Critical Anatomical Regions for Reinforcement in Periacetabular Metastases: How Do We Prevent Progression to Protrusio?

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INTRODUCTION: Protrusio acetabuli is the most painful disabling consequence of osteolytic periacetabular metastases. Prevention of pathological protrusio acetabuli or fractures is a critical driver of prophylactic fixation. However, there is controversy regarding whether minimally invasive reinforcement (cement, screws, and ablation) provides sufficient fixation compared to total hip arthroplasty and which acetabular areas are critical for pain and progression to protrusio. Periacetabular metastatic bone loss presents in unique anatomical locations depending on lesion location. This study aims to identify the most critical periacetabular anatomic locations that are associated with the development of pathological protrusio in patients with periacetabular metastases.

METHODS:

A single-institution, cohort study was performed to identify all cases of surgically managed periacetabular metastases from 2017 through 2024. Exclusion criteria included primary bone tumors, follow-up <14 days, and age<18 years. Clinical characteristics included demographics, treatment history, validated functional scores (ECOG, combined pain and functional score), and metastatic extent.

Secondary analysis was performed to compare patients with protrusio or no protrusio using coronal CT cuts from 1-3 months prior to presentation or development of protrusio. Radiographical variables included fracture or cortical involvement of subchondral cortical bone (sourcil), subchondral trabecular bone, lateral wall, inner wall, femoral notch sign, and other markers. Hounsfield unit analysis was performed to approximate the extent of bone loss in cortical and trabecular subchondral bone. Initial univariable analysis was performed. Radiographical scoring criteria was then created and plotted on a receiver operating curve (ROC). Area under the curve analysis was performed to identify sensitivity and specificity.

RESULTS:

123 acetabuli across 116 patients (7 bilateral) were identified (average follow-up 14.1±15.9 months). Average pre-operative combined functional scores was 4.6±2.1 (1=bedbound, 10=full ambulation) while average ECOG performance score was 2.9±1.1. 20 patients progressed to protrusio prior to surgery and a subsequent 6 patient developed protrusio post-operatively. Patients with protrusio demonstrated significantly lower performance and pain scores ($p<0.05$).

After selecting for patients with appropriate CT imaging, 87 patients (20 protrusio; 67 non-protrusio) were included for radiographical marker analysis. After univariable analysis (**Table 1**), significant radiographical signs (acetabular sourcil bone loss, lateral and inner wall fractures, femoral notch sign, and sourcil bone mass assessment) were used to generate a protrusio acetabuli radiographical risk model (PARRM) scoring system (**Table 2, Figure 1**). A cut-off of 5.5 (sensitivity 90.0%, specificity 85.0%) was calculated from the ROC (0.991 [0.976, 1.006]).

DISCUSSION AND CONCLUSION: The PARRM scoring system provides effective risk stratification of protrusio acetabuli in patients with periacetabular metastases and identifies the most critical anatomical areas for surgical reinforcement. Traditionally, protrusio classifications are derived from osteoarthritis etiologies based on predominantly medial wall wear from weightbearing. These classifications are outdated and do not reflect the critical anatomical areas seen in osteolysis from metatstatic disease. In periacetabular metastases, lesion location and bone loss occur at varying periacetabular anatomical sites, making it difficult to identify the most critical regions for reinforcement. In this study, we find subchondral cortical bone loss is a strong predictor of progression to protrusio (**Figure 2**). It is critical that stabilization of periacetabular osteolysis targets reinforcement of this area. Patients later diagnosed with protrusio had worse ECOG and combined pain and functional scores, suggesting involvement of anatomical regions identified in the PARRM scoring system are associated with increased pain. Additional large-scale results on a testing cohort are needed to further validate the scoring system. In summary, the PARRM system effectively stratifies risk of protrusio using well-defined CT parameters.

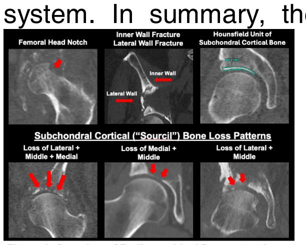

Figure 1. Overview of Radiographical Parameters in the PARRM Scoring System.

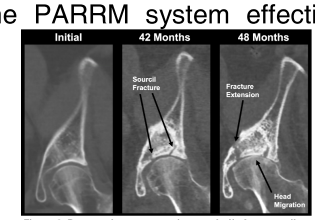

Figure 2. Progression to protrusio acetabuli after sourcil segmental fracture from initial cancer diagnosis.

Table 1. Risk factors for progression to protrusio acetabuli.

	Non-Protrusio (n=67)	Protrusio (n=20)	Odds-Ratio	P-value
Clinical Course				
Presence of Extra skeletal Metastases	39 (58.21%)	10 (50.00%)	0.72 [0.26, 1.96]	p = 0.516
Presence of Skeletal Metastases (non-acetabulum)	55 (82.09%)	18 (90.00%)	1.96 [0.40, 99.62]	p = 0.398
Radiation Therapy	23 (34.33%)	13 (65.00%)	**3.55 [1.25, 10.13]**	**p = 0.015**
Chemotherapy	54 (80.60%)	16 (80.00%)	0.96 [0.28, 3.37]	p = 0.953
Bone-Modifying Agents	17 (25.37%)	7 (35.00%)	1.58 [0.54, 4.62]	p = 0.398
Sourcil Bone Loss				
Any Middle Involvement	**5 (7.46%)**	**19 (95.00%)**	**235.60 [25.91, 2142.71]**	**p < 0.001**
Lateral + Middle ONLY	**1 (1.49%)**	**3 (15.00%)**	**11.65 [1.14, 119.12]**	**p = 0.011**
Medial + Middle ONLY	**4 (5.97%)**	**5 (25.00%)**	**5.25 [1.26, 21.95]**	**p = 0.014**
Lateral + Middle + Medial	**0 (0.00%)**	**11 (55.00%)**	**2.22 [1.37, 3.61] ***	**N/A**
Radiographical Measurements				
Sourcil Fracture	**2 (2.99%)**	**12 (60.00%)**	**48.8 [9.20, 258.29]**	**p < 0.001**
Lateral Wall Fracture	**3 (4.48%)**	**7 (35.0%)**	**11.49 [2.62, 50.37]**	**p < 0.001**
Lateral Wall Cortical Involvement	**33 (49.25%)**	**19 (95.00%)**	**19.58 [2.48, 154.69]**	**p < 0.001**
Inner Wall Fracture	**43 (64.18%)**	**19 (95.00%)**	**23.03 [6.31, 84.00]**	**p < 0.001**
Inner Wall Cortical Involvement	**5 (7.46%)**	**13 (65.00%)**	**10.61 [1.34, 84.21]**	**p < 0.001**
Femoral Notch Sign	**1 (1.49%)**	**5 (25.00%)**	**22.00 [2.39, 202.36]**	**p < 0.001**
Acetabular Calcar Bone Loss	**47 (70.15%)**	**19 (95.00%)**	**8.09 [1.01, 64.58]**	**p = 0.023**

Table 2. Protrusio Acetabuli Radiographic Risk Model.

	Scoring Criteria
High-Risk Radiographical Markers - Femoral head notching - Subchondral cortical bone loss in all three zones (lateral + middle + medial)	**+ 4 (each)**
Intermediate-Risk Radiographical Markers - Subchondral cortical bone (measured on coronal CT) Hounsfield ratio compared to contralateral side is < 0.50 - Displaced fracture of subchondral cortical bone	**+ 3 (each)**
Lower-Risk Radiographical Markers - Inner wall fracture alone - Lateral wall fracture alone - Subchondral cortical bone loss of either pattern: a) Lateral + middle b) Medial + middle	**+ 2 (each)**