Peculiarities of Brain Functioning in Children with Adolescence Idiopathic Scoliosis (AIS) According to EEG Studies

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Abstract. Brain structures with bioelectric activity (BA) different from BA of the same structures in healthy peers were revealed using an original 3DLocEEG analysis of EEGs that solves so-called "reverse EEG task". These were the following structures: thalamus, pineal gland, hypothalamic area, including suprahiasmatic nuclei, and infratemporal cortex. The shift of BA focus to structures of the left hemisphere including left thalamus was recorded in patients with AIS; the shift increased both with worsening of deformation and increasing progression activity. This was not observed in healthy children (aged 7 – 14 years), although it is natural for older adolescents (15 – 17 years) and healthy adults. In other words, the interhemispheric asymmetry of brain BA in children with AIS becomes typical for the definitive brain much earlier. This phenomenon may be used for future development of a method for prediction of deformation progression patterns. A number of differences obtained in comparative analysis of EEGs, processed by 3DLocEEG method, between right-side and left-side AIS allow us to hypothesize about aetiology and pathogenesis differences of these two AIS clinical forms. Data obtained suggest that brain structures play a much more important role in aetiology and pathogenesis of AIS right-side forms compared with left-side ones. Primary subclinical dysfunctions of brain regulatory systems leading to disturbances of spinal cord and brain associated growth and subsequently to scoliosis development are supposed to play the main role in pathogenesis of right-side AIS forms (or their substantial part). Evidently, the major reason for manifesting these latent dysfunctions is an overstrain of central nervous system (CNS) adaptation-compensation mechanisms during the pubertal period.

Keywords. EEG, equivalent dipole sources, right-side and left-side AIS forms, functional interhemispheric asymmetry, CNS

Introduction

The hypothesis about a role of CNS in development of spinal column deformation is one of the most popular among hypotheses AIS aetiology and pathogenesis.

Objectives

To detect a role of particular CNS structures in aetiology and pathogenesis of AIS, the study using an original program for assessment of brain bioelectric activity (BA) – 3DLoc EEG was performed.

Materials and Methods

We used 3DLocEEG program [1] based on dynamic calculation of equivalent dipole coordinates, that may be treated as sources of EEGs recorded on the scalp. Mathematic algorithm used in the program allows solving so-called "reverse EEG task", i.e. to identify sources of resulting potentials recorded on the scalp (EEG and EP); these sources are located in the three-dimensional brain space [2]. Equivalent dipole sources (EDS) recorded every 4 ms are represented on 1 cm layer-by-layer brain cuts in horizontal, sagittal and frontal planes according to the atlas by J.K.Mai et al. [5]. Cut-offs are scaled up by individual patient's skull sizes. For this purpose, during EEG registration 32 measurements are performed between EEG recording electrodes and skull reference points; these data are further used in the program for individual triangulation of skull surface.

EEGs mathematically analyzed in 334 children aged from 10 to 17 years with AIS and 84 healthy children aged from 7 to 17 years and 31 healthy adult subjects aged from 20 to 45 years. An amount of EDS recorded in the left and right hemispheres as a percentage of total number of recorded EDS in the brain volume was calculated. Further, interhemispheric asymmetry indices (IHAI), which are the ratio of sum BA (EDS quantity) of left hemisphere to that of the right one, were calculated. Subsequently, the whole brain volume was divided into 1 cm^3 cubes. Each cube had three coordinates in horizontal, frontal and sagittal planes according to the system of axes used in the atlas. EDS quantity in similar cubes during 80 seconds of registration was compared between patients with AIS and healthy children using the t-test for independent samples. Comparison was performed in different subgroups by age, deformation shape (right-side and left-side bending of the main scoliosis arch), progression pattern - rapid progressive; progressive; stable according to [4], deformation severity according to accepted in Russia V.D. Chaklin classification (grade I: 1° – 10°; grade II: 11° – 25°; grade III: 26° – 50°; grade IV > 50° by Cobb).

Results

Statistically significant difference in EDS distribution between the left and right hemisphere in healthy subjects and their peers with AIS was recorded. Changes in functional interhemispheric asymmetry (FIA) were previously demonstrated in patients with AIS according to neuropsychological tests [5] and brain morphometry during MRT studies [6]. It should be noted that progressive IHAI increase in patients with AIS compared with IHAI value in healthy subjects was observed both with increasing of deformation and rising of progression activity in groups of patients with right-side or left-side scoliotic arches (Table 1,2). Dominating activity of deep right hemisphere structures also seems natural in healthy children not only of pubertal age. Thus, in group of 17 healthy children aged 7 – 9 years, activity of the right hemisphere exceeded that of the left one (IHAI = 0.82, p= 0.0011). At the same time, among healthy children in age group of 15 – 17 years the left hemisphere activity predominated, i.e. a typical pattern for adult subjects was observed.

Table 1. Interhemisheric asymmetry index (IHAI) in healthy subjects and in patients with right-side and left-side IS of different severity. Age group of 10 – 15 years.

Deformation severity (by Chaklin)	Left-side AIS			Right-side AIS		
	Number of patients	IHAI	t-test	Number of patients	IHAI	t-test
Healthy subjects	64	0.93	p=0.037 *	64	0.93	p=0.037 *
Grade I AIS	19	0.95	p=0.054 *	23	1.0	p=0.491 NS
Grade II AIS	37	0.98	p=0.12 NS	57	1.05	p=0.0005
Grade III AIS	27	1.05	p=0.0428 *	46	1.07	p=0.0002 ***
Grade IV AIS	9	1.15	p=0.0001 ***	34	1.14	p=0.0001 ***

NS=not significant; *=p<0.05; ** = p<0.01; *** = p<0.001

Table 2. Interhemisheric asymmetry index (IHAI) in healthy subjects and in patients with right-side and left-side IS with different patterns of scoliotic deformation progression. Age group of 10 – 15 years.

Deformation severity (by Chaklin)	Left-side AIS			Right-side AIS		
	Number of patients	IHAI	t-test	Number of patients	IHAI	t-test
Healthy subjects	64	0.93	p=0.037 *	64	0.93	p=0.037 *
Rapid progressive AIS	46	1.05	p=0.04 *	93	1.11	p=0.0002 ***
Progressive AIS	37	0.97	p=0.27 NS	52	1.03	p=0.211 NS
Stable AIS	9	0.91	p=0.049 *	12	0.95	p=0.193 NS

To study differences in EDS quantity between different brain structures more closely, the number of 1 cm^3 cubes was analyzed, in which EDS quantity statistically significantly ($p<0.01$) differed by the t-test between healthy subjects and patients with AIS. The major part of these cubes was similar for left-side and right-side deformations. It is interesting to note an absence of differences between patients from subgroups with rapid progressive and progressive left-side AIS. At the same time, among patients with right-side AIS, statistically significant differences were recorded in EDS quantity in some cubes between patients with rapid progressive and progressive course of disease.

Some of the most important brain structures, in which statistically significant differences of EDS quantity between patients with AIS and healthy peers were found, were analyzed separately. First of all, it concerns the thalamus due to not only its important role in brain activity and hypotheses of its involvement in aetiology and pathogenesis of AIS [7], but also for the thalamus being quite a large brain structure.

In general, the left thalamus activity was significantly higher ($p<0.001$) in patients with both rapid progressive and progressive disease course of left-side or right-side AIS, both in left-handers and right-handers; on the contrary, in healthy children the right dorsal-lateral and anterior thalamus activity was higher. Attention should be paid to statistically significant differences between patients with AIS and healthy peers concerning EDS quantity in pituitary and hypothalamic areas, in optic chiasm (area of suprachiasmal nuclei) and in pineal gland region.

Discussion

Data we obtained suggests FIA factor involvement in AIS pathogenesis; FIA seems to play an adaptive and compensatory role. Although there is a genetic predisposition for one or another FIA type, however an observed significant increase of interhemispheric BA asymmetry suggests its evident association with both increased deformation and progression. Progressive increase of EDS quantity in the left hemisphere, is most likely

the one of important components of brain pathology associated with scoliotic deformation. This suggests, on one hand, a gradual decompensation in diencephalic structures responsible for a normal puberty and having more close functional relationships with the right hemisphere, and on the other, reciprocal increase of reticular stem structures activity more associated with left hemisphere [8].

Shift of BA focus into the left hemisphere in the beginning and middle of puberty, is the main distinctive feature of patients with progressive AIS course. At final stages, this sign has no prognostic value because normally (from 14 – 15 years) gradual FIA inversion occurs.

Along with common signs of brain activity changes typical for two AIS forms (right-side and left-side), there are serious differences between them. In children with AIS, EEGs reflect both responses of CNS structures to a deformation being developed and abnormal activity in one or another CNS structure (if a central hypothesis about AIS origin due to a primary brain structure pathology is true). Reflected in EDS number and distribution) brain structure responses to a developed deformation are supposed to be common for both scoliosis forms. Patients with right-side AIS as compared with left-side AIS (with similar severity and progression patterns) have more cubes with statistically significant differences in EDS quantity vs. healthy subjects. The above in combination with statistically significant differences in EDS quantity between patients with rapid progressive and progressive right-side AIS and absence of such differences in left-side AIS more likely suggest brain structure dysfunctions in right-side AIS, not observed in patients with left-side AIS. Therefore, these data more likely suggest about differences in aetiology and pathogenesis of left-side and right-side AIS.

Observed abnormalities of BA in patients with right-side AIS (congenital or acquired) are supposed to be primary (in a considerable number of cases, anyway). And exactly they lead to pathologic deformations in patients with this AIS form in contrast to left-side scoliosis, which aetiology is still unknown. However, these causes more likely have no direct relation to primary brain dysfunctions.

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