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Prediction of the functional outcome of cerebral ischemic supratentorial stroke acute period on the basis of spectral analysis of the brain bioelectrical activity

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The purpose of this study was to determine the most informative parameters of the brain bioelectrical activity spectral analysis for the functional outcome of cerebral ischemic supratentorial stroke (CISS) acute period prediction.

Materials and methods. Prospective, cohort and comparative study was conducted among 103 patients in CISS acute period (61 men and 42 women, mean age was 67.7 ± 0.8 years). Electroencephalographic study was conducted on the 2nd–3rd day of the disease with the use of 19-channel electroencephalographic scanner. The values of absolute spectral rhythm power of delta (0.5–4.0 Hz), theta (4–8 Hz), alpha (8–13 Hz), beta (13–35 Hz), theta1 (4–6 Hz), theta2 (6–8 Hz), alpha1 (8–10 Hz), alpha2 (10–13 Hz), beta1 (13–25 Hz) and beta2 (25–35 Hz) bands in the affected hemisphere (AH) and intact hemisphere (IH) were determined. The relative spectral rhythm power (RSRP), fronto-occipital rhythm gradient (FORG) and the severity of interhemispheric rhythm asymmetry (IHRA) were calculated. The functional outcome of the disease acute period was assessed on the 21st day on the basis of the modified Rankin Scale (mRS), while the value of mRS score >3 was considered as an unfavourable functional outcome.

Results. Unfavourable functional outcome of the CISS acute period was registered in 46 (44.6 %) patients. In accordance with the data of multivariate regression analysis it was determined that RSRP of delta band in the IH (OR 95 % CI = 1.31 (1.13–1.52), P = 0.0004), FORG of alpha band in the AH (OR 95 % CI = 29.07 (1.86–455.15), P = 0.0224) and IHRA of alpha band (OR 95 % CI = 0.01 (0.0001–0.80), P = 0.0402) were independently associated with functional outcome of the CISS acute period. The RSRP of delta band in the IH > 18.4 % (Se = 87.0 %, Sp = 87.7 %, AUC 95 % CI = 0.94 (0.87–0.98), P < 0.0001), FORG of alpha band in the AH >-0.066 (Se = 67.4 %, Sp = 70.0 %, AUC 95 % CI = 0.74 (0.65–0.82), P<0.0001) and IHRA alpha band ≤-0.066 (Se = 60.9 %, Sp = 70.2 % AUC 95 % CI = 0.66 (0.56–0.75), P < 0,0039) were the optimal cut-off values as for the unfavourable functional prognosis of CISS acute period.

Conclusions. The RSRP of delta band in the IH, FORG of alpha band in the AH and the IHRA of alpha band are the most informative parameters of the brain bioelectrical activity spectral analysis for the prediction of the functional outcome of cerebral ischemic supratentorial stroke acute period.

Ключові слова:
інфаркт мозку, електроенцефалографія, прогноз.

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Прогнозування функціонального виходу гострого періоду мозкового ішемічного супратенторіального інсульту на підставі спектрального аналізу біоелектричної активності головного мозку

А. А. Кузнєцов

Мета роботи – визначити найбільш інформативні параметри спектрального аналізу біоелектричної активності головного мозку для прогнозування функціонального виходу гострого періоду мозкового ішемічного супратенторіального інсульту (МІСІ).

Матеріали та методи. Виконали проспективне, когортне, порівняльне дослідження 103 пацієнтів у гострому періоді МІСІ (61 чоловік і 42 жінки, середній вік – 67,7 ± 0,8 року). Рівень неврологічного дефіциту оцінювали за National Institute of Health Stroke Scale. Електроенцефалографічне дослідження виконали на 2–3 добу захворювання. Окремо для ураженої півкулі (УП) і неураженої півкулі (НП) встановлювали значення абсолютної спектральної потужності, відносної спектральної потужності ритмів (ВСПР) дельта (0,5–4 Гц), тета (4–8 Гц), альфа (8–13 Гц), бета (13–35 Гц) діапазонів, тета1 (4–6 Гц), тета2 (6–8 Гц), альфа1 (8–10 Гц), альфа2 (10–13 Гц), бета1 (13–25 Гц) та бета2 (25–35 Гц) піддіапазонів, а також лобно-потиличні градієнти (ЛПГР) і вираженість міжпівкульної асиметрії ритмів (МПАР). Функціональний вихід гострого періоду МІСІ оцінювали на 21 добу захворювання за модифікованою шкалою Ренкіна (мШР), при цьому несприятливим функціональним наслідком вважали значення >3 бали за мШР.

Результати. Несприятливий функціональний вихід зареєстрували у 46 (44,6 %) пацієнтів. На підставі мультиваріантного логістичного регресійного аналізу визначено параметри спектрального аналізу електроенцефалографічного патерну, які незалежно асоційовані з функціональним виходом гострого періоду МІСІ: ВСПР дельта-діапазону ІП (ВШ 95 % ДІ = 1,31 (1,13–1,52), p = 0,0004), ЛПГР альфа-діапазону УП (ВШ 95 % ДІ = 29,07 (1,86–455,15), p = 0,0224) та МПАР альфа-діапазону (ВШ 95 % ДІ = 0,01 (0,0001–0,80), p = 0,0402), при цьому оптимальними точками відсікання значень названих показників для верифікації функціонального прогнозу є ВСПР дельта-діапазону ІП > 18,4 % (Se = 87,0 %, Sp = 87,7 %, AUC 95 % ДІ = 0,94 (0,87–0,98), p < 0,0001), ЛПГР альфа-діапазону УП >-0,066 (Se = 67,4 %, Sp = 70,0 %; AUC 95 % ДІ = 0,74 (0,65–0,82), p < 0,0001) та МПАР альфа-діапазону ≤-0,066 (Se = 60,9 %, Sp = 70,2 %, AUC 95 % ДІ = 0,66 (0,56–0,75), p < 0,0039).

Висновки. Найбільш інформативними параметрами спектрального аналізу біоелектричної активності головного мозку для визначення функціонального прогнозу завершення гострого періоду МІСІ є відносна спектральна потужність ритмів дельта-діапазону інтактної півкулі, лобно-потиличний градієнт ритмів альфа-діапазону ураженої півкулі та міжпівкульна асиметрія ритмів альфа-діапазону.

Прогнозирование функционального исхода острого периода мозгового ишемического супратенториального инсульта на основании спектрального анализа биоэлектрической активности головного мозга

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Ключевые слова: инфаркт мозга, электроэнцефалография, прогноз.

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Цель работы – определить наиболее информативные параметры спектрального анализа биоэлектрической активности головного мозга для прогнозирования функционального исхода острого периода мозгового ишемического супратенториального инсульта (МИСИ).

Материалы и методы. Проведено проспективное, когортное, сравнительное исследование 103 пациентов в остром периоде МИСИ (61 мужчина и 42 женщины, средний возраст – 67,7 ± 0,8 года). Уровень неврологического дефицита оценивали по National Institute of Health Stroke Scale. Электроэнцефалографическое исследование проводили на 2–3 сутки заболевания. Отдельно для пораженного полушария (ПП) и непораженного полушария (НП) определяли значения абсолютной спектральной мощности, относительной спектральной мощности ритмов (ОСМР) дельта (0,5–4 Гц), тета (4–8 Гц), альфа (8–13 Гц), бета (13–35 Гц) диапазонов, тета1 (4–6 Гц), тета2 (6–8 Гц), альфа1 (8–10 Гц), альфа2 (10–13 Гц), бета1 (13–25 Гц) и бета2 (25–35 Гц) поддиапазонов, а также лобно-затылочные градиенты (ЛЗГР) и выраженность межполушарной асимметрии ритмов (МПАР). Функциональный исход острого периода МИСИ оценивали на 21 сутки заболевания по модифицированной шкале Рэнкина (мШР), при этом в качестве неблагоприятного функционального исхода рассматривали значение >3 балла по мШР.

Результаты. Относительно неблагоприятный функциональный исход зарегистрирован у 46 (44,6 %) пациентов. На основании мультивариантного логистического регрессионного анализа определили параметры спектрального анализа ЭЭГ-паттерна, которые независимо ассоциированы с функциональным исходом острого периода МИСИ: ОСМР дельта-диапазона ИП (ОШ 95 % ДИ = 1,31 (1,13–1.52), p = 0,0004), ЛЗГР альфа-диапазона ПП (ОШ 95 % ДИ = 29,07 (1,86–455,15), p = 0,0224) и МПАР альфа-диапазона (ОШ 95 % ДИ = 0,01 (0,0001–0,80), p = 0,0402), при этом оптимальными точками отсечения значений указанных показателей для верификации функционального прогноза выступают ОСМР дельта-диапазона ИП >18,4% (Se = 87,0 %, Sp = 87,7 %, AUC 95 % ДИ = 0,94 (0,87–0,98), p < 0,0001), ЛЗГР альфа-диапазона ПП >-0,066 (Se = 67,4 %, Sp = 70,0 %; AUC 95 % ДИ = 0,74 (0,65–0,82), p < 0,0001) и МПАР альфа-диапазона ≤-0,066 (Se = 60,9 %, Sp = 70,2 % AUC 95 % ДИ = 0,66 (0,56–0,75), p < 0,0039).

Выводы. Наиболее информативные параметры спектрального анализа биоэлектрической активности головного мозга для определения функционального прогноза исхода острого периода МИСИ: относительная спектральная мощность ритмов δ-диапазона интактного полушария, лобно-затылочный градиент ритмов α-диапазона пораженного полушария и межполушарная асимметрия ритмов α-диапазона.

Introduction

Cerebral ischemic supratentorial stroke (CISS) as the most common form of cerebrovascular pathology is a global problem of modern times. Its special medical and social significance is due to the leading positions in the structure of death and disability causes in most countries of the world [1–3]. One of the most appropriate means to improve the effectiveness of treatment activities in patients with CISS is a differentiated approach development for the optimal tactics selection on the basis of an individual prognosis [4–5].

All of the mentioned above justifies the necessity of brain damage severity objectification at the onset of CISS. Electroencephalography (EEG) is one of the most informative methods to study the brain functional state. This method is highly sensitive to changes in brain bioelectrical activity that are induced by acute focal ischemia [6–8]. In combination with a millisecond time resolution, that is impossible to be used in diffusion-mediated magnetic resonance imaging and positron emission tomography [9], it explains the fact that EEG has been used for more than 40 years for cerebral ischemia detection during carotid surgery [10]. Additional advantages of the method are: non-invasiveness and absence of contraindications. Quantitative (spectral) analysis of EEG pattern allows increasing the diagnostic informative value of the method [11–14]. At the same time, the unified criteria for the determination of the short-term functional prognosis of CISS acute period outcome, which take into consideration the results of spectral analysis of the brain spontaneous bioelectrical activity, are currently absent, and the purpose of this study was to determine the most informative parameters of spectral analysis of the electroencephalographic pattern for the functional outcome of cerebral ischemic supratentorial stroke acute period prediction.

Materials and methods

Prospective, cohort and comparative study was conducted among 103 patients in CISS acute period (61 men and 42 women, mean age was 67.7 ± 0.8 years), who were hospitalized within the first 24 hours from the onset of the disease and who did not undergo thrombolytic therapy.

CISS pathogenic subtype was determined in accordance with the Trial of Org 10172 in Acute Stroke Treatment (TOAST) criteria [15]. Clinical and neurological study included the neurological deficit level assessment using National Institute of Health Stroke Scale (NIHSS) in acute period dynamics. The visualization of cerebral structures was made with the help of CT scanner “Siemens Somatom Spirit” (Germany). The lesion size and the displacement of brain median structures were assessed.

The study excluded patients with acute cerebral circulation disorders, craniocerebral injury and epileptic seizures in the anamnesis, combined with the cerebral hemorrhage, hemorrhagic transformation of brain infarction, oncologic and/or decompensated somatic pathology.

Electroencephalographic study was conducted on the 2nd–3rd day of the disease with the use of 19-channel

Table 1. Relative spectral rhythm power, fronto-occipital rhythm gradient and interhemispheric asymmetry values in patients with CISS on the 2nd–3rd day of the disease, Me (IQR)

Indexes	Affected hemisphere	Intact hemisphere
RSRP of delta band, %	18.0 (10.1; 34.9)	17.3 (10.2; 26.3)
RSRP of theta1 band, %	10.7 (7.2; 14.4)	9.7 (6.6; 12.7)
RSRP of theta2 band, %	12.6 (8.2; 17.5)	11.6 (8.0; 19.2)
RSRP of theta band, %	24.4 (18.1; 30.6)	21.9 (16.9; 32.3)
RSRP of alpha1 band, %	16.8 (9.9; 25.2)	18.1 (12.5; 28.0)
RSRP of alpha2 band, %	8.3 (5.4; 13.2)	9.5 (6.3; 15.6)
RSRP of alpha band, %	27.2 (17.0; 41.6)	31.7 (22.5; 43.2)
RSRP of beta1 band, %	14.5 (8.8; 22.1)	14.8 (9.1; 22.8)
RSRP of beta2 band, %	3.5 (1.9; 6.3)	3.2 (1.7; 5.4)
RSRP of beta band, %	18.6 (10.9; 29.0)	18.6 (11.8; 28.6)
FORG of delta band	0.053 (-0.152; 0.192)	0.047 (-0.091; 0.171)
FORG of theta1 band	0.135 (-0.055; 0.296)	0.112 (-0.022; 0.228)
FORG of theta2 band	0.040 (-0.122; 0.258)	0.064 (-0.125; 0.205)
FORG of theta band	0.054 (-0.085; 0.240)	0.061 (-0.057; 0.187)
FORG of alpha1 band	-0.092 (-0.328; 0.147)	-0.163 (-0.366; 0.010)
FORG of alpha2 band	-0.038 (-0.229; 0.130)	-0.201 (-0.359; 0.020)
FORG of alpha band	-0.099 (-0.283; 0.097)	-0.203 (-0.396; -0.024)
FORG of beta1 band	0.103 (0.001; 0.283)	0.072 (-0.031; 0.175)
FORG of beta2 band	0.247 (0.066; 0.440)	0.170 (-0.021; 0.371)
FORG of beta band	0.144 (0.037; 0.314)	0.103 (-0.014; 0.217)
IHRA of delta band	0.084 (-0.056; 0.219)	
IHRA of theta1 band	0.092 (-0.043; 0.209)	
IHRA of theta2 band	0.055 (-0.090; 0.196)	
IHRA of theta band	0.065 (-0.041; 0.189)	
IHRA of alpha1 band	-0.026 (-0.164; 0.123)	
IHRA of alpha2 band	-0.033 (-0.184; 0.081)	
IHRA of alpha band	-0.040 (-0.171; 0.102)	
IHRA of beta1 band	0.001 (-0.069; 0.106)	
IHRA of beta2 band	0.050 (-0.048; 0.206)	
IHRA of beta band	0.032 (-0.070; 0.109)	

Table 2. The analysis of EEG pattern rhythm structure (%) in patients with CISS on the 2nd–3rd day of the disease versus the acute period outcome of the disease, Me (IQR)

Indexes	Unfavourable functional outcome (n = 46)	Favourable functional outcome (n = 57)	P
RSRP of delta band AH	37.9 (30.3; 43.4)	10.1 (7.5; 14.7)	<0.0001
RSRP of theta1 band AH	11.4 (8.7; 16.3)	8.9 (6.4; 13.8)	0.0226
RSRP of theta2 band AH	13.5 (8.7; 17.6)	11.2 (7.4; 14.2)	0.2706
RSRP of theta band AH	24.9 (22.4; 34.1)	21.9 (15.1; 26.7)	0.0196
RSRP of alpha1 band AH	10.3 (8.2; 15.5)	22.3 (17.2; 31.6)	<0.0001
RSRP of alpha2 band AH	5.7 (4.5; 8.7)	13.6 (8.3; 18.0)	<0.0001
RSRP of alpha band AH	17.3 (12.4; 24.3)	40.8 (29.9; 47.4)	<0.0001
RSRP of beta1 band AH	11.0 (6.4; 16.6)	20.8 (14.4; 26.8)	<0.0001
RSRP of beta2 band AH	2.3 (1.1; 5.7)	3.9 (2.2; 8.3)	0.0068
RSRP of beta band AH	13.6 (7.7; 22.4)	25.5 (17.9; 33.8)	<0.0001
RSRP of delta band IH	28.4 (22.1; 39.8)	9.5 (7.1; 13.1)	<0.0001
RSRP of theta1 band IH	10.0 (6.8; 13.9)	8.5 (6.1; 11.6)	0.1201
RSRP of theta2 band IH	13.5 (9.7; 20.0)	10.1 (7.7; 14.2)	0.0727
RSRP of theta band IH	25.1 (19.4; 36.2)	19.3 (15.8; 24.0)	0.0203
RSRP of alpha1 band IH	14.7 (10.1; 21.2)	21.5 (16.4; 31.0)	0.0029
RSRP of alpha2 band IH	8.0 (5.7; 12.7)	14.9 (9.4; 23.0)	0.0005
RSRP of alpha band IH	24.9 (17.3; 32.0)	40.3 (31.9; 52.5)	<0.0001
RSRP of beta1 band IH	10.9 (7.6; 15.6)	19.2 (13.8; 27.1)	<0.0001
RSRP of beta2 band IH	2.0 (1.3; 3.7)	4.2 (2.5; 6.4)	0.0002
RSRP of beta band IH	13.7 (8.9; 18.5)	24.2 (17.2; 32.8)	<0.0001

electroencephalographic scanner "NeuroCom Standard" (XAI-Medica, Ukraine). Electrodes were placed in accordance with the international system "10–20". The oculographic, rheographic and electrocardiographic artifacts were rejected with the use of software tools and the Independent Component Analysis (Blind Sourse Separation Technology) procedure. The 60-second epochs after artifact rejection were selected for the spectral analysis. The spectral analysis was carried out with the help of fast Fourier transform method. The values of absolute spectral rhythm power of delta (0.5–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), beta (13–35 Hz), theta1 (4–6 Hz), theta2 (6–8 Hz), alpha1 (8–10 Hz), alpha2 (10–13 Hz), beta1 (13–25 Hz) and beta2 (25–35 Hz) bands in the affected hemisphere (AH) and intact hemisphere (IH) were determined. The relative spectral rhythm power (RSRP) values of the specified frequency bands (%) were calculated. To quantify the zonal differences of the rhythm distribution within AH and IH, the values of the fronto-occipital rhythm gradient (FORG) were calculated using the following formula: FORG = (ASRP in the frontal region – ASRP in the occipital region) / (ASRP in the frontal region + ASRP in the occipital region). The severity of interhemispheric rhythm asymmetry (IHRA) was determined on the basis of the following formula: IHRA = (ASRP in the AH – ASRP in the IH) / (ASRP in the AH + ASRP in the IH).

All patients received standard therapy in accordance with the Unified Clinical Protocol for medical care "Ischemic stroke (urgent, primary and secondary (specialized) medical care, medical rehabilitation)", approved by the order of the Ministry of Health of Ukraine №604 of August 03, 2012. The functional outcome of the disease acute period was assessed on the 21st day on the basis of the modified Rankin Scale (mRS), while the value of mRS score > 3 was considered as an unfavourable functional outcome, whereas mRS score ≤3 was considered as a favourable one.

Statistical analysis of the results was carried out using the software Statistica 6.0 (StatSoft Inc., USA, series number AXXR712D833214FAN5) and MedCalc (version 16.4). The distribution normality of the studied traits was estimated in accordance with the Shapiro–Wilk criterion. Descriptive statistics are presented in the form of M ± m for values with normal distribution and in the form of median (Me) and interquartile range (IQR) for parameters with non-normal distribution. To determine the intergroup differences in the studied characteristics, the Mann-Whitney criterion was used. Factors that had significant predictive value in the univariate logistic regression analysis were step by step included in the multivariate model in order to determine independent predictors. The cut-off points for independent predictors with the optimum sensitivity (Se) and specificity (Sp) were determined on the basis of the ROC analysis. Statistical significance of results was defined as a P value <0.05.

Results of the study

Patients with brain infraction in the left hemisphere dominated in the studied cohort (62.1 %). Cerebral ischemic supratentorial stroke etiologic factors structure in accordance with TOAST classification was presented as follows: large-artery atherosclerosis (47.6 %), cardioembolism (18.4 %),

small-vessel occlusion (20.4 %) and stroke of undetermined etiology (13.8 %).

The total value in accordance with NIHSS score and infarct volume on admission constituted 9.0 (7.0; 14.0) and 20.6 (6.0; 59.2) mL, respectively, septum pellucidum displacement and pineal gland displacement were detected in 8 (7.8 %) patients.

The results of EEG pattern spectral analysis in patients with CISS on the 2nd-3rd day of the disease are shown in *Table 1* and *Table 2*.

Unfavourable functional outcome (mRS score >3 on the 21st day of the disease) was detected in 46 (44.6 %) patients. Patients with an unfavourable functional CISS acute period outcome at onset of the disease has a higher severity of neurologic deficit in accordance with the NIHSS (14,5 (10,3; 16,0) versus 7,0 (6,0; 9,0), P < 0.0001) and a larger infarct volume (45,4 (15,7; 93,0) mL versus 11,4 (4,0; 37,1) mL, P = 0.0006).

The analysis of EEG pattern rhythm structure (%) was made in patients with CISS on the 2nd–3rd day of the disease versus the acute period outcome of the disease (*Table 2*).

The presented data shows that patients with an unfavourable functional outcome of CISS acute period had higher RSRP of delta band on the 2nd–3rd day of the disease (37.9 (30.3; 43.4) % versus 10.1 (7.5; 14.7) % in the AH; 28.4 (22.1; 39.8) % versus 9.5 (7.1; 13.1) % in the IH, P<0.0001 for both values) and RSRP of theta band (24.9 (22.4; 34.1) % versus 21.9 (15.1; 26.7) % in the AH; 25.1 (19.4; 36.2) % versus 19.3 (15.8; 24.0) % in the IH, P < 0.05 for both values) along with lower RSRP of alpha band (17.3 (12.4; 24.3) % versus 40.8 (29.9; 47.4) % in the AH; 24.9 (17.3; 32.0) % versus 40.3 (31.9; 52.5) % in the IH, P < 0.0001 for both values) and RSRP of beta band (13.6 (7.7; 22.4) % versus 25.5 (17.9; 33.8) % in the AH; 13.7 (8.9; 18.5) versus 24.2 (17.2; 32.8) % in the IH, P < 0.0001 for both values). The revealed changes in RSRP of alpha and delta bands dominated in the AH, whereas changes in RSRP of beta and theta bands had bilateral character. Rhythms of alpha and delta bands dominated in the EEG-structure in patients with favourable functional outcome of CISS acute period on the 2nd-3rd days of the disease.

The inversion of negative FORG of alpha, alpha1 and alpha2 bands in the AH was representative of patients with unfavourable functional outcome of CISS acute period, as well as a positive tendency of FORG of delta, beta, beta1 bands on the 2nd-3rd day of the disease, whereas the reduction of negative FORG of alpha2 band was detected in the intact hemisphere (*Table 3*).

Patients with CISS and unfavourable functional outcome on the 2nd and 3rd day of the disease had IHRA of alpha, alpha1 and alpha2 bands, which was proved by negative values of corresponding indexes (*Table 4*).

Parameters of EEG pattern spectral analysis were determined on the basis of the univariate logistic regression analysis. They were associated with the functional outcome of CISS acute period. Independent interrelation was determined only for 3 of them: RSRP of delta band in the IH (OR 95 % CI = 1.31 (1.13–1.52), P = 0.0004), FORG of alpha band in the AH (OR 95 % CI = 29.07 (1.86–455.15), P = 0.0224) and IHRA of alpha band (OR 95 % CI = 0.01 (0.0001–0.80), P = 0.0402) (*Table 5*).

Cut-off points for these indexes with optimal sensitivity and specificity interrelation were determined on the basis of the ROC-analysis for functional outcome of the disease acute period prognosis: RSRP of delta band in IH >18.4 % (Se = 87.0 %, Sp = 87.7 %; AUC 95 % CI = 0.94 (0.87–0.98), P < 0.0001), FORG of alpha band in the AH > -0.066 (Se = 67.4 %, Sp = 70.0 %; AUC 95 % CI = 0.74 (0.65–0.82), P < 0.0001) and IHRA of alpha band ≤ -0.066 (Se = 60.9 %, Sp = 70.2 %; AUC 95 % CI = 0.66 (0.56–0.75), P < 0.0039).

The frequency distribution of unfavourable functional outcome of the CISS acute period in terms of RSRP of delta band in the IH, FORG of alpha band in the AH and IHRA of alpha band is shown in *Table 6*.

As a result, the RSRP of delta band in the IH >18.4 %, FORG of alpha band in the AH >-0.066 and IHRA of alpha band (Se = 60.9 %, Sp = 70.2 % AUC 95 % CI = 0.66 (0.56–0.75), P < 0.0039) were associated with increased risk of the unfavourable outcome of CISS acute period 7.0 – fold (95 % CI 3.7–17.1, P < 0.0001), 2.4 (95 % CI 1.5–3.8, P = 0.0004) and 2.0 – fold (95 % CI 1.3–3.1, P = 0.0022), respectively.

Table 3. Analysis of zonal differences in the EEG-pattern of affected and intact hemispheres in patients with CISS on the 2nd–3rd day of the disease versus the functional outcome of the disease acute period, Me (IQR)

Indexes	Unfavourable functional outcome (n = 46)	Favourable functional outcome (n = 57)	P
FORG of delta band AH	0.119 (-0.135; 0.315)	0.003 (-0.155; 0.145)	0.0403
FORG of theta1 band AH	0.171 (-0.044; 0.333)	0.068 (-0.062; 0.225)	0.1124
FORG of theta2 band AH	0.102 (-0.089; 0.354)	0.016 (-0.134; 0.223)	0.1217
FORG of theta band AH	0.187 (-0.040; 0.307)	0.023 (-0.091; 0.214)	0.0545
FORG of alpha1 band AH	0.048 (-0.161; 0.215)	-0.197 (-0.481; 0.024)	0.0002
FORG of alpha2 band AH	0.074 (-0.140; 0.223)	-0.126 (-0.301; 0.003)	0.0001
FORG of alpha band AH	0.030 (-0.122; 0.199)	-0.168 (-0.415; -0.027)	<0.0001
FORG of beta1 band AH	0.212 (0.062; 0.365)	0.052 (-0.033; 0.177)	0.0040
FORG of beta2 band AH	0.287 (0.102; 0.494)	0.217 (0.060; 0.424)	0.3393
FORG of beta band AH	0.233 (0.075; 0.375)	0.071 (0.021; 0.220)	0.0096
FORG of delta band IH	0.045 (-0.078; 0.195)	0.048 (-0.128; 0.148)	0.6320
FORG of theta1 band IH	0.074 (-0.019; 0.202)	0.148 (-0.024; 0.238)	0.7891
FORG of theta2 band IH	0.039 (-0.093; 0.162)	0.099 (-0.141; 0.275)	0.3228
FORG of theta band IH	0.052 (-0.047; 0.163)	0.068 (-0.064; 0.229)	0.4733
FORG of alpha1 band IH	-0.143 (-0.338; 0.017)	-0.192 (-0.400; 0.003)	0.6414
FORG of alpha2 band IH	-0.080 (-0.344; 0.106)	-0.249 (-0.396; -0.057)	0.0397
FORG of alpha band IH	-0.117 (-0.385; 0.030)	-0.234 (-0.401; -0.095)	0.1170
FORG of beta1 band IH	0.079 (-0.006; 0.201)	0.047 (-0.050; 0.159)	0.2073
FORG of beta2 band IH	0.157 (-0.029; 0.392)	0.179 (-0.010; 0.355)	0.9185
FORG of beta band IH	0.122 (-0.011; 0.250)	0.073 (-0.026; 0.170)	0.3810

Table 4. Intergroup analysis of IHRA differences versus acute period outcome of the disease, Me (IQR)

Indexes	Unfavourable functional outcome (n = 46)	Favourable functional outcome (n = 57)	P
IHRA of delta band	0.108 (-0.093; 0.233)	0.079 (-0.054; 0.186)	0.3529
IHRA of theta1 band	0.124 (-0.016; 0.212)	0.082 (-0.043; 0.205)	0.2706
IHRA of theta2 band	0.014 (-0.092; 0.205)	0.067 (-0.060; 0.191)	0.5721
IHRA of theta band	0.059 (-0.042; 0.203)	0.065 (-0.032; 0.175)	0.8975
IHRA of alpha1 band	-0.106 (-0.215; 0.059)	0.032 (-0.114; 0.142)	0.0133
IHRA of alpha2 band	-0.086 (-0.219; -0.001)	0.015 (-0.085; 0.112)	0.0141
IHRA of alpha band	-0.108 (-0.222; 0.031)	0.019 (-0.098; 0.131)	0.0061
IHRA of beta1 band	-0.007 (-0.100; 0.114)	0.028 (-0.045; 0.094)	0.3293
IHRA of beta2 band	0.090 (-0.034; 0.224)	0.038 (-0.059; 0.175)	0.2537
IHRA of beta band	0.016 (-0.095; 0.121)	0.038 (-0.039; 0.105)	0.5676
IHRA total	0.036 (-0.050; 0.158)	0.052 (-0.075; 0.112)	0.5454

Table 5. Dependent and independent predictors of CISS acute period unfavourable functional outcome (univariate and multivariate models)

Indexes	Univariate logistic regression model		Multivariate logistic regression model	
	OR (95 % CI)	P	OR (95 % CI)	P
Admission NIHSS score	1.65 (1.37–1.98)	<0.0001	1.61 (1.15-2.24)	0.0050
Infarct volume	1.02 (1.00–1.03)	0.0056		
RSRP of delta band AH	1.20 (1.13–1.28)	<0.0001		
RSRP of theta1 band AH	1.08 (1.00–1.15)	0.0231		
RSRP of alpha1 band AH	0.89 (0.84–0.94)	<0.0001		
RSRP of alpha2 band AH	0.78 (0.70–0.88)	<0.0001		
RSRP of alpha band AH	0.89 (0.85–0.93)	<0.0001		
RSRP of beta1 band AH	0.90 (0.85–0.95)	0.0002		
RSRP of beta2 band AH	0.87 (0.77–0.99)	0.0337		
RSRP of beta band AH	0.93 (0.89–0.97)	0.0001		
RSRP of delta band IH	1.35 (1.21–1.52)	<0.0001	1.31 (1.13–1.52)	0.0004
RSRP of alpha1 band IH	0.95 (0.92–0.99)	0.0091		
RSRP of alpha2 band IH	0.89 (0.83–0.96)	0.0011		
RSRP of alpha band IH	0.93 (0.91–0.97)	0.0001		
RSRP of beta1 band IH	0.90 (0.85–0.95)	0.0002		
RSRP of beta2 band IH	0.77 (0.67–0.91)	0.0026		
RSRP of beta band IH	0.93 (0.88–0.96)	0.0002		
FORG of alpha1 band AH	15.36 (3.39–69.56)	0.0004		
FORG of alpha2 band AH	34.52 (4.86–245.31)	0.0004		
FORG of alpha band AH	34.91 (5.81–209.92)	0.0001	29.07 (1.86–455.15)	0.0224
FORG of beta1 band AH	9.23 (1.46–58.17)	0.0180		
FORG of alpha2 band IH	5.13 (1.08–24.42)	0.0355		
IHRA of alpha1 band	0.08 (0.01–0.54)	0.0100		
IHRA of alpha2 band	0.09 (0.01–0.81)	0.0319		
IHRA of alpha band	0.05 (0.01–0.43)	0.0067	0.01 (0.0001–0.80)	0.0402

Table 6. Frequency distribution of unfavourable functional outcome of the CISS acute period in terms of RSRP of delta band in the IH, FORG of alpha band in the AH and IHRA of alpha band

Parameters	Value	Number of patients	Unfavourable functional outcome of the CISS acute period (%)
RSRP of delta band in IH, %	>18.4	47	85.1
	≤18.4	56	10.7
FORG of alpha-range in AH	>-0.066	48	64.6
	≤-0.066	55	27.2
IHRA of alpha band	≤-0.066	45	62.2
	>-0.066	58	31.0

Discussion

Thus, on the basis of the EEG patterns spectral analysis comparative analysis it was determined that patients with the unfavourable outcome of CISS acute period on the 2nd–3rd day of the disease had a higher severity of bioelectric brain activity impairment in affected and intact hemispheres. This cohort of patients had higher values of RSRP of delta and theta bands and lower levels of RSRP of alpha and beta bands, whereas the increase in demonstrated changes severity was in the affected hemisphere. In addition, patients with the unfavourable outcome of CISS acute period on the 2nd–3rd day of the disease had ipsilateral reduction of zonal rhythm differences of alpha, alpha1 and alpha2 bands, which was due to a more severe depression of the absolute spectral power of the specified rhythms in caudal parts of the affected hemisphere. It was accompanied by the generation of interhemispheric asymmetry of absolute spectral rhythm power of alpha band and complied with the results of other studies.

Thus, in accordance with S. P. Finnigan et al. (2007) sub-acute delta/alpha power ratio (R = 0.91, P < 0.001) and relative alpha power (R = -0.82, P < 0.01) were significantly correlated with 30-day NIHSS score [16]. The study of R. V. Sheorajpanday et al. (2011) determined that the EEG pairwise derived Brain Symmetry Index (pdBSI) was significantly correlated with the modified Rankin Scale (mRS) score at month 6 (R = 0.46, P < 0.0005) [17]. In accordance with the data of X. Xin et al. (2017) poor functional outcomes were associated with higher BSI [18]. Our research studied the prognostic value of interhemispheric different frequency bands asymmetry indexes, while independent association with the functional outcome of CISS acute period was only determined for IHRA of alpha band. The prognostic value of FORG of alpha band in the AH on the 2nd–3rd day of CISS was proved, which confirms the advisability to define not only IHRA of alpha band, but also alpha-rhythm zonal differences in order to prognosticate the functional outcome of the disease acute period.

It should be noted, that the results of our study revealed the presence of RSRP delta-range of IH in the spectral of independent predictors of the unfavourable functional outcome of CISS acute period. It was also determined that this index has a higher informative value than IHRA of alpha band and the FORG of alpha band in the AH for the determination of a short-term functional prognosis. The obtained data complies with the results of other studies. Thus, in the study of G. Assenza et al. (2013), an increase in contralesional delta band power was mediated by interhemispheric disconnection providing negative prognosis in acute stroke [19]. In accordance with M. E. Wolf et al. (2017), generalized (but not focal) slowing were associated with clinical deterioration [20]. Thus, the intact hemisphere dysfunctional severity is also associated with the functional outcome of CISS acute period.

We determined the following cut-off points for the values of these indexes with the optimal sensitivity and specificity level for the functional outcome of CISS acute period prognosis: RSRP of delta band in the IH > 18.4 % (Se = 87.0 %, Sp = 87.7 %), FORG of alpha band in the AH > -0.066 (Se = 67.4 %, Sp = 70.0 %) and IHRA of alpha band ≤ -0.066 (Se = 60.9 %, Sp = 70.2 %). It is advisable to use the obtained criteria for the determination of a short-term functional prognosis as the basis for the optimization of therapy measures applied to patients with CISS.

Conclusions

1. The following are the parameters which had the highest informative value as for EEG pattern spectral analysis on the 2nd-3rd day of CISS and which have an independent association with the functional outcome of the disease acute period: RSRP of delta band in the IH (OR 95 % CI = 1.31 (1.13–1.52), P=0.0004), FORG of alpha band in the AH (OR 95 % CI = 29.07 (1.86–455.15), P = 0.0224) and IHRA of alpha band (OR 95 % CI = 0.01 (0.0001–0.80), P = 0.0402).

2. Predictors of the unfavourable functional outcome of CISS acute period were the RSRP of delta band in the IH > 18.4 % (Se = 87.0 %, Sp = 87.7 %; AUC 95 %

CI = 0.94 (0.87–0.98), P < 0.0001; RR (95 % CI) = 7.0 (3.7–17.1), P < 0.0001), FORG of alpha band in the AH > -0.066 (Se = 67.4%, Sp = 70.0 %; AUC 95 % CI = 0.74 (0.65–0.82), P < 0.0001; RR (95 % CI) = 2.4 (1.5–3.8), P = 0.0004) and IHRA of alpha band ≤ -0.066 (Se = 60.9 %, Sp = 70.2 %; AUC 95 % CI = 0.66 (0.56–0.75), P < 0.0039; RR (95 % CI) = 2.0 (1.3–3.1), P = 0.0022) on the 2nd–3rd day of the disease.

The perspective for the further scientific research is the criteria of the unfavourable vital outcome of CISS acute period elaboration on the basis of EEG pattern spectral analysis.

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