Original Article

Brain volumetrics, regional cortical thickness and radiographic findings in children with cyanotic congenital heart disease using quantitative magnetic resonance imaging

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ABSTRACT

Background: Hypoxia in children with cyanotic congenital heart disease may cause structural brain changes.

Objectives:
1. To assess brain volumetrics and ischemic brain lesions in children with cyanotic congenital heart disease using quantitative MRI.
2. To study the correlation between MRI findings, oxygen saturations and some laboratory measures.

Participants and methods: Fifty children with CCHD and a mean oxygen saturation of 83 ± 2.2% were investigated using quantitative MRI. Brain volumetric results were compared with 20 controls.

Results: Dilated Ventricles were found in 14 cases (28%). 23 cases (46%) had PWM hyper-intensity. The common sites for DWML were sub-cortical that was detected in 17 cases (34%). Sub-cortical lacunar infarcts in GM were found in 8 cases (16%). Significant WM and GM volume loss was found in cyanosed subjects. The volumes of the thalamus ($P = 0.01$), putamen ($P = 0.003$), and caudate ($P = 0.042$) were significantly reduced in the cyanotic group. Local regions of decreased cortical thickness were detected in frontal, parietal and temporal lobes.

Conclusions: Children with CCHD show MRI evidence of micro- and macro vascular injury, reduced brain volume and cortical thickness. Brain volume loss correlated with hsCRP, oxygen saturation and packed cell volume.

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Abbreviations: MRI, magnetic resonance imaging; CCHD, cyanotic congenital heart disease; GM, gray matter; WM, white matter; DWM, deep white matter; hsCRP, high-sensitivity C-reactive protein; CSF, cerebrospinal fluid; VBM, voxel-based morphometry; VSD, ventricular septal defect; TGA, transposition of great arteries; PVWMCs, periventricular white matter changes; DWMCs, deep white matter changes.

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1. Introduction

Congenital heart disease (CHD) reported to happen in 5–8 per 1000 survive births [1]. Brain injuries arise with high incidence in newborns having CHD [2]. Brain development is particularly rapid in the first 2 years of life; GM reaches its greatest volume in the order of 2 years of age but WM has a slower development that continues during childhood. Thus, cyanosis may cause differing neurological effects according to the developmental phase at which it occurs [3].

In children having CHD, impaired cerebral blood flow with reduced cerebral oxygen release, both in utero [4] and after delivery, [5] may impair subsequent brain growth and development. New studies have reported that in utero brain development is delayed in children with complex CHD; thus, the brain is less mature and more susceptible at birth than recommended by gestational age [6].

In childhood decreased gray matter (GM) volume, white matter (WM) injury and impaired cognitive outcomes have been well-documented in cyanotic CHD. Conventional neuroimaging studies stated that a high proportion of those children suffered brain injury. Advanced neuroimaging modalities reported that fetuses showed delayed third trimester brain growth, and newborns showed reduced white matter maturation, reduced N-acetylaspartate, and increased lactate [7].

Reduced brain volume and changed metabolism have been confirmed using magnetic resonance imaging (MRI) and spectroscopy in third trimester in fetuses having cyanotic CHD. The accurate mechanisms leading to these results are not exactly characterized but may be, in part, an outcome of reduced cerebral blood flow. Many studies have reported that third-trimester fetuses having CHD had reduced volumetric brain growth [8].

Decreased oxygen saturations have been reported to strongly correlate with decreased frontal GM volume in infants having cyanotic CHD [9], with an association between CHD and structural brain injuries or microcephaly that may cause neurological impairments and developmental delay [10].

2. Aims of the work

The aims of our study were to assess brain volumetrics and ischemic brain lesions in children with cyanotic congenital heart disease using quantitative MRI and to study the correlation between MRI findings, oxygen saturations and some laboratory measures.

3. Participants and methods

3.1. Participants

This study was carried out in the period between May 2015 and January 2016 on 50 children with cyanotic congenital heart diseases. They were 30 males and 20 females with a mean age of 3.57 ± 1.2 years. They were referred to MRI unit in Radiology and Imaging Department in Tanta University Hospital from Cardiology Unit in Pediatric Department in Tanta University. Age and sex matched twenty healthy children were selected as a control group.

The inclusion criterion was children with cyanotic congenital heart diseases and oxygen saturations chronically ≤90%.

Exclusion criteria were a contraindication to MRI, neurological disorders, previous head trauma, chromosomal...
abnormality or a major physical or intellectual impairment, congenital infections, mental retardation, an extra cardiac abnormality and post operative cases.

The type of cardiac abnormality was defined by echocardiography and included Fallot Tetralogy (n = 23), Double outlet right ventricle (n = 14), transposition of great arteries (TGA) and ventricular septal defect (n = 5), Epstein anomaly (n = 3), partial anomalous pulmonary venous return without obstruction (n = 2), Truncus arteriosus (n = 2), and single ventricle (n = 1).

Children were participated after their parents had given informed written consent. The ethics review board of our institution accepted the protocol of the study.

### 3.2. Methods

All participants were subjected to the following:

1. Complete history taking: stressing on developmental history, general examination including weight, head circumference, neurological examination and local cardiac examination.
2. Oxygen saturation: it was calculated by transcutaneous approach.
3. Laboratory investigations: complete blood count was done and high-sensitivity C-reactive protein (hsCRP) was measured using enzyme linked immune sorbent assay (ELISA).
4. Echocardiography was used to verify cardiac diagnosis.
5. Cerebral MRI.

MR imaging was done using 1.5-Tesla General Electric scanner (GE Medical Systems, Milwaukee) with 8-channel head coil. Sedation was required for all participants (chloral hydrate syrup in a dose of 50–75 mg/kg). They were examined in the supine position with the head in a neutral position. Axial spin echo T2-weighted images were acquired with echo time (TE) 105 ms, repetition time (TR) 4200 ms, field of view (FOV) 19 × 19 mm, matrix size 256 × N 192, and slices thickness of 5 mm. FLair was

<table>
<thead>
<tr>
<th>Clinical presentation</th>
<th>Studied subjects (N = 50)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
</tr>
<tr>
<td>Cyanosis</td>
<td>50</td>
</tr>
<tr>
<td>Clubbing of fingers</td>
<td>40</td>
</tr>
<tr>
<td>Dyspnea</td>
<td>45</td>
</tr>
<tr>
<td>Palpitation</td>
<td>40</td>
</tr>
<tr>
<td>Neurobehavioral deficits</td>
<td>28</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
</tr>
</tbody>
</table>

Fig. 1. MRI axial images T2 WI (A, B, C, D) showing mild dilated ventricular system with normal subarachnoid spaces (central brain volume loss).
obtained with TE 158 ms, TR 8000 ms, inversion time 2200 ms and slice thickness 5 mm. Axial T1-weighted MR images were acquired with TE (10 ms), TR (600) ms, and slices thickness of 5 mm.

White matter scoring was done using the Scheltens Scale primarily using the FLair data. The Scale of Scheltens performed separately for PVWMCs and DWMCs, assessing the presence and extent of PVWMCs and DWMCs in different anatomic regions with a 0-to-6-point scale. PVWMCs are scored as follows: 0 = absent, 1 = ≤5 mm, and 2 = >5 mm and <10 mm in 3 regions [frontal (caps), occipital (caps), along the ventricles (bands)], with a maximum of 6 points. DWMC scoring changes in deep white matter, in the basal ganglia, and in infratentorial regions according a 0-to-6-point scale: 0 = absent, 1 = <3 mm in ≤5 regions, 2 = <3 mm in ≥6 regions, 3 = 4–10 mm in ≤5 regions, 4 = 4–10 mm in ≥6 regions, 5 = <11 mm in >1 region, and 6 = confluent. Deep white matter is divided into frontal, parietal, occipital, and temporal region scoring with a maximum of 24 points. Basal ganglia are separated into caudate nucleus, putamen, globus pallidus thalamus, and internal capsule, scoring a maximum of 30 points.

Fig. 2. Axial brain MRI images with flair sequences (A, B, C, D) & T2 WI (E) showing periventricular and deep white matter high signal intensity at the fronto-parietal region denoting white matter hypoxic/ischemic lesions.
Infratentorial foci are scored in the cerebellum, mesencephalon, pons, and medulla, scoring a maximum of 24 points. Lacunar infarcts were scored using lobar, subcortical and infratentorial divisions using a semiquantitative scale by assigning a score from 0 to 3 (0 = absent, 1 = mild (single lacune), 2 = moderate (2 lacunes), and 3 = severe (3 lacunes or larger infarct)) for each region [11].


Cortical reconstruction and volumetric segmentation were done using the Freesurfer image analysis suite. In each participant, the margin between the GM and WM and the outer surface of the cortex was segmented. Cortical thickness size at each point across the cortex was measured as the closest distance from the GM and WM boundary to the GM and cerebrospinal fluid margin [12].

3.3. Statistical analysis

Data were analyzed using SPSS software (Statistical Package for the Social Sciences). Quantitative data were described as mean and standard deviations (SD). Unpaired Student “t” test was used to compare mean values of two groups. Simple Pearson correlation coefficient was measured to quantify the correlation between continuous variables. Qualitative data were described as number and percentage and Chi-squared ($\chi^2$) test was used to compare qualitative data of two groups. $P$ value < 0.05 was considered as significant.

4. Results

4.1. General and clinical characteristics of participants

We studied 50 children with CCHD and 20 controls, of them 41 were males (30 cases, 11 controls, $P = 0.62$). Their ages ranged from 2 to 6 years. The mean age for controls was 3.62 ± 1.1 years and for cases it was 3.57 ± 1.2, $P = 0.54$. The mean values of oxygen saturation were 96.4 ± 1.7 for controls versus 83 ± 2.2 for cases, $P = 0.001$. High-sensitivity C-reactive protein and packed cell volume were significantly higher in cases than in controls, $P < 0.05$.

Table 2 shows echocardiographic diagnosis of cardiac anomalies. The most common cardiac anomaly was Fallot Tetralogy represented in 46% of cases, followed by double...
outlet right ventricle represented in 28%. D-TGA and VSD were found in 5 cases (10%). Epstein anomaly was detected in 3 cases (6%). Truncus arteriosus and partial anomalous pulmonary venous return without obstruction were found in 2 cases each and single ventricle was diagnosed in one case.

Clinical presentation of studied subjects is summarized in Table 3. Cyanosis was found in all cases (100%), clubbing of fingers in 40 cases (80%), dyspnea in 45 cases (90%), and palpitation in 40 cases (80%). Neurobehavioral deficits including decreased attention, decreased self-awareness, speech delay, language delay, feeding problems, changes in memory and decreased learning abilities were detected in 28 cases (56%).

### 4.2. Conventional cerebral MRI

Mild dilation of ventricles was found in 14 cases (28%), Fig. 1. Twenty-three cases (46%) had PVWM hyper-intensity with five cases (10%) belonging to score 1, eight cases to score 2 (16%), six cases (12%) to score 3 and four cases (8%) to score 4. The most common sites for DWM hyper-intensity were sub-cortical that were detected in 17 cases (34%), Fig. 2. Sub-cortical lacunar infarcts in GM were the most common which were found in 8 cases (16%) Fig. 3. Four cases (8%) with lacunar infarcts in cortical and one case in infra-tentorial GM were detected Table 4.

### Table 5

Significant regions of reduced cerebral cortical thickness and brain volumes in cyanotic and control subjects.

<table>
<thead>
<tr>
<th>Region</th>
<th>Right/left</th>
<th>Control (n = 20) Mean ± SD</th>
<th>Patients (n = 50) Mean ± SD</th>
<th>p-Value of t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-central gyrus</td>
<td>R</td>
<td>2.524 ± 0.003</td>
<td>2.351 ± 0.069</td>
<td>0.043*</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>2.654 ± 0.52</td>
<td>2.241 ± 0.11</td>
<td>0.013*</td>
</tr>
<tr>
<td>Rostral middle frontal gyrus</td>
<td>R</td>
<td>2.958 ± 0.06</td>
<td>2.863 ± 0.047</td>
<td>0.043*</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>3.067 ± 0.71</td>
<td>2.635 ± 0.21</td>
<td>0.001*</td>
</tr>
<tr>
<td>Superior frontal</td>
<td>R</td>
<td>3.439 ± 0.13</td>
<td>3.418 ± 0.11</td>
<td>0.634</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>3.489 ± 0.13</td>
<td>3.387 ± 0.11</td>
<td>0.035*</td>
</tr>
<tr>
<td>Medial orbitofrontal</td>
<td>R</td>
<td>3.069 ± 0.31</td>
<td>2.941 ± 0.22</td>
<td>0.085</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>2.935 ± 0.08</td>
<td>2.781 ± 0.04</td>
<td>0.08</td>
</tr>
<tr>
<td>Isthmus of the cingulate gyrus</td>
<td>R</td>
<td>3.583 ± 0.21</td>
<td>3.308 ± 0.16</td>
<td>0.057</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>3.463 ± 0.24</td>
<td>3.102 ± 0.05</td>
<td>0.011*</td>
</tr>
<tr>
<td>Supramarginal gyrus</td>
<td>R</td>
<td>3.115 ± 0.32</td>
<td>2.935 ± 0.21</td>
<td>0.035*</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>3.068 ± 0.41</td>
<td>2.610 ± 0.21</td>
<td>0.01*</td>
</tr>
<tr>
<td>Dorsolateral prefrontal cortex</td>
<td>R</td>
<td>3.295 ± 0.52</td>
<td>3.001 ± 0.14</td>
<td>0.02*</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>3.249 ± 0.83</td>
<td>2.885 ± 0.23</td>
<td>0.001*</td>
</tr>
<tr>
<td>Superior parietal lobule</td>
<td>R</td>
<td>2.938 ± 0.82</td>
<td>2.639 ± 0.14</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>2.979 ± 0.12</td>
<td>2.746 ± 0.04</td>
<td>0.032*</td>
</tr>
<tr>
<td>Inferior parietal lobule</td>
<td>R</td>
<td>3.269 ± 0.62</td>
<td>2.929 ± 0.15</td>
<td>0.001*</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>3.355 ± 0.73</td>
<td>3.154 ± 0.12</td>
<td>0.042*</td>
</tr>
<tr>
<td>Precuneus</td>
<td>R</td>
<td>3.429 ± 0.23</td>
<td>3.211 ± 0.076</td>
<td>0.033*</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>3.362 ± 0.65</td>
<td>2.828 ± 0.23</td>
<td>0.01</td>
</tr>
<tr>
<td>Middle temporal gyrus</td>
<td>R</td>
<td>2.759 ± 0.43</td>
<td>2.598 ± 0.03</td>
<td>0.024*</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>2.713 ± 0.52</td>
<td>2.372 ± 0.04</td>
<td>0.033*</td>
</tr>
<tr>
<td>Thalamus</td>
<td>R</td>
<td>6.439 ± 0.75</td>
<td>5.997 ± 0.02</td>
<td>0.012*</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>6.592 ± 0.51</td>
<td>6.103 ± 0.21</td>
<td>0.01</td>
</tr>
<tr>
<td>Putamen</td>
<td>R</td>
<td>4.439 ± 0.41</td>
<td>4.1587 ± 0.01</td>
<td>0.032*</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>4.488 ± 0.71</td>
<td>4.082 ± 0.12</td>
<td>0.003*</td>
</tr>
<tr>
<td>Caudate</td>
<td>R</td>
<td>2.942 ± 0.11</td>
<td>2.768 ± 0.02</td>
<td>0.042*</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>2.894 ± 0.32</td>
<td>2.663 ± 0.07</td>
<td>0.47</td>
</tr>
<tr>
<td>Hippocampus</td>
<td>R</td>
<td>3.249 ± 0.02</td>
<td>3.223 ± 0.001</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>3.157 ± 0.02</td>
<td>3.143 ± 0.001</td>
<td>0.88</td>
</tr>
<tr>
<td>Amygdala</td>
<td>R</td>
<td>1.093 ± 0.0001</td>
<td>1.096 ± 0.001</td>
<td>0.845</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>1.041 ± 0.001</td>
<td>1.054 ± 0.001</td>
<td>0.983</td>
</tr>
<tr>
<td>Total intracranial volume</td>
<td></td>
<td>1191.726 ± 0.002</td>
<td>1189.92 ± 0.001</td>
<td>0.963</td>
</tr>
<tr>
<td>Total GM volume</td>
<td></td>
<td>629.368 ± 0.83</td>
<td>591.133 ± 0.31</td>
<td>0.001*</td>
</tr>
<tr>
<td>Supra-tentorial cortical GM</td>
<td></td>
<td>334.265 ± 0.61</td>
<td>307.642 ± 0.21</td>
<td>0.01</td>
</tr>
<tr>
<td>Sub-cortical structures</td>
<td></td>
<td>48.875 ± 0.54</td>
<td>41.58 ± 0.11</td>
<td>0.036</td>
</tr>
<tr>
<td>Cerebellar GM volume</td>
<td></td>
<td>92.456 ± 0.04</td>
<td>89.462 ± 0.03</td>
<td>0.783</td>
</tr>
<tr>
<td>Total WM volume</td>
<td></td>
<td>313.496 ± 0.62</td>
<td>303.669 ± 0.01</td>
<td>0.001*</td>
</tr>
<tr>
<td>CSF</td>
<td></td>
<td>9.384 ± 0.51</td>
<td>10.4066 ± 0.11</td>
<td>0.821</td>
</tr>
</tbody>
</table>

* Statistically significant.
Fig. 4. MRI flair sequence axial images (A, B & C) showing widened subarachnoid spaces (fissures and sulci) and regional brain volumetric analysis (D, E, F, G & H) showing cortical and subcortical brain volume loss at the frontal, temporal and parietal regions.
4.3. Cerebral cortical thickness and brain volumes

Areas of significant reduced cortical thickness were detected in the dorsal and lateral side of superior and middle frontal gyrus with localized changes present in the area corresponding to the dorsolateral prefrontal cortex. Regarding the parietal lobe, bilateral changes were found medially in the precuneus and posteriorly in the inferior, superior and supramarginal gyri. Bilateral focal changes were seen in the middle temporal gyrus, and also left sided focal changes were found in the isthmus of the cingulate. These results are summarized in Table 5 and illustrated in Figs. 4 and 5.

Significant volume loss was detected in the thalamus \( (p = 0.01) \), putamen \( (p = 0.003) \), and caudate \( (p = 0.042) \) in cyanotic subjects. There was no significant difference in volumes of hippocampus \( (p = 0.88) \) and amygdala \( (p = 0.845) \) between the two groups, Table 5.

There was no significant difference in total intracranial volume between the two groups (cases: 1189.920 mL vs. controls: 1191.726 mL, \( p = 0.963 \)). Significant GM volume loss was detected in cyanosed subjects (591.133 mL in cyanosed subjects versus 629.368 mL in control, \( P = 0.001 \)). This difference was caused mostly (52%) by supratentorial GM loss (307.624 mL in cyanosed subjects versus 334.265 mL in control, \( p = 0.027 \)). The residual volume loss was mostly caused by sub-cortical structures volume loss (41.58 mL in cyanosed subjects versus 48.875 mL in control, \( p = 0.05 \)). No significant difference in cerebellar GM volume was observed between the two groups (89.462 mL in cases versus 92.456 mL in control, \( p = 0.783 \)) Table 5.

Fig. 5. Regional brain volumetric analysis: axial brain tissue segmentation images (A, B, C), coronal images (D, E) and sagittal image (F) showing cortical, subcortical and central brain volume loss at frontal, temporal, parietal and occipital regions.
WM volume was decreased in cyanosed subjects (303.669 mL in cases versus 313.469 mL in control, \( p = 0.046 \)). The volume of ventricular cerebrospinal fluid was more in cases relative to controls (10.407 mL versus 9.384 mL, respectively, \( p = 0.821 \)) Table 5.

4.4. Correlation between MRI findings, oxygen saturations and laboratory measures

Cortical GM volume negatively correlated with hs CRP (\( R = -0.756, \ p < 0.001 \)). Significant positive correlations were detected between assessed measures of brain volume and oxygen saturations and packed cell volume (\( R = 0.624, \ p < 0.01 \)) (see Fig. 6).

5. Discussion

This study was carried on 50 children with cyanotic congenital heart diseases. They were 30 males and 20 females with a mean age of 3.57 ± 1.2 years. They were investigated using quantitative MRI. Brain volumetric results were compared with 20 controls.

The current study showed that dilated ventricles were found in 14 cases (28%). This result was supported by Shian et al. [13] who stated that in infants and children with cyanotic congenital heart disease and neurological abnormalities, ventriculomegaly was a common result.

In this study we found that 23 cases (46%) had PVWM hyper-intensity. Deep white matter lesion (DWML) was detected in 22 cases. The most common sites for DWML were sub-cortical that were detected in 17 cases (34%). Sub-cortical lacunar infarcts in GM were the most common which were found in 8 cases (16%). Four cases (8%) with lacunar infarcts in cortical and one case in infra-tentorial GM were detected. These results coincided with the following studies.

Herberg and Hövels-Gülich [14] reported that delayed brain maturation and hypoxic injury commonly in the white matter were found on neuroimaging in foetuses with CHD before surgery.

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**Fig. 6.** Cortical reconstruction and regional volumetric segmentation of different brain regions: (A, B) sagittal cortical reconstructed images. Axial (C, D), coronal (E) and sagittal (F) brain tissue segmentation images showing normal brain volumetric study in a control case.
Steven et al. [15] found in their study on 41 newborns with congenital heart disease and with the use of magnetic resonance imaging before cardiac surgery that injury of white-matter was detected in 13 newborns with congenital heart disease (32%) and normal WM in the control group.

Ortinau et al. [17], Shedeed and Elfaytouri [18] stated that WM injury was present from soon after birth in about one-third of infants with cyanotic CHD.

Also, Licht et al. [6] detected focal areas of cerebral infarction in 10% of infants with cyanotic CHD before surgery. Also by MRI infants with TGA had decreased head circumference and total brain maturation score.

Licht et al. [5] performed brain MRI before surgery on 25 infants with CHD. They found 53% of them had acquired brain injuries and/or developmental abnormalities including PVWM hyper-intensity (28%), microcephaly (24%), and incomplete closure of the operculum (16%).

In a systematic review and meta-analysis study which was carried out by Khalil et al. [16] they reported that in 13 studies (n = 425 cases) reporting on brain abnormalities either before surgery or in those who did not undergo congenital cardiac surgery. On neuroimaging brain lesions prevalence was 49% in left-sided heart lesions, 46% in mixed/unspecified cardiac lesions and 34% in transposition of the great arteries.

In the current study the global GM volume was reduced in cyanosed subjects. Also bilateral cortical thickness reductions were detected in the frontal, parietal and temporal lobes. These findings were similar to those detected by Ortinau et al. [17] who reported that decreased cortical thickness in the frontal and parietal lobes was found in infants with cyanotic CHD.

Limperopoulos et al. [8] studied 55 fetuses with CHD using MRI and MRS and the results were compared to those of 50 controls. Total brain volume, cerebrospinal fluid volume and fetal intracranial cavity volume were measured using 3-dimensional volumetric MRI. MRI study showed a progressive decrease in age-adjusted intracranial cavity volume and total brain volume in fetuses having CHD compared to controls.

Limperopoulos et al., reported in their studies that infants with cyanotic CHD and oxygen saturation <85% had a higher frequency of brain abnormalities [19,20].

In our study, there were significant positive correlations between brain volume measures and oxygen saturations and packed cell volume (R = 0.624, p < 0.01). In addition, significant negative correlation was found between cortical GM volume and hsCRP (R = -0.756, p < 0.001).

Our findings were supported by Chock et al. [21] who reported in their study that increased nucleated red blood cell count calculated after birth was a risk factor for acute neurological event before surgery.

Also the findings of this study coincided with the hypothesis that erythrocytosis results from chronic cyanosis increasing blood viscosity and shear stress on blood vessel [22]. This might lead to varying degrees of endothelial inflammation and dysfunction with damage to cerebral tissue [23].

Also our findings supported the results from the Framingham and Rachael et al. [24,25] studies that have revealed that inflammatory markers are correlated negatively with brain volume signifying that individual inflammatory and endothelial responses might have a significant role in ischemic change and brain atrophy.

The limitation of this study was the small number of cases and also the cases had various cardiac anomalies that did not allow further subgroup analysis.

6. Conclusion

Children with CCHD show MRI evidence of micro- and macro vascular injury, reduced brain volume and cortical thickness. Brain volume loss correlated with hsCRP, oxygen saturation and packed cell volume.

Conflict of interest

We have no conflict of interest to declare.

References


