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MORPHOLOGICAL ANALYSIS OF LIVER METASTASES WITH MR VOLUMETRY

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Abstract

An increase in the incidence of metastatic liver disease is registered, especially among young women with breast cancer and young men with colorectal cancer.

Metastatic liver deposits have a specific morphological appearance on MR.

MR morphological imaging of metastases is based on proton spin of hepatocytes, while hepatic metastases have a different presentation in the same sequences. On T1-sequence, they are shown as focal hypo- to isosignal round to oval irregular lesions of varying diameter, sometimes with a deeper central signal. T2-sequence has a mixed signal depending on the type of vascularization, but specificity is obtained after intravenous contrast administration, where metastases are shown with deep central signal but significant peripheral hypersignal in the form of a peripheral ring.

Liver volumetry using magnetic resonance imaging (MRI) is a method for quantitative measurement of the size and volume of the liver using MRI data. This is a non-invasive technique that provides important information about the anatomy of the liver and can help in the assessment of diseases and liver conditions, such as cirrhosis, liver tumors, metastases or fatty liver disease.

In metastatic liver disease, hepatic volumetry as a method for calculating the residual liver volume has been developing with the development of metastasis treatments, both surgical and oncological. The method represents a mathematical approach to assessing residual liver volume and for evaluating the regenerative hepatic process without affecting the liver function. Magnetic resonance imaging and volumetry are superior methods for diagnosis and treatment of metastases.

Keywords: MRI, volumetry, metastases, liver, segments

Introduction

The liver is located in the upper right hemiabdomen. Topographically, it is adjacent to the small intestine and participates in processing nutrient-rich venous blood from the digestive tract. The liver has approximately 500 metabolic functions, including its gluconeogenesis, synthesis of plasma proteins, and bile pigment production. The main blood vessels, portal vein and hepatic artery, lymphatic vessels and nerves, together with the main biliary tract form the hilus of the liver. From the hilus towards the liver parenchyma, they branch out in parallel, forming portal channel that branches up to sinusoids which are actually capillary network of the liver [1].

At the level of the sinusoids, venous blood from the portal vein, which has low blood pressure, communicates with the arterial blood from the hepatic artery, which has high blood pressure. This communication allows blood to pass through the sinusoids, collector branches, and through the hepatic veins exits the liver [2].

Portal ducts drain into central veins and form lobules which are composed of hepatocytes connected by interconnecting plates. The space between the plates forms a sinusoid. Several such structures form an acinus (Figure1).

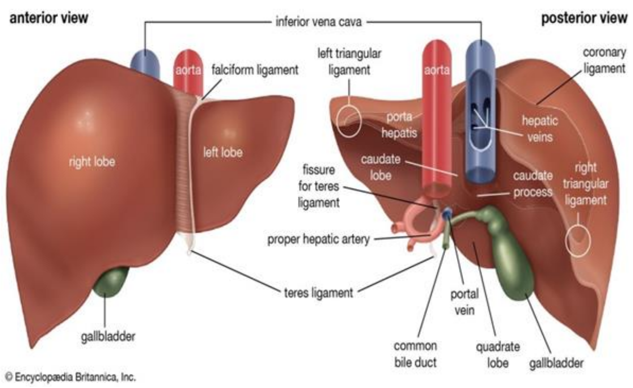

Figure 1. Anatomy of liver

The functional unit of the liver is called the acinus, which is divided into 3 zones:

- periportal zone around the portal canal circularly placed,
- central zone placed circularly around a central vein,
- middle zone, localized between periportal and pericentral zone.

The functional anatomy of the liver consists of 8 functional segments, based on the distribution of portal vein branches in the parenchyma (Figure 2). The liver is anatomically divided into right and left lobes by the median plane of the hepatic vein, extending from the inferior vena cava to the gallbladder, and this demarcation is called Cantlie's line. The three major hepatic veins lie between these lobes, dividing the left and right into sectors. Each sector is divided to 2 segments which are vascularized by a branch of *a. hepatica propria*, *v. porta* and proper bile duct. Segments I, II, III, IV make up the functional left lobe, and segments V, VI, VII, VIII make up the functional right lobe [3].

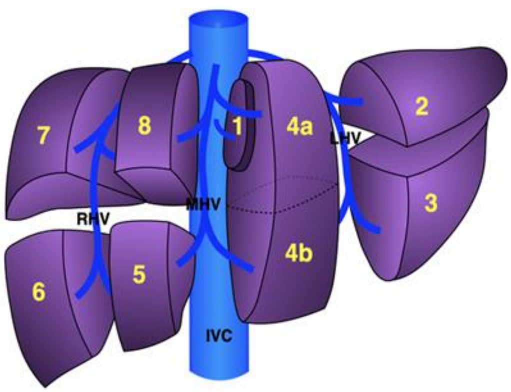

Figure 2. Liver segments according to Couinaud classification

Metastatic liver deposits have a specific morphological appearance on MR.

MR morphological imaging of metastases is based on proton spin of the hepatocytes, while the hepatic metastases have different presentation [4]. On T1-sequence, they are shown as focal hypo- to isosignal round to oval irregular lesions of varying diameter, sometimes with deeper central signal (Figure 3). On T2-sequence, metastases exhibit a mixed signal depending on the type of vascularization [5-6]. However, specificity is obtained after intravenous gadolinium application contrast, where metastases are shown with a deep central signal and a pronounced peripheral hypersignal in the form of a peripheral ring,

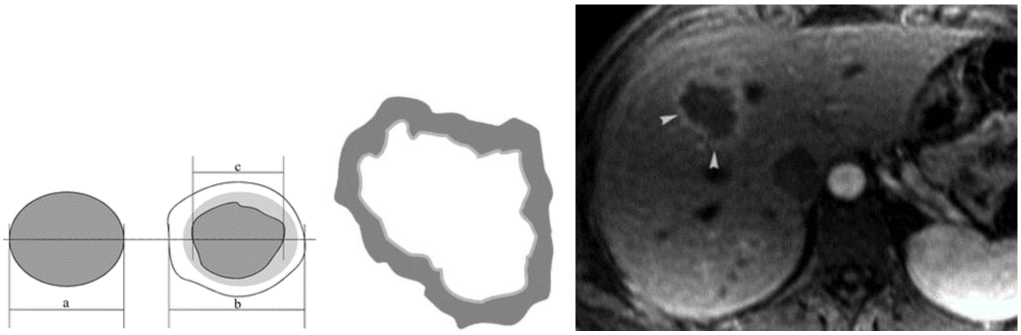

Figure 3. Peripheral ring of liver metastases on MR

Aim of the study

Application of MRI volumetry as a method can bring precise diagnosis in treatment of liver metastases with possible prediction of residual liver parenchyma with normal function.

Methodology

The study group consisted of 19 patients with liver metastases from various malignant diseases. These patients were identified and included in the study over a two-year period (2019 – 2021) at the City General Hospital "8th September" in Skopje.

Patients were selected according to the following criteria:

a) Patients with a previously diagnosed primary malignancy, proven histopathological results with a previous biopsy

b) Patients with previously diagnosed primary malignancy, proven after surgical treatment

c) Patients with metastatic liver deposits detected on US or CT.

Exclusion criteria:

a) Patients who have undergone oncological treatment

b) Patients who were surgically treated with liver resection due to metastases

c) Patients with liver resection for primary hepatic malignant disease

d) Patients with ferromagnetic implants

e) Patients with cardiac electrical stimulators

f) Patients with a stent in blood vessels implanted for at least 6 months

g) Patients with diabetes mellitus

h) Patients with kidney diseases

i) Pregnant and lactating women

Eleven patients were female, and eight male.

Hepatic volumetry as a method used for calculating the residual liver volume has been developing with the development of metastasis treatments, both surgical or oncological. The method represents a mathematical approach in determining the healthy hepatic parenchyma (Figure 4), which would be residual and responsible for the regenerative hepatic process, without affecting its function postoperatively.

Liver volumetry using magnetic resonance imaging (MRI) is a method for quantitative measurement of the size and volume of the liver using MRI data. It is a non-invasive technique that provides important information about the anatomy of the liver and can help in the assessment of diseases and liver conditions, such as cirrhosis, liver tumors, or fatty liver disease.

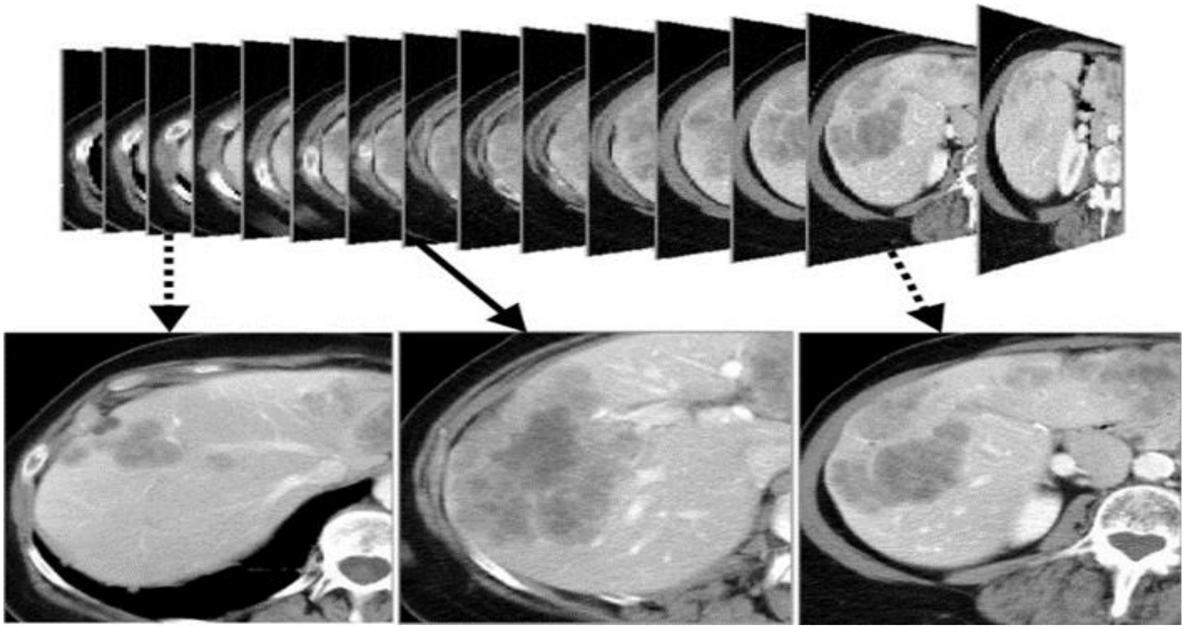

Figure 4. Display of MS volumetry with manual marking to determine the residual liver volume

The method is performed according to the Couinaud classification [7] of the hepatic segments with prior determination of the entire volume of the liver and metastases, and then, on the healthy volume of each section in an axial plane.

In our study, volumetry was performed on 24 metastases smaller than 10 mm localized in different segments in 19 patients.

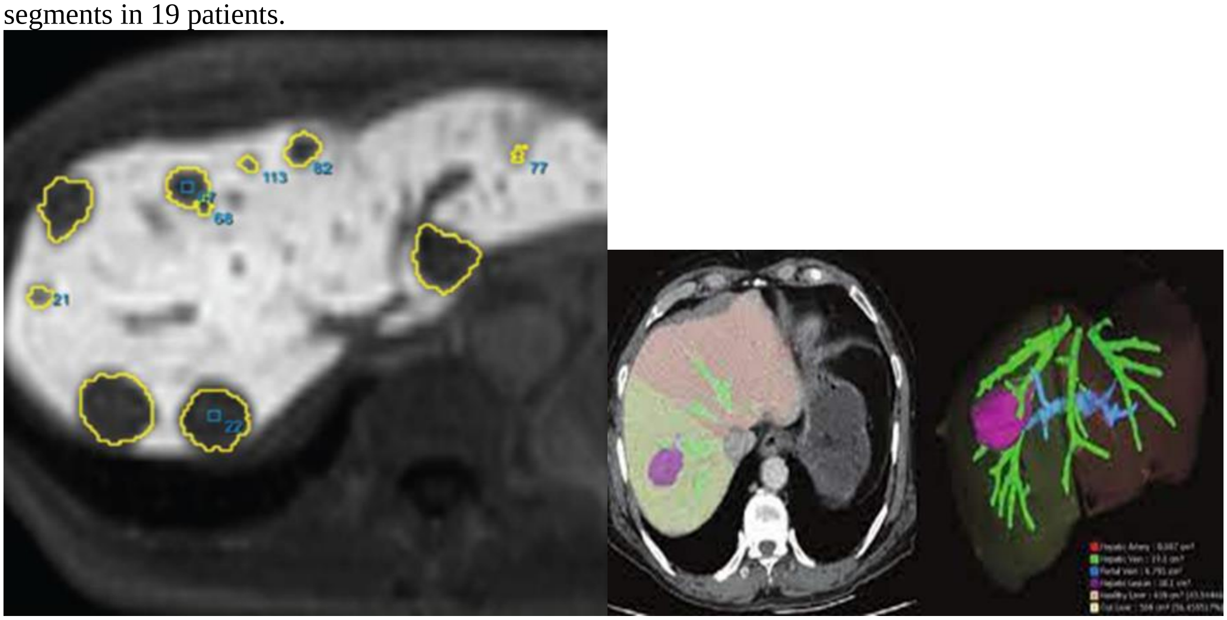

Figure 5

General guidelines for the MRI [8,9] liver volumetry procedure:

- Recording protocol: Different MRI sequences, such as T1-sequence, T2-sequence and post-intravenously applied Gadolinium sequence.
- Image acquisition: The obtained MRI-images are transferred to OSRIX Md analysis computer workstation. Pictures should be of high quality and with sufficient resolution for accurate volumetric measurements, which is why cooperation with the patient and appropriate inspirations and expirations affecting excursion of liver is necessary.
- Image processing: Specialized software or computer algorithms are used to process the MRI images. Liver segmentation involves separating the liver from the surrounding structures and background to generate a detailed liver picture or mask.
- Volume analysis: Once the liver is accurately segmented, software calculates its volume based on the number of voxels (three-dimensional pixels) contained within the liver mask. The calculation takes into account the size of the voxels and assumptions about liver density expressed in signals.
- Quality control: It is important to perform quality checks to ensure the accuracy of volumetric measurements. This may include review of the segmented images, verification of the correct definition of the liver and necessary corrections of marking the volume of each section in an axial plane.
- Report: The calculated liver volume can be expressed in absolute values (for example, in milliliters) or to normalize to the patient's body surface area (BSA). The results can be compared with reference values or used for longitudinal monitoring of liver changes over time.

Liver volumetry by MRI can provide important information on surgical planning, evaluation of treatment results, as well as to monitor the progress of the disease.

The most significant benefit of liver volumetry is the ability to determine the volume [10] of metastatic deposits with a comparative determination of the volume of residual healthy liver parenchyma, using the following formula for liver volume calculator:

- Volume = CC x LL x AP x 0.31
- Total liver volume = 191.8 + (18.51 x weight in kgs)

The circadian rhythm of the liver, which is narrow, is also taken into account.

There is an association between patient hydration and nutrition [12].

According to a study by Leung NW. *et al.*, the liver reaches its minimum volume around 12 noon (-7.5 to + 3.2%).[13]

This ratio provides insight into the calculation of residual healthy parenchyma post-interventional or mastectomy.

Results

1. Patient Demographics:
    - 19 patients included in the study
    - Age range: 23 to 78 years
    - Gender distribution: 11 females (57.9%) and 8 males (42.1%)
    - Majority of patients (71.43%) had metastases from breast cancer
2. Vascular and Biliary Invasion:
    - Vascular invasion was significantly associated with the presence of a peripheral ring on MR imaging ($p<0.0001$)
    - Biliary invasion was not significantly associated with the peripheral ring ($p=0.335$)
    - 17 out of 19 patients (94%) with a peripheral ring showed vascular infiltration
    - Only 2 out of 19 patients (20%) without a peripheral ring showed vascular infiltration.

The data suggests that the presence of a peripheral ring on MR imaging is a strong indicator of vascular invasion in hepatic metastases. This finding could be clinically relevant for assessing the extent of disease and planning treatment strategies (Table 1).

Primary diseases	Ca mamae	Ca ovarii	Ca pulmonum	AdneoCa recti	Ca sigmae
Patients	9	1	3	3	3
Localization	V, VI VII	IV, V, VII, VII	VII	VII, VIII, II, V	V, VI, VII,
Size of metastases	20 mm до 9 mm	23 mm-10 mm	34-10 mm	22 mm- 9 mm	40 mm-9 mm
Vascular infiltration and size of peripheral ring	Yes 2 mm	Yes 4 mm	Yes 2 mm	Yes 1 mm	Yes 4 mm
Biliary invasion	Yes	Yes	Yes	Yes	Yes

Table 1. Description of patients and localization with size of peripheral ring related to vascular and biliary invasion

However, there are some inconsistencies and areas that require clarification. The total number of patients with hepatic metastases (19) in the vascular invasion analysis did not match the initially stated 17 patients. This discrepancy needs to be addressed.

Discussion

There are many studies on the demographics of patients with liver metastases, the type of the primary malignant disease, and the occurrence of liver metastases. These studies have shown a direct correlation with prognosis, which has a serious impact on treatment of various types of cancer.

According to primary diseases, patients in our study were operated on for breast cancer (71.43 %). The majority of patients were females, which revealed a significant difference in the distribution of primary diseases by sex. The analysis showed a higher incidence of metastatic liver changes, according to the distribution of primary cancers and the number of metastases. This correlates with the study by Sasaki S. *et al.* [10], which analyzed the demographic and clinical characteristics of patients with hepatic metastases from breast cancer. The study concluded that the most common risk group for liver metastases included women older than 50 years, with invasive breast cancer, and Herceptin positive.

The distribution of liver metastases is of great importance in building a treatment strategy for these patients. Understanding the characteristics of primary diseases with predilection sites for metastases spread is one of the key issues. However, several studies have demonstrated that diagnostic methods with a high precision have shown that liver segments II, III, and IV are more frequently affected by metastases than other segments. Segments VI and VII are considered less prone to metastases due to their location and large vascular appendages [11]. In patients with colorectal cancer, the distribution of liver metastases has been investigated. Results have indicated that metastases mostly occur in segments V and VIII.

In fact, the location of liver metastases can vary from patient to patient depending on various factors, such as the type of tumor, the stage of the disease and the individual characteristics of the patient. Liver metastases usually appear in the lower segment of the right lobe (segment V and VIII) because these segments have better vascularization than the remaining segments. However, metastases can also occur in other segments of the liver. De Greef K. *et al.* investigated the efficacy of anatomical liver resections in patients with metastases from colorectal cancer. The results showed that metastases were mostly localized in segments II, III, IVb and VIII. [12]

Another study, published by Vera R. *et al.*, investigated the distribution of liver metastases, in order to build criteria according to which patients were treated with radiofrequency ablation. The results showed that most frequently metastases occurred in segments V (71.1 %) and VI (63.6 %), followed by segments VIII (53.9 %) and VII (49.3 %). Segments I (17.6 %) and IV (28.7 %) were considered less prone to metastases [13].

The segmentation and determination of the exact localization of liver metastases play a very important role in determining the criteria according to which patients would be surgically treated with metastasectomy [14]. Studies have shown that metastases are mostly localized in segments II, III, IVb, V, and VIII.

In our study, metastatic deposits in the liver measuring less than 10 mm were mostly localized in segment V – observed in 14 (20 %) patients; in 33 (47.14 %) patients, metastases were localized in more than one hepatic segment. The largest number of metastases were multiple, or in only 10% of cases solitary metastases occurred and usually involved different lobes.

Liver deposits can be classified by distribution as solitary and multiple, by location as segmental or lobed, and they can be different by size diameter.

According to the type of vascularization, metastases can be hypovascularized or hypervascularized depending on the primary cancer from which they originate. Due to the different variations in the occurrence of liver metastases, which is also called metastatic liver cancer, with colorectal cancer being the most frequent one, a group of authors in 2020 developed medical rules and protocols for the detection, analysis and treatment of metastatic liver cancers originating from colorectal cancer [15].

Hepatic metastases show a peripheral ring which can be associated with their appearance related to the vascular or biliary invasion, which is visible on MR [16].

Nowadays, histopathological examinations have shown that this ring is an extra-lesional desmoplastic reaction zone of the surrounding liver tissue. This raises questions, such as: when measuring the diameter, what is the importance of this zone in determining the size of the metastasis, whether this desmoplastic reaction is essential? [17].

A characteristic and specific sign in analyzing the occurrence of metastases is the formation of a so-called peripheral ring, detectable on T2-sequence of magnetic resonance during the hepatobiliary stage in hypovascular metastases. Another important feature is called "target sign”. This is actually peripheral "rim washout sign" presented in the parenchymal phase with peri-tumoral intensive signal zone in hypervascular liver metastases. There are other specific presentations and signs of liver metastases, such as the appearance of calcifications, tumor necrosis, cystic zones, absence of a penetrating vascular sign and, very rarely, intraductal metastases [18].

In our study, the analysis of the peripheral ring from a morphological aspect focused on typical peripheral hypersignals in metastases by analysis of vascular and biliary invasion. A statistically significant difference was confirmed in the distribution of patients with liver metastases, with and without vascular infiltration, depending on the degree of metabolic activity metastases ($p=0.038$). Vascular invasion was registered mostly in patients with lesions with high metabolic activity – 22 (91.67%), followed by lesions with moderate and low metabolic activity – 20 (62.5%) and 9 (64.29%) patients, respectively.

Patients with hepatic metastases, with and without biliary invasion, did not differ significantly in terms of the degree of metabolic activity lesions ($p=0.11$). Patients with high metabolic activity of the lesions insignificantly more often than patients with low and moderate metabolic activity had lesions with infiltration of the biliary tract – 12 (52.17%) *versus* 3 (23.08%) *versus* 9 (28.13%).

In correlation with other factors in our study, the relationship between presentation of primary diseases with the presentation of liver metastases and "imaging" methods was analyzed. In our study, 12 malignant diseases were analyzed in relation to the type and mode of distribution of liver metastases, showing the close relationship between the malignant potential of the primary diseases and the type and distribution of occurrence of liver metastases. The highest potential due to hypervascularization of the primary disease was demonstrated by colorectal cancer with 15 metastases of different diameters, all highly vascularized.

Other studies [19] have shown that individual techniques and sequences of MR, with and without intravenous contrast administration, possess high specificity in detecting liver metastases and demonstrate, not only localization, but also parenchymal and biliary invasion.

Hepatic resection as a surgical method and radiofrequency ablation as an interventional radiological method have proven to be the most appropriate methods in the treatment of metastatic deposits, which originate from various primary malignancies in patients with hepatic metastases, primarily originating from colorectal cancer. Surgical resection has shown a great benefit in prolonging life. Patients in whom metastases are metachronous, small, few in number and hypovascularized are with the best prognosis. A survival time of 5 years is found in patients with 5 hepatic metastases (73-79%), while in patients with more than 5 metastases of liver the percentage of 5-year survival decreases to 47% [20]. Investigations are still being conducted in relation to the smaller metastatic deposits (smaller than 3 mm) with so-called SPIO-enhanced MR magnetic techniques resonance, where a highly specific contrast is used, which contains ferroxide, but limited results are obtained [21]. The largest number of metastases are multiple, or rather only 10% of cases are with solitary metastases and usually involve different lobes [22]. Due to the liver specific circulation, metastases can occur in various segments. The hepatobiliary phase complements the sequence in DWI, displays metastases smaller than 10 mm [23], with a higher degree of delineation compared to other modalities, such as 18 FDG PET CT and CT.

The complexity of the hepatic vascularization and microenvironment provide an opportunity for development and invasion of liver parenchyma by malignant cells due to their slow movement or rather stagnation in the liver sinusoids. The portal vein primarily delivers tumor emboli from the malignant changes in different organs.

Our study included an analysis of metastases and their MRI presentation in DWI phase and post-contrast port phase. MRI was shown to be a more sensitive method for smaller metastatic deposits of 10 mm (found in 91% of patients) [24].

In the study by Souza *et al.* [25], which included 15 patients with suspected liver metastases of various malignant origins, an analysis was made using PET CT and MRI 3 Tesla magnetic field strength. This assessment was based on a per-patient analysis and demonstrated that for the detection of metastases smaller than 10 mm, MRI with intravenous contrast application was a superior method, showing up to 96% sensitivity compared to PET CT, which was also confirmed in our study. However, the specificity of MR relative to PET CT is somewhat lower, which can be attributed to the limitations of our device, which is 1.5 Tesla magnetic field strength.

In the study by Matteo Renzulli *et al.* [26], an analysis of scientific research studies in the last 10 years has been made, where the development of new magnetic resonance techniques has been described.

Those techniques, such as DWI contrast administration techniques and specific hepatobiliary contrast, led to a remarkable progress in detection and analysis of metastatic liver deposits of different malignant origin. Their study reviewed systematically and sequentially the developmental approaches in the detection of hepatic metastases presented by different authors in 4800 papers that were analyzed over the course of 10 years. The focus was on two specific methods in the case of metastases smaller than 10 mm. The hepatobiliary phase, used complementarily with the sequence in DWI, where restricted movement of the water molecules in the tissue molecules is detected, shows identification of metastases smaller than 10 mm with better delineation of their margins compared to other modalities.

In our study, MR detected 6 (8.57%) patients with 4-5 lesions smaller than 10 mm, 4 (5.71%) patients with >5 lesions less than 10 mm. In a retrospective comparative study by Fernadez *et al.* [27], patients with liver metastases from colorectal cancer were included, and were prepared to undergo a hepatectomy.

Other studies [28] presented a specific method and MR sequence using Gadobenate contrast medium application dimeglumine (MultiHance, Gd-BOPTA), which is a hepatobiliary specific contrast for biliary pathway and gives a clearer morphological view of metastases smaller than 10 mm. In a study by Luisa Paulatto *et al.*, a correlation between MRI and CT findings with pathohistological findings of hepatic metastases was made. It was explained that the peripheral ring-like zone in some types of metastases was a proliferative part of metastasis and its occurrence was an important prognostic sign. In a study by Semelka *et al.*, a correlation of the perilesional zone with pathohistological correlation was made, indicating that the perivascular ring was due to vascular and biliary infiltration [29].

Other studies [30-31] have shown that individual techniques and sequences of MR images, with and without intravenous contrast administration, demonstrate high specificity for liver metastases, and enable not only localization but also evaluation of parenchymal and biliary invasion.

Hepatic resection as a surgical method and radiofrequency ablation as an interventional radiological method have proven to be currently the most appropriate methods in the treatment of metastatic deposits originating from various primary malignancies [32-33].

Liver volumetry is a method for calculating the volume of the liver. It is based on using liver images obtained by different methods, such as computed tomography (CT), magnetic resonance imaging (MRI) and ultrasound. By using special algorithms, images are analyzed to calculate the exact volume of the liver [34-35].

Liver volumetry is useful in clinical practice, especially for patients with liver cirrhosis, and it can help doctors to assess the organ and determine the necessary therapy.

Liver volumetry can be used to monitor tumor growth or evaluate surgical results, such as liver enlargement in the case of liver donors. MRI-volumetry is performed using specialized image analysis software that can recognize the contours of hepatic tissues and measure their values. This software applies mathematical algorithms to calculate the liver volume, based on contour measurements [36-38]. Initially, for liver volumetry, a series of MRI images is taken in different places of the liver. These images are taken in different orientations, such as coronary (from the head to the feet), sagittal (from the chest to the back) and transversal (from right to left). After taking these images, an image segmentation process follows that differentiates various tissues within the images. In this case, the goal is to segment hepatic tissues in the image.

Once the segmentation is done, a volumetric process follows. In this process, the software measures the areas of the segmented tissues on each image, and then builds a 3D representation of the liver with the calculated volume. This information can be useful for precise planning and monitoring the treatment of various liver diseases, including metastases [39-40].

Calculation of liver volume can be performed using a special software that will mark the borders of the liver on each 3D image. The computer can calculate the volume of the liver, which can be useful for diagnosis and monitoring of various diseases of this organ [41-43], and is an important predictive factor for loss of liver function depending on the degree and volume of the lesion.

In our study, volumetric analysis was performed on 28 metastases smaller than 10 mm, localized in different segments in 19 patients.

Conclusion

According to the results of our study, it can be seen that the progress and introduction of new MR techniques provide opportunities for multiple sequences and models, with and without contrast administration, providing an accurate assessment of the type of metastatic invasion, whether biliary or vascular.

On the other hand, hepatic segmentation with MRI volumetry at the level of several segments of the liver parenchyma offers an opportunity for more accurate planning of the surgical treatment of hepatic metastases.

Both methods, although complementary, provide a precise framework for treatment of patients with malignant diseases with detected metastatic deposits. Additionally, they are important in building the criteria for patients who would be candidates for metastases resection or radiofrequency ablation. Magnetic resonance is a method that detects metastatic deposits smaller than 10 mm as well as enables estimation of the residual volume of healthy liver parenchyma.

References

1. Munemasa R, Akihiro C, New Liver Anatomy: Portal Segmentation and the Drainage Vein 2009; (3):28-31.
2. Yuichiro Hirano Y. ; Couinaud classification of hepatic segments ; 2022; 28 (3)
3. Ronot M , Ashley K. ,Clift D, Richard P., Baum E, Aviral S. , Harshad R., Kulkarni A., Frilling D. , Vilgrain V , Morphological and Functional Imaging for Detecting and Assessing the Resectability of Neuroendocrine Liver Metastases, Neuroendocrinology ;2012 234(2) 230-330.
4. Sonnenschein C, Soto M. A "Carcinogenesis and Metastasis Now in the Third Dimension—What's in It for Pathologists?, Am J Pathol. 2006; 123(3) 120-310.
5. Fadaka A, Ajiboye B, Ojo O, Adewale O, Olayide I, Emuowhochere R. Biology of glucose metabolization in cancer cells. Journal of Oncological Sciences 2012; 3 (1) 1-34.
6. Kinkel K, Lu Y, Both M, Warren RS, Thoeni RF. Detection of hepatic metastases from cancers of the gastrointestinal tract by using noninvasive imaging methods (US, CT, MR imaging, PET): a meta-analysis. 2002 Radiology 224(3) 748–756.
7. Fernandez FG, Drebin JA, Linehan DC, Dehdashti F, Siegel BA, Strasberg SM. Five-year survival after resection of hepatic metastases from colorectal cancer in patients screened by positron emission tomography with F-18 fluorodeoxyglucose (FDG-PET). Ann Surg 2004;240:(9) 438–447.450.
8. Bipat S, Van Leeuwen MS, Comans EF et al. Colorectal liver metastases: CT, MR imaging and PET for diagnosis - meta-analysis. Radiology 2005: 237(1): 123-31.
9. Oliveira R.T.M, Vieira B, Apio RicardoNazarethDias R.N ,Falcão A.S.C , Aprotocol of hepatic volume measurement using magnetic resonance imaging in individuals from the Eastern Brazilian Amazon population PLoS ONE15(3): e022952
10. Sasaki S, Ohtsuka T, Akimoto T. Prediction of post-hepatectomy liver failure using MRI-based liver volumetry and hepatocyte fraction in patients with hepatic metastases, Journal of Surgical Oncology 2021; 23(3) 120-127.
11. Gotra A, Sivakumaran l, Chartrand G, Vu K K-N, Vandenbroucke F, KauffmannK, Kadoury S, Gallix B,A. de Guise J Tang A. Liver segmentation: indications, techniques and future directions Insights Imaging 2017 8:377–392
12. Yu JS, Rofsky NM. Hepatic metastases: perilesional enhancement on dynamic MRI. AJR Am J Roentgenol. 2006;(186) :1051–8.
13. Kim, T. K., Jang, H. J., & Burns, P. N. Diagnosis of liver metastasis: value of contrast-enhanced ultrasonography versus contrast-enhanced CT and MR imaging." Radiology 2011; (78) 228 – 308
14. Kierans, A. S., Kuo, Y. C., Hahn, P. F., Sahani, D. V., & Mueller, P. R. Detection of liver metastases: comparison of contrast-enhanced CT, contrast-enhanced US, superparamagnetic iron oxide-enhanced MRI, and gadoxetate disodium-enhanced MRI." Journal of computer assisted tomography 2011; 34(2):326-35
15. Luisa Paulatto, Marco Dioguardi Burgio, Riccardo Sartoris1, Aurélie Beaufrère, François Cauchy, Valérie Paradis, Valérie Vilgrain and Maxime Ronot, Paulatto et al. Colorectal liver metastases: radiopathological correlation Insights into Imaging 2020; 11(1):99
16. Healey M,Pring J, Metcalfe T, MRI liver volumetry for prediction of postoperative liver volume in patients undergoing hepatectomy for liver metastases, European Radiology 2018. 38(5):868-874
17. D'Onofrio M, De Robertis R,Demozzi E,Crosara S, Canestrini S, Pozzi Mucelli R . Liver volumetry: Is imaging reliable? Personal experience and review of the literature World J Radiol 2014 ; 6(4): 62-71.
18. Semelka RC, Cance WG, Marcos HB, Mauro MA. Liver metastases: comparison of current MR techniques and spiral CT during arterial portography for detection in 20 surgically staged cases. Radiology. 1999;213:86–91.
19. Yu JS, Rofsky NM. Hepatic metastases: perilesional enhancement on dynamic MRI. AJR Am J Roentgenol. 2006;186:1051–1058.

20. Semelka RC, Hussain SM, Marcos HB, Woosley JT. Perilesional enhancement of hepatic metastases: correlation between MR imaging and histopathologic findings-initial observations. Radiology. 2000;215:89–94.
21. Baron RL, Peterson MS. Liver tumor detection: comparison of Gd-BOPTA-enhanced MR, contrast-enhanced CT, and CT arterial portography (abstract) Radiology. 1995;197:415.
22. Caudana R, Morana G, Pirovano GP, et al. Focal malignant hepatic lesions: MR imaging enhanced with gadolinium benzyloxypropionictetra-acetate (BOPTA) –preliminary results of phase II clinical application. Radiology. 1996;199:513–520.
23. Reimer P, Rummeny EJ, Daldrup HE, et al. Enhancement characteristics of liver metastases, hepatocellular carcinomas, and hemangiomas with Gd-EOB-DTPA: preliminary results with dynamic MR imaging. Eur Radiol. 1997;7:275–280.
24. Hagspiel KD, Neidl KF, Eichenberger AC, Weder W, Marincek B. Detection of liver metastases: comparison of superparamagnetic iron oxide-enhanced and unenhanced MR imaging at 1.5 T with dynamic CT, intraoperative US, and percutaneous US. Radiology. 1995;196:471–478.
25. D'souza MM, Sharma R, Jaimini A, Saw SK, Pandey S, et al. (2017) Detection of hepatic metastases by 18F-FDG PET/ CT and MRI. J Nucl Med Radiol Imaging 2017: JNMRI-101.
26. Renzulli M, Clemente A, Ierardi AM, et al. Imaging of Colorectal Liver Metastases: New Developments and Pending Issues.Cancers (Basel). 2020;12(1):151.
27. Oudkerk M, van den Heuvel AG, Wielopolski PA, Schmitz PI, Borel Rinkes IH, Wiggers T. Hepatic lesions: detection with ferumoxide-enhanced T1-weighted MR imaging. Radiology. 1997;203:449–456
28. BlokhuisTJ, van der Schaaf MC, van den Tol MP, Comans EF, Manoliu RA, van der Sijp JR: Results of radio frequency ablation of primary and secondary liver tumors: long-term follow-up with computed tomography and positron emission tomography-18F-deoxyfluoroglucose scanning. Scand J Gastroenterol Suppl 2004;241:93–97.
29. Paulatto L, Dioguardi Burgio M, Sartoris R, et al. Colorectal liver metastases: radiopathological correlation.Insights Imaging. 2020;11(1):99.
30. Tirumani SH, Jagannathan JP, Braschi-Amirfarzan M, et al. Value of hepatocellular phase imaging after intravenous gadoxetate disodium for assessing hepatic metastases from gastroenteropancreatic neuroendocrine tumors: comparison with other MRI pulse sequences and with extracellular agent.Abdom Radiol (NY). 2018;43(9):2329-2339.
31. TahtabasiM, Erturk SM, Basak M. Comparison of MRI and 18F-FDG PET/CT in the Liver Metastases of Gastrointestinal and Pancreaticobiliary Tumors.Sisli Etfal Hastan Tip Bul. 2021;55(1):12-17.
32. Hardie AD, Naik M, Hecht EM, et al. Diagnosis of liver metastases: value of diffusion-weighted MRI compared with gadolinium-enhanced MRI.Eur Radiol. 2010;20(6):1431-1441.
33. Karaosmanoglu AD, Onur MR, Ozmen MN, Akata D, Karcaaltincaba M. Magnetic Resonance Imaging of Liver Metastasis.Semin Ultrasound CT MR. 2016;37(6):533-548.
34. Seneterre E, Taourel P, Bouvier Y, et al. Detection of hepatic metastases: ferumoxides-enhanced MR imaging versus unenhanced MR imaging and CT during arterial portography. Radiology. 1996;200:785–792.
35. Coates GG, Borrello JA, McFarland EG, Mirowitz SA, Brown JJ. Hepatic T2-weighted MRI: a prospective comparison of sequences, including breath-hold, half-Fourier turbo spin echo (HASTE).J Magn Reson Imaging1998; 8:642-649
36. Dromain C, de BaereT, Baudin E, et al. MR imaging of hepatic metastases caused by neuroendocrine tumors: comparing four techniques.AJR Am J Roentgenol. 2003;180(1):121-128.
37. d'Assignies G, Fina P, Bruno O, et al. High sensitivity of diffusion-weighted MR imaging for the detection of liver metastases from neuroendocrine tumors: comparison with T2-weighted and dynamic gadolinium-enhanced MR imaging.Radiology. 2013;268(2):390-399.

38. Carlbom L, Caballero-Corbalán J, Granberg D, Sörensen J, Eriksson B, Ahlström H. Whole-body MRI including diffusion-weighted MRI compared with 5-HTP PET/CT in the detection of neuroendocrine tumors.Ups J Med Sci. 2017;122(1):43-50.
39. L Carlbom et al. Whole-body MRI including diffusion weighted MRI compared with 5-HTP PET/CT in the detection of neuroendocrine tumors Upsala J Med Sci, 2017.
40. Caudana R, Morana G, Pirovano GP, et al. Focal malignant hepatic lesions: MR imaging enhanced with gadolinium benzyloxypropionictetra-acetate (BOPTA) – preliminary results of phase II clinical application. Radiology. 1996;199:513–20.
41. S. Yoon, J.S. Lee, and J.H. Lee "MRI-based liver volumetry in patients with hepatic metastases: comparison with intraoperative estimation of liver volume", Abdominal Radiology 2018.45(6): 230-236.
42. J.R. Lewis JR, Do RK, Kirsch JS. Hepatic Metastases: Evaluation with MRI Volumetry, American Journal of Roentgenology 2017; 8(4):741-56
43. Lee VS, Lavelle MT, Rofsky NM, Laub G, Thomasson DM, Krinsky GA et al. Hepatic MR imaging with a dynamic contrast-enhanced isotropic volumetric interpolated breath-hold examination: feasibility, reproducibility, and technical quality. Radiology 2000; 215: 365–72.