

EREKETI
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ORIGINAL ARTICLE

Determination of hemorrhagic transformation risk in acute ischemic cerebrovascular disease: The relationship between ADC values and GRE hemo sequence microhemorrhage

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A vérzéses transzformáció kockázatának meghatározása akut ischaemiás agyérbetegségben: Az ADC-értékek és a GRE hemoszekvencia-mikrovérzés összefüggése

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Background and purpose – To determine the risk of hemorrhagic transformation in patients with acute ischemic cerebrovascular disease, we investigated the relationship between Apparent Diffusion Coefficient Magnetic Resonance Imaging values measured within the infarct area and microbleeds observed on Gradient Echo Sequence Magnetic Resonance Imaging.

Methods – A total of 172 patients who were hospitalized to the Neurology Clinic of the Istanbul Provincial Directorate of Health Erenkoy Mental and Nervous Diseases Training and Research Hospital between June 2019 and March 2020 were included in this cross-sectional study. The patients were classified according to their demographic and clinical characteristics, by age, gender, hypertension, diabetes mellitus, smoking, and alcohol use. In the Cranial Magnetic Resonance Imaging taken in the application for the diagnosis of acute ischemic cerebrovascular disease, the infarction area in Apparent Diffusion Coefficient sequences with the Region of Interest value and the relationship between microhemorrhage observed in Gradient Echo hemo-sequence was evaluated in Magnetic Resonance Imaging applied between 3-7 days. While calculating spherical Region of Interest values, 5 Region of Interest values were obtained for lesions larger than 1.5x1.5 cm, and their arithmetic mean was obtained, and single spherical Region of Interest value was taken for smaller ones. Apparent Diffusion Coefficient Magnetic Resonance Imaging Region of Interest

Háttér és cél – Az akut ischaemiás cerebrovascularis betegségben szenvedő betegeknek a vérzéses transzformáció kockázatának meghatározása érdekében mágneses rezonancia-képalkotással (MRI) vizsgáltuk az infarktus területén belül mért Apparent Diffusion Coefficient (ADC-) értékek és a gradiens echo szekvencián (MRI) megfigyelt mikrovérzések közötti kapcsolatot.

Módszerek – A keresztmetszeti vizsgálatba összesen 172 beteget vontunk be, akiket 2019 júniusa és 2020 márciusa között az Isztambul Tartományi Egészségügyi Igazgatóság Erenkoy Mentális és Idegbetegségek Oktatási és Kutatási Kórház Neurológiai Klinikáján kezeltek. A betegeket demográfiai adatok és klinikum alapján csoportosítottuk, figyelembe véve az életkort, nemet, magas vérnyomást, cukorbetegséget, dohányzást és alkoholfogyasztást. Az akut ischaemiás cerebrovascularis betegség diagnosztizálására alkalmazott, a 3. és 7. nap között elvégzett koponya-MRI-n értékeltük az ADC-térképen látott értékek és a gradiens echo szekvencián megfigyelt mikrovérzések közötti kapcsolatot. Az ADC-értékek alapján két csoportot határoztunk meg $< 500 \times 10^{-6} \text{ mm}^2/\text{s}$ és $> 500 \times 10^{-6} \text{ mm}^2/\text{s}$ értékekkel.

Eredmények – Azon betegcsoport esetében, akinél $500 \times 10^{-6} \text{ mm}^2/\text{s}$ -nél alacsonyabb ADC-értéket mértünk, szignifikánsan nagyobb volt ($p: 0,001$) a mikrovérzések valószínűsége, nemcsak az infarktus területén, hanem az agyállomány más területein is ($p: 0,001$). A mikrovérzéssel rendelkező betegeknél az újabb mikrovérzések megjelenésének

mean values were divided into 2 groups as $<500 \times 10^{-6} \text{ mm}^2/\text{s}$ and $>500 \times 10^{-6} \text{ mm}^2/\text{s}$.

Results – Patients in the group with Apparent Diffusion Coefficient Region of Interest mean values below $500 \times 10^{-6} \text{ mm}^2/\text{s}$, had a significantly higher probability for microhemorrhage observed in Gradient Echo Sequence Magnetic Resonance Imaging ($p: 0.001$) and also more likely to experience microhemorrhage in other areas, which was statistically significant ($p: 0.001$). The probability of another micro-bleeding observed in patients with microhemorrhage Gradient Echo Sequence Magnetic Resonance Imaging was also statistically significant ($p: 0.001$). The risk of microbleeding in areas other than ischemia was also found to be significantly higher in patients with microbleeding in the ischemia area in Gradient Echo Sequence Magnetic Resonance Imaging.

Conclusion – In our study, a statistically significant relationship was found between the microhemorrhage in the infarct area and the Apparent Diffusion Coefficient Region of Interest values. When the literature was reviewed, no such study was found to determine the risk of bleeding.

Keywords: apparent diffusion coefficient, gradient echo, hemorrhagic transformation, ischemic cerebrovascular disease, microhemorrhage

valószínűsége szignifikánsan magasabb volt ($p: 0.001$).

Következtetés – Vizsgálatunkban statisztikailag szignifikáns összefüggést találtunk az infarktus területén lévő mikrovérzések és az ADC-térkép értékei között. A vérzés kockázatának becslésére irányuló hasonló tanulmányt az irodalomban ez idáig nem találtunk.

Kulcsszavak: Apparent Diffusion Coefficient, grádiens echo szekvencia, haemorrhagiás transzformáció, ischaemiás agyérbetegség, mikrovérzés

The development of secondary bleeding in the infarction area after ischemic cerebrovascular disease is called hemorrhagic transformation (HT). The incidence of HT has been found to be different in many studies. In a study conducted with 527 people diagnosed with ischemic cerebrovascular disease, this rate was found to be 17.7%, while in another study conducted in Italy, this rate varied between 8.5% and 30%^{1, 2}, and the incidence of HT in the Asian population was 43%³. HT is one of the natural consequences of ischemic stroke.

Hemorrhage can range from silent, gyriform petechial hemorrhage to parenchymal hematoma with mass effect. When combined with the methods we use in treatment, HT can both increase and lead to morbidity and mortality⁴. Reducing the risk of HT is one of the goals of stroke treatments. HT is most common in the first 3-7 days after stroke^{5, 6}.

Many factors cause the development of HT: clinical risk factors, stroke symptom severity, high blood glucose level, advanced age, time to start of treatment, low platelet level, hypertension, history of congestive heart disease, and car-

dioembolic etiology⁷. The gold standard imaging method in the diagnosis of ischemic stroke is Diffusion Weighted Imaging (DWI) magnetic resonance imaging (MRI). Acute ischemic cerebrovascular disease is associated with increased intensity on DWI as well as low Apparent Diffusion Coefficient (ADC) intensity values, which are assumed to be due to changes in energy expenditure, changes in microcirculation, tissue acidosis and cytotoxic edema⁸.

In recent studies, MRI findings including risk factors for HT are summarized as follows: a) DWI lesion is greater than 1/3 of the Middle Cerebral Artery (MCA) area, b) Perfusion Weighted Imaging (PWI) lesion is greater than 100 cc and T max >8, c) Cerebral blood flow is less than 0.18 in MR perfusion examination, d) Low ADC values (between $300 \times 10^{-6} \text{ mm}^2/\text{s}$ and $500 \times 10^{-6} \text{ mm}^2/\text{s}$), e) Visible transcerebral veins on T2 examinations, f) Moderate or advanced deep white matter lesions, g) Early parenchymal enhancement, h) Increased permeability in T1 scans with dynamic contrast^{9, 10}.

Gradient Echo (GRE) imaging is a T2 imaging method that is sensitive to signal loss due to heterogeneity in

the magnetic field. GRE is also sensitive to bleeding and hemorrhagic areas that appear hypointense on GRE imaging¹¹. While GRE has the same sensitivity as Computed Tomography (CT) in hyperacute hemorrhages, it is more sensitive than CT in subacute or chronic hemorrhages¹².

While previous studies have shown that GRE has high sensitivity in determining the risk of HT after ischemic cerebrovascular disease, new studies have shown that ADC examinations also have high sensitivity in terms of the risk of hemorrhagic transformation¹³.

The aim of this study is to evaluate ADC values and GRE imaging in acute ischemic stroke patients without symptomatic HT and also not receiving acute thrombolytic therapy. We also investigated to find out whether any relationship between the observed microbleeding areas existed.

Patients and methods

This investigation was approved by the ethical committee of the Neurology Clinic of the Istanbul Provincial Directorate of Health Erenkoy Mental and Nervous Diseases Training and Research Hospital (No. 30, 06.05.2019). Written informed consent was obtained from the patients.

Between June 2019 - March 2020, people aged 18 years and over, who were interned with the diagnosis of acute ischemic cerebrovascular disease in The Neurology Clinic of the Istanbul Provincial Directorate of Health Erenkoy Mental and Nervous Diseases Training and Research Hospital and were not suitable for intravenous thrombolytic therapy and/or mechanical thrombectomy treatment were included in the study.

A total of 172 patients who had single hemisphere and single artery infarction and used the same single antithrombotic therapy during follow-up were included in the study. Age, gender, arterial area (anterior or posterior system infarction), localization (right or left side), and risk factors (hypertension, diabetes mellitus, smoking, alcohol use) were recorded. Routine biochemical and hematological blood tests, carotid vertebral artery doppler ultrasonography, cranial and cervical CT angiography, electrocardiography, echocardiography, holter electrocardiography tests were performed on all patients. Patients who underwent intravenous thrombolytic therapy and/or mechanical thrombectomy, who did not apply within the first 24 hours from the onset of the complaint, who could not undergo a control cranial MRI, who had cardioembolism in the etiology, and who had infarction in multiple artery areas were excluded from the study.

All MRI examinations were performed with an MRI 1.5T MR scanner (Tim; Siemens, Erlangen, Germany) in accordance with the protocol for stroke. In DWI MRI taken at the time of initial diagnosis and 3-7 days after the event, axial DWI (maximum b factor, 0-1000 s/mm²) and ADC were present. On the other hand, the follow-

ing sequences were obtained in the cranial MRI taken on the following days: Axial and sagittal T1-weighted spin-echo (TR/TE, 500/20 ms), axial and coronal T2, axial FLAIR (Fluid Attenuated Inversion Recovery) (TR/TE/TI, 8150/130/2200 ms) axial GRE (TR/TE: 50, 50/40, FA: 15), axial DWI (maximum b factor, 0-1000 s/mm²) and ADC at 2 mm slice thickness. All images other than GRE were 5 mm thick.

In the MRI ADC sequence taken at the time of diagnosis, an area that included the ischemic area but did not extend to the external healthy tissue (targeting the center of the infarction) was identified in patients diagnosed with acute ischemic cerebrovascular disease; beside, inclusion criteria and spherical ROI mean values were examined.

ROI mean values were calculated automatically in mm²/s and divided into 2 groups: <500x10⁶ mm²/s and >500x10⁶ mm²/s. While calculating the spherical ROI values, 5 spherical ROI mean values were obtained for lesions larger than 1.5x1.5 cm, and their arithmetic average was taken. For smaller ones, a single spherical ROI mean value (an area of 10 mm²) was taken.

The relationship between the presence and amount of microbleeding on GRE MRI taken 3 to 7 days after the stroke and ADC ROI mean values were examined. In addition, the relationship between ADC ROI mean values and microbleeds in areas outside the infarct area, and microbleeds observed in the infarct area in GRE were examined.

The relationship between age, gender, arterial area (anterior or posterior system infarction), localization (right or left side) and risk factors (hypertension, diabetes mellitus, smoking, alcohol use) and ADC ROI mean values were investigated.

Statistical analysis

NCSS (NumberCruncher Statistical System) 2007 (Kaysville, Utah, USA) program was used for statistical analysis. While evaluating the study data, the distribution of the data was evaluated with the Shapiro-Wilk Test as well as the descriptive statistical methods (Mean, Standard Deviation, Median, Frequency, Ratio, Minimum, Maximum). The Mann-Whitney U Test was used to compare the quantitative data between two independent groups that did not show normal distribution. Chi-Square test was used for the analysis of qualitative data. Significance was evaluated at p<0.01 and p<0.05 levels.

Results

The study was carried out between June 2019 and March 2020 at The Neurology Clinic of the Istanbul Provincial Directorate of Health Erenkoy Mental and Nervous Diseases Training and Research Hospital. The study was conducted with a total of 172 patients, aged between 34

and 92 with the diagnosis of acute ischemic cerebrovascular disease. Patients who had an acute intracerebral infarction area in a single hemisphere and with a single artery, had no proven cardioembolic etiology, and received the same single antithrombotic treatment were included in the study. Patients who underwent intravenous thrombolytic therapy and/or mechanical thrombectomy, who did not apply within the first 24 hours from the onset of the complaint, who could not undergo a control cranial MRI, who had cardioembolism in the etiology, and who had infarction in multiple artery areas were excluded from the study.

The mean age of the patients was 67.42 ± 12.40 years, 50% (n=86) of them were female. Anterior system infarction was present in 67.4% (n=116) of the patients, and posterior system infarction was present in 32.6% (n=56). While 58.7% (n=101) of these infarct areas were located in the left hemisphere, 41.3% (n=71) were in the right hemisphere. Hypertension was present in 82.6% (n=142) of the patients and diabetes mellitus (DM) in 40.7% (n=70), history of smoking in 20.9% (n=36) and history of alcohol use in 1.7% (n=3) (Table 1).

ADC ROI mean values were examined, and the values were divided into two groups: $<500 \times 10^{-6} \text{ mm}^2/\text{s}$ and $>500 \times 10^{-6} \text{ mm}^2/\text{s}$. There was no significant difference between the two groups in terms of mean age, infarct site (anterior or posterior system), infarct localization (left or right), presence of hypertension, DM, smoking, alcohol use ($P>0.05$) (Table 2).

When demographic characteristics were analyzed according to ADC ROI mean values, ADC ROI mean value was found to be significantly higher in patients with left infarct side ($p=0.032$; $p<0.05$). No significant difference was found between the other demographic characteristics examined (Table 3).

A significant correlation was found between ADC ROI mean values and the presence of GRE microbleeds, the number of GRE microbleeds, and the presence of other microbleeds ($p=0.001$; $p<0.01$) (Table 4).

The patients were followed up and the relationship between the ADC ROI mean values, the presence of GRE microbleeding and the presence of HT were examined. Significantly more hemorrhagic transformation was observed in the group with $<500 \times 10^{-6} \text{ mm}^2/\text{s}$ and the group with microbleeding ($p=0.001$; $p<0.01$) (Table 5 and 6).

Table 1. Clinical characteristics of the patients

Age (years)	67.42 ± 12.40
Sex (n) F:M	86:86
Anterior system infarction (n)	116
Posterior system infarction (n)	56
Left hemisphere (n)	101
Right hemisphere (n)	71
Hypertension (n)	142
Diabetes mellitus (n)	70
Smoking (n)	36
Alcohol use (n)	3

Table 2. Relation of ADC ROI mean values with general characteristics

		ADC ROI	
		ADC $< \times 10^{-6} \text{ mm}^2/\text{s}$	$>500 \times 10^{-6} \text{ mm}^2/\text{s}$
Age ^o	N	43	129
	Med $\pm$ S.d	67.56 ± 12.3	67.37 ± 12.49
	Min-max (Median)	41–92 (67)	34–92 (70)
	p ^o	0.915	
Gender	Female	17 (39.5%)	69 (53.5%)
	Male	26 (60.5%)	60 (46.5%)
	p	0.113	
Infarct area	Anterior system	26 (60.5%)	90 (69.8%)
	Posterior system	17 (39.5%)	39 (30.2%)
	p	0.260	
Infarct side	Left	21 (48.8%)	80 (62%)
	Right	22 (51.2%)	49 (38%)
	p	0.128	
Hypertension	–	7 (16.3%)	23 (17.8%)
	+	36 (83.7%)	106 (82.2%)
	p	0.510	
Diabetes mellitus	–	24 (55.8%)	78 (60.5%)
	+	19 (44.2%)	51 (39.5%)
	p	0.591	
Smoking	–	31 (72.1%)	105 (81.4%)
	+	12 (27.9%)	24 (18.6%)
	p	0.194	
Alcohol use	–	41 (95.3%)	128 (99.2%)
	+	2 (4.7%)	1 (0.8%)
	p	0.155	

^o Is analysed with Mann-Whitney U test, ^o $p<0.05$, ^{oo} $p<0.001$, rest is analyzed with Chi-Square test ** $p<0.01$

Discussion

Stroke is defined as sudden onset of neurological dysfunction lasting 24 hours or longer. Ischemic cerebral infarcts constitute approximately 80% of all cerebrovascular events¹⁴. Secondary bleeding that develops within the infarct area after ischemic cerebrovascular disease is called hemorrhagic transformation (HT)¹⁵. In the study of *Terruso et al.*, HT was observed at a rate of 12% in acute ischemic stroke patients who did not receive thrombolytic therapy¹⁶, *Choi et al.* found this rate to be 11.9% in patients who received thrombolytic therapy¹⁷. *Celik et al.* from Turkey observed HT in 40.7% of patients with acute MCA infarction¹⁸. Early recognition of HT is important for treatment and prognosis¹⁹.

In a meta-analysis conducted in Italy, 47 different studies and a total of 8242 patients were examined. The clinical risk factors of these patients for HT were: high blood pressure and blood glucose level, high platelet count and matrix metalloproteinase level, antiplatelet, anticoagulant or thrombolytic therapy²⁰. In another study in France, the severity of the initial clinical deficit in terms of conditions predisposing to HT increased the risk approximately 2.5 times, the presence of early ischemic findings in CT examination increased the risk approximately 3.5 times, and intravenous thrombolytic therapy also given to people aged 65 and over has been shown to increase approximately 3.6 times²¹. *Choi et al.* have showed that the most common etiological factor in HT patients was atherosclerosis (36.2%)¹⁷. Among the types of HT, arterial hypertension was found to be a risk factor, especially for parenchymal hematoma formation^{22, 23}.

In a study conducted in 2017 *Ge et al* examined 199 patients for the risk of developing HT before and after intravenous thrombolytic therapy, and it was observed that AF was a risk factor for HT with NIHSS 2 hours after thrombolytic therapy, and no significant relationship was found with the admission NIHSS²⁴. Cardioembolism is the etiological condition frequently accused in determining the risk of HT, and cardioembolism is generally associated with large infarcts and serious clinical conditions². In our study, when the patients were classified according to their demographic characteristics – age, gender, infarct area, infarct side, hypertension, DM, smoking and alcohol use – no difference was found between the groups, and this increases the reliability of the study in

Table 3. Relation of general characteristics with ADC ROI mean values

		N	Med ± S.d	Min-max (Median)	p
Gender	Female	86	609.39 ± 150.08	346.28–1067.48 (594.92)	0.319
	Male	86	587.34 ± 170.04	258.67–1146.77 (581.87)	
Infarct area	Anterior system	116	608.78 ± 165.24	286.14–1146.77 (596.15)	0.199
	Posterior system	56	576.79 ± 148.61	258.67–1067.48 (583.24)	
Infarct side	Left	101	621.85 ± 177.53	258.67–1146.77 (610.86)	0.032*
	Right	71	564.96 ± 125.73	309.59–977.17 (564.15)	
Hypertension	–	30	600.81 ± 175.1	258.67–1054.9 (584.3)	0.960
	+	142	597.85 ± 157.64	286.14–1146.77 (589.38)	
Diabetes mellitus	–	102	611.17 ± 170.96	258.67–1114.39 (596.15)	0.330
	+	70	579.71 ± 142.45	286.14–1146.77 (580.15)	
Smoking	–	136	606.23 ± 168.37	258.67–1146.77 (596.15)	0.235
	+	36	568.66 ± 122.6	286.14–916.4 (576.71)	
Alcohol use	–	169	600.76 ± 159.17	258.67–1146.77 (589.5)	0.240
	+	3	463.5 ± 201.51	286.14–682.62 (421.74)	

Mann-Whitney U test *p<0.05, **p<0.001

terms of examining the risk of HT through the ADC values.

Radiological findings that may predispose to HT, such as cortical infarction, massive cerebral infarction, delayed vascular recanalization, and significant cerebral microbleeding, were reported as early CT findings²¹. Among the early CT findings, loss of density, especially in the lentiform nucleus and insular region, appears to be associated with an increased risk of HT²⁵. Since the appearance of hyperdense OSA image is thought to be frequently associated with high NIHSS at the time of admission, the risk of HT was found to be high in these patients²⁶.

A study in the USA in 2002 showed that the ADC values for HT observed after ischemic stroke are also useful in determining the risk¹³. In this experimental study with an embolic ischemic infarct mouse model, 45 mice were examined and the risk of HT after thrombolytic therapy

Table 4. Relationship between GRE microbleeding, GRE microbleeding counts, other microbleeds and hemorrhagic transformation

		ADC ROI mean	
		ADC < $\times 10^{-6}$ mm ² /s	>500 $\times 10^{-6}$ mm ² /s
GRE microbleeding	–	11 (25.6%)	127 (98.4%)
	+	32 (74.4%)	2 (1.6%)
	p	0.001**	
GRE microbleeds count	0	11 (25.6%)	127 (98.4%)
	0–5	6 (14.0%)	2 (1.54%)
	5–10	20 (46.5%)	0 (0.0%)
	Max	6 (14.0%)	0 (0.0%)
	p	0.001**	
Other microbleeds	–	35 (81.4%)	128 (99.2%)
	+	8 (18.6%)	1 (0.8%)
	p	0.001**	
Hemorrhagic Transformation	–	33 (19.2%)	128 (74.4%)
	+	10 (5.8%)	1 (0.6%)
	p	0.001**	

Chi-Square test **p<0.01

Table 5. Relationship between ADC ROI mean and hemorrhagic transformation

		Hemorrhagic transformation		p
ADC ROI mean		–	+	0.001**
	<500 $\times 10^{-6}$ mm ² /s	33 (19.2%)	10 (5.8%)	
	>500 $\times 10^{-6}$ mm ² /s	128 (74.4%)	1 (0.6%)	

Chi-Square test **p<0.01

Table 6. Relationship Between GRE microbleeding and hemorrhagic transformation

		Hemorrhagic transformation		p
GRE micro-bleeding		–	+	0.001**
	Yok	138 (80.2%)	0 (0%)	
	Var	23 (13.4%)	11 (6.4%)	

Chi-Square test **p<0.01

was evaluated. There was no significant difference between the groups in terms of physiological characteristics. In the group with higher mean arterial pressure, HT was more frequently observed after thrombolytic therapy, cortical bleeding was observed in 12 animals, basal gan-

glia bleeding was observed in 3, and both areas were affected in 5 animals. This study showed that ADC values reach their lowest point in 8-32 hours and maintain this low level for 72 hours. HT, on the other hand, is at its maximum level, especially in the first 3-7 days of stroke. At the same time, it has been shown in this study that HT is observed more frequently in patients with significantly lower ADC values (limit value: 550 mm²/s). ADC examination is thought to be a very important predictor for determining HT risk. The lower the ADC value, the greater the risk of bleeding. Within the infarct area, the area most responsible for the hemorrhagic transformation is the central area and this area has the lowest ADC value; that is, the area most susceptible to tissue necrosis is the central area.

In another study by *Chen et al.* in 2018, 58 ischemic stroke patients were examined and patients were evaluated with MRI within 2 weeks after admission²⁷. There were 40 men and 18 women in the study, the age range was between 35 and 89. When patients were divided into groups with and without HT in terms of age, gender, hypertension, DM, smoking and alcohol use, no statistically significant difference was found between them. In patients with ischemic cerebrovascular disease, in the group with HT minimum ADC values were found to be between 250 $\times 10^{-6}$ mm²/s and 470 $\times 10^{-6}$ mm²/s, and ADC mean values between 350 $\times 10^{-6}$ mm²/s and 530 $\times 10^{-6}$ mm²/s. In the group without HT, the minimum ADC values were found to be between 390 $\times 10^{-6}$ mm²/s and 740 $\times 10^{-6}$ mm²/s, and the ADC mean values between 460 $\times 10^{-6}$ mm²/s and 790 $\times 10^{-6}$ mm²/s. Minimum and mean ADC values were significantly lower in the HT group than in the other group (p<0.05). In this study, the cut-off value of 500 $\times 10^{-6}$ mm²/s was shown to have high sensitivity and specificity for HT observed after ischemic cerebrovascular disease²⁷. In our study, when hypertension, DM, smoking and alcohol use were also examined, no statistically significant difference was found between the groups with and without HT.

In the study of *Tong et al.*, 17 patients with ischemic stroke were examined with ADC values in the first 8 hours²⁸. Control imaging was performed within 1 week. The mean age was 70 $\pm$ 10 years, and 9 of the patients were male and 8 were female. Patients received

intravenous thrombolytic therapy according to their suitability. In total, 11 patients received thrombolytic therapy, 6 of them in the HT group and 5 in the other group. ADC value was found to be significantly lower in patients with HT compared to the other group. ADC mean values were $<550 \times 10^{-6} \text{ mm}^2/\text{s}$ in the HT group, and it was found to be higher in the other group²⁸. For the ADC mean value, we determined $500 \times 10^{-6} \text{ mm}^2/\text{s}$ as the cut-off value; in our study, the minimum ADC in the group with microbleeding in the GRE examination values were $102 \times 10^{-6} \text{ mm}^2/\text{s}$ and $551 \times 10^{-6} \text{ mm}^2/\text{s}$, and ADC mean values were between $258.67 \times 10^{-6} \text{ mm}^2/\text{s}$ and $690.27 \times 10^{-6} \text{ mm}^2/\text{s}$. Microbleeding on GRE in the non-observed group, the minimum ADC values were found to be between $244 \times 10^{-6} \text{ mm}^2/\text{s}$ and $889 \times 10^{-6} \text{ mm}^2/\text{s}$, and the ADC mean values were between $371.43 \times 10^{-6} \text{ mm}^2/\text{s}$ and $980.96 \times 10^{-6} \text{ mm}^2/\text{s}$.

Our study is the first to examine the relationship between ADC value and GRE microbleeding in addition to examining whether HT developed in these patients. ADC mean value was between $314.41 \times 10^{-6} \text{ mm}^2/\text{s}$ and $624 \times 10^{-6} \text{ mm}^2/\text{s}$ in the developing HT group. Microbleeding observed in GRE hemosequence examina-

tion was found to be a risk factor for HT, and it was also shown that HT was more common in infarcts with a lower ADC value. The role of these two MRI methods in revealing the risk of HT has been perceived critical – the aim of this study was to examine the relationship between ADC MRI and GRE MRI in terms of the risk of developing HT.

Conclusion

When the literature is examined, our study is the first to evaluate microbleeding, which poses a risk for HT, together with ADC values. Calculation of the ADC values of the infarct area is easy with cranial MRI examination and does not require an additional examination. We think that it is an important marker in determining the risk of microbleeding or HT during stroke treatment and follow-up, and is very important in terms of prognosis.

CONFLICT OF INTEREST – None of the authors have any conflict of interest.

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