Original Article

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Correlation of 3T Diffusion-weighted MRI and ^{18}F-FDG-PET/CT in Liver Metastases: SUV Versus ADC

Karaciğer Metastazlarında 3T Difüzyon Ağırlıklı MRG ve ^{18}F-FDG-PET/BT Korelasyonu: SUV'a Karşı ADC

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Abstract

Objectives: Positron emission tomography/computed tomography (PET/CT) and magnetic resonance imaging (MRI) are widely used in the diagnosis and follow-up of liver metastases. Both modalities provide anatomical and functional information and have advantages and disadvantages. The objective of this study was to investigate the correlation between apparent diffusion coefficient (ADC) and standardized uptake value (SUV) values in metastatic liver lesions.

Methods: Abdominal magnetic resonance (MR) scans performed between April 2021 and 2024 using the 3T MR scanner were retrospectively evaluated. Thirty-three patients with liver metastases, less than one month between magnetic resonance imaging (MRI) and PET/CT, no treatment during this period, and lesions larger than 1 cm were included in the study. In each MRI scan, an index lesion was selected for ADC measurement. The radiologist and nuclear medicine specialist measured the same index lesion without the patient being informed of the results.

Results: The mean age of the 33 patients was 59±12 years, with 17 (51%) men and 16 (49%) women. The mean size of the index lesions was 27±9 mm. In MRI, mean ADC_{min}: (0.54±0.2) $\times10^{-3}mm^2/s$; ADC_{mean}: (1.02±0.2) $\times10^{-3}mm^2/s$; ADC_{max}: (1.48±0.44) $\times10^{-3}mm^2/s$; and region of interest area was calculated as 6±4.6 cm^2. In PET/CT, mean SUV_{mean}: 5.8±3.3; SUV_{peak}: 6.8±4.3; SUV_{max}: 10.7±5.6; and metabolic tumor volume: 12.1 (7.4-20.7) cm^3. No statistically significant correlation was found between ADC and SUV values.

Conclusion: There was no correlation between ADC and SUV values in liver metastases. Prospective studies with a large patient group are needed.

Keywords: Liver neoplasms, diffusion magnetic resonance imaging, positron emission tomography computed tomography, apparent diffusion coefficient, standardized uptake value

Öz

Amaç: Pozitron emisyon tomografisi/bilgisayarlı tomografi (PET/BT) ve manyetik rezonans görüntüleme (MRG) karaciğer metastazlarının tanı ve takibinde yaygın olarak kullanılmaktadır. Anatomik ve fonksiyonel bilgi sağlayan her iki modalitenin de avantaj ve dezavantajları vardır. Bu çalışmanın amacı metastatik karaciğer lezyonlarında görünür difüzyon katsayısı (ADC) değerleri ile standardize uptake değeri (SUV) değerleri arasındaki korelasyonu araştırmaktır.

Yöntem: Nisan 2021 ve 2024 tarihleri arasında 3T MR cihazı kullanılarak gerçekleştirilen abdominal MR taramaları retrospektif olarak değerlendirilmiştir. Çalışmaya, karaciğer metastazı olan ve lezyonları 1 cm'den büyük olan 33 hasta dahil edildi. Bu hastalar, bir aydan kısa süre içinde MRG ve PET/BT taramalarından geçti ve bu süreçte herhangi bir tedavi almadı. Her MRG taramasında, ADC ölçümü için bir indeks lezyon seçildi. Radyolog ve nükleer tıp uzmanı, birbirlerinin sonuçlarından habersiz bir şekilde aynı indeks lezyon üzerinde ölçüm yaptı.

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Öz

Bulgular: Ortalama yaşı 59±12 olan 33 hastanın 17'si (%51) erkek, 16'sı (%49) kadındı. İndeks lezyonların ortalama boyutu 27±9 mm idi. MRG'de ortalama ADC_{min}: (0,54±0,2) $\times 10^{-3} mm^2/s$; ADC_{ort}: (1,02±0,2) $\times 10^{-3} mm^2/s$; ADC_{maks}: (1,48±0,44) $\times 10^{-3} mm^2/s$; ve ilgi alanı 6±4,6 cm^2 olarak hesaplandı. PET/BT'de ortalama SUVmean: 5,8±3,3; SUV_{pik}: 6,8±4,3; SUV_{maks}: 10,7±5,6; ve metabolik tümör hacmi: 12,1 (7,4-20,7) cm^3. ADC ve SUV değerleri arasında istatistiksel olarak anlamlı bir korelasyon bulunmadı.

Sonuç: Karaciğer metastazlarında ADC ve SUV arasında korelasyon bulunmamıştır. Geniş bir hasta grubuyla yapılacak prospektif çalışmalara ihtiyaç vardır.

Anahtar kelimeler: Karaciğer neoplazmları, difüzyon manyetik rezonans görüntüleme, pozitron emisyon tomografi bilgisayarlı tomografi, görünür difüzyon katsayısı, standardize uptake değeri

Introduction

The liver is the organ most frequently affected organ by metastases in the abdomen. For diagnosing and monitoring these lesions, magnetic resonance imaging (MRI) and ^{18}F-fluorodeoxyglucose (^{18}F-FDG) positron emission tomography/computed tomography (PET/CT) are commonly used imaging techniques. However, PET/CT has several disadvantages, including the exposure of patients to high radiation doses. Additionally, it involves complex preparation procedures for both patients and ^{18}F-FDG and requires long ^{18}F-FDG uptake and scanning times (1). Additionally, PET/CT scan is less sensitive than MRI for detecting liver lesions smaller than 1 cm (2). As a radiation-free alternative, MRI with diffusion-weighted imaging (DWI) sequences has been widely researched for its efficacy in oncological imaging (3), providing anatomical and functional data comparable to PET/CT.

Although apparent diffusion coefficient (ADC) values from DWI provide insights into tissue cellularity and organization, standardized uptake value (SUV) values from PET/CT reflect glucose metabolism (4). Numerous studies have explored the correlation between ADCs and SUVs, hypothesizing a link between the cellular density of malignancies and their glucose metabolism. Despite some variability in the results, most studies have shown a correlation between these two values (3,5,6). Although there has been research on this correlation in various tumor types, such as lung, breast and rectum, we have not found similar studies focusing specifically on liver metastases.

The aim of this study was to investigate the correlation between ADC and SUV values in metastatic liver lesions.

Materials and Methods

This study was approved by the Aydın Adnan Menderes University Rectorate Faculty of Medicine Dean's Office Non-Interventional Clinical Research Ethics Committee (approval no: 20, date: 13.06.2024). Informed consent was not obtained for this retrospective study.

Study Group and Design

All abdominal MRI scans performed between April 2021 and April 2024 using the 3T MRI scanner were evaluated retrospectively. From a total of 2543 examinations, 254 scans with a preliminary diagnosis of liver metastases were selected based on the following inclusion criteria:

Inclusion Criteria

1. The time between MRI and PET/CT should be 1 month.
2. There should be no artifacts in the lesion of interest on the ADC map, and the lesion should not be smaller than 1 cm.
3. There should be no follow-up patients with complete response to treatment.
4. No systemic or local treatment for malignancy should be provided between MRI and PET/CT.
5. Malignancy should be confirmed by histopathological examination.

A total of 33 patients who met the inclusion criteria were included in the study (Figure 1). Each MRI scan revealed one metastasis. In cases of multiple metastases, the most opacified lesion in the contrast-enhanced series, the lesion with the least or no cystic-necrotic component, and the largest lesion were selected as the index lesion. DWI and PET/CT measurements were performed on the same index lesion (Figures 2,3).

Index lesion size on MRI, liver segment, malignancy type, interval between MRI and PET-CT, patient age and sex, and new diagnosis or treatment follow-up were recorded. The correlation between ADC and SUV values was investigated in groups of all metastases, gastrointestinal metastases, and others, and new diagnosis and treatment response follow-up.

DWI and ADC

Images were acquired using a 3T MR scanner (GE Signa Pioneer, GE Healthcare, United States). For abdominal MRI, a body coil with a 30-channel anterior array and a

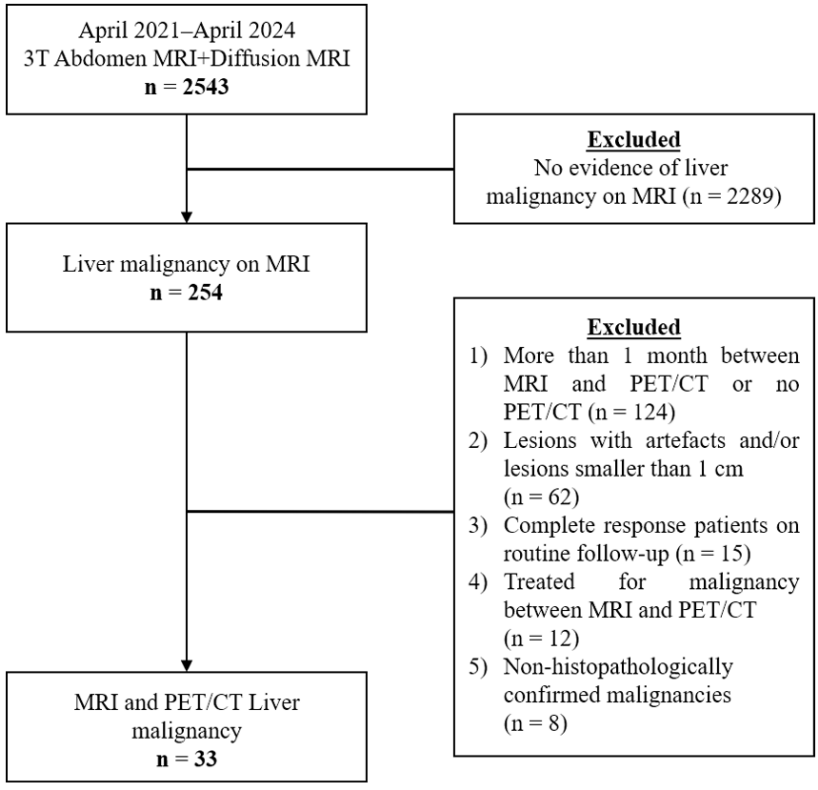

Figure 1. Flowchart showing the selection of the working group

MRI: Magnetic resonance imaging, PET/CT: Positron emission tomography/computed tomography

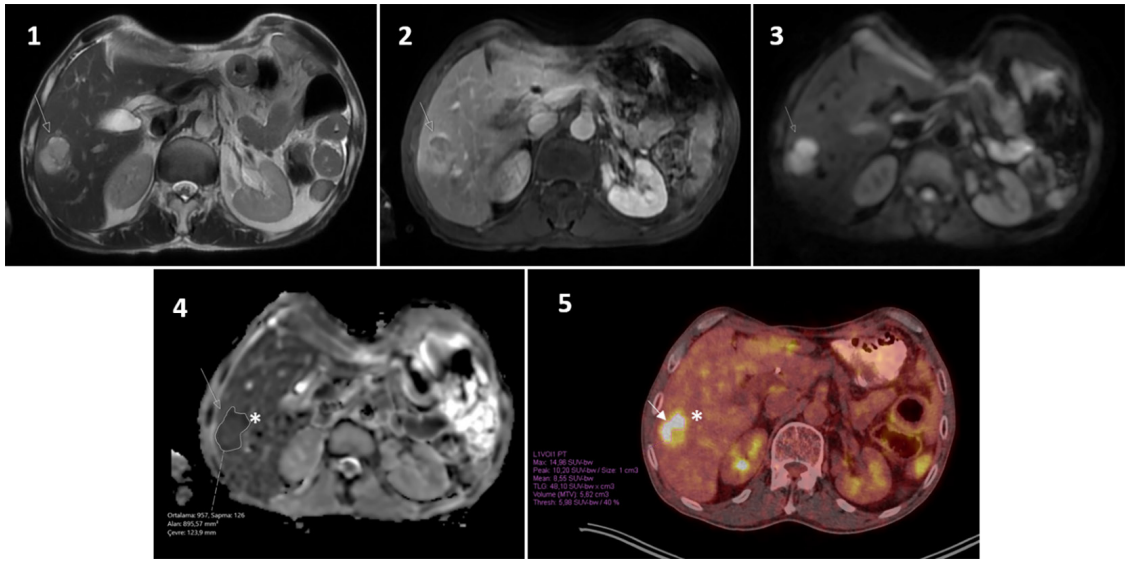

Figure 2. A 58-year-old male patient with metastatic gastric adenocarcinoma/systemic treatment response evaluation (MRI and PET/CT scans) 1–5) Axial T2, contrast-enhanced fat-suppressed T1, DWI, ADC, and PET/CT images from 1–5 show liver metastasis, respectively (white arrow). The 4th figure shows the ROI for the ADC measurement, and the 5th figure shows the VOI (volume of interest) for the SUV measurement (*). ADC_{min}: 0.68×10^{-3} mm^2/s, ADC_{mean}: 0.96×10^{-3} mm^2/s, ADC_{max}: 1.25×10^{-3} mm^2/s, SUV_{mean}: 8.6, SUV_{peak}: 10.2, SUV_{max}: 15 were calculated.

MRI: Magnetic resonance imaging, PET/CT: Positron emission tomography/computed tomography, ADC: Apparent diffusion coefficient, SUV: Standardized uptake value, DWI: Diffusion-weighted imaging, ROI: Region of interest

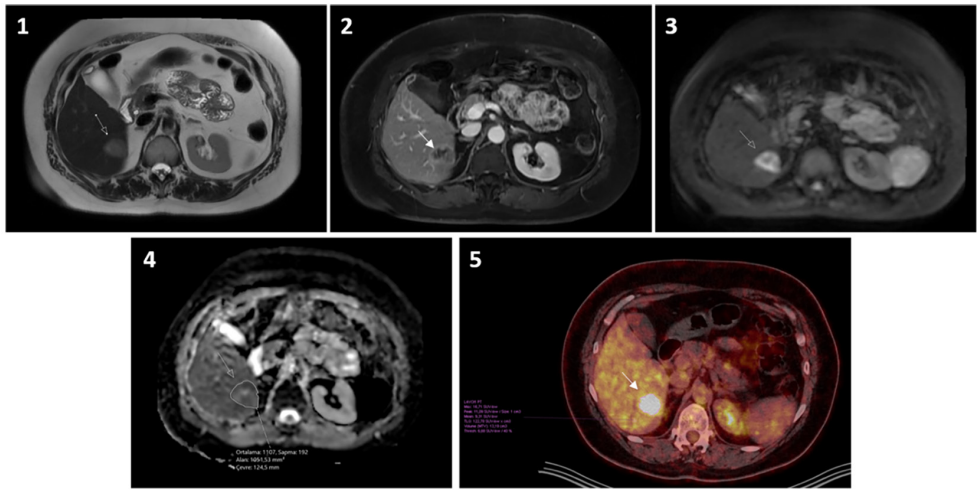

Figure 3. A 46-year-old woman with newly diagnosed metastatic ovarian cancer
(1-5) Axial T2, contrast-enhanced fat-suppressed T1, DWI, ADC, and PET/CT images from 1-5 show liver metastasis, respectively (white arrow). The 4th figure shows the ROI for the ADC measurement, and the 5th figure shows the VOI for the SUV measurement. ADC_{min}: 0.73×10^{-3} mm^2/s, ADC_{mean}: 1.10×10^{-3} mm^2/s, ADCmax: 1.79×10^{-3} mm^2/s, SUV_{mean}: 9.3, SUV_{Mean}: 11.1, SUV_{max}: 16.7 were calculated.

DWI: Diffusion-weighted imaging, ADC: Apparent diffusion coefficient, PET/CT: Positron emission tomography/computed tomography, ROI: Region of interest, SUV: Standardized uptake value

32-channel posterior array configuration was used. DWI was acquired using the echo planar imaging sequence with the following parameters: Echo time of 60-100 ms, repetition time of 4000-8000 ms, field of view of 240-460 mm, matrix size of 128×128, slice thickness of 5 mm with an interslice gap of 1 mm, and b-values of 0, 600, and 1000 s/mm². Before and after 180° pulses, a motion-probing gradient was applied to the DWI images along the x, y, and z axes. The ADC value for each pixel was then reconstructed using b-values of 0 and 1000 s/mm² with the standard software on the console.

Two experienced radiologists blinded to the PET/CT results performed ADC measurements and selected the index lesion to be measured. The region of interest (ROI) in the ADC map was manually drawn in the widest axial plane, avoiding borders at the periphery of the index lesion (7). The minimum, mean, and maximum ADC values of the ROI area were calculated automatically using the image software program (Sectra Workstation v. 24.2, Linköping, Sweden).

PET/CT and SUV

All PET/CT images were acquired using a Siemens scanner (Biograph mCT 20). The scan was performed when blood glucose was below 180 mg/dL after 6-8 hours of fasting. Patients rested in a quiet room after intravenous administration of 270-370 MBq ^{18}F-FDG. After a rest period of 60 min, imaging was performed from the base of the skull to the thigh. The CT transmission scan was acquired at 140 kVp and 110 mA with a slice thickness of 3 mm. The PET scan was acquired for 2-4 minutes per bed position.

An experienced nuclear medicine specialist who was blinded to the MRI findings evaluated the PET/CT scans and measured the SUV of the index lesion. Maximum, peak, and mean SUV and metabolic tumor volume (MTV) were calculated using image processing software (Syngo. via) with semi-automatic ROI drawing in selected index lesions.

Statistical Analysis

Statistical analysis were performed using the Statistical Package for the Social Sciences software (version 26.0, SPSS, Chicago, IL, USA). The Kolmogorov-Smirnov test was used to determine whether the data were suitable for normal distribution. Normally distributed data are expressed as mean ± standard deviation. The correlation between ADCs and SUVs was examined using Pearson's correlation test. A value of $p<0.05$ was considered statistically significant.

Results

The mean age of the 33 patients was 59±12 years; 17 (51%) patients were male and 16 (49%) were female. The mean size of the index lesion was 27±9 mm, and the most common liver sites were segments 6 (27%) and 7 (27%). The most common liver metastases were adenocarcinomas of the gastrointestinal tract (colon: 9, rectum: 5, stomach: 1, esophagus: 1) (49%). The remainder were metastases of the breast (5, 15%), pancreas (3, 9%), ovary (3, 9%),

cervix (2, 6%), bladder (2, 6%), and lung (2, 6%). A total of 30% of the metastases were newly identified, while 70% were followed up for response to treatment. The mean interval between MRI and PET/CT was 14±7 days (Table 1).

In DWI measurements, the mean ADC_{min}: (0.54±0.2) $\times10^{-3}mm^2/s$; ADC_{mean}: (1.02±0.2) $\times10^{-3}mm^2/s$; ADC_{max}: (1.48±0.44) $\times10^{-3}mm^2/s$; and ROI area were calculated as 6±4.6 cm^2. In PET/CT measurements, mean SUV_{mean}: 5.8±3.3; SUV_{peak}: 6.8±4.3; SUV_{max}: 10.7±5.6; and MTV (metabolic tumor volume): 12.1 (7.4-20.7) cm^3 (Table 1). No statistically significant correlation was observed between ADC and SUV measurements (Table 2).

Discussion

This study concluded that there was no significant correlation between ADC and SUV levels in liver metastases. However, in our study, the ADC and SUV values were individually supportive of malignancy (8,9). The ADC has long been used to diagnose and assess treatment response in malignant liver lesions (10,11). With recent advancements in PET/MRI technology, the use of ADC in routine clinical practice has become more widespread, and its correlation with SUV has been explored in several studies. One study involving 68 neoplastic lesions on PET/MRI found a weak correlation between ADC and SUV, suggesting that they may provide complementary information for evaluating treatment response (12). Similarly, another study involving 71 patients with head and neck cancer reported no correlation between ADC and SUV (13). However, in a different study of 56 patients with lymphoma and sarcoma, ADC and SUV were found to be 88% consistent in indicating treatment response (14). Although ADC and SUV are both valuable markers for assessing treatment response, there are inconsistencies in their correlation findings.

Increased glucose uptake with increased cell density requires decreased ADCs and increased SUVs, i.e., an inverse correlation. Previous studies have investigated the presence of this inverse correlation in different tumor types and reported different results. For example, three out of six studies investigating the correlation between SUV and ADC in breast cancer found no correlation between these two variables (15,16,17), whereas three studies found weak to moderate inverse correlations (6,18,19). Furthermore, no correlation was found between SUV max and ADC min in primary cervical cancer (20), whereas a strong inverse correlation was found between SUV max and mean ADC in rectal cancer (21).

There are several reasons for the results of our study. First, in the case of multiple metastases, the ADC and SUV values of the selected index lesion on MRI were assumed to be representative of the other metastases. This assumption can be refuted, but it is currently not possible to measure each metastasis separately. For example, in a hybrid PET/MRI study of liver metastases, the lesion selected for measurement was not clearly defined (22). Second, the cellularity of the tumor and the reflection of glucose metabolism in the complex background of the liver parenchyma may not be the same as in other isolated regions. For example, it has been reported that there is no correlation between ADC and

Table 1. Demographic characteristics of the patients, index lesion, ADC, and SUV

n=33	
Age	59±12
Gender (male/female)	17 (51%)/16 (49%)
Index lesion	
Diameter (mm)	27±9
Liver location	
Segment 6	27%
Segment 7	27%
Segment 8	21%
Segment 4	15%
Segments 2, 3, and 5	10%
Primary tumour	
Gastrointestinal tract	16 (49%)
Breast	5 (15%)
Pancreas	3 (9%)
Over	3 (9%)
Cervix	2 (6%)
Bladder	2 (6%)
Lung	2 (6%)
Newly diagnosed	10 (30%)
Follow-up of treatment response	23 (70%)
Interval between MRI-PET/CT (day)	14±7
Minimum ADC ($\times10^{-3}mm^2/s$)	0.54±0.2
Mean ADC ($\times10^{-3}mm^2/s$)	1.02±0.2
Maximum ADC ($\times10^{-3}mm^2/s$)	1.48±0.44
ADC ROI (cm^2)	6±4.6
SUV_{mean}	5.8±3.3
SUV_{peak}	6.8±4.3
SUV_{max}	10.7±5.6
*MTV (cm^3)	12.1 (7.4-20.7)

*Shown as median (25^{th}-75^{th} percentile)
ADC: Apparent diffusion coefficient, SUV_{mean}: Mean standardized uptake value, SUV_{peak}: Peak standardized uptake value, SUV_{max}: Maximum standardized uptake value, MTV: Metabolic tumor volume

Table 2. Pearson correlation analysis results between ADC and SUV values

		ADC_{min} SUV_{max}	ADC_{min} SUV_{peak}	ADC_{min} SUV_{mean}	ADC_{mean} SUV_{max}	ADC_{mean} SUV_{peak}	ADC_{mean} SUV_{mean}	ADC_{max} SUV_{max}	ADC_{max} SUV_{peak}	ADC_{max} SUV_{mean}
All patients (n=33)	r	-0.130	-0.163	-0.099	0.300	0.276	0.309	0.090	-0.004	0.032
	p	0.470	0.365	0.584	0.399	0.441	0.385	0.805	0.992	0.930
Treatment response follow-up (n=23)	r	-0.330	-0.360	-0.308	0.003	-0.018	0.034	0.210	0.224	0.253
	p	0.124	0.091	0.153	0.990	0.934	0.876	0.337	0.305	0.244
Newly diagnosed (n=10)	r	0.198	0.127	0.188	0.300	0.276	0.309	0.090	-0.004	0.032
	p	0.584	0.726	0.603	0.399	0.441	0.385	0.805	0.992	0.930
Gastrointestinal metastases (n=16)	r	-0.094	-0.145	-0.051	0.308	0.233	0.308	0.160	0.097	0.135
	p	0.729	0.592	0.851	0.245	0.385	0.245	0.553	0.722	0.617
Other metastases (n=17)	r	-0.265	-0.256	-0.230	-0.189	-0.137	-0.109	0.290	0.315	0.332
	p	0.305	0.321	0.375	0.467	0.600	0.678	0.259	0.217	0.193

r: Pearson correlation coefficient, ADC: Apparent diffusion coefficient, SUV: Standardized uptake value

SUV levels in hepatocellular carcinoma (23). In addition, the inclusion of benign lesions (such as hemangiomas and focal nodular hyperplasia) as well as malignant liver lesions in future studies may provide a clearer understanding of how different types of lesions behave within liver tissue. Finally, as suggested in the literature, there is the possibility that cell density and glucose metabolism may not be directly related to each other. Alternatively, this assumption may not be valid for all tumor types.

Study Limitations

The primary limitations of this study were its retrospective nature and limited number of patients. The selected index lesion may be open to question. The criteria and assessment were based on the consensus of two experienced radiologists. The scans were not taken simultaneously; thus, changes in tumor behavior may have occurred during the selected period.

Conclusion

In conclusion, although both MRI and PET/CT are routinely used in the diagnosis and follow-up of liver metastases, their different advantages can confuse the choice of imaging modality. Understanding the strengths and weaknesses of each modality can help healthcare providers make more informed decisions when diagnosing and treating patients. Although ADC is a cheap and rapid tumor biomarker, its standardization and correlation remain under development. Prospective studies with a large patient group are needed.

Ethics

Ethics Committee Approval: This study was approved by the Aydın Adnan Menderes University Rectorate Faculty of Medicine Dean's Office Non-Interventional Clinical Research Ethics Committee (approval no: 20, date: 13.06.2024).

Informed Consent: Informed consent was not obtained for this retrospective study.

Footnotes

Authorship Contributions

Surgical and Medical Practices: A.T., R.A., Y.Y., Concept: A.T., R.A., Y.Y., Design: A.T., Y.Y., Data Collection or Processing: A.T., R.A., E.H.N., Analysis or Interpretation: A.T., E.H.N., Y.Y., Literature Search: A.T., R.A., E.H.N., Y.Y., Writing: A.T., Y.Y.

Conflict of Interest: No conflict of interest was declared by the authors.

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