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Optimal Magnetic Resonance Sequence for Assessment of Central Cartilage Tumor Scalloping

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Abstract

Background Magnetic resonance imaging (MRI) is key in evaluating central cartilage tumors. The BACTIP (Birmingham Atypical Cartilaginous Tumour Imaging Protocol) protocol assesses central cartilage tumor risk based on the tumor size and degree of endosteal scalloping on MRI. It provides a management protocol for assessment, follow-up, or referral of central cartilage tumors.

Objective Our study compared four MRI sequences: T1-weighted (T1-w), fluid sensitive (Short Tau Inversion Recovery (STIR)- weighted, STIR-w), and grayscale inversions (T1-w GSI and short tau inversion recovery [STIR] GSI) to see how reliably endosteal scalloping was detected.

Materials and Methods Two senior consultant musculoskeletal radiologists with experience reviewed randomly selected 60 representative central cartilage tumor cases with varying degree of endosteal scalloping to reflect a spectrum of BACTIP pathologies. The endosteal scalloping was graded as per the definition of BACTIP A, B, and C. They agreed on a consensus BACTIP grade for each of the 240 key images (60 cases × 4 sequences), which was considered the final “consensus” BACTIP grade. These 240 images were then randomized into a test set and given to two fellowship-trained consultant musculoskeletal radiologists for analysis. They assigned a BACTIP grade to each of the 240 selected images while being blinded to the final “consensus” BACTIP grade. The training set was further subdivided into three groups based on the MR image quality (good quality, average quality, and poor quality) to ascertain if the quality of the acquired images influenced intraobserver and interobserver agreements on the BACTIP grading. The two observers were blinded to the grade assigned to the image quality.

Results Linearly weighted kappa analysis was performed to measure the agreement between the BACTIP grading answers by two observers and the “consensus” BACTIP grading answers, as well as the BACTIP grading agreement between the two observers themselves.

The analysis revealed that T1-w and STIR-w sequences demonstrated more consistent and higher agreement across different image qualities. However, the T1-w GSI and

Keywords

- ► BACTIP
- ► endosteal scalloping
- ► MRI
- ► GSI
- ► central cartilage tumor
- ► chondrosarcoma

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STIR-w GSI sequences exhibited lower agreement, particularly for poor-quality images. T1-w imaging demonstrated substantial agreement between BACTIP gradings for poor-quality images, suggesting potential resilience of T1-w sequence in challenging imaging conditions.

Conclusion T1-w imaging is the best sequence for BACTIP grading of endosteal scalloping, followed by fluid-sensitive STIR sequences.

Introduction

Intraosseous central cartilage tumors pose a significant challenge in the field of musculoskeletal radiology due to difficulty in differentiating entirely benign lesions from low-grade malignant lesions, as well as high-grade lesions from low-grade lesions. Excision of these tumors is often complicated with significant morbidity potential and so it is crucial to accurately risk stratify these lesions. A key predictor of malignant lesions is significant endosteal scalloping. The assessment of tumor margins is hence crucial for determining the aggressiveness of the disease, its extent, planning treatment strategies, and predicting patient outcomes. Magnetic resonance imaging (MRI) has emerged as a valuable tool in this regard, offering superior soft-tissue contrast and multiplanar imaging capabilities.[1]

With the widespread availability of MRI, the apparent incidence of central cartilage tumors has increased. BACTIP (Birmingham Atypical Cartilaginous Tumour Imaging Protocol), which assesses cartilage tumor risk based on the size and extent of endosteal scalloping on MR images, provides a pragmatic imaging management protocol, which defines criteria for the assessment of, following up, or referral of central cartilage tumors (►**Figs. 1**–**2**).[1] The BACTIP protocol has been adopted with and without minor modifications by many United Kingdom–based tertiary referral oncology/sarcoma centers and cited in several recent publications.[2–10] By integrating BACTIP into routine practice, general radiologists can improve their diagnostic accuracy, optimize patient management, and contribute to better clinical outcomes for patients with cartilage tumors (►**Fig. 3**). BACTIP.co.uk is revolutionizing the way cartilage tumors are diagnosed and managed by offering a comprehensive, user-friendly platform that supports health care professionals in navigating the complexities of cartilage tumors imaging.[11]

Images are typically displayed in grayscale, which radiologists are trained to interpret. Grayscale inversion (GSI) is a simple tool available in most image viewers and Picture Archiving and Communication System (PACS), making it easy to obtain inverted images.[12] Inversion images in some

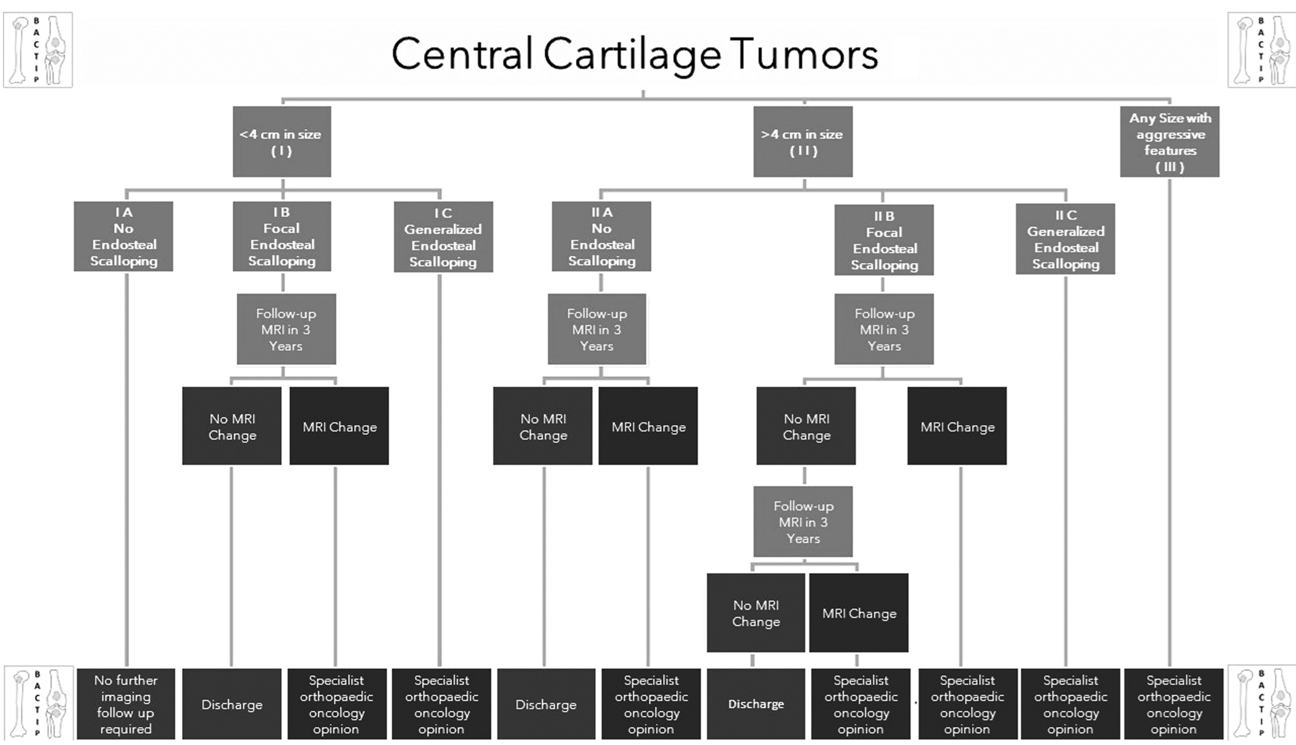

Fig. 1 Illustration showing the BACTIP (Birmingham Atypical Cartilaginous Tumour Imaging Protocol) categories and how to do measurements. MRI, magnetic resonance imaging.

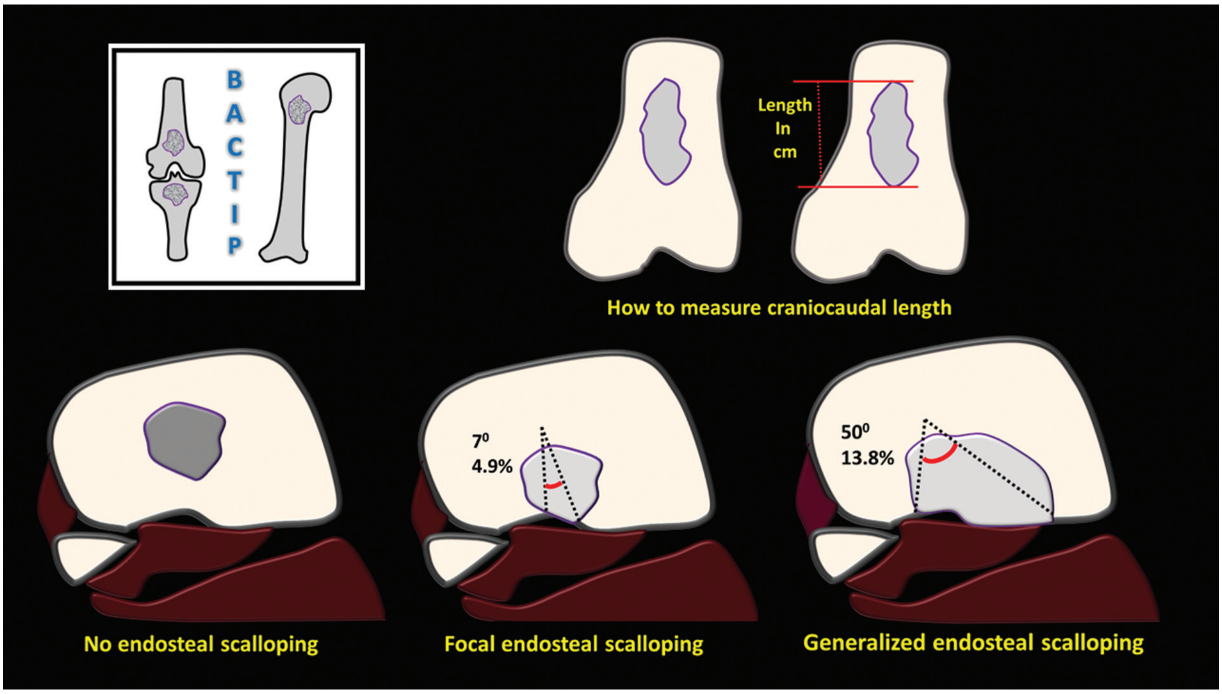

Fig. 2 The BACTIP (Birmingham Atypical Cartilaginous Tumour Imaging Protocol) flowchart.

newer sequences, such as T1 volumetric interpolated breath-hold examination (VIBE), have been found to provide additional inputs compared with grayscale images, allowing for the delineation of osseous anatomy better than grayscale images with almost the same accuracy as a computed tomography (CT) scan.[13]

>This study aimed to compare the detection accuracy of endosteal scalloping on four MRI sequences: T1-weighted (T1-w), fluid-sensitive (STIR-w), and GSIs (T1-w GSI and STIR-w GSI). T1-w sequences provides excellent anatomical detail and fat contrast; they are essential for initial assessment and detecting intralesional fat. Short tau inversion recovery (STIR) sequences are highly sensitive to fluid and edema, and they help in the detection of inflammatory changes and soft-tissue involvement. T1-w GSI is thought to enhance the image contrast for better visualization of

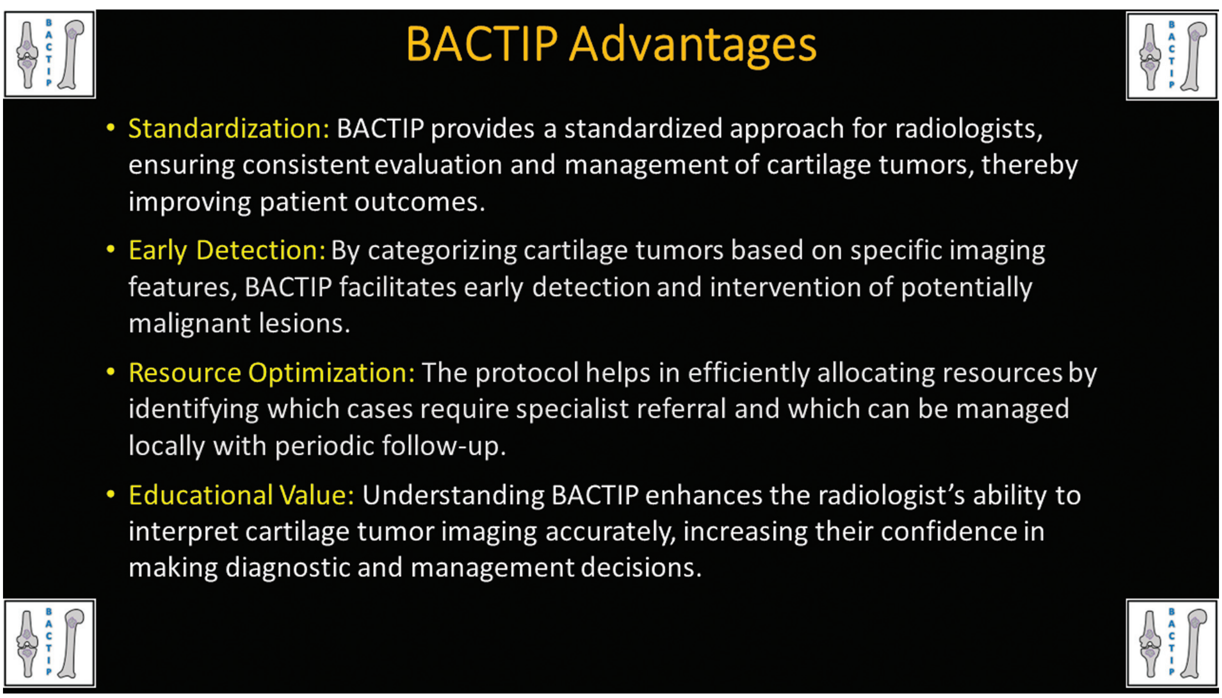

Fig. 3 Advantages of the BACTIP (Birmingham Atypical Cartilaginous Tumour Imaging Protocol).

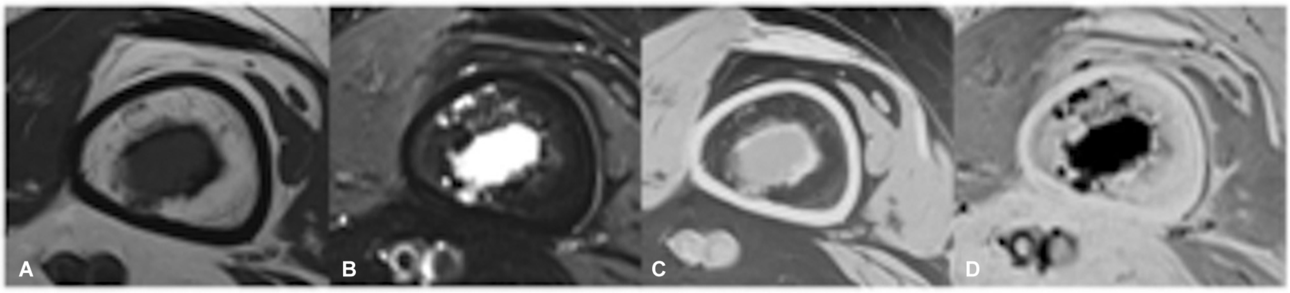

Fig. 4 (**A**) Axial T1, (**B**) short tau inversion recovery (STIR), (**C**) T1 inversion, and (**D**) STIR inversion showing central cartilage tumor without endosteal scalloping (BACTIP A).

tumor margins and subtle soft tissue changes. STIR-w GSI is thought to combine the benefits of high fluid sensitivity and enhanced image contrast for a comprehensive assessment of both the tumor and surrounding tissues. The study aimed to compare the level of agreement between the radiologists' BACTIP grading and the gold standard BACTIP grading on the above four sequences. It will also highlight any significant differences observed in the performance of the MRI sequences in detecting different grades of tumor invasions.

Materials and Methods

Study Design

Two senior consultant musculoskeletal radiologists with decades of experience performed a retrospective search of our tertiary orthopaedic oncology institute's oncology and radiology database (radiology information system [RIS], PACS, and computerized radiology information system (CRIS) for the keyword "BACTIP " "central cartilage tumours" and selected 60 representative cases (20 BACTIP A, 20 BACTIP B, and 20 BACTIP C) to reflect a spectrum of BACTIP pathologies.

Endosteal scalloping was graded as BACTIP A, B, and C as per the following definitions: BACTIP A cases showed no endosteal scalloping. BACTIP B (focal endosteal scalloping) cases involve less than 10% of the lesion's circumference, equating to an angle of less than 36 degrees. In comparison, BACTIP C (generalized endosteal scalloping) cases involved 10% or more, equating to an angle of 36 degrees or more (►**Fig. 1**). This is calculated by superimposing a circle of best fit around the edge of the bone and drawing lines from the edges of the scalloped endosteum to the center of the circle. The individual percentages are added together if normal bone separates multiple scalloping areas.[14]

The most representative single-key axial image demonstrating maximum endosteal scalloping was selected from four sequences (T1-w, fluid-sensitive [STIR-w], and GSIs [T1-w GSI and STIR-w GSI]), resulting in a set of 240 images in total (►**Figs. 4–6**). The two principal reviewers agreed on a consensus BACTIP grade for each of the 60 key images, which

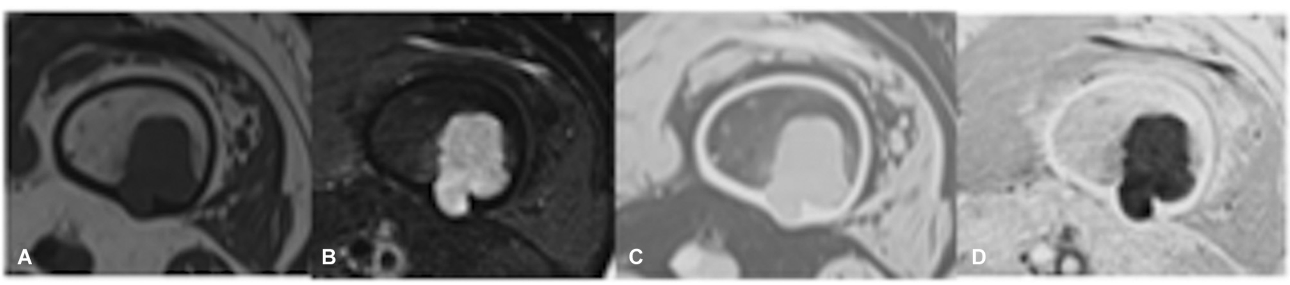

Fig. 5 (**A**) Axial T1, (**B**) short tau inversion recovery (STIR), (**C**) T1 inversion, and (**D**) STIR inversion showing central cartilage tumor with focal endosteal scalloping (BACTIP B).

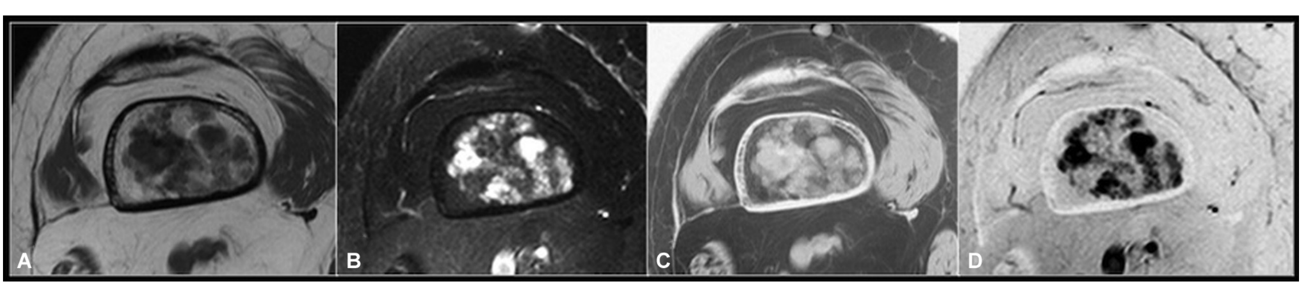

Fig. 6 (**A**) Axial T1, (**B**) short tau inversion recovery (STIR, (**C**) T1 inversion, and (**D**) STIR inversion showing central cartilage tumor with generalized endosteal scalloping (BACTIP C).

Table 1 Showing the kappa analysis reference values based on Landis and Koch (1977)

Kappa value interpretation
<0: no agreement
0–0.20: slight
0.21–0.40: fair
0.41–0.60: moderate
0.61–0.80: substantial
0.81–1.0: perfect

Abbreviations: BACTIP, Birmingham Atypical Cartilaginous Tumour Imaging Protocol; GSI, grayscale inversion; STIR, short tau inversion recovery; T1-w, T1-weighted.

was considered the final "consensus" BACTIP grade. The 240 images were randomized in order, and a training set was created.

The training set was given to two fellowship-trained consultant musculoskeletal radiologists with a combined orthopaedic oncology experience (observer 1 and observer 2) of greater than 10 years for analysis. They were blinded to the final "consensus" BACTIP grade. They reviewed the 240 selected images and assigned a BACTIP grade to each image.

The training set was further divided into three sets of images (good quality, average quality, and poor quality) depending on the MR image quality to ascertain if the quality of the acquired images influenced intraobserver and interobserver agreements on the BACTIP grading. The two observers were blinded to the grade assigned to the image quality.

Results

A linearly weighted kappa analyses (Landis and Koch's [1977] scale; ►**Table 1**) between the BACTIP grading answers by the two observers and the "consensus" answers, as well as between the two observers revealed the following results.[15]

Analysis by imaging sequence (►**Table 2**):

- *T1-w imaging sequence*: The analysis shows moderate agreement (0.55–0.58) for overall, good-, and average-quality images, with substantial agreement (0.65) observed for poor-quality images. A fair to moderate agreement is noted between observer 1 and the consensus BACTIP grading, while observer 2 demonstrates fair to substantial agreement with the consensus BACTIP grading.
- *STIR-w imaging sequence*: Moderate agreement (0.48–0.42) is observed for overall and average-quality images, but only fair agreement (0.33) for good- and poor-quality images. Both observer 1 and observer 2 show fair agreement with the consensus BACTIP grading.
- *T1-w GSI imaging sequence*: Fair agreement (0.39–0.29) is noted for overall, good-, and average-quality images. Observer 1 shows slight to fair agreement with the consensus BACTIP grading, as does observer 2.
- *STIR-w GSI imaging sequence*: Moderate agreement (0.42–0.16) is observed for overall, good-, and average-quality images. Both observer 1 and observer 2 show fair to slight agreement with the consensus BACTIP grading.

Analysis by Image Quality

- *Good-quality images*: Moderate agreement is observed across all imaging sequences. Both observer 1 and observer 2 show fair to moderate agreement with the consensus BACTIP grading (►**Table 3**).
- *Average-quality images*: Moderate agreement is noted for T1-w, STIR-w, and T1-w GSI sequences, but only fair agreement for STIR-w GSI. Observer 1 shows slight to moderate agreement with the consensus BACTIP grading, while observer 2 shows slight to fair agreement (►**Table 4**).
- *Poor-quality images*: Substantial agreement is observed for T1-w and STIR-w sequences, but only fair agreement for T1-w GSI and STIR-w GSI. Observer 1 shows moderate to substantial agreement with the consensus BACTIP grading, while observer 2 shows fair to substantial agreement, except for STIR-w GSI where there is a lack of agreement (►**Table 5**).

In summary, the T1-w and STIR-w sequences demonstrate more consistent and higher agreement across different image quality strata. The T1-w GSI and STIR-w GSI sequences, on the other hand, exhibit lower agreement, particularly for poor-quality images.

Table 2 Showing the kappa analysis between the two observers BACTIP grading and the "consensus" BACTIP grading answers, as well as between the two observer's BACTIP gradings

Overall	Interobserver BACTIP grading	Observer 1 vs. consensus BACTIP grading	Observer 2 vs. consensus BACTIP grading
T1-w	0.55 (moderate)	0.38 (fair)	0.58 (moderate)
STIR-w	0.48 (moderate)	0.33 (fair)	0.29 (fair)
T1-w GSI	0.39 (fair)	0.20 (slight)	0.29 (fair)
STIR-w GSI	0.42 (moderate)	0.33 (fair)	0.16 (slight)

Abbreviations: BACTIP, Birmingham Atypical Cartilaginous Tumour Imaging Protocol; GSI, grayscale inversion; STIR, short tau inversion recovery; T1-w, T1-weighted.

Table 3 Showing the kappa analysis between interobserver, observer 1 versus consensus BACTIP grading and observer 2 versus consensus BACTIP grading for good-quality images

Good-quality images	Interobserver BACTIP grading	Observer 1 vs. consensus BACTIP grading	Observer 2 vs. consensus BACTIP grading
T1-w	0.51 (moderate)	0.32 (fair)	0.52 (moderate)
STIR-w	0.37 (fair)	0.29 (fair)	0.31 (fair)
T1-w GSI	0.49 (moderate)	0.24 (fair)	0.32 (fair)
STIR-w GSI	0.36 (fair)	0.29 (fair)	0.35 (fair)

Abbreviations: BACTIP, Birmingham Atypical Cartilaginous Tumour Imaging Protocol; GSI, grayscale inversion; STIR, short tau inversion recovery; T1-w, T1-weighted.

Table 4 Showing the kappa analysis between interobserver, observer 1 versus consensus BACTIP grading and observer 2 versus consensus BACTIP grading for average-quality images

Average-quality images	Interobserver BACTIP grading	Observer 1 vs. consensus BACTIP grading	Observer 2 vs. consensus BACTIP grading
T1-w	0.50 (moderate)	0.25 (fair)	0.44 (moderate)
STIR-w	0.46 (moderate)	0.28 (fair)	0.28 (fair)
T1-w GSI	0.41 (moderate)	0.07 (slight)	0.18 (slight)
STIR-w GSI	0.41 (moderate)	0.28 (fair)	0.23 (fair)

Abbreviations: BACTIP, Birmingham Atypical Cartilaginous Tumour Imaging Protocol; GSI, grayscale inversion; STIR, short tau inversion recovery; T1-w, T1-weighted.

Table 5 Showing the kappa analysis between interobserver, observer 1 versus consensus BACTIP grading and observer 2 versus consensus BACTIP grading for poor-quality images

Poor-quality images	Interobserver BACTIP grading	Observer 1 vs. consensus BACTIP grading	Observer 2 vs. consensus BACTIP grading
T1-w	0.65 (substantial)	0.59 (moderate)	0.66 (substantial)
STIR-w	0.55 (moderate)	0.34 (fair)	0.25 (fair)
T1-w GSI	0.15 (slight)	0.10 (slight)	0.30 (fair)
STIR-w GSI	0.46 (moderate)	0.34 (fair)	−0.13 (no agreement)

Abbreviations: BACTIP, Birmingham Atypical Cartilaginous Tumour Imaging Protocol; GSI, grayscale inversion; STIR, short tau inversion recovery; T1-w, T1-weighted.

Discussion

Our study provides valuable insights into interpreting endosteal scalloping of central cartilage tumor on four different sequences (T1-w, fluid-sensitive [STIR-w], T1-w GSI, and STIR-w GSI). There were variable levels of agreement across the four imaging sequences with T1-w and STIR-w sequences consistently demonstrating moderate agreement across all image qualities. However, the GSI images (T1-w GSI and STIR-w GSI) exhibited only fair to slight agreement, especially when the quality of the images was poor. Poor image quality appears to challenge the reliability of the BACTIP grading process, particularly in the T1-w GSI and STIR-w GSI sequences. However, T1-w imaging demonstrated substantial agreement between BACTIP gradings for poor-quality images suggesting potential resilience of T1-w sequence in challenging imaging conditions. Based on the findings, it is advisable to prioritize T1-w and STIR-w sequences when assessing endosteal scalloping, as these sequences consistently demonstrate moderate agreement. However, caution is warranted when relying on T1-w GSI and STIR-w GSI sequences, particularly in poor image quality scenarios. Optimizing the imaging protocols, exploring alternative imaging sequences or alternative imaging modalities like CT scan, could enhance reliability in these challenging conditions. Central cartilage tumors of bone vary from benign enchondromas to high-grade chondrosarcomas. Enchondroma is the second most common benign bone tumor, often found in the hands, feet, knee area, and proximal humerus. Its malignant counterpart, central chondrosarcoma, can be graded based on cellularity, mitosis, and cellular atypia. Distinguishing enchondromas from intermediate- and high-grade chondrosarcomas is relatively straightforward, but differentiating it from low-grade chondrosarcoma can be challenging both on imaging and histologically.[1] A widely accepted predictor of malignancy is increasing endosteal scalloping. The BACTIP is intended as a tool for radiologists to assess central cartilage tumors and determine cases appropriate for referral to specialist orthopaedic oncology units. For small tumors (<4 cm) with no endosteal scalloping, discharge is recommended. Tumors with focal endosteal scalloping are advised for a follow-up MRI after 3 years, recognizing that measurable changes may take time. Tumors with general endosteal scalloping, a rarity, merit a follow-up MRI at 1 year. Larger lesions (≥4 cm) without endosteal scalloping are recommended for a follow-up MRI after 3 years, while those with focal endosteal scalloping should undergo an earlier scan at 1 year. Lesions with general endosteal scalloping, possibly representing low-grade chondrosarcomas, should be referred to a specialist orthopaedic oncology unit. Referral is also advised for cases showing changes on subsequent MR images, defined as an increase in tumor length by 1 cm, increasing endosteal scalloping, or development of aggressive/malignant features.[1]

GSI imaging is a technique used in radiology to convert positive radiographic images into negative images. This method, also known as contrast inversion, GSI, or "bones black" imaging, is easily accessible and applicable across various imaging modalities such as CT, MRI, fluoroscopy, and radiographs. The science behind GSI is rooted in human perception, as the brain is wired to identify details better in a positive polarity contrast, where dark objects are against a light background. This positive polarity enhances the perception of details, particularly in radiological diagnosis, with studies showing better performance with decreasing object size compared with negative polarity.[16,17] The conversion technique is straightforward, requires no additional scanning time, hardware, or software, and should not add significant time to the reporting time. It can be performed with a single click on most PACS systems.[17] In MRI, GSI, particularly using 3D T1 VIBE sequences, has been found to be an excellent alternative to CT imaging, providing a quick diagnosis, better management, and patient satisfaction while avoiding ionizing radiation.[12,16,18]

Our study offers significant insights into the interpretation of endosteal scalloping of central cartilage tumors with T1-w and STIR-w sequences consistently demonstrating moderate BACTIP grading agreement across all image qualities. Poor-image quality seems to challenge the reliability of the BACTIP grading process, especially on the T1-w GSI and STIR-w GSI sequences. However, T1-w imaging demonstrates significant resilience for poor-quality images and is therefore recommended as the imaging sequence of choice while grading endosteal scalloping followed by fluid-sensitive STIR-w sequences.

Future Directions

Future studies should target exploration of specific image quality factors like presence of image noise or artifacts that contributed to the observed variances in BACTIP grading agreements. Refinement and standardization of tumor imaging protocols may also improve the reproducibility of BACTIP assessments.

Limitation

This is a retrospective study with imaging acquired at one institution. Future work should explore the impact of different scanners and protocols on interobserver agreement.

While the use of kappa statistics offers a quantifiable measure of agreement, they do not shed light on the underlying causes of grading discrepancies. Therefore, it is crucial to also consider qualitative measures such as image quality and variability due to factors such as image matrix size, field of view (FOV), the use of specific coils (dedicated extremity coils, body coils, or surface coil imaging coils), inhomogeneous fat suppression, and other image artifacts.

Conclusion

We recommend the assessment of endosteal scalloping on the T1W sequence as this results in greater interobserver agreement, which is likely to improve the consistency of patient management.

Funding
None.

Conflict of Interest
None declared.

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