N=33)			Intramedullary nailing (N=69)			Plate Fixation (N=13)		
	Proximal Humerus N=29 ^a	Diaphyseal Humerus N=3 ^a	Distal Humerus N=1 ^a	Proximal Humerus N=6 ^a	Diaphyseal Humerus N=62 ^a	Distal Humerus N=1 ^a	Proximal Humerus N=2 ^a	Diaphyseal Humerus N=6 ^a	Distal Humerus N=5 ^a
Dead	24 (82.8)	3 (100.0)	1 (100.0)	3 (50.0)	49 (79.0)	1 (100.0)	2 (100.0)	2 (33.3)	2 (40.0)
Alive	5 (17.2)	0 (0.0)	0 (0.0)	3 (50.0)	13 (21.0)	0 (0.0)	0 (0.0)	4 (66.7)	3 (60.0)
Haemoglobin preoperative									
Median (Q1, Q3)	12.6 (11.9, 13.7)	11.4 (10.0, 14.4)	11.9 (11.9, 11.9)	11.4 (10.0, 12.3)	11.7 (10.2, 12.8)	10.7 (10.7, 10.7)	12.4 (11.9, 12.8)	11.8 (10.5, 13.2)	12.7 (10.5, 13.3)
Haemoglobin postoperative									
Median (Q1, Q3)	11.8 (9.6, 12.3)	9.9 (8.5, 11.2)	NA (NA, NA)	10.3 (8.9, 11.5)	10.3 (9.6, 11.1)	10.2 (10.2, 10.2)	10.0 (9.4, 10.6)	10.0 (9.1, 10.5)	10.5 (9.9, 11.0)
Leucocyte count preoperative									
Median (Q1, Q3)	7.3 (5.7, 9.7)	5.4 (5.3, 6.8)	4.0 (4.0, 4.0)	7.8 (5.5, 10.2)	6.7 (5.4, 8.8)	6.2 (6.2, 6.2)	5.5 (4.6, 6.5)	6.8 (5.6, 9.2)	8.5 (5.8, 10.2)
Alkaline Phosphatase									
Median (Q1, Q3)	83.5 (63.0, 110.0)	110.0 (59.0, 233.0)	102.0 (102.0, 102.0)	118.0 (91.0, 185.0)	100.0 (86.0, 131.0)	60.0 (60.0, 60.0)	103.0 (84.0, 122.0)	92.5 (55.5, 148.5)	214.5 (123.0, 306.0)
C-Reactive Protein									
Median (Q1, Q3)	1.2 (0.5, 3.1)	0.1 (0.1, 0.5)	0.1 (0.1, 0.1)	3.6 (0.8, 8.2)	1.5 (0.6, 3.9)	2.8 (2.8, 2.8)	0.4 (0.2, 0.5)	0.7 (0.2, 0.7)	9.6 (0.3, 12.8)
Estimated sedimentation rate									
Median (Q1, Q3)	43.0 (26.0, 63.0)	7.0 (7.0, 11.0)	2.0 (2.0, 2.0)	53.0 (53.0, 53.0)	57.0 (33.5, 98.0)	48.0 (48.0, 48.0)	NA (NA, NA)	32.5 (32.0, 33.0)	59.5 (30.0, 89.0)

^an (%); (Q1, Q3)—Interquartile range**Table 2** Surgical data

	Modular Prosthesis (N=33)			Intramedullary nailing (N=69)			Plate Fixation (N=13)		
	Proximal Humerus N=29 ^a	Diaphyseal Humerus N=3 ^a	Distal Humerus N=1 ^a	Proximal Humerus N=6 ^a	Diaphyseal Humerus N=62 ^a	Distal Humerus N=1 ^a	Proximal Humerus N=2 ^a	Diaphyseal Humerus N=6 ^a	Distal Humerus N=5 ^a
Use of cement	-	-	-	0 (0.0)	0 (0.0)	0 (0.0)	2 (100.0)	6 (100.0)	1 (25.0)
Operative time (minutes)									
Median (Q1, Q3)	91.5 (62.5, 130.5)	88.0 (78.0, 122.5)	59.0 (59.0, 59.0)	94.0 (74.8, 98.3)	91.0 (72.5, 110.8)	108.0 (108.0, 108.0)	121.0 (98.5, 143.5)	91.5 (81.8, 101.8)	115.5 (104.25, 119.75)
Complications	6 (20.7)	0 (0.0)	0 (0.0)	0 (0.0)	9 (14.5)	0 (0.0)	0 (0.0)	3 (50.0)	1 (20.0)
Complication Type									
Local disease progression	1 (16.7)	0 (NA)	0 (NA)	0 (NA)	7 (77.8)	0 (NA)	0 (NA)	1 (33.3)	0 (0.0)
Deep infection	1 (16.7)	0 (NA)	0 (NA)	0 (NA)	0 (0.0)	0 (NA)	0 (NA)	0 (0.0)	1 (100.0)
Dislocation	3 (50.0)	0 (NA)	0 (NA)	0 (NA)	0 (0.0)	0 (NA)	0 (NA)	0 (0.0)	0 (0.0)
Implant failure	0 (0.0)	0 (NA)	0 (NA)	0 (NA)	1 (11.1)	0 (NA)	0 (NA)	2 (66.7)	0 (0.0)
Other	1 (16.7)	0 (NA)	0 (NA)	0 (NA)	1 (11.1)	0 (NA)	0 (NA)	0 (0.0)	0 (0.0)
Life status									
Dead	24 (82.8)	3 (100.0)	1 (100.0)	3 (50.0)	49 (79.0)	1 (100.0)	2 (100.0)	2 (33.3)	2 (40.0)
Alive	5 (17.2)	0 (0.0)	0 (0.0)	3 (50.0)	13 (21.0)	0 (0.0)	0 (0.0)	4 (66.7)	3 (60.0)

^an (%)

intramedullary nailing and one patient (7.6%) treated with plate fixation. Electrochemotherapy was used in 12 patients (17.3%) treated with intramedullary nailing and one patient (7.6%) treated with plate fixation.

Results

Complications, reoperations, and revisions were analyzed separately. Reoperation was defined as surgical treatment for a complication with implant retention, whereas revision required implant removal.

Overall, 17 of 115 patients (14.7%) experienced complications. Among the 33 patients treated with modular prosthesis, five patients had complications (Fig. 2). Three of 33 patients had instability or subluxation at 2.2, 8.6, 85.5 months respectively, which were treated conservatively. One of 33 patients had a local disease progression at 8.1 months postoperatively, which was treated conservatively with embolization and radiotherapy. One of 33 patients developed an infection 1.2 months postoperatively, which was managed with a one-stage revision, including replacement of the polyethylene component and coverage of the prosthesis's body with vancomycin-loaded cement. This patient subsequently experienced a subluxation 1.1 months later, managed conservatively.

Among 29 patients with proximal humerus metastasis treated with modular prosthesis, at six months, the cumulative incidence of the first complication was 10.3 [95% CI (2.54, 24.6)], whereas the cumulative incidence of death was 20.7 [95% CI (8.20, 37.1)]. At first year and thereafter, the cumulative incidence of a first complication was 17.2% [95% CI (6.11–33.1)], whereas the cumulative incidence of death was increasing from 27.6 [95% CI (12.8, 44.7)] up to 57.7% [95% CI (36.2–74.2)] at five years (Fig. 3).

Among the 69 patients treated with intramedullary nailing, eight patients experienced complications (Fig. 2). Local disease progression occurred in seven patients between 2 and 9.3 months postoperatively. One patient underwent reoperation with curettage and plate fixation, one patient was treated with electrochemotherapy, three patients received radiotherapy, one patient was managed with medical therapy, and one patient was managed with a combination of radiotherapy and embolization. Mechanical implant failure occurred in one of 69 patients at 2.5 months postoperatively, due to pull-out of the distal screw; this patient was treated with screw replacement.

Among 62 patients with diaphyseal humeral metastasis treated with intramedullary nailing, at six months, the cumulative incidence of the first complication was 8.20 [95% CI (2.99, 16.8)], whereas the cumulative incidence of death was 23.0 [95% CI (13.3, 34.2)]. At first year and thereafter,

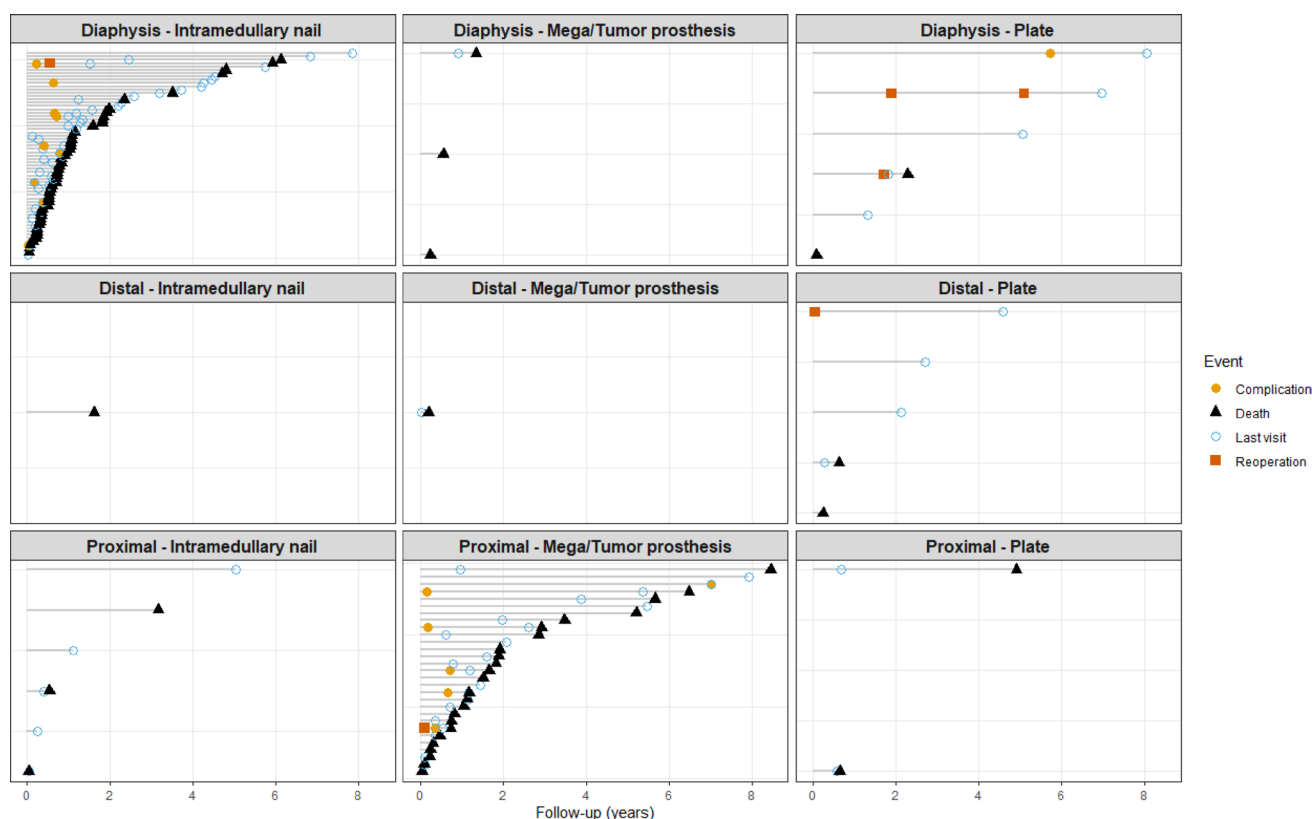


Fig. 2 This figure shows the follow-up of the patients with the events of complication, death, last follow up and reoperation

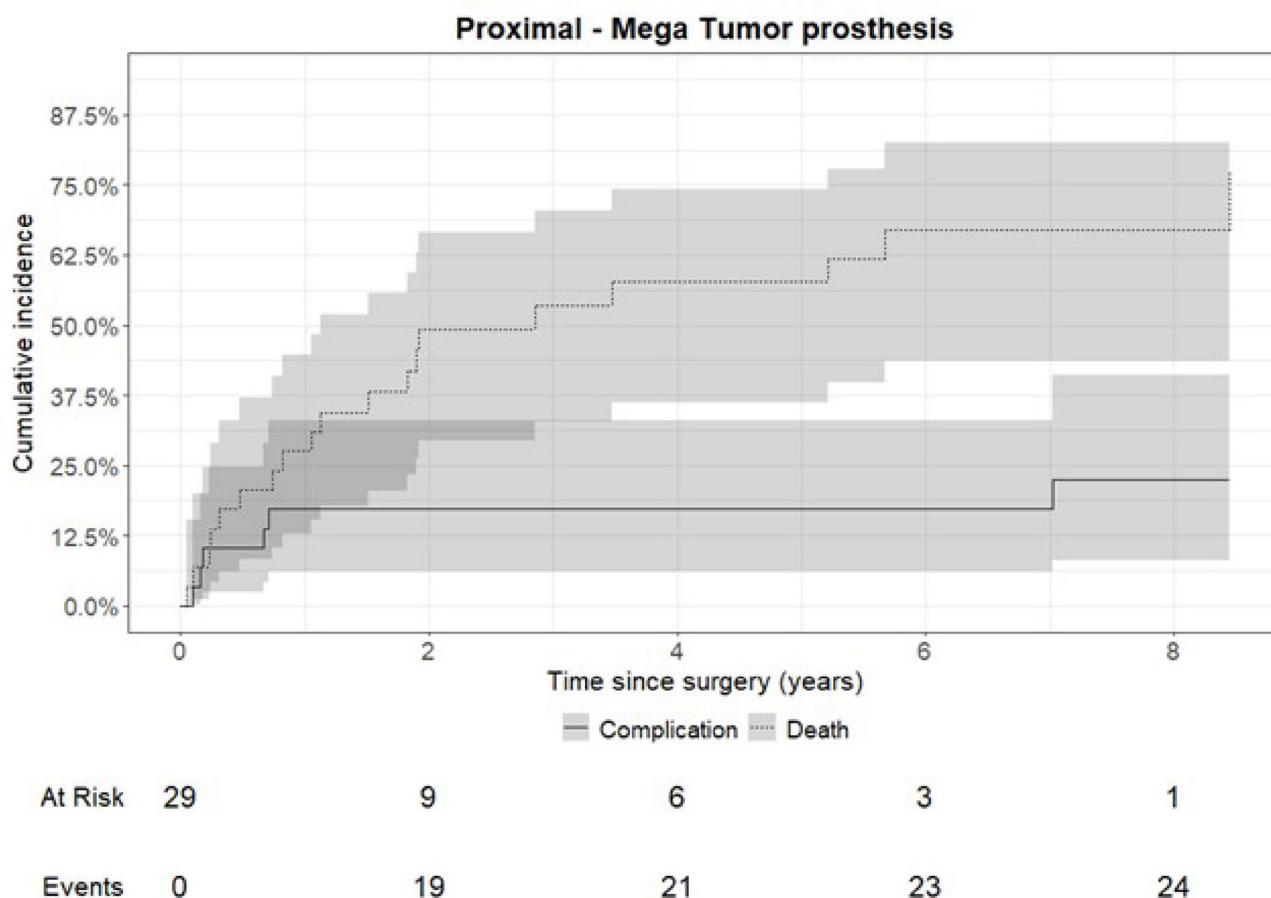


Fig. 3 Cumulative incidence of first complication and death in patients with proximal humerus metastases treated with modular prosthesis. The solid line represents the cumulative incidence of complications, and the dashed line represents the cumulative incidence of death, with

shaded areas indicating 95% confidence intervals. Death was treated as a competing event in the analysis. Numbers at risk and cumulative events are presented below the x-axis

the cumulative incidence of a first complication was 14.8% [95% CI 7.19–24.9], whereas the cumulative incidence of death was increasing from 44.3 [95% CI (31.4, 56.3)] up to 70.8% [95% CI (54.5–82.1)] at five years (Fig. 4).

Among the 13 patients treated with plate fixation, four experienced complications (Fig. 2). One patient developed local disease progression, resulting in plate fracture at 20.6 months postoperatively; this patient was managed with revision plate fixation. Two patients experienced mechanical implant failure. In one patient, loosening of the proximal part of the plate occurred at 69.6 months postoperatively and was managed conservatively with bracing. In the other patient, plate breakage occurred at 23.1 months postoperatively and was treated with double-plate fixation and cement augmentation. A subsequent plate breakage occurred 39.8 months later and was managed with conversion to a total elbow modular prosthesis. One patient developed an infection at 0.56 months postoperatively, which was managed with surgical debridement and antibiotic therapy.

Overall, six of 115 patients (5.2%) required reoperation, while three of 115 patients (2.6%) required revision with implant removal (Table 3). Revision surgery with implant removal was required in one of 33 patients treated with a modular prosthesis due to infection. Among 69 patients treated with intramedullary nailing, reoperation was required in two patients: one due to local disease progression and one due to mechanical implant failure. No patients treated with intramedullary nail fixation required revision surgery with implant removal. Reoperation was required in three of 13 patients treated with plate fixation due to local disease progression, mechanical implant failure and infection, respectively. Revision surgery with implant removal was required in two of these three patients due to local disease progression and mechanical implant failure, respectively.

Survival of patients was 77.1% [95% CI (69.8, 85.2)] at six months, 56.7% [95% CI (48.3, 66.6%)] at one year and 24% [95% CI (16.7, 34.5)] at five years (Fig. 5). By the end of follow-up, 28 of 115 patients (24.3%) were alive.

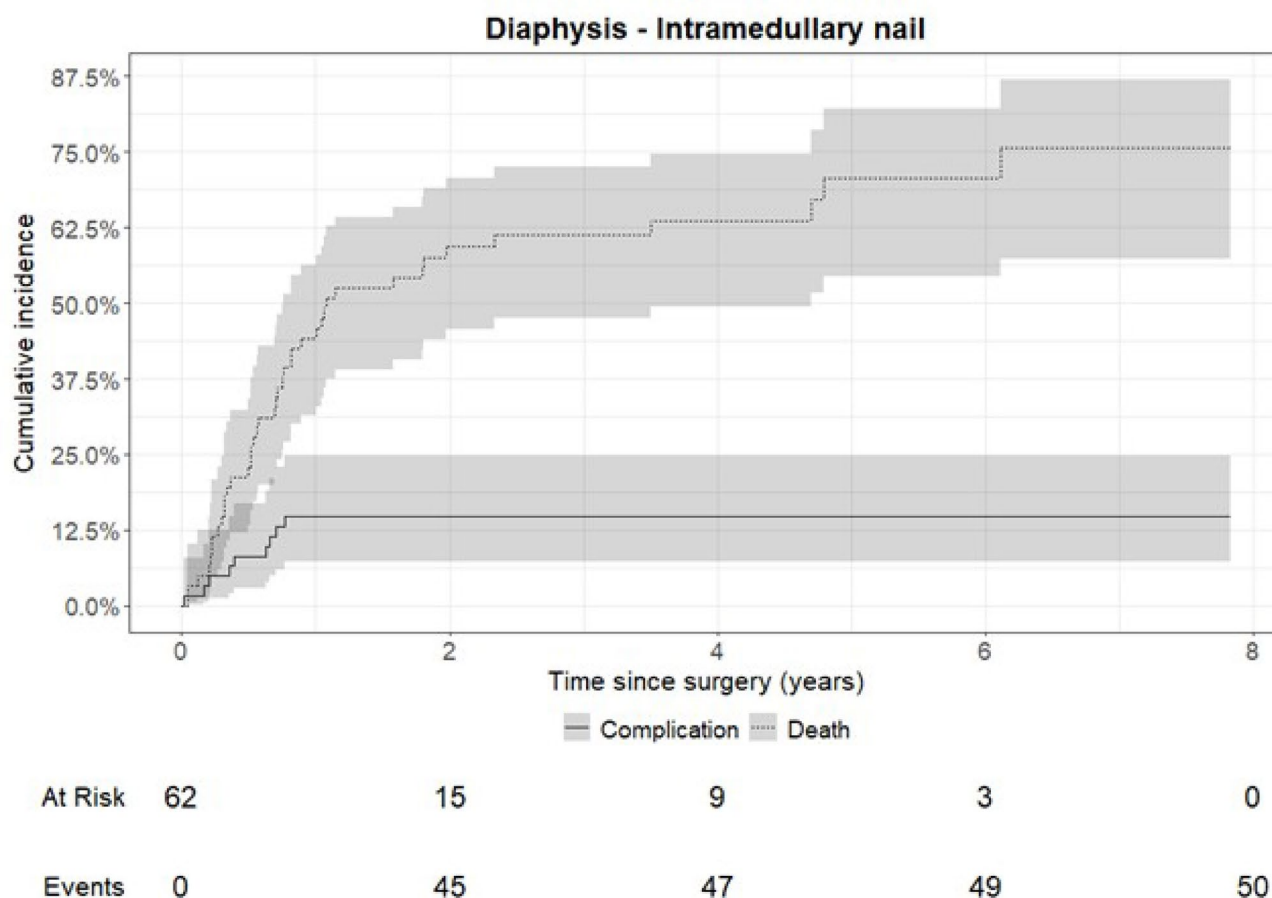


Fig. 4 Cumulative incidence of first complication and death in patients with diaphyseal humerus metastases treated with intramedullary nailing. The solid line represents the cumulative incidence of complications, and the dashed line represents the cumulative incidence of

death, with shaded areas indicating 95% confidence intervals. Death was treated as a competing event in the analysis. Numbers at risk and cumulative events are presented below the x-axis

Discussion

Surgical management of humeral metastases includes modular prosthesis, intramedullary nailing, or plate fixation, selected according to anatomical location, extent of bone destruction, and patient survival [1]. Given the heterogeneity in anatomical site and surgical indications the validity of comparative analyses is limited [7, 10]. Therefore, we performed a descriptive analysis of postoperative complications, reoperations, and revisions in patients with humeral metastases treated with modular prosthesis, intramedullary nailing or plate fixation. Complications varied according to different surgical techniques. Although complications were observed in all treatment groups, patients treated with plate fixation demonstrated high proportions of reoperations and revisions. Modular prosthesis for proximal humeral metastases was associated with high cumulative risk of complications at first year, predominantly due to instability, but low proportion of revision or reoperation. Intramedullary nailing was associated with a high cumulative risk of complications

at first year, with high proportion of local disease progression, without need of revisions.

This study has several limitations. First, its retrospective design is inherently subject to selection bias. Second, the small number of patients within each anatomical location and surgical treatment limited the ability to perform comparative or multivariable analyses; consequently, associations between demographic, oncological, and surgical variables and complications could not be reliably assessed. The treatment groups represented fundamentally different anatomical locations and indications; therefore, observed complication patterns cannot be attributed solely to implant choice and should not be interpreted as comparative treatment outcomes. Third, detailed oncological variables that may influence local disease control, including surgical margin status, timing of radiotherapy relative to surgery, systemic treatments, and tumor-specific biological characteristics, were not consistently documented and therefore could not be analyzed. Furthermore, intramedullary nailing in metastatic bone disease is generally performed as a

Table 3 Complications, reoperations and revisions

Sex	Age	Primary tumor	Location	Surgical Technique	Complication	Time of Complications (months)	Treatment
F	58	Kidney	Proximal	Modular Prosthesis	Dislocation	2.2	Brace
F	59	Kidney	Proximal	Modular Prosthesis	Dislocation	8.6	Brace
F	60	Colon	Proximal	Modular Prosthesis	Dislocation	85.5	Brace
M	64	Kidney	Proximal	Modular Prosthesis	Local disease progression	8.1	Brace, embolization and radiotherapy
F	76	Breast	Proximal	Modular Prosthesis	Infection	1.2	Revision with replacement of the polyethylene component and coverage with vancomycin-loaded cement. Dislocation 1.1 months later treated with brace
M	59	Kidney	Proximal	Modular Prosthesis	Cephalic vein thrombosis	2	Anticoagulation therapy
F	68	Kidney	Diaphysis	Intramedullary nailing	Local disease progression	7.3	Reoperation with lesion excision and plate fixation
F	60	Breast	Diaphysis	Intramedullary nailing	Local disease progression	8	Electrochemotherapy
F	64	Lung	Diaphysis	Intramedullary nailing	Local disease progression	4.3	Radiotherapy
M	80	Prostate	Diaphysis	Intramedullary nailing	Local disease progression	8.5	Radiotherapy
M	61	Liver	Diaphysis	Intramedullary nailing	Local disease progression	4.8	Radiotherapy and embolization
F	58	Kidney	Diaphysis	Intramedullary nailing	Local disease progression (in thoracic wall)	2	Conservatively
F	74	Liver	Diaphysis	Intramedullary nailing	Local disease progression (in thoracic wall)	9.3	Local Radiotherapy
F	68	Thyroid	Diaphysis	Intramedullary nailing	Mechanical Implant failure (pull-out of distal screw)	2.5	Reoperation with replacement of the distal screw
F	92	Gastric	Diaphysis	Intramedullary nailing	Seroma	0.2	Resolved spontaneously
F	77	Kidney	Diaphysis	Plate fixation	Local disease progression (resulting in plate fracture)	20.6	Revision plate fixation and a homoplastic cortical splint
M	69	Lung	Diaphysis	Plate fixation	Mechanical implant failure (loosening of proximal part of the plate)	69.6	Brace
M	70	Kidney	Diaphysis	Plate fixation	Mechanical implant failure (plate breakage)	23.1	Revision with double-plate fixation and cement augmentation. Re-breakage 39.8 months later managed with total elbow prosthesis
M	71	Myeloma	Distal	Plate fixation	Infection	0.56	Surgical debridement and antibiotic therapy

F Female, M Male

palliative intralesional procedure, and surgical margins are not routinely assessed in the same manner as for primary bone sarcomas. Consequently, factors potentially associated with local disease progression could not be evaluated. Fourth, the heterogeneity of primary tumors may limit the generalizability of the findings. In addition, while the complications after surgical treatment of humeral metastases have been reported previously, the present study does not aim to introduce a novel treatment strategy; rather, its contribution lies in the anatomical and treatment-specific descriptive reporting of complications, reoperations, and revisions, avoiding aggregation or forced comparisons that could bias the interpretation of results in small and heterogeneous

cohorts. Importantly, as highlighted by our recent systematic review, the current literature remains dominated by small retrospective cohorts with pooled reporting of different anatomical locations and reconstruction methods, limiting treatment-specific interpretation of complications and revision risk. Additionally, the low number of events prevented meaningful multivariable analyses and therefore potential confounding factors could not be adjusted for. Finally, functional outcomes and patient-reported measures were not assessed, precluding correlation between complications, postoperative function and quality of life.

Published studies on proximal humeral metastases treated with modular prostheses have reported complication rates

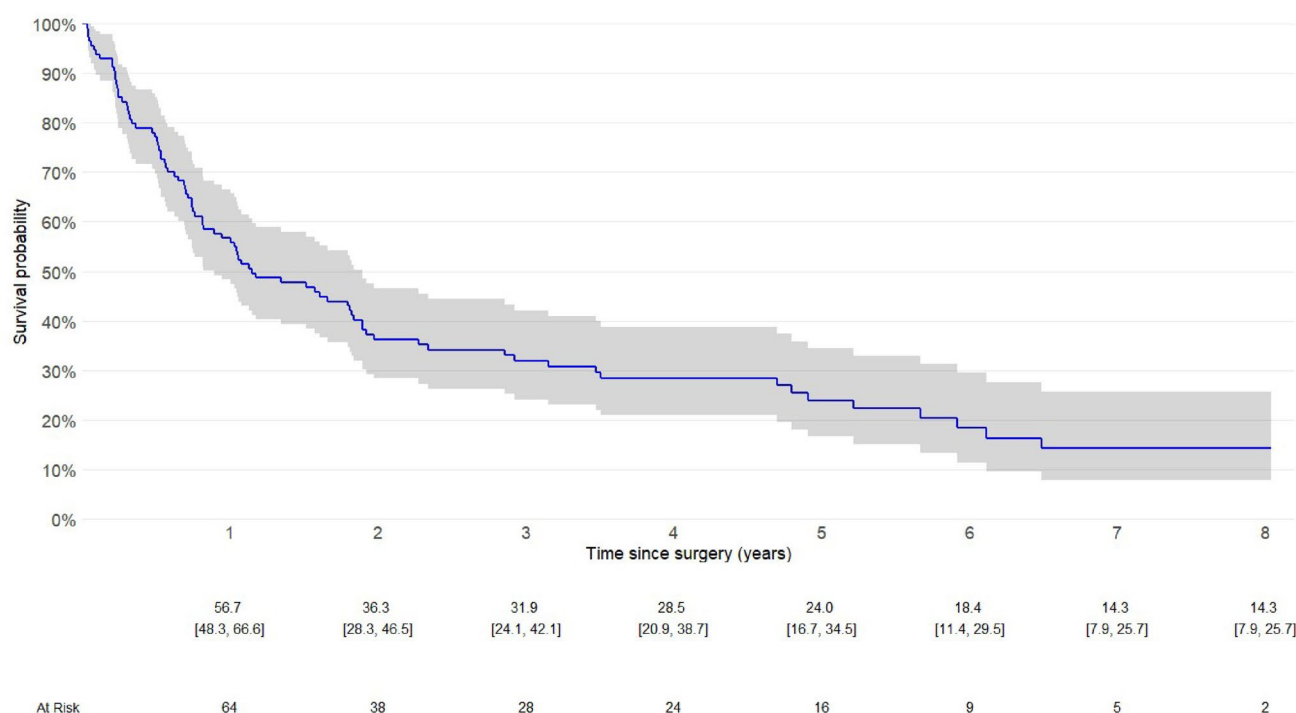


Fig. 5 Kaplan–Meier overall survival curve for patients with humeral metastases following surgical treatment. The solid line represents estimated survival probability over time, and the shaded area indicates the

95% confidence interval. Survival estimates with corresponding 95% confidence intervals are presented at selected time points below the x-axis. The number of patients at risk is shown beneath the plot

ranging from 0 to 40%, with instability and infection representing the most frequent events [4, 11–14]. Reoperation and revision rates have ranged from 0 to 20%, most commonly due to instability and infection [4, 15–18]. Consistent with these reports, instability or subluxation represented the most common complication in our cohort, whereas revision surgery was uncommon.

A systematic review and meta-analysis including 114 patients with diaphyseal humeral metastases treated with plate fixation and 223 patients treated with intramedullary nailing reported no differences in implant failure, local recurrence, or wound complications between these two different surgical techniques ($p=0.989$); however, plate fixation was associated with a higher incidence of postoperative radial nerve palsy ($p=0.008$) [19]. In a retrospective series of 91 patients treated with intramedullary nailing, reoperation was required due to nonunion (3.2%), aseptic loosening (2.1%) peri-implant fracture (1%) [10]. Retrospective series evaluating intramedullary nailing with cement augmentation have reported overall complication rates ranging from 0 to 39%, most commonly related to local disease progression [5, 6]. Similarly, local disease progression represented the most frequent complication in our cohort, whereas revision surgery was not required. These findings are consistent with previous reports describing local disease progression as the most frequent complication after intramedullary nailing, whereas revision surgery remains uncommon.

Published studies of plate fixation for humeral metastases have reported highly variable complication rates ranging from 14 to 75%, including infection, implant failure, neurological injury, peri-implant fracture, and local disease progression [3, 4, 17]. In metastatic distal humerus, plate fixation remains the most frequently reported reconstructive strategy but has been associated with relatively high complication and reoperation rates [17, 20]. Similarly, we observed a high proportion of complications and revisions in this small subgroup of patients; however, given the limited sample size, these findings should be interpreted cautiously.

Surgical management of humeral metastases seems to be associated with distinct complication, reoperation, and revision profiles that vary according to surgical strategy. Modular prosthesis, intramedullary nailing and plate fixation were associated with distinct complication profiles. Modular prostheses were most commonly associated with instability, intramedullary nails with local disease progression, and plate fixation with a relatively high proportion of complications and revisions. Given the heterogeneity of anatomical location and treatment indications, these findings should be interpreted descriptively rather than as evidence of superiority of one technique over another.

Acknowledgements This work was supported by European Union NextGenerationEU, Missione 4 Componente 2 -CUP: J53D23012420006.

Author contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by K.S., F.T., M.C., F.Z. and B.Z. The first draft of the manuscript was written by K.S., F.T., D.M.D and C.E. and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding This work was supported by European Union NextGenerationEU, Missione 4 Componente 2 -CUP: J53D23012420006.

Data availability All data supporting the findings of this study are available within the paper.

Declarations

Competing interests The authors declare no competing interests.

Human Ethics and Participate declarations Ethical approval for this study was obtained from the Ethics Committee of our Institute (Approval No. NCT03416959). Informed consent was obtained from all individual participants included in the study.

References

- Frassica FJ, Frassica DA (2003) Evaluation and treatment of metastases to the humerus. *Clin Orthop Relat Res*. <https://doi.org/10.1097/01.blo.0000093052.96273.a7>
- Chen CM, Wu PK, Tsai SW, Chen CF, Chen WM (2017) Prognosis-based shoulder hemiarthroplasty after resection of proximal humeral malignancy. *Artif Organs* 41:1162–1172. <https://doi.org/10.1111/aor.12915>
- Wu K, Lin T, Lee CH (2023) Intramedullary nailing versus cemented plate for treating metastatic pathological fracture of the proximal humerus: a comparison study and literature review. *J Orthopaed Traumatol*. <https://doi.org/10.1186/s10195-023-00721-7>
- Casadei R, Drago G, Di Pressa F, Donati D (2018) Humeral metastasis of renal cancer: surgical options and review of literature. *Orthopaed Traumatol Surg Res* 104:533–538. <https://doi.org/10.1016/j.otsr.2018.03.009>
- Choi ES, Han I, Cho HS, Park IW, Park JW, Kim HS (2016) Intramedullary nailing for pathological fractures of the proximal humerus. *CiOs Clin Orthoped Surg* 8:458–464. <https://doi.org/10.4055/cios.2016.8.4.458>
- Park JW, Kim Y, Kang HG, Kim JH, Kim HS (2018) Joint-preserving palliative surgery using self-locking screws of intramedullary nail and percutaneous cementoplasty for proximal humeral metastasis in the advanced cancer patients. *World J Surg Oncol*. <https://doi.org/10.1186/s12957-018-1397-3>
- Solou K, Tamburini F, Cosentino M, Bordini B, Dozza B, Donati DM et al (2025) Complication and revision risks of surgical treatment for proximal humerus metastases: a systematic review. *Eur J Orthop Surg Traumatol* 35:408. <https://doi.org/10.1007/s00590-025-04527-7>
- Capanna R, Campanacci DA (2001) The treatment of metastases in the appendicular skeleton. *J Bone Joint Surg*
- Errani C, Mavrogenis AF, Cevolani L, Spinelli S, Piccioli A, Maccauro G et al (2017) Treatment for long bone metastases based on a systematic literature review. *Eur J Orthopaed Surg Traumatol*. <https://doi.org/10.1007/s00590-016-1857-9>
- Janssen SJ, van Dijke M, Lozano-Calderón SA, Ready JE, Raskin KA, Ferrone ML et al (2016) Complications after surgery for metastatic humeral lesions. *J Shoulder Elbow Surg* 25:207–215. <https://doi.org/10.1016/j.jse.2015.08.009>
- Bonnevalle N, Mansat P, Lebon J, Laffosse JM, Bonnevalle P (2015) Reverse shoulder arthroplasty for malignant tumors of proximal humerus. *J Shoulder Elbow Surg* 24:36–44. <https://doi.org/10.1016/j.jse.2014.04.006>
- Güven MF, Aslan L, Botanlioglu H, Kaynak G, Kesmezacar H, Babacan M (2016) Functional outcome of reverse shoulder tumor prosthesis in the treatment of proximal humerus tumors. *J Shoulder Elbow Surg* 25:e1–6. <https://doi.org/10.1016/j.jse.2015.06.012>
- El Motassime A, Meschini C, Di Costa D, Rovere G, Matrangolo MR, De Maio F et al (2023) Functional outcomes and shoulder instability in reconstruction of proximal humerus metastases. *Curr Oncol* 30:3571–3579. <https://doi.org/10.3390/curroncol30040272>
- Wang Z, Guo Z, Li J, Li X, Sang H (2010) Functional outcomes and complications of reconstruction of the proximal humerus after intra-articular tumor resection. *Orthop Surg* 2:19–26. <https://doi.org/10.1111/j.1757-7861.2009.00058.x>
- Scotti C, Camnasio F, Peretti GM, Fontana F, Frascini G (2008) Modular prostheses in the treatment of proximal humerus metastases: review of 40 cases. *J Orthopaed Traumatol*. <https://doi.org/10.1007/s10195-008-0097-0>
- Streitbueger A, Henrichs M, Gosheger G, Ahrens H, Nottrott M, Guder W et al (2015) Improvement of the shoulder function after large segment resection of the proximal humerus with the use of an inverse tumour prosthesis. *Int Orthop* 39:355–361. <https://doi.org/10.1007/s00264-014-2560-2>
- Wedin R, Hansen BH, Laitinen M, Trovik C, Zaikova O, Bergh P et al (2012) Complications and survival after surgical treatment of 214 metastatic lesions of the humerus. *J Shoulder Elbow Surg* 21:1049–1055. <https://doi.org/10.1016/j.jse.2011.06.019>
- Sullivan MH, Arguello AM, Barlow JD, Morrey ME, Rose PS, Sanchez-Sotelo J et al (2024) Comparison of reconstructive techniques for nonprimary malignancies in the proximal humerus. *J Surg Oncol* 130:64–71. <https://doi.org/10.1002/jso.27693>
- Chen B-K, Tai T-H, Lin S-H, Chen K-H, Huang Y-M, Chen C-Y (2024) Intramedullary nail vs. plate fixation for pathological humeral shaft fracture: an updated narrative review and meta-analysis of surgery-related factors. *J Clin Med* 13:755. <https://doi.org/10.3390/jcm13030755>
- De Fazio A, Mazzella GG, Miele G, Bocchi MB, El Ezzo O, Capece G et al (2025) Epidemiology and treatment of metastatic lesions around the elbow: a systematic review. *J Clin Med* 14:6297. <https://doi.org/10.3390/jcm14176297>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.

Authors and Affiliations

Konstantina Solou¹ · Filippo Tamburini¹ · Monica Cosentino² · Federica Zuccheri¹ · Barbara Dozza³ · Barbara Bordini² · Davide Maria Donati¹ · Costantino Errani¹ 

✉ Costantino Errani
costantino.errani@ior.it

Konstantina Solou
k.solou@gmail.com

Filippo Tamburini
filippo.tamburini@ior.it

Monica Cosentino
monica.cosentino@ior.it

Federica Zuccheri
federica.zuccheri@ior.it

Barbara Dozza
barbara.dozza@ior.it

Barbara Bordini
barbara.bordini@ior.it

Davide Maria Donati
davidemaria.donati@ior.it

- ¹ Clinica Ortopedica e Traumatologica III a Prevalente
Indirizzo Oncologico, Musculoskeletal Oncology
Department, IRCCS Istituto Ortopedico Rizzoli, Bologna,
Italy
- ² Medical Technology Laboratory, IRCCS Istituto Ortopedico
Rizzoli, Bologna, Italy
- ³ Department of Biomedical and Neuromotor Sciences
(DIBINEM), Alma Mater Studiorum, University of Bologna,
Bologna, Italy