Association of MRI findings with intra-articular tumour extension

a single-centre retrospective diagnostic accuracy case-control study

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Aims

Treatment of high-grade limb bone sarcoma that invades a joint requires en bloc extra-articular excision. MRI can demonstrate joint invasion but is frequently inconclusive, and its predictive value is unknown. We evaluated the diagnostic accuracy of direct and indirect radiological signs of intra-articular tumour extension and the performance characteristics of MRI findings of intra-articular tumour extension.

Methods

We performed a retrospective case-control study of patients who underwent extra-articular excision for sarcoma of the knee, hip, or shoulder from 1 June 2000 to 1 November 2020. Radiologists blinded to the pathology results evaluated preoperative MRI for three direct signs of joint invasion (capsular disruption, cortical breach, cartilage invasion) and indirect signs (e.g. joint effusion, synovial thickening). The discriminatory ability of MRI to detect intra-articular tumour extension was determined by receiver operating characteristic analysis.

Results

Overall, 49 patients underwent extra-articular excision. The area under the curve (AUC) ranged from 0.65 to 0.76 for direct signs of joint invasion, and was 0.83 for all three combined. In all, 26 patients had only one to two direct signs of invasion, representing an equivocal result. In these patients, the AUC was 0.63 for joint effusion and 0.85 for synovial thickening. When direct signs and synovial thickening were combined, the AUC was 0.89.

Conclusion

MRI provides excellent discrimination for determining intra-articular tumour extension when multiple direct signs of invasion are present. When MRI results are equivocal, assessment of synovial thickening increases MRI's discriminatory ability to predict intra-articular joint extension. These results should be interpreted in the context of the study's limitations. The inclusion of only extra-articular excisions enriched the sample for true positive cases. Direct signs likely varied with tumour histology and location. A larger, prospective study of periarticular bone sarcomas with spatial correlation of histological and radiological findings is needed to validate these results before their adoption in clinical practice.

Take home message

- Preoperative MRI is critical in determining the presence of intra-articular extension of periarticular bone sarcomas, which in turn guides the extent of resection.

- In cases where direct radiological signs of joint involvement are indeterminent, the grading of synovial thickening may increase the discriminatory ability of preoperative imaging.

Introduction

High-grade bone sarcoma of the limbs is treated with wide en bloc excision.[1] When periarticular tumour invades the joint, extra-articular excision is necessary to achieve wide margins.[2,3] While limb salvage is often possible with extra-articular excision, morbidity is greater due to sacrifice of the joint capsule and surrounding tendons and ligaments.[2] For instance, the lack of supporting tissues about the hip leads to increased risk of prosthetic dislocation,[4,5] whereas sacrifice of the knee extensor mechanism typically results in a functionally significant extensor lag.[3,6] Conversely, failure to perform extra-articular excision in the appropriate scenario may lead to tumour recurrence, failure of limb salvage, and compromised survival, though the degree of joint invasion that is oncologically relevant remains unclear. The decision to pursue extra-articular rather than intra-articular excision is a consequential one, and is commonly made by scrutiny of preoperative MRI.

Three modes of tumour extension into the joint have been established: direct tumour extension through articular cartilage; extension around cartilage, beneath the joint capsule; and extension along osseotendinous or intra-articular ligamentous structures.[7] While these findings may be readily apparent on pathological examination of the surgical specimen, their presence on preoperative imaging can be less obvious. Physical examination is of limited utility, as the source of joint pain is often poorly localized, and other findings (e.g. joint stiffness, swelling) do not differentiate joint invasion from mass effect of nearby tumour outside the joint. Clinicians thus rely on interpretation of CT and MRI.[8-10] However, radiological assessment of intra-articular tumour extension has limitations: image resolution may be insufficient; the desired imaging planes may be unavailable; the tumour may be difficult to distinguish from oedema; and the intra-articular involvement (e.g. tumour extending past articular cartilage but delimited by synovium) may not be clearly defined. While prior studies have suggested that MRI may help rule out intra-articular tumour involvement, the ambiguity of findings can lead to false-positive results and overtreatment with extra-articular tumour resection.[7,10,11]

When preoperative imaging is inconclusive for intra-articular extension, indirect radiological signs (e.g. joint effusion) are often interpreted as suggestive of joint invasion, which influences surgical planning. However, scant literature exists correlating the presence of effusions with intra-articular tumour extension.[9,10] Quan et al[9] described ten patients who had periarticular osteosarcoma with a joint effusion on preoperative MRI. None of the resection specimens had histologically evident invasion of articular cartilage, though five demonstrated invasion into a cruciate ligament. In a study of 46 patients with periarticular osteosarcoma, including ten with pathologically confirmed joint invasion, joint effusion was present on preoperative MRI in nine of ten patients (90%) with joint invasion and 24 of 36 patients (67%) of those without invasion, yielding a 92% negative predictive value, but only a 27% positive predictive value.[10] Despite concerns that it may lead to overtreatment, the incorporation of joint effusion into surgical decision-making remains common. This may be due partly to the limitations of the literature, as prior studies did not quantify the degree of effusion, included only osteosarcoma patients, and did not consider other imaging abnormalities in the joint, such as synovial thickening.

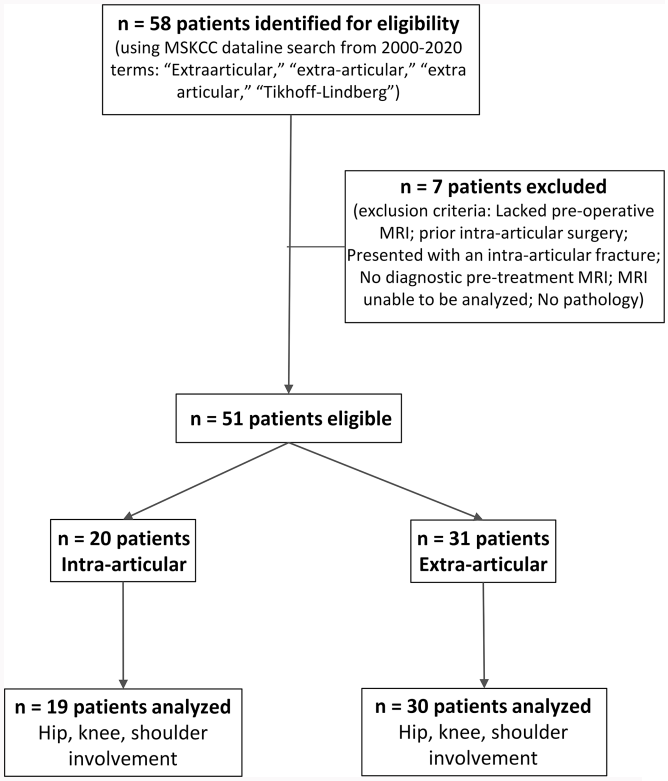

Fig. 1
Flow diagram of patients included in study. MSKCC, Memorial Sloan Kettering Cancer Center.

In this study, we investigated the ability of preoperative MRI to predict histologically confirmed intra-articular extension of periarticular bone sarcoma. We evaluated the accuracy of using direct MRI signs of joint invasion, such as breach of anatomical borders; the additive value of using indirect signs (e.g. degree of joint effusion) in cases with equivocal direct findings; and the accuracy with which a combination of direct and indirect signs can predict intra-articular tumour extension.

Methods

Patient selection

We conducted a single-institution, retrospective, diagnostic accuracy case-control study with post hoc grouping and analysis. After obtaining Institutional Review Board approval (protocol #16-1123), we searched the electronic medical record (EMR) for all patients who underwent extra-articular excision between 1 June 2000 and 1 November 2020. This timeline was designed to maximize inclusion of relevant cases. Earlier cases were not included because our EMR system could not be queried regarding cases before 2000.

We identified 58 patients who had an extra-articular excision for bone sarcoma (Figure 1). Seven were excluded; reasons for exclusion included lack of preoperative MRI (n = 2), absence of malignant pathology (n = 1), presentation with an intra-articular fracture (n = 1), or prior intra-articular surgery (n = 3); prior surgery or fracture could have led to intra-articular

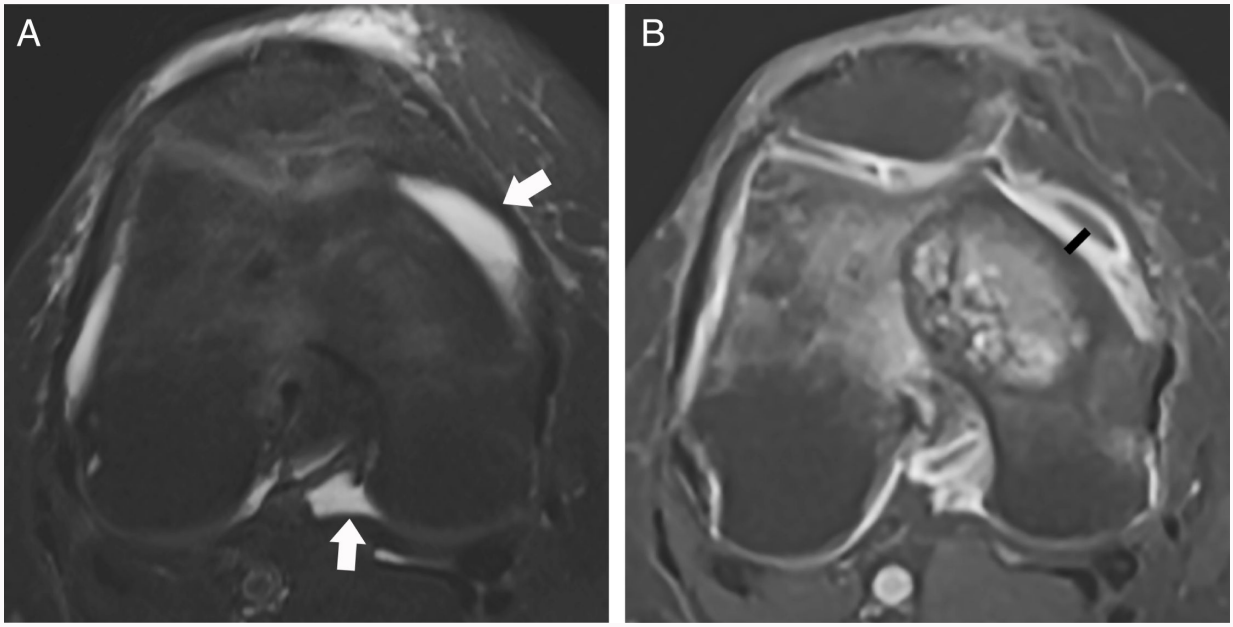

Fig. 2
Case example of MRI assessment of a knee with tumour invasion. A 58-year-old female presented with left distal femur osteosarcoma and intra-articular extension on pathology. a) Axial T2FS image shows grade 1 knee joint effusion (arrows) in the medial patellofemoral recess and posterior to posterior cruciate ligament. b) Axial T1FS postcontrast shows grade 2 synovial thickening (line) measuring 3 mm in the medial patellofemoral recess.

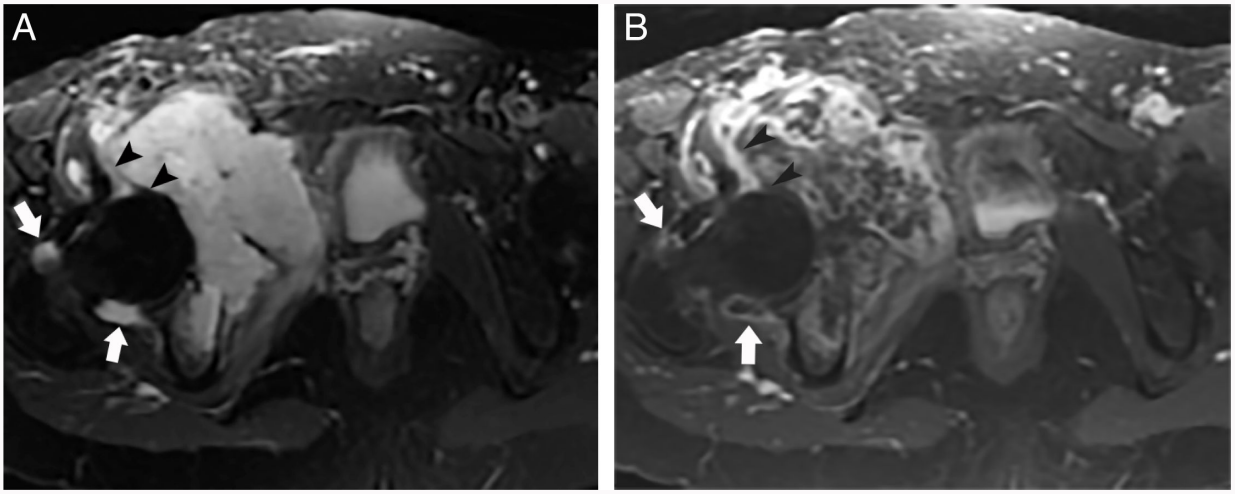

Fig. 3
Case example of MRI assessment of a hip with tumour invasion. A 64-year-old female presented with right acetabular chondrosarcoma and intra-articular extension on pathology. a) Axial T2FS image shows grade 2 hip joint effusion anterior and posterior to femoral head-neck junction (white arrows). b) Axial T1FS postcontrast image shows grade 2 synovial thickness (arrows) and tumour invasion manifested by cortical and cartilage bone destruction (black arrowheads).

imaging abnormalities and thus confounded the results. Our sample therefore comprised 51 patients.

We determined the presence of intra-articular tumour extension using final surgical pathology reports. We then reviewed patients' preoperative MRIs, documented the presence and grade of joint effusion, and assessed correlations between effusion on MRI and intra-articular tumour extension on surgical pathology.

MRI protocol

Multiphasic MRI at our institution (Memorial Sloan Kettering Cancer Center, USA) and outside institutions was performed on 1.5 or 3.0 T MR machines. MRI protocols were heterogeneous, especially for scans at outside institutions. They included axial T1-weighted (T1W) sequences; axial fluid-sensitive sequences, such as STIR or T2-weighted (T2W) fat-suppressed (FS) sequences; coronal or sagittal T1W sequences; coronal or sagittal T2W FS sequences; and axial pre- and postcontrast T1W FS sequences.

MRI analysis

Preoperative MRI images were retrospectively reviewed jointly by two musculoskeletal radiologists (one clinical fellow (MAEA) and one radiologist (SH)) with > 15 years' experience who

Table I. Joint effusion grade.

Grade	Shoulder	Hip	Knee
0 (normal)	None of the distension of the subscapularis recess, fluid in the long head biceps tendon sheath,* or fluid in the axillary recess	A thin layer of fluid without distended hip recess (analyzed as 4 quadrants with respect to the femoral head)	No distension of tricompartmental recesses,† popliteal cyst,* or popliteus tendon sheath*
1 (small)	Distension of 1 recess	Distension of 1 recess	Distention of 1 to 2 recesses
2 (moderate)	Distension of 2 recesses	Distension of 2 recesses	Distension of 3 to 4 recesses
3 (large)	Distension of all recesses	Distension of 3 to 4 recesses	Distension of ≥ 5 recesses

*Counted as recesses.
†Includes medial and lateral suprapatellar recess, medial and lateral patellofemoral recess, posterior and medial to posterior cruciate ligament (PCL), and posterior and lateral to PCL.

were blinded to patients' surgical treatment and to histological analyses of surgical specimens. Morphological signs of joint invasion were evaluated on multiple imaging planes and included cortical bone breach, capsular disruption, and articular cartilage involvement. Tumours of the shoulder, knee, and hip were evaluated for involvement of the intra-articular portion of tendons and ligaments, but as these findings were specific to each joint, they were not included in the combined analysis of predictive value. Indirect signs of joint invasion included joint effusion and synovial thickening, which were evaluated on axial T1W FS postcontrast images (fluid-sensitive sequences if postcontrast imaging was unavailable). Joint effusion was graded on a four-point scale based on the number of distended recesses in each joint (Table I). Synovial thickness was measured and graded as 0 if no enhancement of synovial tissue was evident, grade 1 if synovial thickening was < 2 mm, grade 2 if thickening measured 2 to 4 mm, and grade 3 if thickening was > 4 mm or nodular in pattern. Figure 2 and Figure 3 provide examples of synovial thickness and joint effusion grading. We created a post-hoc variable indicating whether intra-articular tumour extension had been identified from pathological review of the extra-articular resection specimen.

Treatment

Patients who presented with bone sarcoma were evaluated by a multidisciplinary team that included an orthopaedic oncologist and a sarcoma medical oncologist. Neoadjuvant chemotherapy and/or radiotherapy were administered when appropriate. MRI was routinely repeated following neoadjuvant therapy and prior tumour excision, and this latest presurgical MRI was analyzed for the study. Clinical and radiological information was reviewed at orthopaedic oncology tumour board meetings, where decisions regarding extent of resection were made. If intra-articular tumour extension was strongly suspected based on the latest MRI, the patient underwent extra-articular excision, with either limb salvage surgery or amputation.

Pathology protocol

Resected specimens were cut coronally using a band saw to expose the joint. A representative slice of tumour was then mapped (including bone, soft-tissue articular surfaces, and joint) to assess tumour histology, presence of intramedullary tumour, and extension into soft-tissue and joint. Routine histology processing was performed after specimen fixation in formalin and routine decalcification procedures. Haematoxylin and eosin section slides were prepared by standard protocols.

Statistical analysis

We report patient characteristics (including demographic, clinical, and pathological data) by invasion status. Differences between groups were identified using chi-squared tests (categorical data) and independent-samples *t*-test (non-categorical data). The discriminatory ability of MRI-derived features was assessed by receiver operating characteristic (ROC) analysis. Differences were assessed using the DeLong test. Analyses were performed in R v. 4.0.5 (R Foundation for Statistical Computing, Austria).

Results

Sample

Of the 51 patients, 20 had intra-articular tumour extension on histological analysis and 31 did not. Tumours predominantly involved the knee (n = 29), hip (n = 10), and shoulder (n = 10). We excluded two patients whose tumour involved the wrist (n = 1) or elbow (n = 1), as the numbers were insufficient to evaluate joint-specific imaging parameters. This left 49 patients (19 with intra-articular tumour extension and 30 without) for analysis (Figure 3).

Most patients (65%) were male (Table II), and had a mean age of 32.8 years (SD 21.5); patients with joint invasion were older than those without (41.8 years vs 27.0 years; p = 0.014). Notably, the percentage of patients with chondrosarcoma was greater in the joint invasion group (40% vs 6%), while the percentage with osteosarcoma was greater among those without invasion (77% vs 35%). Overall, 45% of patients with joint invasion underwent neoadjuvant chemotherapy, as did 74% of those without. Only one patient had radiation therapy; this patient had Ewing's sarcoma with joint invasion of the shoulder.

Direct signs and intra-articular involvement

We assessed three joint invasion signs on MRI (cortical bone breach, joint capsule disruption, articular cartilage invasion) as predictors of intra-articular tumour involvement (Table III). All three correlated with intra-articular tumour extension on pathology (Figure 4); the AUCs were 0.740 for cortical bone

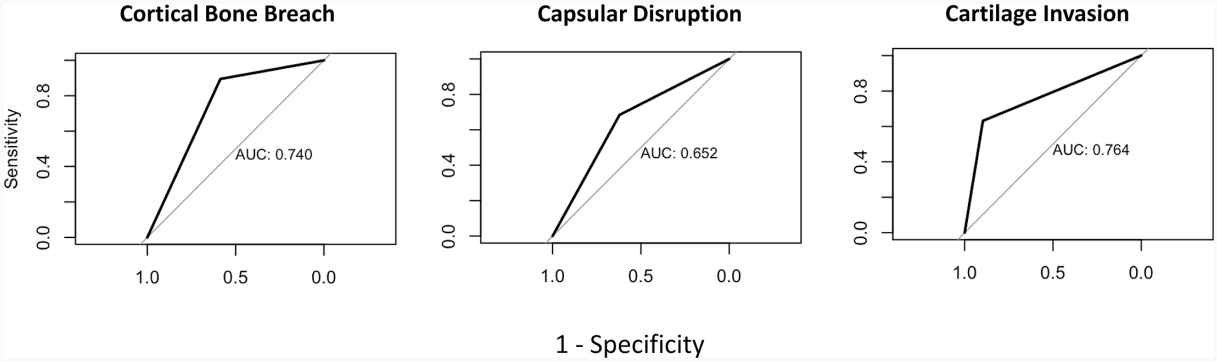

Fig. 4
Receiver operating characteristic curves for MRI direct signs of joint invasion. AUC, area under the curve.

Table II. Baseline demographic and other characteristics.

Characteristic	All patients (n = 51)	Joint invasion (n = 20)	No joint invasion (n = 31)	p-value
Mean age (SD)	32.8 (21.5)	41.8 (23.5)	27.0 (18.1)	0.014*
Male sex, n (%)	33 (65)	14 (70)	19 (61)	0.525†
Received neoadjuvant chemotherapy, n (%)	30 (59)	9 (45)	21 (68)	0.107†
Progression on chemotherapy, n (%)‡	9 (30)	4 (44)	5 (24)	0.258†
Pathology, n (%)				
Osteosarcoma	31 (61)	7 (35)	24 (77)	
Chondrosarcoma	10 (20)	8 (40)	2 (6)	
Ewing's sarcoma	5 (10)	3 (15)	2 (6)	
UPS	4 (8)	1 (5)	3 (10)	
Leiomyosarcoma	1 (2)	1 (5)	0 (0)	
Joint involved, n (%)				
Shoulder	10 (20)	4 (20)	6 (19)	
Hip	10 (20)	7 (35)	3 (10)	
Knee	29 (57)	8 (40)	21 (68)	
Wrist	1 (2)	0 (0)	1 (3)	
Elbow	1 (2)	1 (5)	0 (0)	
Adjuvant therapy, n (%)				
Chemotherapy	40 (78)	13 (65)	27 (87)	
Neoadjuvant chemotherapy	32 (63)	9 (45)	23 (74)	
Radiation	1 (2)	1 (5)	0 (0)	

*Independent samples t-test.
†Chi-squared tests
‡Among patients who received chemotherapy.
UPS, undifferentiated pleomorphic sarcoma.

Table III. Predictive value of direct MRI signs of joint invasion.

Sign	Joint invasion (n = 19)	No joint invasion (n = 30)	AUC	p-value*
Cortical bone breach, n (%)	17 (89)	13 (43)	0.740	0.0012
Capsular disruption, n (%)	13 (68)	11 (37)	0.652	0.0303
Articular cartilage involvement, n (%)	12 (63)	4 (13)	0.764	0.0003
1 to 2 signs, n (%)	12 (63)	14 (47)	0.610	0.2597
All 3 signs, n (%)	7 (37)	2 (7)	0.832	0.0079

*Receiver operator curve analysis and the DeLong test.
AUC, area under the curve.

breach (p = 0.001, DeLong test), 0.652 for capsular disruption (p = 0.030), and 0.764 for articular cartilage involvement (p < 0.001, DeLong test). When all three variables were present, the AUC increased to 0.832 (p = 0.008; Figure 5). However, only seven of 19 patients (37%) with joint invasion had all three direct signs; the remaining 12 (63%) had one to two signs. Because 14 of the 30 patients (47%) without invasion also had one to two signs, this threshold was not a predictor of intra-articular tumour extension (p = 0.26).

Indirect signs and intra-articular involvement

For the 26 patients with one to two direct MRI signs of joint invasion, we evaluated the predictive value of five indirect signs (Table IV). Only two of these associations were significant: synovial thickness grade (AUC 0.850; p = 0.010) and synovial thickness sum (AUC 0.523; p = 0.008). No association with intra-articular tumour involvement was evident for the other indirect signs (number of distended recesses (AUC 0.641), effusion thickness grade (AUC 0.632), and effusion thickness sum in mm (AUC 0.583). The addition of synovial thickness grade increased the AUC for patients with one to two direct signs from 0.610 to 0.775 (p = 0.003). However, the combination of joint invasion signs and synovial thickness grade (Figure 5) had a significantly higher association with intra-articular tumour extension than joint invasion signs alone (AUC 0.887 vs 0.846; p = 0.020). The optimal discriminatory cut-off was determined as the presence of at least one direct sign of joint invasion plus moderate (grade 2 out of 3) synovial thickening, which had a sensitivity of 100% and specificity of 73%.

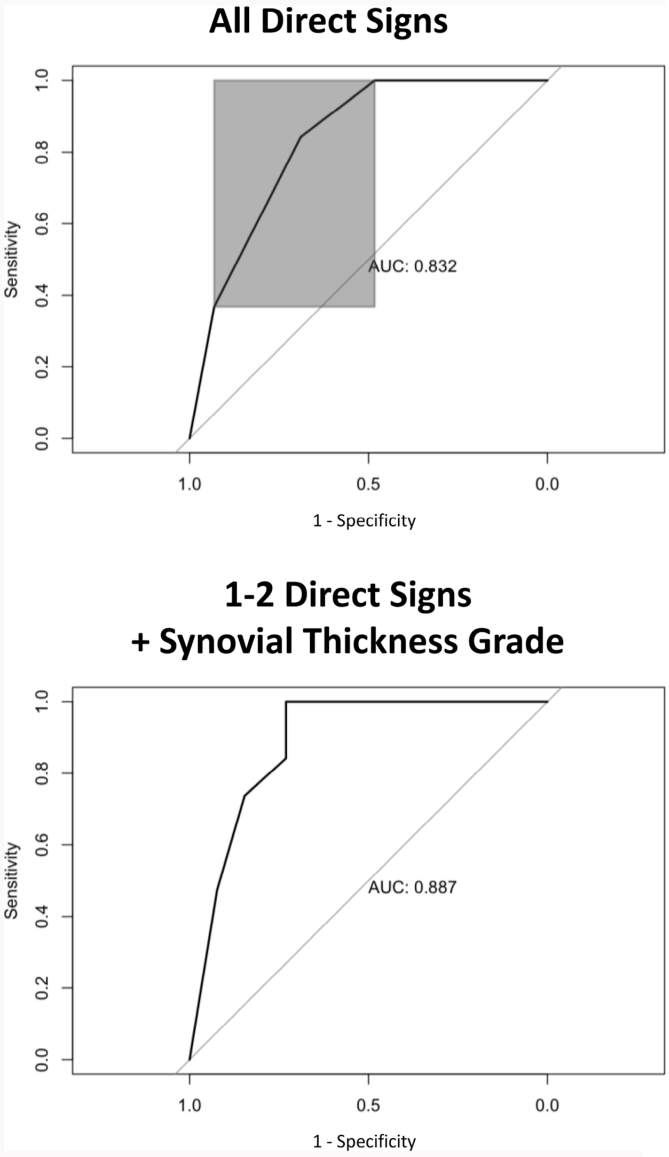

Fig. 5

Receiver operating characteristic curves for a) all direct signs and b) combined analysis. The latter represents cases selected with only one to two joint invasion signs present (shaded box at the top) and shows the increased performance when synovial thickness is added as a diagnostic criterion to this subgroup. AUC, area under the curve.

Concordance of MRI signs and pathology

For patients with confirmed intra-articular invasion, we examined whether those with specific MRI signs of joint invasion (cortical bone breach, capsular disruption, articular cartilage invasion, cruciate ligament involvement) had evidence of joint invasion on pathology concordant with the mechanism predicted by MRI (Table V). Overall, 15 patients had MRI signs of cortical bone breach, but only four had concordant pathology findings. None of the ten patients with MRI signs of capsular disruption had concordant findings on pathology. Finally, concordance with pathology was evident for seven of 11 patients with MRI signs of articular cartilage invasion and four of nine with MRI signs of cruciate ligament involvement.

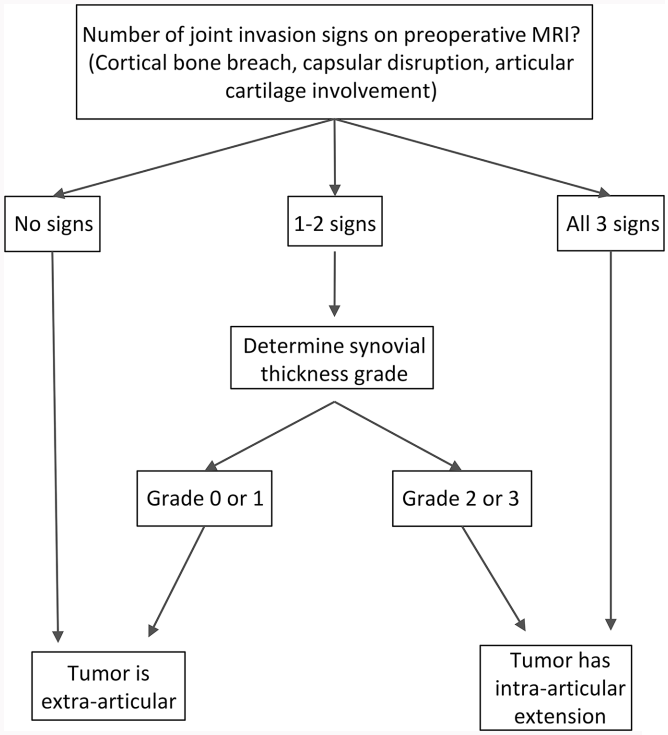

Fig. 6

Proposed decision-making algorithm for intra-articular tumour extension.

Discussion

Evaluating intra-articular tumour extension is critical in deciding whether to perform an extra-articular resection. MRI remains the best tool for identifying sarcomas that invade the joint. While MRI is highly sensitive, the proximity of joint structures, the sometimes indistinct anatomical boundaries, and the presence of tumorous oedema can lead to false-positive conclusions and unnecessary extra-articular excisions, which can result in greater morbidity.[2,5] Our findings are consistent with prior evidence that direct MRI signs of joint invasion have high sensitivity but low specificity for identifying invasion. We find that assessment of intra-articular tumorous involvement is conclusive in patients exhibiting no direct signs or all three (capsular disruption, articular cartilage involvement, cortical break). However, the presence of one to two signs is diagnostically inconclusive. To improve predictive ability in these cases, we incorporated the assessment of indirect signs of joint invasion into the analysis.

Of the 51 eligible patients with an extra-articular excision, only 20 had joint involvement on final pathological assessment. Final pathology suggests that 60% of the patients could have undergone a lesser surgical procedure if our tools for preoperative assessment were better. Our clinical experience is similar to that reported by others. An analysis of ten extra-articular resections performed for presumed intra-articular involvement found that only one had joint invasion.[7] In a study of 46 patients with periarticular osteosarcomas, preoperative MRI correctly predicted all ten instances of pathologically confirmed joint invasion (100% sensitivity) but yielded 11 false positives (69% specificity).[10] Other reports have quoted similarly high rates of false positives,[9,11] underscoring the need for more accurate preoperative evaluation.

Table IV. Predictive value of indirect MRI signs of joint invasion in patients with one to two direct MRI signs.

Sign	Joint invasion	No joint invasion	AUC	p-value*
Median effusion thickness grade (IQR)	1 (0 to 2)	1 (0 to 1)	0.632	0.320
Median synovial thickness grade (IQR)	2 (2 to 2)	1 (1 to 2)	0.850	0.010
Median number of distended recesses (IQR)	0 (0 to 2.5)	0 (0 to 1)	0.641	0.324
Mean sum effusion thickness, mm (SD)	8.9 (9.7)	4.2 (6.8)	0.583	0.174
Mean sum synovial thickness, mm (SD)	8.3 (3.3)	4.9 (2.4)	0.523	0.008

*Receiver operator curve analysis and the DeLong test.
AUC, area under the curve.

Table V. Concordance between mode of invasion on MRI and pathology review.

Mode of invasion on MRI	Pathology concordant	Pathology discordant
Cortical bone breach, n	4	11
Capsular disruption, n	0	10
Articular cartilage invasion, n	7	4
Cruciate ligament involvement, n	4	5

MRI is the best-known modality for evaluating intra-articular tumour extension.[8,10] It assesses three main modes of tumour entry into a joint: invasion across articular cartilage; extension beneath the joint capsule; and penetration through an osseous-tendinous junction of an intra-articular ligament.[3,9,12] Our MRI assessment focused on three main signs: capsular disruption, articular cartilage involvement, and cortical bone breach. Of these, the last two had the highest AUCs (0.764 and 0.740, respectively). Prior works also included such signs as epiphyseal extension and visualization of intrasynovial tumour tissue.[11,13] These assessments have shown excellent sensitivity for identifying lack of joint involvement, but specificity has varied from 69% to 85%. No single MRI sign of tumour invasion has strong accuracy (see Table VI for summary), perhaps because tumours invade joints by multiple modes. Even when joint invasion is correctly identified on preoperative MRI, the mode of invasion is often discordant with postoperative pathology findings. We found the likelihood of intra-articular tumour invasion is highest when all signs of joint involvement are present. Conversely, patients with no direct signs of invasion are unlikely to have joint involvement.

Joint effusion and synovial thickening/contrast enhancement has been studied as an indirect sign of intra-articular tumour extension.[9,10,13,14] Kurisunkal et al[14] found joint effusion to have high sensitivity (91%) but low specificity (35%) in identifying pathologically confirmed joint invasion. It is important to note that this study included patients with intra-articular fractures, while ours excluded them due to the confounding effect of such fractures on joint effusion. Schima et al[10] reported that nine of ten patients with joint invasion had an effusion, but so did 24 of 36 without invasion; accordingly, joint effusion had low positive but high negative predictive value. They noted that contrast-enhanced images helped identify intra-articular tumour, but also that synovial enhancement was mistakenly assessed as tumour. Quan et al[9] reported that ten of 27 patients analyzed for joint involvement had an effusion, but none had joint involvement on pathology. Bodden et al[13] found that joint effusion had poor sensitivity (54% to 63%) and high specificity (75% to 96%) for joint invasion, whereas synovial contrast enhancement had high sensitivity (87% to 96%) and poor specificity (56% to 65%). Like prior studies, our analysis did not find that joint effusion was an accurate predictor of joint invasion on pathology. Although we examined this radiological sign more robustly than prior studies had (we measured effusion thickness and the number of distended capsular recesses), accuracy remained poor.

The reason for the weak association between joint effusion and histological joint invasion is unclear, but likely rests with the poor distinction between reactive and malignant effusion. Studies of metastatic tumour in joints have found that patients with malignant synovitis or effusion tend to have bloody joint aspirate with a white blood cell predominance.[3,12,15] However, in a study of 24 patients undergoing aspiration, only 12 had positive cytology, and subsequent synovial biopsy revealed lesions in only six additional patients.[12] Shahid et al[3] grossly analyzed joint fluid intraoperatively to decide on extent of resection of periarticular bone sarcoma with equivocal preoperative MRI, with blood-tinged fluid signalling the need for extra-articular resection. However, joint fluid was not analyzed cytologically, and the authors did not report whether the intraoperative analysis correlated with postoperative pathological findings. It remains unknown whether cytological or molecular analysis of a joint effusion can identify intra-articular tumour extension.

Conversely, we found that synovial thickness grade increased discriminatory ability in patients with inconclusive (one to two) direct MRI signs of tumour invasion: AUC increased from 0.610 to 0.775, resulting in 100% sensitivity and 73% specificity. Accordingly, we propose a simple diagnostic algorithm (Figure 6), which can improve the accuracy of preoperative MRI in identifying joint invasion and thus aid surgical planning. Direct signs of joint invasion are evaluated first. Cases with all three direct signs are deemed likely to have involvement and cases with no direct signs are deemed unlikely. Ambiguous cases are assessed for synovial thickening. Patients with high-grade synovial thickening (grade 2 or higher) are deemed likely to have intra-articular involvement, while those without high-grade synovial thickening are deemed unlikely.

Our study has several limitations. This is a single-centre retrospective study with a small sample. However, given the rarity of joint-invasive bone sarcoma, our cohort of 51 patients represents one of the largest published datasets for extra-articular excision. Nonetheless, the sample size precluded conducting meaningful subgroup analyses or withholding a

Table VI. Summary of prior studies assessing MRI signs of joint involvement.

Study	Patients, n	Surgeries, n	Confirmed joint involvement, n	Joints involved	Direct MRI signs	Indirect MRI signs
Bloem et al[8]	56	53 (3 EARs, 50 amputations)	17	Knee, hip, shoulder	N/R	N/R
Schima et al[10]	46	21 EARs	10	Knee	Capsular disruption, cortical destruction, AC involvement, cruciate ligament	Joint effusion, synovial contrast enhancement, epiphyseal marrow arthroplasty
Quan et al[9]	27	2 EARs	0	Knee, hip, shoulder	AC involvement, cruciate ligament	Joint effusion
Chelli Bouaziz et al[11]	42	21 (15 EARs, 6 amputations)	16	Knee	AC involvement, tibial spine involvement, direct visualization of intra-articular tumour, capsular disruption	Epiphyseal marrow arthroplasty
Simon et al[7]	10	10 EARs	1	Knee	AC involvement, cruciate ligament	Joint effusion
Bodden et al[13]	48	N/R	24	Knee, hip, shoulder	Cortical destruction, AC involvement, cruciate ligaments, direct visualization of intra-articular tumour	Joint effusion, synovial contrast enhancement, epiphyseal marrow arthroplasty

AC, articular cartilage; EAR, extra-articular resection; N/R, not reported.

portion of the cohort to internally validate our proposed algorithm; these should be done in future studies. We also note that the study focused on patients with suspected joint invasion who underwent extra-articular excision, suggesting that the clinical suspicion was sufficiently high to justify this intervention. This likely enriches our patient sample for true positive cases and introduces a selection bias that may inflate the sensitivity and performance characteristics of the described diagnostic approach. An alternative study design would be to focus on all periarticular tumours.[10,11,13] While this would yield sensitivity and specificity analyses applicable to the broader population of patients with periarticular bone sarcoma (irrespective of suspicion of joint invasion), our smaller cohort allowed us to make detailed, comprehensive measurements of the variables of interest. To generalize our findings, we included all diagnoses of bone sarcoma. However, certain histologies may be more inflammatory than others and therefore produce more robust joint effusion or synovial thickening in the setting of joint invasion. The common mechanisms of joint invasion (and thus direct signs on MRI) may also differ by tumour histology and anatomical location, but such an analysis would require a greater number of patients. Another limitation is the heterogeneity of MRI protocols, since the study period spanned two decades and outside examinations were included. Given the rarity of the problem being studied, it would be unfeasible to include only patients with strictly comparable studies.

Concordance between the suspected mode of joint invasion on preoperative MRI and the mode of invasion on pathology was poor, which is consistent with prior findings.[14] Our study was retrospective and relied on previously processed tissue specimens that were not necessarily sectioned and oriented optimally for our purposes. A prospective study would allow more precise anatomical coordination between radiological and pathological examinations, and would be expected to better define the precision with which preoperative MRI can establish the mode of joint invasion.

In conclusion, we have confirmed previous findings that the assessment of direct signs of joint invasion on preoperative MRI has limited accuracy for identifying pathologically confirmed joint invasion. While obvious cases, with either all or none of the direct signs, can be accurately assessed with this finding alone, this leaves a significant number of inconclusive cases that are at risk for overtreatment or undertreatment. We found that assessment of synovial thickening increased the discriminatory ability of preoperative MRI in these cases, and that the combination of direct signs and synovial thickening yielded good diagnostic performance. The algorithm we developed holds promise as an aid in the diagnosis of joint invasion of periarticular bone sarcoma on preoperative MRI, but requires validation in a prospective study that includes all periarticular bone sarcomas, regardless of inclusion of the entire joint in the surgical resection.

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Data sharing

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