Eur Radiol (2014) 24:232–240
DOI 10.1007/s00330-013-3003-y

MUSCULOSKELETAL

MRI differentiation of low-grade from high-grade appendicular chondrosarcoma

Hassan Douis · Leanne Singh · Asif Saifuddin

Received: 1 May 2013 / Accepted: 11 August 2013 / Published online: 10 September 2013

Abstract
Objectives To identify magnetic resonance imaging (MRI) features which differentiate low-grade chondral lesions (atypical cartilaginous tumours/grade 1 chondrosarcoma) from high-grade chondrosarcomas (grade 2, grade 3 and dedifferentiated chondrosarcoma) of the major long bones.
Methods We identified all patients treated for central atypical cartilaginous tumours and central chondrosarcoma of major long bones (humerus, femur, tibia) over a 13-year period. The MRI studies were assessed for the following features: bone marrow oedema, soft tissue oedema, bone expansion, cortical thickening, cortical destruction, active periostitis, soft tissue mass and tumour length. The MRI-features were compared with the histopathological tumour grading using univariate, multivariate logistic regression and receiver operating characteristic curve (ROC) analyses.
Results One hundred and seventy-nine tumours were included in this retrospective study. There were 28 atypical cartilaginous tumours, 79 grade 1 chondrosarcomas, 36 grade 2 chondrosarcomas, 13 grade 3 chondrosarcomas and 23 dedifferentiated chondrosarcomas. Multivariate analysis demonstrated that bone expansion ($P=0.001$), active periostitis ($P=0.001$), soft tissue mass ($P<0.001$) and tumour length ($P<0.001$) were statistically significant differentiating factors between low-grade and high-grade chondral lesions with an area under the ROC curve of 0.956.
Conclusions On MRI, bone expansion, active periostitis, soft tissue mass and tumour length can reliably differentiate high-grade chondrosarcomas from low-grade chondral lesions of the major long bones.

H. Douis (✉) · L. Singh · A. Saifuddin
Department of Radiology, The Royal National Orthopaedic Hospital NHS Trust, Brockley Hill, Stanmore, Middlesex HA7 4LP, UK
e-mail: h.douis@nhs.net

Key Points
- *Accurate differentiation of low-grade from high-grade chondrosarcomas is essential before surgery*
- *MRI can reliably differentiate high-grade from low-grade chondrosarcomas of long bone*
- *Differentiating features are bone expansion, periostitis, soft tissue mass and tumour length*
- *Presence of these four MRI features demonstrated a diagnostic accuracy (AUC) of 95.6%*
- *The findings may result in more accurate diagnosis before definitive surgery*

Keywords Low-grade chondrosarcoma · High-grade chondrosarcoma · Long bone · MRI · Differentiation

Introduction

Chondrosarcoma (CS) of bone is the third most common primary malignant bone tumour after multiple myeloma and osteosarcoma and is characterised by the production of a cartilaginous matrix. The most common form of CS is central CS of long bone. CSs are histologically differentiated into grade 1, grade 2 and grade 3, dependent on cellularity, cellular atypia and mitosis [1]. Dedifferentiated CS is a highly malignant variant of CS, characterised by the development of a high-grade, non-cartilaginous sarcoma in association with a pre-existing low-grade CS [2]. Grade 1 CSs are classified as low-grade neoplasms, grade 2 as intermediate grade and grade 3 as high-grade lesions. The term "atypical cartilaginous tumour" is used for chondral lesions which are moderately cellular, show myxoid change and mild nuclear atypia with binucleate forms, but do not demonstrate permeative growth. This term is used in a similar fashion to the term "CLUMP (cartilaginous lesion of unknown malignant potential)" or the term "grade 0.5 chondrosarcoma", which have been in practice in other institutions [3, 4]. Atypical chondral

tumours and low-grade CSs of long bones are increasingly being treated with intralesional curettage and local adjuvant therapy. In contrast, intermediate and high-grade CSs, as well as dedifferentiated CSs, are treated with limb-salvage and endoprosthetic reconstruction or amputation [5–8]. Furthermore, the prognosis of CS is directly related to the histological grade of the tumour. However, the differentiation of low-grade, intermediate and high-grade CS is challenging based on histology and imaging [9], and biopsy can lead to erroneous down-grading of intermediate and high-grade CS since only a small area of the lesion is sampled. This in turn may result in inadequate treatment of patients with grade 2 and grade 3 CS with curettage, subsequently necessitating further surgery with an associated increase in morbidity. Therefore, it is crucial to reliably differentiate low-grade from intermediate and high-grade CS before definitive surgery.

Imaging may play a role in the differentiation of low-grade and high-grade CS. Radiography is usually the first imaging technique used in the assessment of bone tumours. However, radiography cannot reliably differentiate low-grade CS from high-grade CS [9]. Skeletal scintigraphy reflects the increased physiologic activity of CS. Therefore, the majority of long bone CSs (82 %) demonstrate marked increased radio-isotope uptake which is greater than the anterior iliac crest on skeletal scintigraphy, whilst this finding is observed in only a minority (21 %) of enchondromas. Furthermore, a heterogeneous pattern of radionuclide uptake is more frequently seen in CS of long bone (63 %) but only in 30 % of enchondromas [10]. However, there is no correlation between the histological grade of CS and the intensity or pattern of uptake on scintigraphy [11]. Conversely, magnetic resonance imaging (MRI) is ideally suited to non-invasively evaluate the extent of a chondral lesion, the degree of endosteal scalloping and the presence of soft tissue extension, and therefore may be more likely to differentiate low-grade from high-grade CS. However, to the best of our knowledge, only a few studies have previously investigated the role of MRI in the differentiation of low-grade from high-grade CS. The results of these studies are hampered by small sample size and the fact that they assessed only a few features which are associated with malignancy in chondral lesions [12–17]. The purpose of our study was to evaluate MRI features which would aid in the differentiation of low-grade from high-grade CS of the major long bones in a large patient cohort.

Materials and methods

Patients

Institutional Review Board approval was obtained before commencement of the study to perform this retrospective review of patient records, pathology reports and imaging as Service Evaluation.

The electronic patient database of a Supra-regional Orthopaedic Oncology Unit was reviewed to identify all patients treated for histologically confirmed central atypical cartilaginous tumours and central CS of the major long bones (humerus, femur and tibia) over a 13-year period. Chondral lesions which arose within the radius, ulna or fibula, periosteal CS, peripheral CS, clear cell CS, myxoid CS and mesenchymal CS were excluded from the study. Data were collected on patient age, sex, site of the tumour and histological grading of the chondral lesions (atypical cartilaginous tumour, grades 1–3 CS and dedifferentiated CS).

MRI

Due to the tertiary referral nature of our centre, the vast majority of MRI studies were performed in other institutions before referral on a variety of MRI systems with differing protocols. However, all studies included at least one T1-weighted (T1W) spin echo (SE), STIR or fat-suppressed T2-weighted (T2W) fast spin-echo (FSE) sequence and all studies included a combination of axial, coronal and sagittal images. Cases imaged at our centre had a routine examination, which consisted of a coronal T1W turbo spin echo (TSE) sequence (TR 450–700, TE 15–20 ms), a coronal STIR sequence (TR 2,000–4,000, TE 50–100, IR 130–150), a sagittal T2W TSE sequence (TR 2,000–3,000, TR 70–100), and axial proton-density-weighted (PDW) and PDW fat-suppressed TSE (TR 3,000–4,000, TE 30– 40) sequences. Intravenous gadolinium-enhanced MRI is not usually performed at our institution for the assessment of bone tumours.

MRI studies were evaluated in consensus by two radiologists with 3 years (H.D.) and 18 years (A.S.) of musculoskeletal radiology experience. In case of disagreement, the opinion of the most senior reviewer was accepted. The reviewers were aware that the patients had atypical cartilaginous tumours/CS but were blinded to the histological grading of the lesions. The MR images were assessed for the following features: the presence of bone marrow oedema, soft tissue oedema, bone expansion, cortical thickening, cortical destruction, active periostitis (manifest by periosteal oedema) and the presence of a soft tissue mass. Furthermore, the maximum length of the tumour was documented.

Histopathology and correlation with MRI features

The electronic histopathology database was accessed, the histopathology reports for all patients with atypical cartilaginous tumours/CS were retrospectively reviewed and the grading was documented. In patients who underwent biopsy before curettage or resection, the final histopathology report, which was based on the curettage or resection specimen, was documented.

At our institution, all chondral lesions are routinely reported by two pathologists at the time of diagnosis. Histological grading of atypical cartilaginous tumours, grade 1, grade 2, grade 3 and dedifferentiated CS was determined according to widely accepted definitions [18, 19].

For the purpose of this study, atypical cartilaginous tumours and grade 1 CS were grouped into low-grade chondral lesions, whilst grade 2, grade 3 and dedifferentiated CSs were classified as high-grade chondral lesions, according to The Musculoskeletal Tumour Society staging system [20].

Statistical analysis

The above-described MRI features were correlated with the diagnosis of low-grade chondral tumours and high-grade chondral tumours. Statistical significance was tested using Fisher's exact test for dichotomous values and *t*-test for continuous variables. Odds ratios by univariate analyses were calculated, together with 95 % confidence intervals. Multivariate logistic regression and receiver operating characteristic (ROC) curve analyses were used to determine the best model to differentiate low-grade chondral tumours from high-grade CS. For all tests, a *P* value of less than 0.05 was considered significant. The statistical analysis was performed using SPSS version 20.0 (SPSS, Chicago, IL, USA).

Results

Two hundred and four patients with atypical central chondral tumours, central grade 1, grade 2, grade 3 and dedifferentiated CS of the femur, tibia and humerus were identified. However, 25 patients had a pathological fracture and were therefore excluded, since the presence of fracture-related oedema would be a confounding factor. In total, 179 patients with atypical central chondral tumours, central grade 1, grade 2, grade 3 and dedifferentiated CS of the femur, tibia and humerus were included. There were 76 male patients and 103 female patients. The median age was 51 years, the mean age was 52.8 years and the patient age ranged from 15 to 85 years.

Ninety eight chondral lesions were located in the femur (54.8 %), 57 in the humerus (31.8 %) and 24 lesions (13.4 %) were located in the tibia. In all cases the final histological diagnosis and grading of the chondral tumours was made on curettage, resection or amputation specimens, considering the highest grade of tumour in the specimen as the final diagnosis.

Twenty-eight patients had an atypical chondral tumour (15.6 %), 79 patients had a grade 1 CS (44.1 %), 36 patients had a grade 2 CS (20.1 %), 13 patients had a grade 3 CS (7.3 %) and 23 patients had a dedifferentiated CS (12.9 %). In total, there were 107 low-grade chondral tumours (59.8 %) and 72 high-grade CSs (40.2 %). In the low-grade chondral tumour group, 53 lesions (49.5 %) were located proximally, 48 distally (44.9 %), 3 were located in the mid-shaft (2.8 %), 2 had a mid- and distal location (1.9 %), and 1 case (0.9 %) was located mid- and proximally. In the high-grade CS group, 42 lesions (58.4 %) were located proximally, 13 distally (18.1 %), 7 cases (9.7 %) involved almost the entire long bone, 5 (6.9 %) were located in a mid- and distal region and 5 lesions (6.9 %) were located in a mid and proximal location.

In the LG chondral tumour group, 43 lesions (40.2 %) were located in the diaphysis, 42 (39.2 %) in the metadiaphysis, 8 (7.5 %) in the metaphysis, 8 (7.5 %) in the metaphysis and epiphysis, 3 (2.8 %) in the diaphysis, metaphysis and epiphysis and 3 (2.8 %) in the epiphysis. In the HG-CS group, 33 lesions (45.8 %) were located in the metadiaphysis, 21 (29.2 %) in the diaphysis, 13 (18 %) in the diaphysis, metaphysis and epiphysis, 2 (2.8 %) in the metaphysis and epiphysis, 2 (2.8 %) in the metaphysis and 1 lesion (1.4 %) in the metaphysis and epiphysis.

Univariate analysis

Table 1 summarises the differentiating MRI features between low-grade chondral tumours and high-grade chondral tumours based on univariate analysis. Cortical thickening (Figs. 1a, 2a, b and 3a) was observed in 16 patients with high-grade CS (22 %) but in no patients with a low-grade chondral tumour. Cortical destruction (Figs. 3b, c and 4) was identified in 40 high-grade CS (56 %) but only in four cases of low-grade chondral tumours (4 %). Bone expansion (Figs. 4 and 5a, b) was seen in 39 high-grade CS (54 %) and in nine low-grade chondral tumours (8 %). Active periostitis (Fig. 5b, c) was observed in 35 high-grade CS (49 %) but only in one low-grade chondral lesion (1 %). Reactive bone marrow oedema

Table 1 MRI-features distinguishing low-grade chondroid tumours and high-grade CS based on univariate analysis

MRI feature	Low-grade chondral tumour ($n=107$)	High-grade CS ($n=72$)	*P* value [a]
Cortical thickening	0 (0 %)	16 (22 %)	<0.001
Cortical destruction	4 (4 %)	40 (56 %)	<0.001
Bone expansion	9 (8 %)	39 (54 %)	<0.001
Active periostitis	1 (1 %)	35 (49 %)	<0.001
Reactive bone marrow oedema	12 (11 %)	26 (36 %)	<0.001
Reactive soft tissue oedema	3 (3 %)	39 (54 %)	<0.001
Soft tissue mass	3 (3 %)	39 (54 %)	<0.001
Intraosseous tumour extent (cm)	5.5 cm (SD 2.4)	11.8 cm (SD 6.1)	<0.001

[a] *P* values are for comparison of low-grade chondroid tumours and high-grade CS using Fisher's exact test for dichotomous values and *t*-test for continuous variables

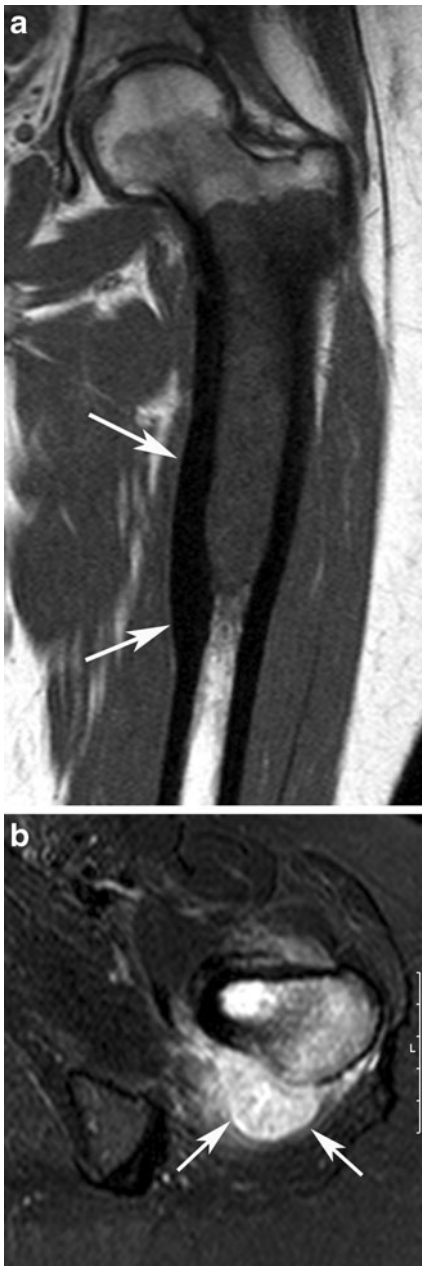

Fig. 1 A 50-year-old female patient with a grade 2 CS of the left proximal femur. **a** Coronal T1W SE MR image showing thickening of the femoral cortex (*arrows*) around the lesion. **b** Axial fat suppressed T2W FSE MR image showing extra-osseous tumour extension (*arrows*). Figure reproduced with kind permission from Douis H, Saifuddin A (2013) Skeletal Radiol 42:611-626

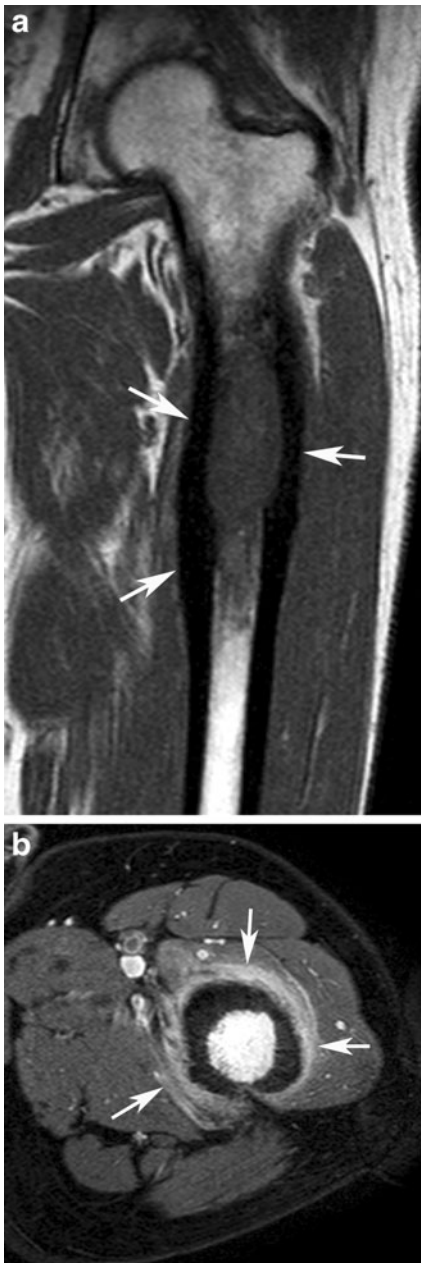

Fig. 2 A 68-year-old male patient with a grade 2 CS of the left proximal femur. **a** Coronal T1W SE MR image showing thickening of the femoral cortex (*arrows*) around the lesion and surrounding bone marrow oedema. **b** Axial fat suppressed T2W FSE MR image showing surrounding soft tissue oedema (*arrows*)

(Fig. 3c) was identified in 26 high-grade CS (36 %) and in 12 low-grade chondral lesions (11 %). Reactive soft tissue oedema (Fig. 2b) and soft tissue extension (Figs. 1b, 3b, c and 4) were observed in 39 high-grade CS (54 %) but only in three low-grade chondral tumours (3 %). Using Fisher's exact test, all of the MRI-findings evaluated above were statistically significant ($P<0.001$). Furthermore, the mean tumour length (Fig. 6) of high-grade CS was 11.8 cm (SD 6.1), whilst the mean length of low-grade chondral tumours was 5.5 cm (SD 2.4). Statistical analysis using the *t*-test for correlation of tumour length and high-grade CS revealed that this finding was statistically significant ($P<0.001$).

The odds ratios for each MRI feature favouring the diagnosis of a high-grade CS over a low-grade chondral tumour on the basis of the univariate analysis are detailed in Table 2. On univariate analysis, all of the evaluated MRI features (cortical destruction, bone expansion, active periostitis, reactive bone

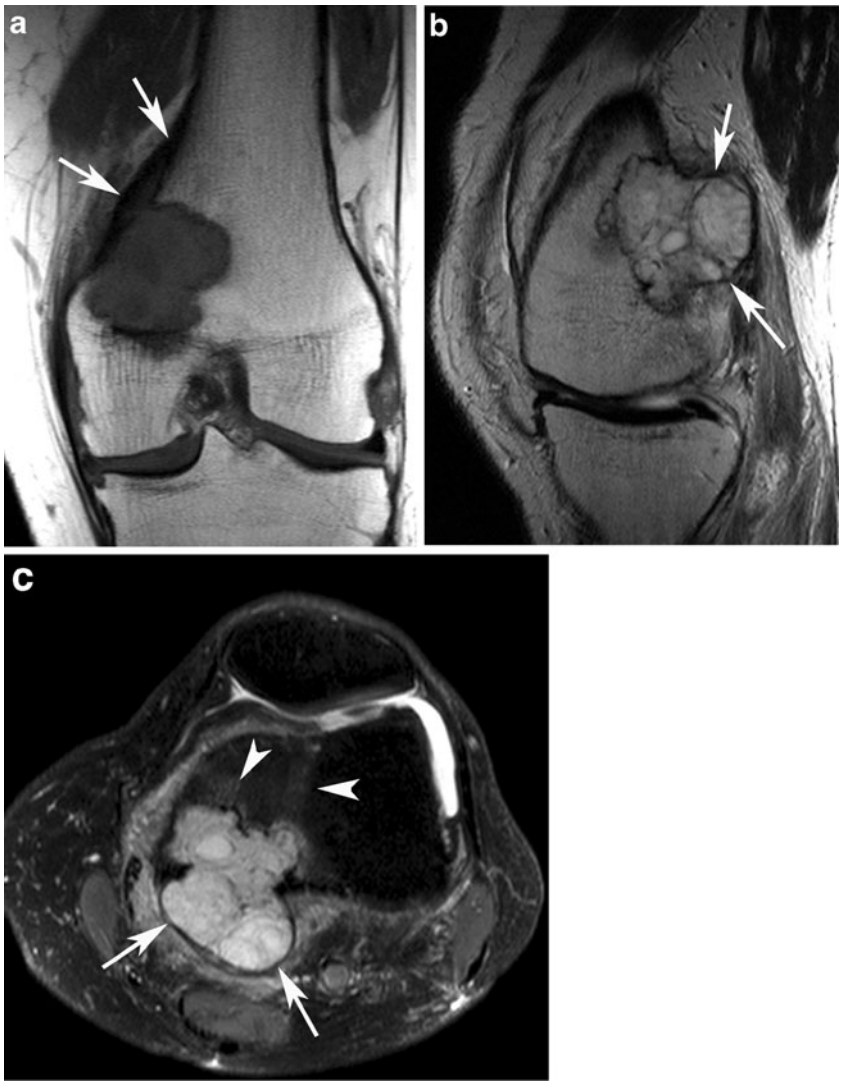

Fig. 3 A 72-year-old female patient with a grade 2 CS of the right distal femur. **a** Coronal T1W SE MR image showing thickening of the femoral cortex (*arrows*) adjacent to the lesion. **b** Sagittal T2W FSE MR image showing cortical destruction and extra-osseous tumour extension (*arrows*). **c** Axial fat suppressed T2W FSE MR image showing mild tumour related reactive marrow oedema-like SI (*arrowheads*) and extra-osseous tumour extension (*arrows*). Figure reproduced with kind permission from Douis H, Saifuddin A (2013) Skeletal Radiol 42:611-626

marrow oedema, reactive soft tissue oedema, soft tissue extension and intraosseous extent of the lesion) favoured a diagnosis of high-grade CS.

Multivariate analysis

Table 3 demonstrates the differentiating features between low-grade chondral tumours and high-grade CS based on multivariate analysis. Although on univariate analysis, all of the evaluated MRI features were statistically significant, the multivariate analysis showed certain differences. On multivariate analysis, only bone expansion, active periostitis, the presence of a soft tissue mass and the intraosseous extent of the tumour were statistically significant. The results of the ROC curve analysis demonstrated that the presence of bone expansion, active periostitis, soft tissue mass and the intraosseous extent of the tumour yielded a diagnostic accuracy (AUC) of 95.6 % (Fig. 7).

Discussion

The differentiation of low-grade chondral tumours from high-grade CSs is challenging based on imaging and histology [9]. Although there has been great emphasis in the literature on the differentiation of enchondromas, atypical chondral tumours and low-grade CSs, these tumours may be treated with the same management strategy, either careful clinical/imaging follow-up or intralesional curettage and cement installation [9, 10, 21–25]. In contrast, differentiation of low-grade chondral tumours from high-grade CSs is crucial because the two tumour grades are treated differently [5–8]. The distinction between low-grade chondral tumours and high-grade CSs is therefore vital. Although biopsy is performed in chondral tumours when surgery is contemplated, tumour heterogeneity may result in sampling of the low-grade chondral component within a high-grade CS. Biopsy may thus result in

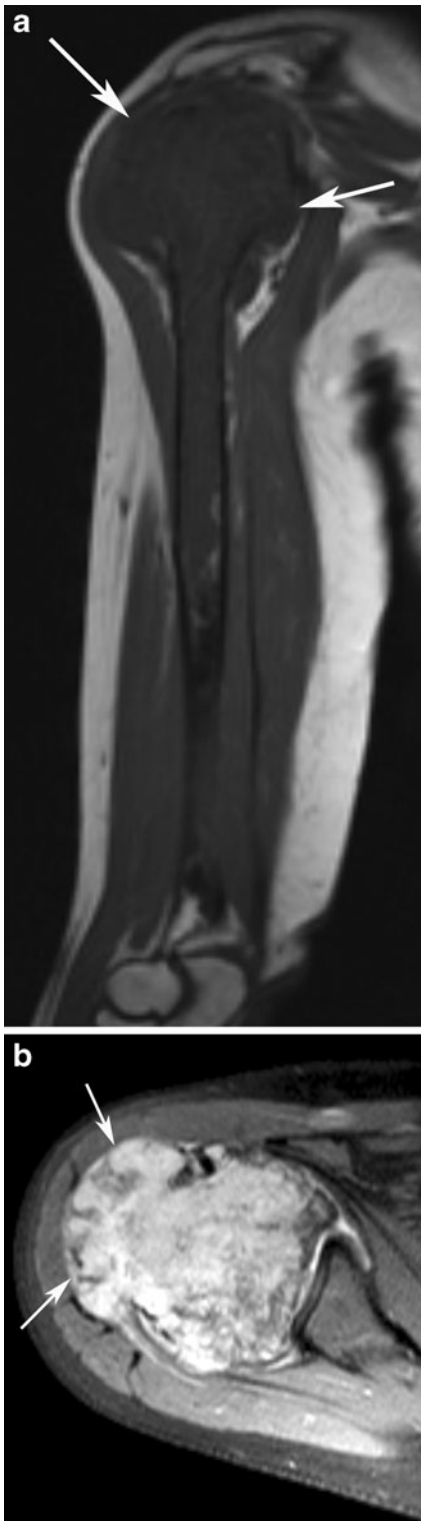

Fig. 4 A 35-year-old female patient with a grade 3 CS of the right humerus. **a** Coronal T1W SE MR image showing marked bone expansion (*arrows*). **b** Axial fat suppressed PDW FSE MR image showing cortical destruction and extra-osseous tumour extension (*arrows*)

erroneous downgrading of chondral tumours. This in turn may lead to inappropriate treatment of a high-grade CS with curettage, and thus may result in further surgery and increased morbidity.

Although, high-grade CSs are thought to demonstrate less extensive matrix mineralisation on radiography, this imaging finding [10] is subjective and not reliable. Furthermore, moth-eaten and permeative bone lysis, which are features of more aggressive lesions, are more frequently associated with mesenchymal, myxoid and dedifferentiated CS than with higher-grade conventional CS [10]. Similarly, higher attenuation within high-grade CS on computed tomography which is thought to be due to reduced water content is not a reliable imaging feature in the differentiation of high-grade from low-grade CS. By comparison, MRI may be of additional value in the differentiation of low-grade chondral tumours and high-grade CS. To the best of our knowledge, only a few studies have evaluated the MRI features of low-grade chondral tumours and high-grade CS. However, these studies included small sample sizes and only assessed a few features that are associated with malignancy in chondral lesions [12–17]. In our study, we attempted to report the MRI features which might differentiate low-grade chondral tumours from high-grade CS of the major long bones in a large patient cohort. We evaluated the presence of bone marrow oedema, soft tissue oedema, bone expansion, cortical thickening, cortical destruction, active periostitis, soft tissue mass and documented the maximum length of the tumour on MRI. We did not investigate septal enhancement because the vast majority of our patients did not undergo contrast-enhanced MRI. Although all of the evaluated features differentiated low-grade chondral tumours from high-grade CS on univariate analysis, bone marrow oedema, soft tissue oedema, cortical thickening and cortical destruction lost their significance on multivariate analysis. Only bone expansion, active periostitis, soft tissue mass and the maximum intraosseous length of the tumour were able to differentiate between low-grade chondral tumours and high-grade CS based on multivariate stepwise logistic regression analysis. The presence of a soft tissue mass has previously been demonstrated to differentiate low-grade from high-grade CS by Yoo et al. [12]. Our results, therefore, confirm this finding. However, the presence of bone expansion, active periostitis and the length of the lesion as differentiating features between low-grade chondral tumours and high-grade CS have not been previously investigated. Of particular interest is that in our study tumour length was an important discriminating factor between low-grade chondral tumours and high-grade CS. In our study, the mean tumour length for atypical chondral tumours/grade 1 CS was 5.5 cm, whilst the mean tumour length for high-grade CS was 11.4 cm. Similarly, tumour length is a widely used imaging feature to differentiate enchondromas from CS [10]. Therefore, increasing tumour length may be a reflection of tumourigenesis in chondral tumours. Furthermore, both bone expansion and active periostitis may reflect the increasing biological aggressiveness of high-grade CS. In contrast, bone marrow oedema, soft tissue oedema, cortical thickening and cortical

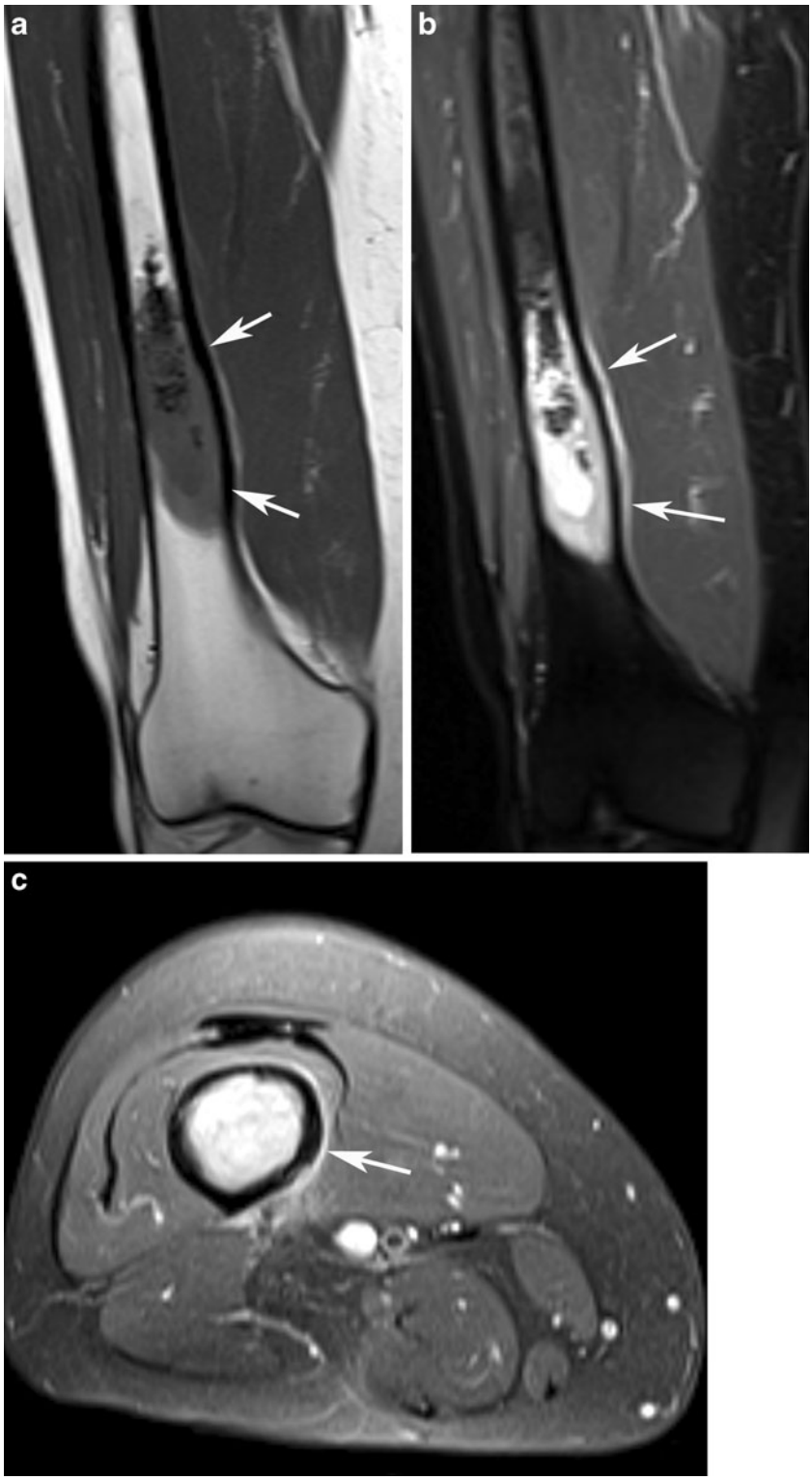

Fig. 5 A 59-year-old female patient with a dedifferentiated CS of the right distal femur. **a** Coronal T1W SE MR image showing mild expansion of the medial femoral cortex (*arrows*). **b** Coronal STIR and **c** axial fat suppressed T2W FSE MR images showing active periostitis (*arrows*)

destruction were not found to be significant in the differentiation of low-grade chondroid tumours from high-grade CS on multivariate analysis. This is partially contrary to a previous study by Janzen et al. [16] which observed that soft tissue oedema was more common in high-grade CS. This study, however, only included 13 CSs, of which only two were high-grade CS of long bones. Although, cortical thickening and cortical destruction have been found to be able to differentiate enchondromas from CS [10], our study did not demonstrate on multivariate analysis that these features could be used to differentiate atypical

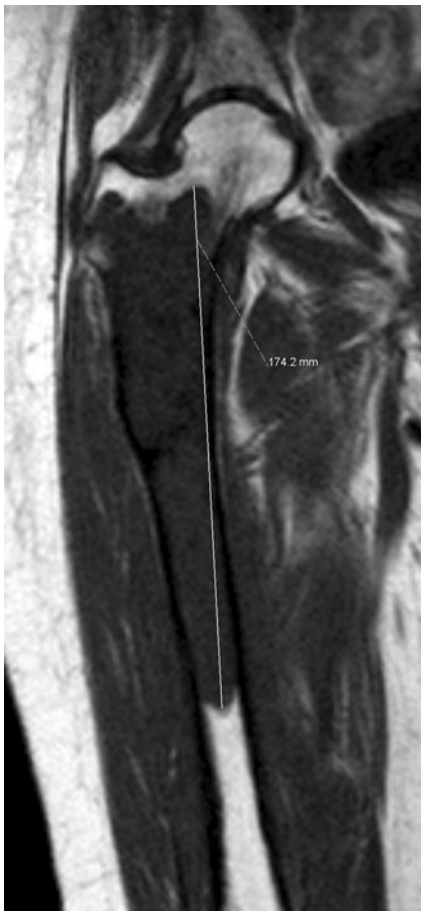

Fig. 6 A 67-year-old female patient with a dedifferentiated CS of the right proximal femur. Coronal T1W SE MR image showing intra-osseous tumour length of 17.4 cm

chondral tumours/low-grade CSs from high-grade CSs. ROC-curve analysis in our study demonstrated that the presence of bone expansion, active periostitis, soft tissue mass and tumour length accurately predict high-grade CS in 95.6 % of all cases.

There are several limitations to our study. Firstly, the retrospective nature of the study resulted in a non-standardised MRI protocol. However, to the best of our knowledge, there are no prospective studies which have evaluated MRI features in the differentiation of low-grade chondral tumours from high-grade CS. Secondly, due to the retrospective nature and because contrast-enhanced MRI is not routinely used in the evaluation of CS in our institution, we were not able to assess the role of contrast-enhanced MRI in the differentiation of high-grade from low-grade CS. Yoo et al. have previously investigated the role of contrast-enhanced MRI in the differentiation of high-grade from low-grade CS and found that large central non-enhancing areas were observed in 64 % of high-grade CSs, whilst this finding was only seen in 7.1 % of low-grade CSs. This finding, however,

Table 2 Odds ratios for MRI features which favour the diagnosis of high-grade CS over low-grade chondral tumour based on univariate analysis

MRI feature	Odds ratio	95 % confidence interval	*P* value
Cortical thickening	[a]	[a]	
Cortical destruction	32.2	10.7-96.9	<0.001
Bone expansion	12.9	5.6-29.4	<0.001
Active periostitis	100.3	13.3-757.9	<0.001
Reactive bone marrow oedema	4.5	2.1-9.7	<0.001
Reactive soft tissue oedema	41	11.9-141.3	<0.001
Soft tissue mass	41	11.9-141.3	<0.001
Intraosseous tumour extent (cm)	1.5	1.3-1.8	<0.001

[a] Omitted as the presence of cortical thickening was only observed in high-grade CS

Table 3 Odds ratios for MRI features favouring the diagnosis of high-grade CS over low-grade chondral tumour based on multivariate analysis

MRI feature	Odds ratio	95 % confidence interval	*P* value
Bone expansion	8.8	2.4-32.4	0.001
Active periostitis	52.8	5-562.2	0.001
Soft tissue mass	21.1	4-111.1	<0.001
Intraosseous tumour extent (cm)	1.4	1.2-1.7	<0.001

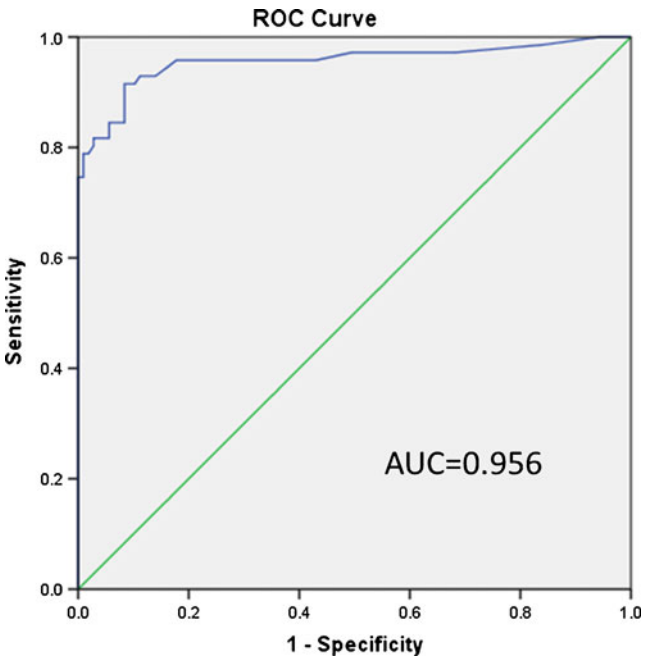

Fig. 7 ROC curve for the presence of bone expansion, active periostitis, soft tissue mass and the intraosseous tumour extent (cm). The overall accuracy for this model is specified by the area under the ROC curve (AUC) (in percentage), which is 95.6 %

was not significant on multivariate analysis [12]. Furthermore, the role of dynamic contrast-enhanced MRI in the differentiation of low-grade from high-grade CS remains elusive. Therefore, both the role of contrast-enhanced and dynamic contrast-enhanced MRI in differentiating low-grade from high-grade CS should be further evaluated in large prospective studies.

Furthermore, owing to the tertiary nature of our hospital, our patient cohort may have consisted of a relatively higher number of high-grade CSs than is usually observed in other series. This may have led to a selection bias. Finally, both the differentiation of enchondromas from low-grade CS and the grading of CS demonstrate low reliability even among specialised pathologists [9, 22]. The difficulty in differentiating enchondromas from low-grade CS is reflected in our study by the fact that we observed 28 atypical chondral tumours. However, all chondral tumours at our institution are reviewed by two musculoskeletal pathologists and the diagnosis of benign versus malignant chondral tumours is made in consensus with radiologists, pathologists and clinicians. Therefore, this multidisciplinary approach has likely resulted in decreased interobserver variability.

In summary, we have identified several MRI features which allow the accurate differentiation of low-grade chondral tumours from high-grade CS of the major long bones. These are the presence of bone expansion, active periostitis, soft tissue mass and tumour length. These imaging findings accurately predict the presence of high-grade CS. Therefore, MRI can reliably be used in the differentiation of low-grade chondral tumours from high-grade CS of the major long bones, thereby potentially avoiding inadequate surgery.

Akcnowledgment The images of the patients in Figs. 1 and 3 have been previously published by us in the following article: The imaging of cartilaginous bone tumours. II. Chondrosarcoma. Douis H, Saifuddin A. Skeletal Radiol. 2013 May;42(5):611-26

We have to emphasize however that the images are not exactly the same and that we either used a different slice position or a different MRI-sequence. Therefore, these exact images have not been previously published. We have nevertheless obtained permission from the publisher Springer to reprint the images.

References

1. Hogendoorn PCW, Bovee JM, Nielsen GP (2013) Chondrosarcoma (grades I-III), including primary and secondary variants and periosteal chondrosarcoma. In: Fletcher CDM, Bridge JA, Hogendoorn PCW, Mertens F (eds) World Health Organization Classification of Tumours of Soft Tissue and Bone. IARC Press, Lyon, pp 264–268
2. Inwards CHP (2013) In: Fletcher CDM, Bridge JA, Hogendoorn PCW, Mertens F (eds) World Health Organization Classification of Tumours of Soft Tissue and Bone. IARC Press, Lyon, pp 269–270
3. Grimer RJ, Carter SR, Tillman RM, Mangham DC, Abudu A, Fiorenza F (2000) Chondrosarcoma of bone. J Bone Joint Surg Am 82-A:1203–1204
4. Lee FY, Mankin HJ, Fondren G et al (1999) Chondrosarcoma of bone: an assessment of outcome. J Bone Joint Surg Am 81:326–338
5. Campanacci DA, Scoccianti G, Franchi A et al (2013) Surgical treatment of central grade 1 chondrosarcoma of the appendicular skeleton. J Orthop Traumatol 14:101–107
6. Donati D, Colangeli S, Colangeli M, Di Bella C, Bertoni F (2010) Surgical treatment of grade I central chondrosarcoma. Clin Orthop Relat Res 468:581–589
7. Hanna SA, Whittingham-Jones P, Sewell MD et al (2009) Outcome of intralesional curettage for low-grade chondrosarcoma of long bones. Eur J Surg Oncol 35:1343–1347
8. Verdegaal SH, Brouwers HF, van Zwet EW, Hogendoorn PC, Taminiau AH (2012) Low-grade chondrosarcoma of long bones treated with intralesional curettage followed by application of phenol, ethanol, and bone-grafting. J Bone Joint Surg Am 94:1201–1207
9. Skeletal Lesions Interobserver Correlation among Expert Diagnosticians (SLICED) Study Group (2007) Reliability of histopathologic and radiologic grading of cartilaginous neoplasms in long bones. J Bone Joint Surg Am 89:2113–2123
10. Murphey MD, Walker EA, Wilson AJ, Kransdorf MJ, Temple HT, Gannon FH (2003) From the archives of the AFIP: imaging of primary chondrosarcoma: radiologic-pathologic correlation. Radiographics 23:1245–1278
11. Hudson TM, Chew FS, Manaster BJ (1982) Radionuclide bone scanning of medullary chondrosarcoma. AJR Am J Roentgenol 139:1071–1076
12. Yoo HJ, Hong SH, Choi JY et al (2009) Differentiating high-grade from low-grade chondrosarcoma with MR imaging. Eur Radiol 19: 3008–3014
13. De Beuckeleer LH, De Schepper AM, Ramon F (1996) Magnetic resonance imaging of cartilaginous tumors: is it useful or necessary? Skeletal Radiol 25:137–141
14. Geirnaerdt MJ, Bloem JL, Eulderink F, Hogendoorn PC, Taminiau AH (1993) Cartilaginous tumors: correlation of gadolinium-enhanced MR imaging and histopathologic findings. Radiology 186:813–817
15. De Beuckeleer LH, De Schepper AM, Ramon F, Somville J (1995) Magnetic resonance imaging of cartilaginous tumors: a retrospective study of 79 patients. Eur J Radiol 21:34–40
16. Janzen L, Logan PM, O'Connell JX, Connell DG, Munk PL (1997) Intramedullary chondroid tumors of bone: correlation of abnormal peritumoral marrow and soft-tissue MRI signal with tumor type. Skeletal Radiol 26:100–106
17. Varma DG, Ayala AG, Carrasco CH, Guo SQ, Kumar R, Edeiken J (1992) Chondrosarcoma: MR imaging with pathologic correlation. Radiographics 12:687–704
18. Evans HL, Ayala AG, Romsdahl MM (1977) Prognostic factors in chondrosarcoma of bone: a clinicopathologic analysis with emphasis on histologic grading. Cancer 40:818–831
19. Dahlin DC, Beabout JW (1971) Dedifferentiation of low-grade chondrosarcomas. Cancer 28:461–466
20. Enneking WF (1986) A system of staging musculoskeletal neoplasms. Clin Orthop Relat Res 204:9–24
21. Douis H, Saifuddin A (2012) The imaging of cartilaginous bone tumours. I. Benign lesions. Skeletal Radiol 41:1195–1212
22. Eefting D, Schrage YM, Geirnaerdt MJ et al (2009) Assessment of interobserver variability and histologic parameters to improve reliability in classification and grading of central cartilaginous tumors. Am J Surg Pathol 33:50–57
23. Geirnaerdt MJ, Hermans J, Bloem JL et al (1997) Usefulness of radiography in differentiating enchondroma from central grade 1 chondrosarcoma. AJR Am J Roentgenol 169:1097–1104
24. Geirnaerdt MJ, Hogendoorn PC, Bloem JL, Taminiau AH, van der Woude HJ (2000) Cartilaginous tumors: fast contrast-enhanced MR imaging. Radiology 214:539–546
25. Weiner SD (2004) Enchondroma and chondrosarcoma of bone: clinical, radiologic, and histologic differentiation. Instr Course Lect 53: 645–649