Construct Durability, Revision Burden, and Resource Use After Fixation Versus Endoprosthetic Reconstruction for Appendicular Metastatic Bone Disease

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Significance & Hypothesis/Techniques:

Selecting between fixation and endoprosthetic reconstruction for appendicular metastatic bone disease requires balancing operative burden, anticipated survival, and implant durability. Fixation is often favored in patients with limited life expectancy but may increase the risk of mechanical failure and revision near end of life. We evaluated whether endoprosthetic reconstruction was associated with lower revision burden and greater construct durability, and whether these benefits offset higher index hospitalization charges. We also sought to develop a simple preoperative risk stratification using laboratory and demographic variables.

Innovation:

This study applies a decision-oriented framework integrating implant durability, survival, resource use, and preoperative risk factors to inform reconstruction choice.

Approach (Materials & Methods):

We performed a retrospective single-institution cohort study of 413 patients with appendicular metastatic bone disease treated from 2013-2024 with fixation (n=230) or endoprosthetic reconstruction (n=183). The primary outcome was revision, analyzed using cumulative incidence methods with death as a competing event. Secondary outcomes included overall survival, 1-year mortality, length of stay, and index hospitalization charges. Adjusted analyses used multivariable Cox and logistic regression, with inverse probability of treatment weighting as a sensitivity analysis. Preoperative predictors of 1-year mortality were selected using Least Absolute Shrinkage and Selection Operator (LASSO) and tested in multivariable logistic regression. Subgroup analyses were performed by primary tumor type, and threshold analysis estimated the revision reduction required for cost neutrality from the difference in index hospitalization charges and mean revision cost.

Results:

Revision rates at 1 and 2 years were 8.2% and 8.7% after endoprosthetic reconstruction versus 18.7% and 21.3% after fixation ($p=0.004$ and $p<0.001$, respectively. Implant survival diverged from patient survival by 1 month after fixation (landmark HR 0.35, 95% CI 0.23–0.54) and by 4 months after endoprosthetic reconstruction (HR 0.17, 95% CI 0.08–0.37; both $p<0.001$). LASSO selected five preoperative predictors of 1-year mortality: albumin <3.5 g/dL, hemoglobin <10 g/dL, Charlson Comorbidity Index (CCI) ≥12, age ≥68 years, and lung cancer as the primary tumor type. In multivariable analysis, albumin <3.5 g/dL, hemoglobin <10 g/dL, and CCI ≥12 independently predicted worse 6-month, 1-year, 2-year, and overall survival. Among tumor subgroups, only lung cancer showed lower mortality with endoprosthetic reconstruction relative to fixation (HR 2.17, 95% CI 1.23–3.84; $p=0.007$). Endoprosthetic reconstruction was associated with higher median index hospitalization charges ($160,875 [IQR $91K–$265K] vs $91,730 [IQR $55K–$185K]; $p<0.001$) and longer median length of stay (7 days [IQR 4–12] vs 4 days [IQR 2–10]; $p<0.001$). Cost neutrality would have required an absolute revision reduction of 28.1%, whereas the maximum observed absolute revision reduction was 15.3% at 10 years.

Discussion & Impact:

Endoprosthetic reconstruction was associated with lower revision burden, while albumin <3.5 g/dL, hemoglobin <10 g/dL, and CCI ≥12 identified patients at higher mortality risk. Although endoprosthetic reconstruction did not achieve cost neutrality with longitudinal follow up, these findings support a durability-aware, patient-centered approach in which avoidance of morbid end-of-life revision may outweigh economic considerations in selected patients.

Figures/Tables:

Table 1. Patient Demographics and Clinical Characteristics

Characteristic	Overall (N=413)	Surgical Approach		p-value[1]
		Endoprosthesis (N=183)	Fixation (N=230)	
Fixation Subtype, n (%)				
IMN/Nail	164 (39.7%)	—	164 (71.3%)	
Plate/ORIF	55 (13.3%)	—	55 (23.9%)	
Other	11 (2.7%)	—	11 (4.8%)	
Age, Mean (SD)	64.0 (12.6)	63.5 (13.5)	64.4 (11.8)	
Age, Median (IQR)	65 (56–72)	65 (56–72)	65 (56–72)	
Sex, n (%)				
Female	238 (57.6%)	109 (59.6%)	129 (56.1%)	0.542
Male	175 (42.4%)	74 (40.4%)	101 (43.9%)	
Primary Tumor, n (%)				
Breast	125 (30.3%)	49 (26.8%)	76 (33.0%)	0.086
Lung	103 (24.9%)	47 (25.7%)	56 (24.3%)	
Renal	52 (12.6%)	29 (15.8%)	23 (10.0%)	
Prostate	47 (11.4%)	20 (10.9%)	27 (11.7%)	
Hepatocellular	16 (3.9%)	11 (6.0%)	5 (2.2%)	
Myeloma	15 (3.6%)	3 (1.6%)	12 (5.2%)	
Other	55 (13.3%)	24 (13.1%)	31 (13.5%)	
Anatomic Site, n (%)				
Proximal Femur	151 (36.6%)	106 (57.9%)	45 (19.6%)	<0.001
Femur	115 (27.8%)	0 (0%)	115 (50.0%)	
Distal Femur	26 (6.3%)	21 (11.5%)	5 (2.2%)	
Proximal Humerus	27 (6.5%)	8 (4.4%)	19 (8.3%)	
Humerus	24 (5.8%)	0 (0%)	24 (10.4%)	
Tibia	7 (1.7%)	1 (0.5%)	6 (2.6%)	
Pelvis/Acetabulum	4 (1.0%)	0 (0%)	4 (1.7%)	
Other	59 (14.3%)	47 (25.7%)	12 (5.2%)	
CCI Score, Mean (SD)	9.5 (2.7)	9.1 (3.3)	9.8 (2.1)	0.096
CCI ≥12, n (%)	81 (19.7%)	28 (15.4%)	53 (23.1%)	0.063
Albumin (g/dL), Mean (SD)	3.72 (0.64)	3.77 (0.60)	3.68 (0.68)	0.327
Low Albumin (<3.5), n (%)	105/337 (31.2%)	50/173 (28.9%)	55/164 (33.5%)	0.423
Hemoglobin (g/dL), Mean (SD)	11.3 (2.0)	11.4 (2.0)	11.1 (2.1)	0.160
Anemia (Hgb <10), n (%)	108/375 (28.8%)	45/181 (24.9%)	63/194 (32.5%)	0.130
Index Hospitalization				
Length of Stay (d), Mean (SD)	8.9 (10.3)	9.5 (8.9)	8.4 (11.3)	<0.001
Length of Stay (d), Median (IQR)	5 (3–10)	7 (4–12)	4 (2–10)	
Total Charges ($), Mean (SD)	183,762 (175,634)	204,455 (156,936)	167,207 (189,577)	<0.001
Total Charges ($), Median (IQR)	118,143 (66K–219K)	160,875 (91K–265K)	91,730 (55K–185K)	
Mortality, n (%)				
30-Day	16 (3.9%)	7 (3.8%)	9 (3.9%)	1.000
90-Day	52 (12.6%)	18 (9.8%)	34 (14.8%)	0.175
6-Month	69 (16.7%)	24 (13.1%)	45 (19.6%)	0.085
1-Year	97 (23.5%)	35 (19.1%)	62 (27.0%)	0.080
2-Year	124 (30.0%)	48 (26.2%)	76 (33.0%)	0.141

Overall	166 (40.2%)	64 (35.0%)	102 (44.3%)	0.060
Survival Time (mo), Mean (SD)	41.7 (39.8)	48.0 (43.8)	36.6 (36.0)	0.007
Survival Time (mo), Median (IQR)	28.3 (8.6–64.7)	32.4 (12.4–75.0)	25.8 (5.8–59.3)	
Revision Surgery, n (%)				
6-Month	51 (12.3%)	12 (6.6%)	39 (17.0%)	0.002
1-Year	58 (14.0%)	15 (8.2%)	43 (18.7%)	0.003
2-Year	65 (15.7%)	16 (8.7%)	49 (21.3%)	0.001
Overall	67 (16.2%)	16 (8.7%)	51 (22.2%)	<0.001
1-Year Mortality by Tumor Type				
Lung	34/103 (33.0%)	9/47 (19.1%)	25/56 (44.6%)	0.007
Colorectal	5/12 (41.7%)	4/8 (50.0%)	1/4 (25.0%)	0.490
Hepatocellular	5/16 (31.2%)	3/11 (27.3%)	2/5 (40.0%)	0.615
Renal	11/52 (21.2%)	4/29 (13.8%)	7/23 (30.4%)	0.138
Breast	23/125 (18.4%)	11/49 (22.4%)	12/76 (15.8%)	0.343
Prostate	8/47 (17.0%)	2/20 (10.0%)	6/27 (22.2%)	0.274
Myeloma	2/15 (13.3%)	0/3 (0.0%)	2/12 (16.7%)	0.999
Thyroid	1/11 (9.1%)	0/3 (0.0%)	1/8 (12.5%)	0.999

Characteristic	**1-Year Mortality**	**p-value**
Albumin, g/dL		
≥3.5 (normal)	39/232 (16.8%)	
<3.5 (low)	46/105 (43.8%)	<0.001
Hemoglobin, g/dL		
≥10 (normal)	42/267 (15.7%)	
<10 (anemia)	48/108 (44.4%)	<0.001
CCI		
<12	67/330 (20.3%)	
≥12	30/81 (37.0%)	0.002
Age, years		
<68	46/243 (18.9%)	
≥68	51/170 (30.0%)	0.013

[1]Wilcoxon rank sum test for continuous variables; Pearson's Chi-squared test or Fisher's exact test for categorical variables.

Abbreviations: CCI, Charlson Comorbidity Index; Hgb, hemoglobin; IMN, intramedullary nail; IQR, interquartile range; ORIF, open reduction internal fixation; SD, standard deviation.

Continuous variables presented as mean (SD) and median (IQR). Categorical variables presented as n (%).

Figure 1: Implant and Patient Survival with Multivariable Mortality Analysis

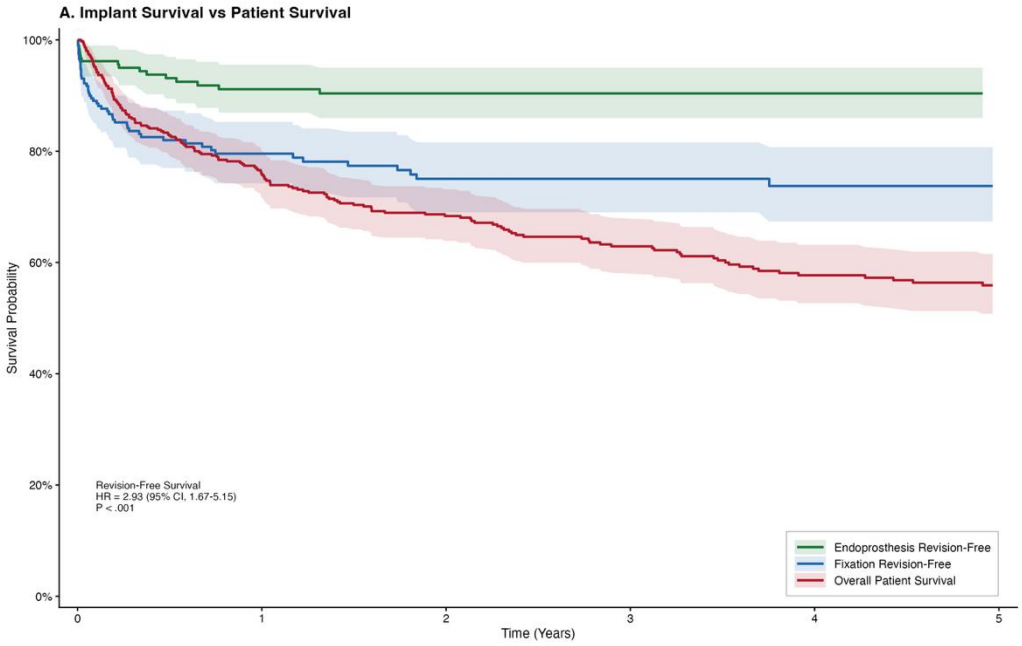
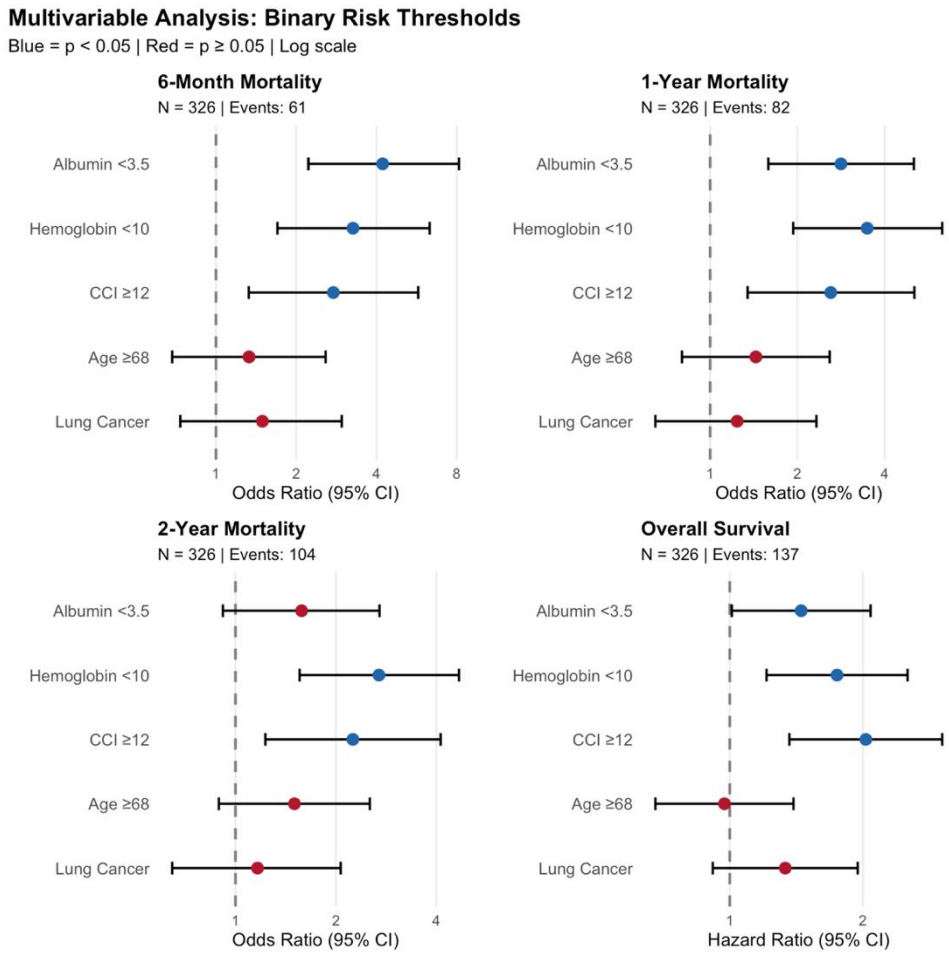
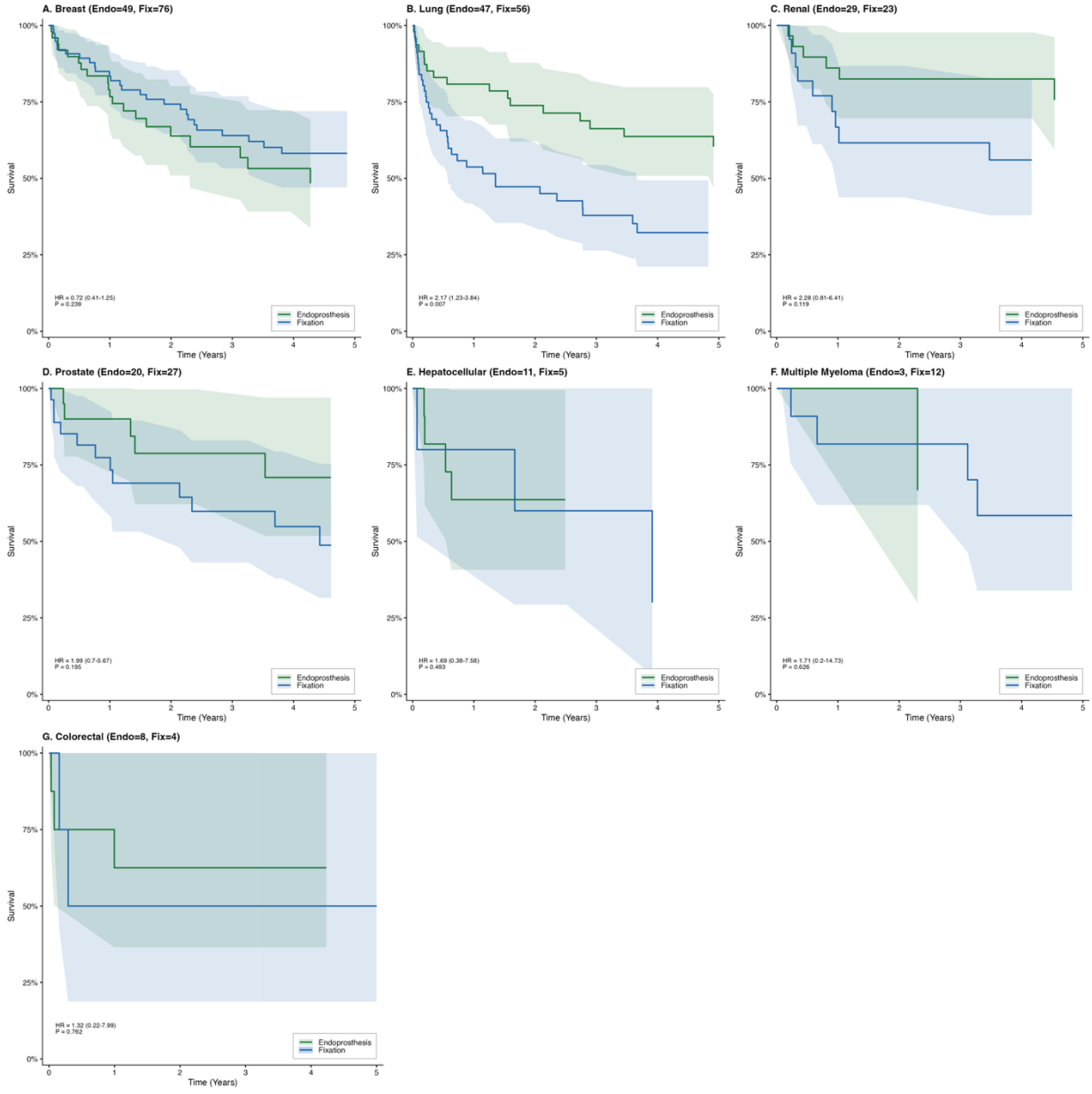


Figure 2: Kaplan-Meier Survival Analysis by Primary Tumor Type

B. Multivariable Analysis




A. Breast (Endo=49, Fix=76)
HR = 0.72 (0.41-1.25)
P = 0.239
B. Lung (Endo=47, Fix=56)
HR = 2.17 (1.23-3.84)
P = 0.007
C. Renal (Endo=29, Fix=23)
HR = 2.28 (0.81-6.41)
P = 0.119
D. Prostate (Endo=20, Fix=27)
HR = 1.99 (0.7-5.67)
P = 0.195
E. Hepatocellular (Endo=11, Fix=5)
HR = 1.69 (0.38-7.58)
P = 0.493
F. Multiple Myeloma (Endo=3, Fix=12)
HR = 1.71 (0.2-14.73)
P = 0.626
G. Colorectal (Endo=8, Fix=4)
HR = 1.32 (0.22-7.99)
P = 0.762
Endoprosthesis
Fixation
Survival
Time (Years)