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Whole blood viscosity and cerebral blood flow velocities in obese hypertensive or obese normotensive adolescents

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Abstract

Background: Obesity affects all major organ systems and leads to increased morbidity and mortality. Whole blood viscosity is an important independent regulator of cerebral blood flow. The aim of the present study was to evaluate the effect of whole blood viscosity on cerebral artery blood flow velocities using transcranial Doppler ultrasound in pediatric patients with obesity compared to healthy controls and analyze the effect of whole blood viscosity and blood pressure status to the cerebral artery blood flow velocities.

Methods: Sixty patients with obesity diagnosed according to their body mass index (BMI) percentiles aged 13–18 years old were prospectively enrolled. They were grouped as hypertensive or normotensive according to their ambulatory blood pressure monitoring. Whole blood viscosity and middle cerebral artery velocities by transcranial Doppler ultrasound were studied and compared to 20 healthy same aged controls.

Results: Whole blood viscosity values in hypertensive (0.0619 ± 0.0077 poise) and normotensive (0.0607 ± 0.0071 poise) groups were higher than controls (0.0616 ± 0.0064 poise), with no significance. Middle cerebral artery blood flow velocities were higher in the obese hypertensive (73.9 ± 15.0 cm/s) and obese normotensive groups (75.2 ± 13.5 cm/s) than controls (66.4 ± 11.5 cm/s), but with no statistical significance.

Conclusions: Physiological changes in blood viscosity and changes in blood pressure did not seem to have any direct effect on cerebral blood flow velocities, the reason might be that the cerebral circulation is capable of adaptively modulating itself to changes to maintain a uniform cerebral blood flow.

Keywords: adolescents; cerebral blood flow; children; hypertension; obesity; whole blood viscosity.

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Introduction

The prevalence of obesity is increasing significantly in the pediatric age group worldwide and is an epidemic public health problem in both many developed and developing countries [1]. Obesity affects all major organ systems and leads to increased morbidity and mortality due to hypertension, dyslipidemia, diabetes, cardiovascular and renal diseases [2–4].

Whole blood viscosity (WBV) is an important independent regulator of cerebral blood flow (CBF) [5]. Hematocrit and serum proteins are the leading components of whole blood viscosity. Abnormal increases in each of them may result in increased WBV and reduced CBF [6].

Transcranial Doppler ultrasound (TCD) is a noninvasive technique that evaluates velocity, direction and other properties of blood flow in basal cerebral arteries by means of a pulsed ultrasonic beam. Flow velocities have been shown to be consistent with direct invasive flow measurements [7, 8].

The aim of the current study was to evaluate the effect of WBV on cerebral artery blood flow velocities using TCD in obese hypertensive or normotensive pediatric patients compared to healthy controls.

Materials and methods

Sixty pediatric patients aged between 13 and 18 years old who were followed-up for obesity were included prospectively in the study. The study population consisted of 60 patients who were followed-up for

obesity for at least 3 years. Patients were divided into two groups based on ambulatory blood pressure monitoring (ABPM) measurements, with one group consisting of obese hypertensive children (34 patients) and the second group comprising obese normotensive children (26 patients). The children in the study population did not have any acute or chronic kidney, cardiac or neurological disorders and were not taking any medication. The control group consisted of 20 healthy normotensive children aged between 13 and 18 years, who were not obese, did not have any kidney, cardiac or neurological disorders and were not taking any medication. These children were selected from children admitted to the Children's and Adolescent Outpatient Clinic for follow-up and subsequently diagnosed as healthy. The study protocol was in accordance with the Helsinki declaration of human rights, and was approved by the Local Ethics Committee. Written informed consent was obtained from the children's parents and assent was obtained from participating children and also from the control group. A face-to-face questionnaire was conducted in order to record the family history, symptoms and cerebrovascular and cardiovascular events. Demographic data and anthropometric characteristics were collected.

Anthropometric measurements

Height was measured with a stadiometer and weight was measured on a calibrated scale with the child wearing light clothing. The body mass index (BMI) was calculated as the ratio of weight/height^2 (kg/m^2). The control group consisted of the same age and gender healthy controls who were not obese and also not hypertensive. Obesity was defined, according to the BMI percentiles for the Turkish population based on gender and age, as being ≥95th percentile [9].

Serum blood sample measurements

Biochemical assessments were performed under fasting conditions in the early morning. Blood glucose, lipids and routine laboratory parameters were measured using enzymatic spectrophotometric methods on an automated clinical chemistry analyzer (Olympus AU2700 plus analyzer, Beckman Coulter Inc., Pasadena, CA, USA). Insulin levels were measured using an electrochemiluminescence immunoassay method (Architect i2000 Analyzer; Abbott Laboratories, Chicago, IL, USA).

Insulin resistance

Insulin resistance (IR) was analyzed using the homeostasis model assessment of insulin resistance (HOMA-IR). HOMA-IR was calculated by the following formula: [fasting glucose (mg/dL) × fasting insulin (U/L)]/405. We assessed insulin sensitivity by using the HOMA-IR index as a surrogate marker of insulin resistance. The HOMA-IR values were calculated using the following formula: fasting insulin level (in μIU/mL) multiplied by fasting glucose level (in mg/dL) and divided by 405. The cut-off point for HOMA-IR was determined as 5.22 in boys and 3.82 in girls [10].

Office blood pressure measurements

On the day of ambulatory blood pressure measurement, the blood pressures and heart rates of each subject were measured 3 times consecutively in the seated position, at 5-min interval, using a mercury sphygmomanometer as recommended in the published data [11]. The mean of three readings was recorded as the office blood pressure. Systolic blood pressure or diastolic blood pressure percentiles were calculated according to the normograms recommended by the National High Blood Pressure in Children and Adolescents Institute [12]. Hypertension is diagnosed in a patient if the mean systolic blood pressure or diastolic blood pressure is above the 95th percentile for sex, age and height on three or more occasions. A child was diagnosed as normotensive if both systolic blood pressure and/or diastolic blood pressure percentiles were <90th percentile. Prehypertension was diagnosed if both or either of the systolic blood pressure and diastolic blood pressure percentiles were ≥90th percentile but both were <95th. For the classification of hypertension, each patient was evaluated by ambulatory blood pressure monitoring.

Ambulatory blood pressure monitoring measurements

Validated oscillometric devices were used to measure ambulatory blood pressures (Spacelabs monitor model no: 90207; SpaceLabs Medical, Redmond, WA, USA). The appropriate cuff, chosen from three different sizes available, was attached to the non-dominant arm. The frequency of automated reading was programmed at 20-min intervals from 8:00 AM to 12:00 AM and at 30-min intervals from 12:00 AM to 6:00 PM. ABPM was performed during a normal weekday that included normal daily activities. Each recording began between 8:30 AM and 9:00 AM. For data analysis, the whole 24-h, awake (between 8:00 AM and 10:00 PM), and sleep (between 12:00 AM and 6:00 AM) periods were considered separately. Awake and sleep periods were defined according to fixed, narrow, clock time intervals, which more closely correspond with the awake and sleep behavioral conditions in all of the subjects. Average of systolic blood pressure and diastolic blood pressure, over 24-h, awake and sleep periods were calculated. ABPM data (24-h mean systolic blood pressure and diastolic blood pressure, daytime systolic blood pressure and diastolic blood pressure, nighttime systolic blood pressure and diastolic blood pressure) were registered. Elevated blood pressure load was defined as more than 25% of recordings of systolic blood pressure or diastolic blood pressure measurements being ≥95th percentile for gender and height, respectively [13]. Office blood pressure percentiles, 24-h mean systolic blood pressure and 24-h mean diastolic blood pressure percentiles and systolic and diastolic blood pressure load were used to classify hypertension in patients [14]. Patients were grouped as having white-coat hypertension, masked hypertension, ambulatory hypertension and severe ambulatory hypertension, respectively, according to the data [14].

Transcranial Doppler ultrasound measurements

Middle cerebral artery blood flow velocity was examined by TCD on the same day of the echocardiographic evaluation by the same neurologist who was blind to the groups in obese patients. Middle cerebral arteries; responsible for ≥80% CBF were insonated through

the temporal windows using standardized protocol. Mean (Vim) velocities of right and left middle cerebral artery (MCA) flow was recorded at depths of 50–60 mm, with a 2-MHz probe by the technique described elsewhere by Aisled [7]. For intraobserver variability MCA blood flow velocity measurements was performed at least 3 times in succession, between each measurement the Doppler probe was moved-out and analysis point was re-positioned. Only measurements with the best signal-to noise ratio were used and the highest values for CBF velocities were selected for analysis. From these measurements, we have chosen the highest value for analysis. Sample volume was 8–10 mm in the axial and 5 mm in the lateral direction at the depth of 50 mm. All TCD studies were performed with the use of commercially available TCD apparatus Viasys/Sonara (Cardinal Health, Madison, WI, USA).

Whole blood viscosity measurements

WBV was studied immediately on the same day of hematological evaluations. Viscoelastic properties were determined via measurement of oscillatory flow in a cylindrical tube called Vilastic Bioprofiler (Vilastic scientific, Inc., Austin, TX, USA). For this measurement, 0.5 mL of sample was used. Before the measurement, the tube was filled with de-ionized water at 37 °C. When the temperature equilibrium was established, the viscosity of de-ionized water was measured and substituted from the sample's viscosity. This was done to eliminate the effect of transport medium on the measurement of the sample's viscosity. All the measurements were performed under constant temperature. To establish this, the device was assured to run under constant temperature for at least 40 min before making all the measurements. To eliminate the effect of time interval between gathering the sample and making the measurement, all the samples were evaluated after a certain and constant time period. The results of viscosity were given as poise units.

Statistical analysis

A power analysis was performed using NCSS PASS 2008 software to determine the appropriate sample size required for the study. The sample size calculation was based on a clinically significant difference of 10 cm/s for middle cerebral artery blood flow velocity with a standard deviation of 8 cm/s, a significance level of 0.05 and a power of 80%, a significance level of 0.05 and a power of 80%. This gave a required sample size of 20 subjects per group with a total of 60 subjects. A 10 cm/s difference in middle cerebral artery blood flow velocity was deemed to be clinically significant according to research previously carried out [6, 15–19]. Data analysis was performed using SPSS 15.0 (Statistical Package for the Social Sciences, Chicago, IL, USA). Normal distribution was tested by the Kolmogorov-Smirnov test or Shaphiro-Wilk test. Continuous variables were presented as a mean and standard deviation for normal distribution or median with interquartile range (IQR) for non-normal distribution, and categorical variables were presented as percentages. The chi-squared (χ^2) test was used for categorical variables. Continuous variables were compared using the t-test for two groups and one-way analysis of variance (ANOVA) with Tukey's post-hoc test or the Kruskal-Wallis H test with a Bonferroni adjusted Mann-Whitney U-test for three groups. Pearson's or Spearman's correlation coefficient was used to explore the associations among variables. A p-value <0.05 was considered to be statistically significant.

Results

Obese patients were divided into two groups: obese hypertensive (n = 34: 16 males, 18 females, mean age: 14.9 ± 1.3 years) and obese normotensive (n = 26: 11 males, 15 females, mean age: 14.7 ± 1.5 years). For controls, we studied with 20 subjects (10 males, 10 females) in the same age range (15.5 ± 1.7 years) with no hypertension or obesity. Our control group did not have any nephrological or neurological disorder either. General characteristics of the patients and control subjects are presented in Table 1.

Weight and BMI values were significantly higher in the obese hypertensive and obese normotensive groups than the normal controls ($p < 0.05$). Systolic and diastolic blood pressures were significantly higher in the obese hypertensive group compared with the controls and obese normotensive group ($p < 0.05$) (Table 1). Mean systolic and diastolic blood pressures were significantly higher in the obese hypertensive group than the obese normotensive and control groups ($p < 0.001$) (Table 2). The ABPM data and restricted laboratory data of the study group were recently published [20].

In the patient family histories, the prevalence of having hypertension was higher in the obese normotensive (66.7%) and obese hypertensive groups (80%) than in the controls (14.3%). In the obese hypertensive group, family histories of smoking and cerebrovascular and cardiovascular diseases were significantly higher than those in the other groups (Table 3). The most common complaint of patients on admission was headache with 25 patients (41.7%). Twenty (58.8%) patients in the obese hypertensive group and 5 (18.5%) in the obese normotensive group

Table 1: General characteristics of the patients and controls.

Variables	OHT (n = 34)	ONT (n = 26)	Control (n = 20)	p-Value
Age, years	14.9 (1.3)	14.7 (1.5)	15.5 (1.7)	0.243
Weight, kg	90.9 (12.8)	86.9 (10.1)	54.4 (10.1)	<0.001[a]
Height, cm	166.2 (8.0)	164.3 (7.2)	163.3 (10.2)	0.442
BMI, kg/m^2	33.1 (4.8)	32.2 (2.6)	20.3 (2.5)	<0.001[a]
SBP, mmHg	125.5 (11.2)	118.7 (11.1)	98.5 (12.3)	<0.001[b]
DBP, mmHg	83.7 (8.8)	76.7 (10.3)	63.5 (9.9)	<0.001[b]

Data was presented as mean (SD). [a]Control group differed from the OHT and ONT groups. [b]The groups differed from each other. SBP, systolic blood pressure; DBP, diastolic blood pressure; OHT, obese hypertensive group; ONT, obese normotensive group.

Table 2: Blood pressure measurements in the patients and controls.

Variables	OHT (n = 34)	ONT (n = 26)	Control (n = 20)	p-Value
Mean SBP, mmHg				
24-h mean SBP	128.2 (10.8)	115.8 (5.2)	109.4 (7.4)	<0.001[a]
Daytime mean SBP	132.5 (10.9)	118.2 (6.8)	112.4 (7.2)	<0.001[b]
Nighttime mean SBP	118.7 (9.9)	111.0 (5.3)	99.6 (6.0)	<0.001[a]
Mean DBP, mmHg				
24-h mean DBP	71.1 (9.8)	63.7 (5.0)	65.4 (6.4)	<0.001[b]
Daytime mean DBP	75.6 (9.0)	66.4 (6.0)	67.6 (4.8)	<0.001[b]
Nighttime mean DBP	64.4 (10.8)	59.6 (7.4)	56.6 (4.9)	<0.001[c]

Data was presented as mean (SD). [a]All groups differed from each other. [b]OHT group differed from the ONT and control groups. [c]Control group differed from the OHT group. SBP, systolic blood pressure; DBP, diastolic blood pressure; OHT, obese hypertensive group; ONT, obese normotensive group.

Table 3: Family history.

Variables	OHT (n = 34)	ONT (n = 26)	Control (n = 20)	p-Value
Hypertension	27 (79.4)	18 (69.2)	2 (10.0)	<0.001[a]
History of smoking	20 (58.8)	5 (19.2)	10 (50.0)	0.007[b]
Cerebrovascular disease	9 (26.5)	3 (11.5)	6 (30.0)	0.254
Myocardial infarction-cardiovascular disease	16 (47.1)	4 (15.4)	8 (40.0)	0.034[b]

Data was presented as frequencies (percentage). [a]Control group differed from the OHT and ONT groups. [b]ONT group differed from the control. OHT, obese hypertensive group; ONT, obese normotensive group.

complained of headache and was significantly higher in the hypertensive group ($p = 0.001$). Other accompanying symptoms, such as nausea, vertigo, tinnitus, blurry vision, neck pain, syncope attacks and epistaxis did not differ significantly among the groups ($p > 0.05$).

The biochemical values and selected laboratory data of patients and controls are presented in Table 4. The numbers of white blood cells and platelets were significantly higher in the obese normotensive and obese hypertensive groups than the controls ($p < 0.05$).

Table 4: Selected laboratory data of the study group.

Variables	OHT (n = 34)	ONT (n = 26)	Control (n = 20)	p-Value
Hb, g/dL	14.0 ± 1.0	13.6 ± 1.4	14.4 ± 1.3	0.074
Rbc, $\times 10^4/mm^3$	5.0 ± 0.4	4.9 ± 0.6	5.0 ± 0.5	0.624
MCV, fl	82.6 ± 5.5	82.4 ± 6.5	85.2 ± 5.2	0.204
Htc, %	41.7 (38.9–42.9)	40.5 (37.8–42.0)	42.2 (40.2–44.6)	0.078
WBC, $\times 10^3/mm^3$	7.45 (6.83–8.20)	6.63 (5.85–7.98)	5.95 (5.24–6.93)	0.002[a]
PLT, $\times 10^3/mm^3$	300.9 (265–330.6)	276.1 (255.0–336.9)	234.1 (212.6–271.55)	0.001[a]
Fasting glucose, mg/dL	87.0 (81.0–91.0)	86.0 (81.0–92.0)	90.0 (88.0–93.0)	0.035[b]
Insulin, U/mL	19.6 ± 7.5	17.8 ± 7.6		0.350
HOMA-IR index	4.2 ± 1.6	3.9 ± 1.8		0.401
Total protein, g/dL	7.8 (7.5–8.0)	7.7 (7.6–7.9)	7.7 (7.6–7.9)	0.367
Albumin, g/dL	4.6 ± 0.3	4.6 ± 0.2	4.8 ± 0.2	0.074
WBV (poise)	0.0619 ± 0.0077	0.0607 ± 0.0071	0.0616 ± 0.0064	0.817
MCABFV, cm/s	73.9 ± 15.0	75.2 ± 13.5	66.4 ± 11.5	0.079
Total cholesterol, mg/dL	172.8 ± 24.1	159.0 ± 26.7	150.0 ± 34.0	0.013[b]
Triglyceride, mg/dL	120.0 (98.0–162.0)	102.0 (77.0–133.0)	80.5 (62.5–95.0)	<0.001[a]

Data was presented as mean ± standard deviation or median (IQR). OHT, obese hypertensive patients; ONT, obese normotensive patients; Hb, hemoglobin; Rbc, red blood cell count; MCV, mean corpuscular volume; Htc, hematocrit; WBC, white blood cell; PLT, platelet count; HOMA-IR index, the homeostasis model assessment of insulin resistance calculated as: plasma insulin (U/mL) × plasma glucose (mg/dL)/405; WBV, whole blood viscosity; MCABFV, middle cerebral artery blood flow velocity. [a]$p < 0.05$ for control versus OHT and ONT; [b]$p < 0.05$ for control versus OHT.

Insulin levels in the obese hypertensive group (19.6 ± 7.5 U/mL) did not differ significantly from those in the obese normotensive group (17.8 ± 7.6 U/mL; $p > 0.05$). HOMA-IR values also did not differ significantly between the obese hypertensive (4.2 ± 1.6) and obese normotensive groups (3.9 ± 1.8) ($p > 0.05$).

WBV values in the obese hypertensive (0.0619 ± 0.0077 poise) and obese normotensive (0.0607 ± 0.0071 poise) groups were higher than that of the controls (0.0616 ± 0.0064 poise), but this difference was not statistically significant ($p > 0.05$). There was no significant difference between the measurements of the right and left arms of the middle cerebral arteries; thus, the data were pooled for further analyses ($p > 0.05$). Middle cerebral artery blood flow velocities were higher in the obese hypertensive (73.9 ± 15.0 cm/s) and obese normotensive groups (75.2 ± 13.5 cm/s) than the controls (66.4 ± 11.5 cm/s), but with no statistical significance ($p > 0.05$).

Total cholesterol levels were significantly higher in obese hypertensive patients than controls ($p < 0.05$). Serum triglyceride levels were significantly higher in obese hypertensive and normotensive patients than controls ($p < 0.001$).

Correlations

WBV was correlated positively with hemoglobin, hematocrit and red blood cell counts in obese patients ($r = 0.450$, $p < 0.001$; $r = 0.481$, $p < 0.001$; and $r = 0.443$, $p < 0.001$, respectively) as well as in control subjects ($r = 0.492$, $p = 0.028$; $r = 0.602$, $p = 0.005$; and $r = 0.653$, $p = 0.002$, respectively).

A non-significant negative correlation of WBV ($r = -0.150$, $p = 0.270$) and a significant negative correlation of hemoglobin ($r = -0.334$, $p = 0.010$) and hematocrit ($r = -0.419$, $p = 0.001$) with middle cerebral artery blood flow velocities were seen in obese patients. Middle cerebral artery blood flow velocities correlated negatively with 24-h mean ambulatory systolic and diastolic blood pressure values in the obese hypertensive group (systolic blood pressure: $r = -0.378$, $p = 0.028$; diastolic blood pressure: $r = -0.353$, $p = 0.040$) but not in the obese normotensive group. BMI correlated positively with middle cerebral artery blood flow velocities in obese patients ($r = 0.203$, $p = 0.123$). Insulin levels and HOMA-IR values were correlated positively with WBV in obese patients ($r = 0.298$, $p = 0.022$; $r = 0.284$, $p = 0.029$, respectively). No correlations were found between WBV values and blood pressure indices, body weights or BMI in both obese hypertensive and normotensive patients.

Discussion

Obesity is associated with abnormalities in microvascular patterns such as reduced small vessel density, inflammation, and impaired endothelial function as well as vascular reactivity in peripheral and central vascular beds [21]. Few studies have evaluated the relationship between BMI and blood flow regulation or established relationship between obesity and reduced large and small vessel arterial compliance, arterial stiffness, and reduced distensibility, including the carotid arteries [21–23]. The present study is designed to reveal this relationship for the first time in obese adolescents.

In the current study, middle cerebral artery blood flow velocities were found higher in the obese hypertensive and obese normotensive groups than in the controls, although the difference was not statistically significant. In the literature, a cross-sectional study conducted in 1323 stroke-free adults using TCD to evaluate CBF velocities revealed that cardiovascular risk factors, such as hypertension, hyperlipidemia, diabetes and obesity were the cause of diminished blood flow velocities in extracranial arteries, although this association was not remarkable in the intracranial arteries [15].

In another study, a TCD study which was performed to assess the hemodynamic status of cerebral arteries in adult patients with hypercholesterolemia revealed that low-density lipoproteins >160 mg/dL did not seem to have a detrimental effect on the hemodynamic status of the intracranial arteries. However, those with higher levels of low-density lipoproteins (>180 mg/dL) and lower levels of high-density lipoproteins (<35 mg/dL) showed significantly lower mean blood flow velocities in the internal carotid arteries [16]. In the current study, serum triglyceride and total cholesterol levels were significantly higher than controls ($p < 0.05$) but no significant relationship was found between TCD velocities and blood lipid profiles.

Hemoglobin, hematocrit levels and serum proteins are considered as important parameters that have the ability to influence whole blood viscosity. Increases in these variables may result in increases in WBV and also decrease in CBF [6, 17–19]. In the current study, as reported before [5, 6, 24–26] there was a negative correlation between middle cerebral artery blood flow velocities and hemoglobin/hematocrit levels. Studies on blood flow conducted in rigid tubes revealed the presence of an inverse relationship between flow velocities and viscosity. If cerebral vessels act as rigid tubes and CBF pressure is kept constant, CBF increases as viscosity decreases [5]. No statistically significant difference in the middle cerebral artery blood flow velocities existed between the

patient and control groups, and no correlation was found between the WBV and middle cerebral artery blood flow velocity in any of our groups. It has been reported that a three-fold variation in plasma viscosity with a two-fold variation in WBV do not significantly alter CBF under normal conditions [5]. Our results are consistent with the studies conducted on animals and humans that found plasma viscosity alone has little or no effect on CBF [5, 25–27], because the cerebral circulation has the ability to respond to changes in viscosity to maintain a constant flow [5, 28].

Insulin levels and HOMA-IR values in the current study correlated positively with WBV and WBV was higher in patients with insulin resistance. Although no significant relation was found between middle cerebral artery blood flow velocities and WBV of obese patients regardless of the blood pressure status, the positive significant relation of insulin resistance and WBV should point to the increased risk of vascular endothelial damage in obese patients.

The current study revealed that CBF increased as BMI increased in obese patients although a previous study conducted in a pediatric population found no correlation between BMI and CBF velocities [29]. Decreases in CBF velocities with increasing body mass have been reported in an adult population [21]. The mechanism of blood flow velocity changes is not clearly understood. However, local strong increases or decreases in flow velocity are correlated with high-grade stenosis. A milder and more generalized flow velocity increase may be due to intracerebral atherosclerosis or arterial narrowing in response to hypertension. In a population-based study in stroke-free subjects in adults, a significant and independent association with the risk of ischemic stroke and middle cerebral artery flow velocities, measured using transcranial Doppler ultrasound, was found [30]. Mild diffuse middle cerebral artery atherosclerosis or middle cerebral artery vasoconstriction in response to systemic hypertension is regarded as the most likely pathophysiological mechanism underlying this association [30]. The literature lacks pediatric studies and ours is very important in this regard. The findings of statistical analysis that have no significance is also an important issue that may highlight future studies.

In our study, a negative correlation between middle cerebral artery blood flow velocities and 24-h mean ambulatory systolic/diastolic blood pressure was found in the obese hypertensive group. On the other hand, there was no significant correlation between blood pressure indices and CBF velocity in another study conducted in children with mild sleep-disordered breathing [29]. In another study conducted in children, vascular reactivity of cerebral vessels to hypercapnia was measured by CBF velocities and diminished velocities were reported in hypertensive children suggesting the impairment of vascular reactivity by hypertension [31]. Under normal conditions, systemic blood pressure changes have no effect on CBF. Indeed, CBF is autoregulated effectively, such that the brain maintains a constant blood flow despite changes in perfusion pressure in both hypertensive and normotensive individuals. The cerebral arterioles constrict when arterial blood pressure rises and dilate when blood pressure falls or intracranial pressure rises to maintain uniform CBF. The lower limit of CBF autoregulation is the blood pressure below which autoregulatory vasodilatation becomes inadequate, leading to decreases in CBF [32, 33]. If this balance is not achieved, autoregulation failure may cause hypoperfusion or cerebral edema.

The limitations of our study are the one-centered, cross-sectional design of the study and the intra-observer reproducibility of middle cerebral artery flow measurements. The power was low in the study.

In conclusion, upon review of the literature we found no previous study evaluating the effects of obesity on CBF velocities in pediatric patients with or without hypertension. Although middle cerebral artery blood flow velocities were higher in the obese hypertensive and obese normotensive groups than the controls, the differences were not significant. Hemoglobin and hematocrit levels correlated inversely with middle cerebral artery blood flow velocity which is responsible for ≥80% of the CBF. Physiological changes in WBV did not seem to have any direct effect on CBF velocities, because the cerebral circulation is capable of adaptively modulating itself to changes in viscosity to maintain a uniform CBF. Further studies with larger samples are required to demonstrate the value of this relationship.

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