Original article

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DIAGNOSTIC VALUE OF DIFFUSION-WEIGHTED IMAGING AND APPARENT DIFFUSION COEFFICIENT IN PREOPERATIVE ASSESSMENTS OF BRAIN ABSCESSES

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To evaluate the diagnostic value of magnetic resonance imaging (MRI) and diffusion-weighted imaging (DWI) in preoperative assessments of brain abscesses.

This retrospective study included 25 patients with brain abscesses who underwent MRI examination on a 1.5 T scanner, up to seven days before surgery, with the standard protocol including T1WI, T2WI, FLAIR, DWI and post-contrast T1WI sequences. DWI was performed using a single-shot spin-echo echo-planar pulse sequence with b=1000 s/mm. The data obtained by DWI were presented by measuring the value of apparent diffusion coefficient (ADC). ADC map was determined using the DP Tools software. ADC values were quantified placing the regions of interest inside the abscess cavity.

Most of abscesses showed on T1WI hypointense (80%) and isointense signals (20%). On T2WI, most of abscesses showed hyperintense (88%) and isointense signals (12%). On FLAIR, the majority of abscesses showed hyperintense (96%) and isointense signals (4%). After the contrast administration, significantly intense peripheral T1WI contrast enhancement was observed in 92% of abscesses, while 8% showed moderate enhancement. All 25 patients with abscesses showed restricted diffusion on DWI, with low mean ADC values for the abscess cavity (0.000164±0.000019 mm2/s).

MRI and DWI with ADC seem to be a valuable tool in the diagnosis of brain abscesses. *Acta Medica Medianae 2016;55(4):52-59.*

Key words: *diffusion, magnetic resonance imaging, abscess*

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Introduction

Abscesses account for 1-2% of space-occupying lesions of the brain in Western countries and 8% in developing countries. They are frequent in adults, while in only 15-30% of cases they affect younger patients (<15 years). Pyogenic brain abscesses are not common, accounting for one third of all the cerebral abscesses (1).

Brain abscesses are focal and purulent infections of the brain parenchyma. They commonly present with seizures, focal neurological deficits, and/or signs of increased intracranial pressure. Brain abscesses can be caused by many different types of pathogens, usually bacterial. Intraparenchymal abscesses can result from hematogenous dissemination from an extracranial site, by direct extension from a contiguous suppurative focus, or secondary to head trauma, neurosurgical procedures, meningitis, or cerebritis. The pathogenesis of brain tumors with abscess formation may be related to multiple factors such as the alteration of the blood-brain barrier (BBB), vessel fenestration, tumor bleeding, and intratumoral necrosis (2).

Evolution of brain abscess has four main stages: early cerebritis, late cerebritis, early capsule formation, and late capsule formation. The stages associated with capsule formation usually begin at the end of the second week after the initial infection, and last several weeks to months.

During these stages, the imaging appearance is mainly of a ring-enhancing lesion surrounded by edema (3). Focal intracranial infections are grouped into three main categories based on their location: epidural abscess, subdural empyema, and brain abscess (4).

It can be difficult to differentially diagnose a ring-enhancing intracranial mass lesion on the basis of clinical symptoms and conventional magnetic resonance imaging (MRI). Neither the visual inspection, nor the measurement of signal intensity means from T1 and T2-weighted images (WI) can differentiate abscesses from cystic/necrotic tumors (5). With respect to diffusion-weighted (DW) MRI examinations, it appears that DW MRI is a sensitive method to discriminate between necrotic/cystic tumors and abscesses. Pyogenic abscesses usually demonstrate a high signal on DW MRI, and low signal and low apparent diffusion coefficient (ADC) values on ADC maps (6).

The aim of this study was to assess the diagnostic value and usefulness of both DWI and MRI in the preoperative assessments of brain abscesses.

Method

This retrospective study included 25 patients (15 males, 10 females; mean age, 50.4±12.53) with histologically proven abscesses in the period 2005-2010, up to seven days before surgery, examined according to the standard protocol using the following examination sequence: T1WI, T2WI, FLAIR, DWI and post contrast T1WI. Patients were classified into a group according to the final diagnosis of an abscess. The final diagnosis was made histopathologically after the surgery. Postoperative histopathologic diagnoses were compared with preoperative diagnosis by MRI and DWI.

Imaging procedures

All the patients showing the evidence of a ring-enhancing brain lesion in post-contrast T1WI of conventional MRI were examined by both MRI and DWI using a 1.5 Tesla MR unit ((Avanto; Siemens, Erlangen,Germany) with a standard quadrature head coil.

Conventional MRI included T1W (TR/TE = 500/ 15 ms), T2WI (TR/TE = 4000/126 ms) and FLAIR (TR/TE= 8000/142 ms, inversion time =2200 ms) sequences; contrast enhanced MRI was done in all patients after an intravenous injection of contrast medium (Gadovist; Schering, Berlin, Germany), at the dose of 0.1 mmol/kg body weight.

Diffusion weighted imaging (DWI)

Diffusion weighted imaging was performed in all patients and acquired in the axial plane using single shot echo-planar spine echo sequence using the following parameters, TR = 3000–4500, TE =80–100, field of view =32–40 cm, matrix size = 192 x 256, slice thickness =5 mm, number of excitations =3, diffusion gradient encoding in three orthogonal directions at b= 1000 s/mm2. The scanning time was 40 s. Signal intensity of a lesion was defined visually as low or high compared to the normal brain parenchyma.

Post-processing of ADC map

Two neuroradiologists performed qualitative visual inspections of DWI and ADC maps with consensus reading using software DP Tools. Three circular regions of interest (ROIs) 1 cm in diameter were placed centrally within the lesion. The ADC values were measured in the center of the lesion (the abscess cavity) and in comparable normal contralateral regions in the white and gray matter of the brain. The lesion center was graded as hypointense, isointense, hyperintense, or markedly hyperintense relative to the white matter in the contralateral cerebral hemisphere. The DWI findings were compared with conventional images and ADC maps to evaluate for the effects of hemorrhage or T2 shine-through. A brain abscess was defined as a ring-enhancing lesion with restricted diffusion and ADC value lower than that of a normal-appearing brain.

Statistical analysis

For the registration, grading, grouping, graphical and tabular representation of the data, Microsoft Excel 2003 software was utilized. The results were processed using the SPSS software, version 10.0. The P value <0.05 was considered significant. The following statistical parameters were shown: arithmetic mean (Xsr), standard deviation (SD), median, minimal value, maximum value and index of structure (%).The comparison of the abscess presentation in various TWI sequences was performed by the Fisher exact probability test of the null hypothesis (Fisher's exact test). The P values <0.05 were considered to indicate statistically significant differences.

Results

The prospective study included 25 patients with abscesses, 15 (60%) male and 10 (40%) female, with the male predominance in incidence M:F=1.5:1. The average age of all patients was 50.40±12.53 years. The youngest patient was 39 and the oldest 77 years. (Table 1, Table 2)

Table 1. Distribution of patients according to the histopathological diagnosis and sex

Histopathological diagnosis	Sex		Total
	Male	Female	
Abscess	15 (60%)	10 (40%)	25 (100%)

%-index structure

Table 2. Distribution of patients according to the histopathological diagnosis and age

Histopathological diagnosis	Parameter				
	Xsr	SD	Med	Min	Max
Abscess	50.40	12.53	51.00	24,00	77.00

X_{sr} – arithmetic mean; SD – standard deviation, min - minimal value; max – maximal value; M-mediana

Anatomic distribution of abscess

The anatomic distribution of abscesses was shown in Table 3.

In our study, 22 patients had a solitary lesion before surgery. Three patients had multifocal lesions. The abscesses were located in the temporo-parietal lobe (10), occipital (3), frontal (4), parietal (2), splenium of the corpus callosum (1), midbrain (2) and multifocally (3).

Table 3. Anatomic distribution of abscesses

Anatomic distribution of abscess	Number of patients (%)
Temporo-parietal lobe	10 (40%)
Frontal lobe	3 (12%)
Occipital lobe	4 (16%)
Parietal lobe	2 (8%)
Splenium of corpus callosum	1 (4%)
Midbrain	2 (8%)
Multifocal	3 (12%)

%- index of structure

According to the results obtained in our study, taking into account the anatomic localization, the temporo-parietal localization (40%) is significantly more frequent compared to other brain localizations.

Radiologic Findings

Hypointense findings on T1WI (80%) were statistically significantly more common (p<0,05 0,01) than isointense findings (20%). Hyperintense and mixed findings were not recorded in the patients examined (Table 4, Figure 1).

Table 4. Signal intensity on T1WI sequences MRI according to the histopathological diagnosis

Histopathological diagnosis	Signal intensity on T1WI sequences			
	Isointense	Hypo-intense	Hyperintense	Mixed
Abscess	5 (20%)	20 (80%)	-	-

%- index of structure

The frequency of intense enhancement on post-contrast T1WI (92%) was significantly higher (p<0,05 0,01) than the frequency of moderate enhancement (8%) (Table 5, Figure 2).

The frequency of hyperintense findings on T2WI (88%) was significantly higher (p<0,05 0,01) compared to the frequency of hypointense findings (12%). Isointense and mixed findings were not recorded in the patients examined. (Table 6, Figure 3)

The frequency of hyperintense findings on FLAIR (96%) was significantly higher (p<0,05 0,01) than the frequency of isointense findings (4%). Hypointense and mixed findings were not

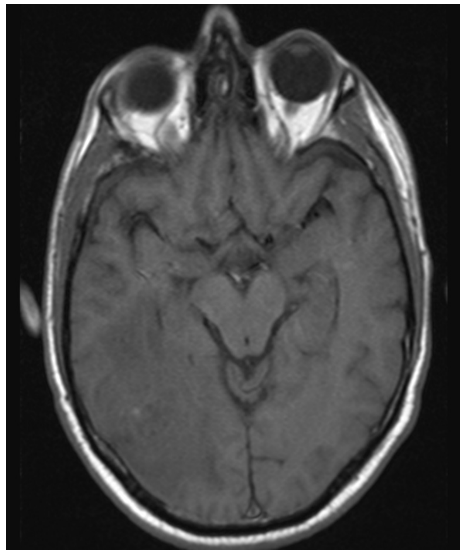

Figure 1. Abscess showing a hypointense signal on T1WI.

Table 5. Enhancement on post-contrast T1WI sequences MRI according to the histopathological diagnosis

Histopathological diagnosis	Enhancement on post-contrast T1WI sequences		
	None	Moderate	Intensive
Abscess	-	2 (8%)	23 (92%)

%- index of structure

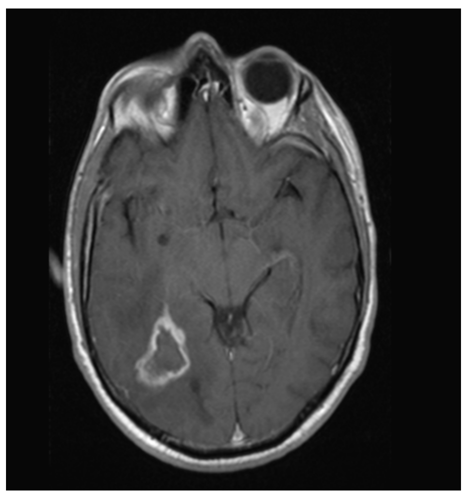

Figure 2. Abscess showing ring enhancement on post-contrast T1WI

Table 6. Signal intensity on T2WI sequences MRI according to the histopathological diagnosis

Histopathological diagnosis	Signal intensity on T2WI sequences			
	Isointense	Hypointense	Hyper-intense	Mixed
Abscess	3 (12%)	-	22 (88%)	-

%- index of structure

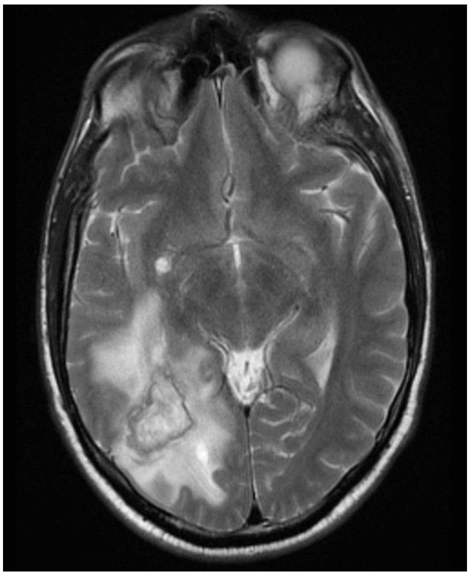

Figure 3. Abscess showing a hyperintense signal in the central part with a hypointense ring on T2WI

Table 7. Signal intensity on FLAIR sequences MRI according to the histopathological diagnosis

Histopathological diagnosis	Signal intensity on FLAIR sequences			
	Isointense	Hypo-intense	Hyperintense	Mixed
Abscess	1 (4%)	-	24 (96%)	-

%- index of structure

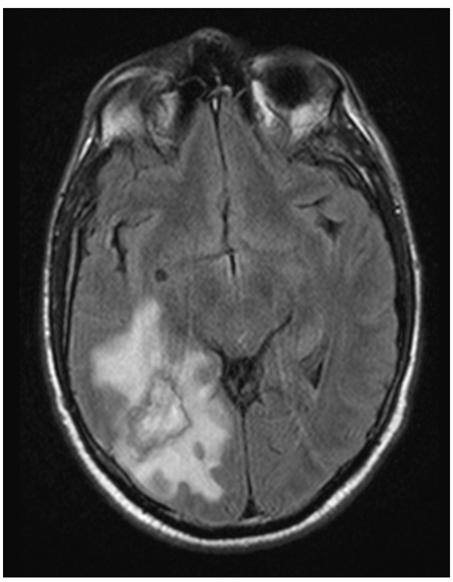

Figure 4. Abscess showing a hyperintense signal in the central part with a hypointense ring on FLAIR

Table 8. DW value (mm2/s) in an abscess

Histo-pathological diagnosis	Parameter				
	Xsr	SD	Med	Min	Max
Abscess	1526.67	33,85	1509.50	1500.00	1571.00

X_{sr} – arithmetic mean; SD – standard deviation, min - minimal value; max – maximal value; M-mediana.

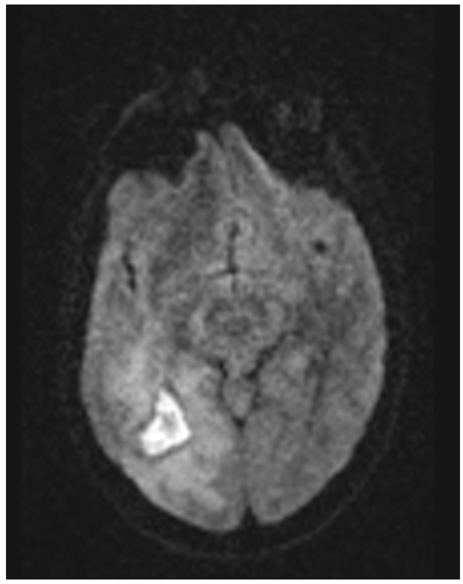

Figure 5. High signal intensity (restricted diffusion) of an abscess on DWI

reported in the patients examined. (Table 7, Figure 4)

Given the intensity of the signal, according to data obtained in our study, the majority of abscesses on T1WI showed hypointense (80%) and isointense signals (20%). On T2WI, the ma-jority of tumors (88%) showed hyperintense and isointense signals (12%). On FLAIR sequence, the majority of tumors showed hyperintense (96%) and isontense signals (4%). After the application of contrast medium, on post-contrast T1WI sequences, 92% of abscesses showed extensive enhancement and 8% moderate enhancement.

All 25 patients showed ring-shaped enhanced lesions after contrast agent administration on conventional T1W.

All 25 patients showed restricted diffusion in DWI (markedly hyperintense) (Table 8, Figure 5). On the quantitative assessment, the mean ADC value of the abscess cavity was 0.000164± 0.000019 mm2/s (Table 9, Figure 6), and all 25 patients showed low ADC values.

Discussion

Conventional MRI shows a pyogenic abscess as a round/oval-shaped mass with a central area of suppurative necrosis and peripheral capsule. The central necrotic area is hypointense relative to the cerebral white matter on T1WI and hyper-intense

Table 9. Abscess ADC values (mm2/s)

Histopathological diagnosis	Parameter				
	Xsr	SD	Med	Min	Max
Abscess	0.000164	0.000009	0.000011	0.000007	0.000012

X_{sr} – arithmetic mean; SD – standard deviation, min - minimal value; max – maximal value; M-mediana

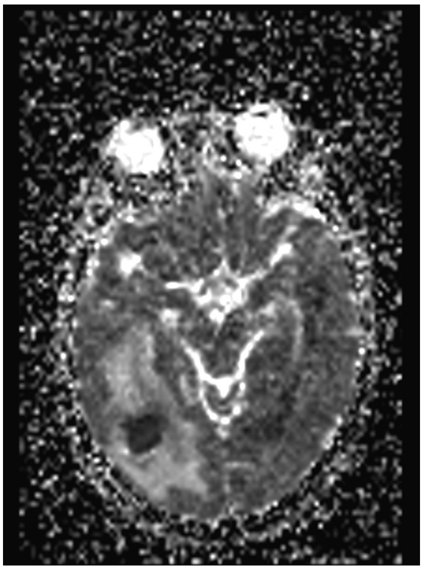

Figure 6. Abscess showing a low value on ADC map.

on T2WI. The external capsule typically appears as completely hypointense on T2WI and hyperintense on T1WI rim. The surrounding vasogenic oedema appears hypointense onT1WI and hyperintense on T2WI. On post-contrast T1WI, an abscess shows a typical peripheral thin and regular „ring enhancement" that corresponds to the T2 hypointense rim. It is important to note that the peripheral contrast enhancement can be stron-ger in the portion of the abscess closest to the grey matter, because of the stronger inflammatory reaction due to a better grey matter vascularization (1, 6).

It is difficult to differentiate between abscesses, necrotic glioblastomas and cystic metastases with conventional MRI. All can appear as expansile rim-enhancing masses with a prominent perifocal edema. DWI is an advanced MR technique used to add important physiological information to that obtained with conventional MRI. The measurements of these advanced techniques can be used to demonstrate the differences between cerebral abscesses and necrotic tumors (5).

DWI is based on the random movement of water molecules known as Brownian motion or translational motion. In DWI, the use of strong gradient pulses applied to conventional spin echo sequences causes freely moving water molecules to lose considerable signal intensity relative to the regions where water molecules remain stationary. Stationary water, water experiencing restricted movement or diffusion, will have a high signal intensity. The quantification of this degree of water motion is known as the ADC. The less the water moves (or the more its movement is restricted), the lower ADC is in differentiating degrees of water restriction within ring-enhancing lesions of various etiologies. Two of the major differential considerations in diagnosing ring-enhancing lesions on imaging are abscesses and necrotic tumors. These lesions resemble each other on conventional imaging (7).

As a rule, on both visual and quantitative assessment of DWI, all brain abscesses are hyperintense, secondary to restricted diffusion, with the corresponding low intensity on ADC map images (6). Low ADC values in abscesses and these low ADC values are attributable to the presence of pus. Pus is a highly viscous, thick, mucoid fluid that contains inflammatory cells, bacteria, proteinaceous exudate and fibrinogen (5, 7). All of these characteristics cause the restriction of translational motion that leads to a hyperintense signal on DWI and reduced ADC (7). High ADC values found in cystic or necrotic lesions were attributable to intra-cavity fluid that is less viscous than that found within abscesses. It consisted of necrotic tissue debris and contained fewer inflammatory cells than abscess fluid (5). The less complex environment of a necrotic or cystic tumor is less restrictive to the Brownian motion of water molecules compared with abscesses, resulting in a lower signal intensity on DWI and a higher ADC (7). The reason for restricted diffusion in brain abscesses is poorly understood. It has been postulated that restricted diffusion could represent the high viscosity of proteinaceous fluid with high concentrations of bacteria and inflammatory cells. The binding of water to large molecules, such as fibrinogen, in pus may also contribute to restricted water diffusion (6).

Server et al. (8) reported that brain abscess display high signal intensity on DWI with low ADC values. Ohba et al. (9) concluded that markedly increased signal intensity of a rim-enhancing brain mass on DW and a low ADC indicating restricted water diffusion are the features that should suggest the diagnosis of brain abscess.

Most of the patients with brain abscesses showed restricted diffusion and low ADC values in contrast to those with cystic and necrotic tumors, which showed free diffusion and high ADC values (5, 10). Ebisu et al. (11) showed that DWI had high signal intensity in a brain abscess. Kim et al. (12) reported a markedly hyperintense signal in abscesses, whereas necrotic or cystic brain tumors gave a hypointense signal. Our results agreed with many previously published studies who reported that all abscess cavities are hyperintense (restricted diffusion) in DWI and with low ADC values.

However, there has been an increasing number of reports in the literature of tumors mimicking abscesses on DWI. Indeed, cerebral lesions that have demonstrated high signal intensity on DWI include pyogenic super infection in a primary brain tumour and areas of radiation necrosis or necrotic metastasis, where it has been postulated that areas of sterile liquefaction necrosis may contain thick pus as the material with high concentrations of polymorphs. Haemorrhagic metastases have also been described as showing high signal on diffusion-weighted images. A lesion that is hyperintense on DWI and hypointense on corresponding ADC maps is likely to be an abscess (6).

In a study by Reiche et al. (13), who reported that all abscess cavities were hyperintense (restricted diffusion) on DWI and with low ADC values, 8 of 10 patients with necrotic glioblastoma and all 6 metastatic cysts revealed hypointensity (free diffusion) on DWI and high ADC values (2). Leuthardt et al. (14) in their study revealed that all abscess lesions were markedly hyperintense with a lower ADC value. Reddy et al. (15) in their study found that: 93 out of 97 patients with brain abscess were hyperintense on DWI with significantly low ADC values, compared with 48 non-abscess lesions. Another study reported that DWI correctly diagnosed 9/11 patients with brain accesses; the sensitivity, specificity of DWI in the group of brain abscesses were 94.7% and 81.8%, respectively (16). Hassan et al. (17) reported that DWI correctly classified patients into abscess or tumor groups in 46 patients (92%) out of the total of 50 patients, with 96.88% sensitivity and 83.33 % specificity.

Holtas et al. (18) suggested that early stage tumor necrosis with intracellular edema, but as yet no liquefaction, may produce DWI findings similar to those for the abscesses at the capsule stage.

Another study described hypointensity on DWI and high ADC in one out of 21 patients with pyogenic abscesses. This patient had already received antibiotic therapy for 21 days. The cause of increasing diffusion in abscess cysts might be the changes in pus composition, and probably reflects increasing pus liquefaction as a result of adequate antibiotic therapy (19).

DWI is also useful to improve the diagnosis of an intra-ventricular rupture of a pyogenic abscess. The purulent fluid appears hyperintense in DWI with low values on ADC maps in comparison with cerebrospinal fluid (1). A pyogenic abscess is typically hyperintense in DWI, with low values on ADC maps because this region of the central necrotic area contains a high concentration of proteins, bacteria, inflammatory cells, and debris, all of which may restrict water diffusion in this setting (3, 20). A similar mechanism is thought to be responsible for restricted water diffusion in the setting of pyogenic ventriculitis. A decrease of DWI signal intensity within a cerebral abscess after appropriate antibiotic therapy has been demonstrated in the literature (20). On the other hand, the findings are usually contrasting to these for necrotic-cystic tumors that usually have low signal on DWI, and high signal and high ADC values on ADC maps. However, a metastatic adenocarcinoma was recently reported with diffusion MRI features similar to those in an abscess (3). However, if an early and accurate diagnosis can be made, antibiotics can be successfully used to treat brain abscesses (5).

Conclusion

MRI and DWI with ADC seem to be a valuable tool in the diagnosis of brain abscesses.

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DIJAGNOSTIČKA VREDNOST DIFUZIJE I DIFUZIONOG KOEFICIJENTA U PREOPERATIVNOJ PROCENI APSCESA MOZGA

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Cilj rada bio je da se proceni dijagnostička vrednost magnetne rezonantne tomografije (MRT) i difuzije (DWI) u preoperativnoj proceni apscesa mozga.

Retrospektivnom studijom obuhvaćeno je 25 bolesnika sa apscesom mozga, pregledanih na aparatu jačine magnetnog polja 1,5T, sedam dana pre operacije, prema standranom protokolu, sa sledećim sekvencama: T1WI, T2WI, FLAIR, DWI i postkontrasna T1WI. Difuzija je izvedena korišćenjem single-shot spin-echo echo-planar pulsne sekvence sa vrednošću b=1000 s/mm. Podaci dobijeni iz DW su predstavljeni merenjem vrednosti difuzionog koeficijenta (ADC). ADC mapa je određena korišćenjem DP Tools softvera. ADC vrednosti su odražavale kvantitativnu vrednost regiona interesa unutar šupljine apscesa.

Većinu apscesa na T1WI sekvenci pokazuju hipointenzni (80%) i izointenzni signali (20%). Na T2WI sekvenci, većinu apscesa pokazuju hiperintenzni (88%) i izointenzni signali (12 %). Na FLAIR sekvenci, većinu apscesa pokazuju hiperintenzni (96%) i izointenzni signali (12%). Nakon aplikacije kontrasta, signifikantno intenzivno prebojavanje na T1WI sekvenci je prisutno u 92% apscesa, dok 8% pokazuje umereno prebojavanje. Svih 25 bolesnika sa apscesima pokazuju restrikciju difuzije na DWI sa niskim vrednostima ADC apscesne šupljine (0,000164±0,000019 mm2/s).

U dijagnostikovanju apscesa mozga značajno sredstvo predstavljaju MRI, DWI i ADC. *Acta Medica Medianae 2016;55(4):52-59.*

Ključne reči: *difuzija, magnetna rezonanca, apsces*