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Original Article

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Variation of the Cerebral Flow Dynamics in Mexican Pregnant Women During the Third Trimester

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Abstract

Background: Dynamic cerebral autoregulation and cerebral perfusion pressure are impaired in pregnancies complicated by preeclampsia compared with normotensive pregnancies, but the relationship between dynamic cerebral autoregulation and complications in preeclampsia remains a puzzle. Although it is well established that ethnicity, maternal age, and gestational age are among the risk factors for preeclampsia, the cerebral dynamics have been studied in different populations but not in the Mexican population. The aim of this study was to characterize the parameters of cerebral dynamics in the Mexican population according to gestational age and chronological age.

Methods: A prospective observational cross-sectional analytical study was carried out in Hospital Central "Dr. Ignacio Morones Prieto", which included 68 healthy pregnant. Cerebral flow dynamics were measured by General Electric Logic P5 ultrasound equipment, and a 3SP multi-frequency sector transducer (1.5 - 3.5 MHz) was used, with right transtemporal pathway at the level of the temporal border on the upper base of the zygomatic arch in front and somewhat tragus, with a slight anterior angulation of the transducer (15 - 30°). Middle cerebral artery was identified, and cerebral dynamics were measured.

Results: No statistically significant differences were found in peak mean diastolic or systolic velocities (peak diastolic cerebral blood flow velocity (PDCV) and peak systolic cerebral blood flow velocity (PSCV)) by chronological age groups. Significantly low cerebral perfusion pressure and systemic diastolic pressure were observed in patients ≤ 19 years. Patients with a gestational age of 32 - 36 weeks had significantly lower cerebral resistance index (2.3 ± 0.9) and brain flow index (BFI, 14.0 ± 6.6 cm/s) than patients with gestations ≤ 32 or ≥ 37 weeks. On the contrary, flow velocities were higher in 32 - 36 weeks compared to < 32 and > 37 weeks.

Conclusions: In Mexican pregnant women during the third trimester chronological age groups do not seem to influence cerebral dynamics in the third trimester, but there is an important difference observed at 32 - 36 weeks of gestation.

Keywords: Pregnancy; Brain flow index; Cerebral perfusion pressure; Cerebral blood flow velocity; Cerebral blood flow

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Introduction

During pregnancy there is an increase in afterload and plasma volume up to 40%, reaching at the 20th week of gestation with a decrease in peripheral vascular resistance [1, 2]. These findings are related to others in which there is a maternal hyperdynamic state, with increased cardiac afterload and reduced peripheral resistance in early pregnancy [3]. It has been shown that there is a physiological increase in cerebral blood flow in the first trimester of pregnancy above 25% and that this gradually decreases as the pregnancy progresses; but in the third trimester, it is still 15% higher than that of women's normal non-pregnant [4]. In one study it has even been determined that cerebral blood flow can rise to 52% of the baseline level during normal pregnancy. Under normal conditions, the autoregulation system allows cerebral blood flow not to be altered despite the occurrence of variation in systemic blood pressure. In cases of very high blood pressure, this autoregulation is lost. [5]. Cerebral autoregulation works on hand with cerebral hemodynamics, which includes cerebral perfusion pressure (CPP) and perfusion velocities [6]. Physiological decrease in the systolic and mean velocity of the cerebral artery has been identified in a linear relationship during normal pregnancy, from 12 weeks to 40 weeks, as well as pulsatility and resistance indices, while diastolic velocity does not change significantly [7]. Systolic velocity ranges from 80 to 112 cm/s, mean velocity ranges from 57 to 81 cm/s, and diastolic velocity ranges from 39 to 47 cm/s. Williams et al found that the systolic velocity of the middle cerebral artery remained constant during the first two trimesters (71 + 22 cm/s), with a decrease between weeks 29 and 36 of gestation (62 + 17 cm/s), while the diastolic velocity did not have an important variation [4].

Nevo et al who stated the characterization of cerebral flow in relation to gestational age in a prospective study reported a significant increase of cerebral blood flow from a pre-pregnancy mean value of 42.2 mL/min/100 g to 44.4 mL/min/100 g in the first trimester, 48.7 mL/min/100 g in the second trimester, and 51.8 mL/min/100 g in the third trimester; also during each week of gestation, the global cerebral blood flow increased by 0.269 mL/min/100 g [8]. The increased potential for negative pregnancy outcomes in both extremes of reproductive age (< 18 and > 35 years) is a well-debated argument. Vavilala et al reported that the autoregulatory index is physiologically lower in normal adolescents 12 - 17 years of age than in adults, also higher middle cerebral artery flow velocities than adults [9].

Dynamic cerebral autoregulation and CPP are impaired in pregnancies complicated by preeclampsia compared with normotensive pregnancies, but the connections of dynamic cerebral autoregulation, CPP, and cerebral complications in preeclampsia remain unclear [9]. In addition, CPP and dynamic cerebral autoregulation are altered in eclampsia and may be important in the pathophysiological pathway, which may constitute a therapeutic target and the prevention of cerebral complications in preeclampsia [10]. These cerebral perfusion parameters are the basis for understanding different phenomena that occur in hypertensive encephalopathies such as cerebral edema in patients with preeclampsia-eclampsia and the future establish treatment bases [11].

Preeclampsia-eclampsia may present at any gestation but is more commonly encountered in the third trimester. The exact etiology of eclampsia is still unclear despite the advances in understanding preeclampsia. It is proposed that there is increased permeability of the blood-brain barrier during preeclampsia, which causes an alteration to cerebral blood flow due to impaired autoregulation. In most studies, antiangiogenic factors PlGF, sFlt-1 and sEng concentrations increased significantly during gestation and were much higher in the third trimester compared to the values measured in the first trimester. This agrees with the theory that the accumulative effect of antiangiogenic factors is more evident in the third trimester with the significantly increased brain barrier permeability, which may lead to convulsions [12-14].

Ethnicity has been an important factor in different pathologies. Studies have reported variation in morbidity of preeclampsia among African Americans, Hispanics, and Maori. It has been estimated that preeclampsia complicates 2-8% of pregnancies globally, but in Latin America and the Caribbean, hypertensive disorders are responsible for almost 26% of maternal deaths, whereas in Africa and Asia they contribute to 9% of deaths. In the United States, African American women have a higher incidence of preeclampsia with a three-fold higher rate of maternal mortality compared to their White counterparts. Additional risk factors associated with preeclampsia include increasing maternal age above 40, and a prior history of preeclampsia. These variations can be explained by different genetic, ethnicity, and environmental predisposition to preeclampsia [15-17].

The Mexican population is almost homogeneous as like other Latin American countries, predominantly Mestizo (Amerindian-Spanish) 62%, predominantly Amerindian 21%, Amerindian 7%, other 10% (mostly European). Therefore, we consider it necessary exploring this population individually. This study was carried out to characterize the parameters of cerebral perfusion in the Mexican population at the third trimester according to gestational age and chronological age. Mexican population as a Latin American population is of high risk for preeclampsia as reported in previous studies, we expect to find special features of cerebral dynamics at the third trimester.

Materials and Methods

Study design

An observational, cross-sectional analytical, prospective study was carried out in Hospital Central “Dr. Ignacio Morones Prieto”, in the Division of Gynecology and Obstetrics. The institutional ethics and research committee approved the study and considered it an investigation with minimal risk. This study was approved by institutional review board (IRB) with registration number of CONBIOETICA-24 CEI-001 20160427. Sixty-nine healthy pregnant subjects (28 weeks or more defined by reliable date of the last menstrual period or 11 to 13.6 weeks’ ultrasound)) who agreed to participate by signing an informed consent were included. Patients with neurological disease, recent head trauma, pre-existing vascular disease, primary and secondary chronic arterial hypertension, pregestational diabetes, kidney disease, and the use of medications that can increase blood pressure were excluded. Transcranial brain Doppler was performed to obtain cerebral blood flow parameters. The study was conducted in compliance with the ethical standards of the responsible institution on human subjects as well as with the Helsinki Declaration.

Brain flow measurements with Doppler

Patient sitting on a consultation chair, a transcranial Doppler ultrasound (General Electric Logic P5 brand with 3SP multifrequency sectoral transducer) was applied at the level of the temporal border on the upper base of the zygomatic arch in front of the tragus, with a slight anterior angulation of the transducer (15 - 30°). The right middle cerebral artery was identified. The following Doppler measurements were calculated: peak systolic cerebral blood flow velocity (PSCV) in cm/s, peak diastolic cerebral blood flow velocity (PDCV) (cm/s), mean peak cerebral blood flow velocity (MPCV) (cm/s), and CPP (mm Hg). The cerebral resistance index (CRI) was calculated by the following formula: (PSCV - PDCV)/PSCV. Cerebral flow rate (cm/s) was obtained by dividing the CPP/cerebrovascular resistance index.

Statistical analysis

Statistical analysis was carried out using the statistical program R version 3.6 in the R Studio 1.4.1717 interface. Descriptive statistics were performed, and continuous variables were expressed as means or medians with their respective standard deviation or interquartile ranges according to the normality of the data as determined by the Shapiro-Wilk test. Discrete variables were expressed in proportions and percentages. Inferential statistics were performed by comparing the mean of the cerebral dynamics of the three groups by classic analysis of variance (ANOVA) or Welch ANOVA depending on the homogeneity test, for non-normal distribution data, Kruskal test was used with the correspondent *post hoc* test. A P < 0.05 was considered significant.

Results

Sixty-eight pregnant patients were included with a mean age of 21.8 ± 5.6 years, 43.5% adolescents (< 19 years), 44.9% 20 - 29 years, and 11.6% 30 years or older; 22.1% were less than 32 weeks, 20.6% were 32 - 36 weeks, and 57.4% were 37 weeks or more. (Table 1).

Patients ≤ 19 years old had significantly lower diastolic blood pressure (69.7 ± 9.4 mm Hg) than patients 20 - 29 years old (75.5 ± 8.1 mm Hg) and ≥ 30 years old (75.5 ± 8.1 mm Hg; P = 0.029). There were no differences in systolic arterial pressure and mean arterial pressure (MAP) between chronological age groups or between gestational age categories. The mean values of PSCV in adolescents were 55.4 ± 17.3 m/s, in patients 20 - 29 years old it was 57.1 ± 20.6 m/s, and in patients 30 years old or older it was 55.0 ± 23.2 (P = 0.928). Significant statistical difference was observed in CPP (mm Hg); by chronological age, < 19 years: 45.2 ± 11.1 mm Hg; 20 - 29 years: 36.3 ± 8.8; and ≥ 30: 40.1 ± 12.1; P value = 0.005 (Table 2).

The following Doppler measurements were calculated: PSCV in cm/s, PDCV (cm/s), MPCV (cm/s), and CPP (mm Hg). The CRI was calculated by the following formula: (PSCV - PDCV)/PSCV. Cerebral flow rate (cm/s) was obtained by dividing the CPP/cerebrovascular resistance index (Table 3).

No statistically significant differences were found in peak diastolic or mean velocities (PDCV and MPCV) by chronological age groups (Table 2). Between weeks 32 - 36 of gestation there is a significant increase in the values of PSCV, PDCV, and MPCV compared to the previous or later weeks. Patients with a gestational age of 32 - 36 weeks had significantly lower CRI (2.3 ± 0.9) and brain flow index (BFI: 14.0 ± 6.6 cm/s) than patients with gestations ≤ 32 or ≥ 37 weeks (Table 3).

Table 1. General Characteristics

Variable	Mean ± SD
Weight (kg)	61.6 ± 5.80
Height (cm)	158.1 ± 5.9
BMI (kg/m^2)	24.7 ± 2.2
Gestational age (weeks)	28.1 ± 11.2
< 32	22.1%
32 - 36	20.6%
> 37	57.4%
Maternal age (years)	21.8 ± 5.6
< 19	43.5%
20 - 29	44.9%
> 30	11.6%

BMI: body mass index; SD: Standard deviations.

Discussion

This study found no differences in systolic arterial pressure

Table 2. Comparison of Hemodynamic and Doppler Values by Chronological Age

Characteristics	≤ 19 years	20 - 29 years	≥ 30 years	P value[a]
Systemic blood pressure measurements				
Systolic (mm Hg)	113.2 ± 9.9	114.2 ±12.0	115.6 ± 11.8	0.851
Diastolic (mm Hg)	69.7 ± 9.4	75.5 ± 8.1	75.0 ± 7.5	0.029*
MAP (mm Hg)	84.2 ± 8.6	88.2 ± 8.3	88.5 ± 7.4	0.144
Flow velocities				
PSCV (cm/s)	55.4 ± 17.3	57.1 ± 20.6	55.0 ± 23.2	0.928
PDCV (cm/s)	21.8 ± 8.2	21.6 ± 8.9	22.2 ± 12.3	0.988
MPCV (cm/s)	32.3 ± 10.3	33.4 ± 12.7	32.6 ± 15.8	0.941
Cerebral perfusion measurements				
CPP (mm Hg)	45.2 ± 11.1	36.3 ± 8.8	40.1 ± 12.1	0.005*
CRI	2.9 ± 1.0	2.9 ± 0.9	3.4 ± 1.7	0.481
BFI (cm/s)	17.8 ± 8.1	14.0 ± 6.6	15.1 ± 9.0	0.151

[a]ANOVA test. *P < 0.05. MAP: mean arterial pressure; PSCV: peak systolic cerebral blood flow velocity; PDCV: peak diastolic cerebral blood flow velocity; MPCV: mean peak cerebral blood flow velocity; CPP: cerebral perfusion pressure; CRI: cerebral resistance index; BFI: brain flow index; ANOVA: analysis of variance.

Table 3. Comparison of Doppler Figures by Gestational Age

Parameters	≤ 32 weeks (n = 14)	32 - 36 weeks (n = 15)	≥ 37 weeks (n = 39)	P value[a]
Systemic blood pressure measurements				
Systolic (mm Hg)	113.2 ± 9.9	114.2 ± 12.0	115.6 ± 11.8	0.689
Diastolic (mm Hg)	71.3 ± 8.3	71.8 ± 6.7	73.7 ± 9.9	0.618
MAP (mm Hg)	85.3 ± 7.4	85.3 ± 7.3	86.4 ± 8.5	0.684
Comparison of Doppler				
CPP (mm Hg)	41.0 ± 8.1	42.8 ± 12.8	40.1 ± 11.3	0.719
CRI	3.1 ± 0.8	2.3 ± 0.9	3.4 ± 1.7	0.028**
BFI (cm/s)	17.8 ± 8.1	14.0 ± 6.6	15.1 ± 9.0	0.007[a]
Flow velocities				
PSCV (cm/s)	52.4 ± 16.2	74.2 ± 25.8	51.5 ± 13.6	< 0.000**
PDCV (cm/s)	19.4 ± 6.4	29.5 ± 11.8	20.2 ± 6.9	0.001**
MPCV (cm/s)	29.5 ± 8.7	43.6 ± 16.2	30.6 ± 8.8	0.001**

[a]ANOVA. **P < 0.05. MAP: mean arterial pressure; PSCV: peak systolic cerebral blood flow velocity; PDCV: peak diastolic cerebral blood flow velocity; MPCV: mean peak cerebral blood flow velocity; CPP: cerebral perfusion pressure; CRI: cerebral resistance; BFI: brain flow index; ANOVA: analysis of variance.

and MAP between chronological age groups or between gestational ages, which means the arterial pressure in the third trimester has uniform behavior throughout.

Serra-Serra et al conducted a retrospective, observational study that reported mean cerebral artery velocities decreased with advancing gestation but increased in the immediate puerperium to levels comparable to those found in nonpregnant women [18]. Batur Cagayan et al in a prospective observational study also demonstrated that the blood flow velocity of the MCA decreased during the late pregnancy period (> 37 weeks) and increased in the early postpartum period to a level similar to that of the nonpregnant group [19]. In a complementary way, we studied these velocities in the whole third trimester through groups given that preeclampsia is frequently observed in this period. Differences were found in the peak flow velocities in the middle cerebral artery according to gestational age, finding that patients with a gestation of 32 - 36 weeks had an increase in the figures of PSCV, PDCV, and MPCV, compared to patients with < 32 weeks and 37 weeks or more, but without statistical significance. More studies are required to determine the actual behavior cerebral velocities in different populations. Williams et al also studied these dynamics in normal pregnancy in each semester and reported that maximum systolic velocity fell significantly in the third trimester (P < 0.01) to the lowest value (62 cm/s); minimum diastolic velocity did not change with gestational age (28 cm/s); mean velocity fell significantly from 25 - 36 weeks, which is contrary to our results; we observed significant peak diastolic and systolic velocity at 32 - 36 weeks with numerical values of 74.2 cm/s and 29.5, respectively [4].

Most studies report cerebral dynamics on the middle cerebral artery, van Veen et al studied the anterior cerebral artery (ACA) and posterior cerebral arteries (PCA) velocities during the normal pregnancy and postpartum period and demonstrated changes in velocity that suggest a shift of cerebral blood flow from the anterior to the posterior cerebral circulation. They also reported the decreased resistance and pulsatility indices during the third trimester of both [20].

Zeeman et al reported that approximately 20% reduction in large artery cerebral blood flow occurs during normal pregnancy, secondary to changes in velocity [21]. For their part, Euser et al demonstrated (in experimental animals) that pregnancy together with other factors contributes to the increase in cerebral permeability and edema formation after autoregulation breakthrough [22]. Sharara in a retrospective study that was conducted to determine the prevalence in Qatar observed that there is a higher incidence of eclampsia in pregnant women under 37 weeks, while some other studies show that the highest incidence of eclampsia is during the puerperium [23]. These structural and hemodynamic changes in the brain during pregnancy were associated with a significant increase in the permeability of the blood-brain barrier, an effect they infer could promote the passage of harmful proteins to the brain and cause the neurological complications of eclampsia, including seizures in the third trimester.

Therefore, based on the findings of this study, the peak flow velocities in the middle cerebral artery vary according to gestational age, and the increases in the systolic and diastolic velocities were found between 32 and 36 weeks could be related to adaptations in the reduction of cerebral blood flow. Meanwhile, the reduction in full-term pregnancy may be due to local adaptations in cerebral blood flow, since there are mechanisms for adapting cerebral blood flow in the presence of changes in blood volume, oxygen content, or anemia states, as happens during pregnancy [24, 25].

The limitation of this study is that being a cross-sectional study we cannot establish the causality of our observations; we rely on theories of the previous studies.

Conclusions

In Mexican pregnant women, during the third trimester, the adolescents' group (< 19 years) had lower diastolic pressure; at the age of 20 - 29 years, lower CPP; the chronological ages do not seem to influence cerebral flow velocities of median cerebral artery; CPP did not show statical differences in throughout third trimester; but lower CRI and BFI was observed in 32 - 36 weeks. In contrary flow, velocities were higher in 32 - 36 weeks compared to < 32 and > 37 weeks. The maternal cerebral adaptation during pregnancy especially in the third trimester is a puzzle to be answered through multiple clinical, biomedical, and radiological research with their correlation or clinical significance, especially in women with hypertensive disorders of pregnancy. These observations may be explained by physical characteristics such as vessel elasticity and blood viscosity. It is necessary the realization of more translational research or clinical cohort studies to establish the physiological explanations of these observations.

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Conflict of Interest

The authors declare no conflicts of interest regarding the contents of this article.

Informed Consent

The authors have obtained the written informed consent of the patients or subjects mentioned in the article. The authors declare that they have followed the protocols of their work center on the publication of patient data.

Author Contributions

RACR and MARA: concept design and patients' recruitment. CDGP and JRVB: methodology and statistical analysis. LLAD, VBK: manuscript redaction and proofreading. All authors have read and approved this manuscript.

Data Availability

The authors declare that data supporting the findings of this study are available within the article.

References

1. Troiano NH. Physiologic and hemodynamic changes during pregnancy. AACN Adv Crit Care. 2018;29(3):273-283.
2. Sanghavi M, Rutherford JD. Cardiovascular physiology of pregnancy. Circulation. 2014;130(12):1003-1008.
3. Soma-Pillay P, Nelson-Piercy C, Tolppanen H, Mebazaa A. Physiological changes in pregnancy. Cardiovasc J Afr. 2016;27(2):89-94.
4. Williams K, Wilson S. Maternal middle cerebral artery blood flow velocity variation with gestational age. Obstet Gynecol. 1994;84(3):445-448.
5. Cipolla MJ, Bishop N, Chan SL. Effect of pregnancy on autoregulation of cerebral blood flow in anterior versus posterior cerebrum. Hypertension. 2012;60(3):705-711.
6. Moerman A, De Hert S. Why and how to assess cerebral autoregulation? Best Pract Res Clin Anaesthesiol. 2019;33(2):211-220.
7. Tan Y, Tan Y, Zhou J, Liu Y, Zhao B, Zeng S. [Blood flow parameters of posterior cerebral artery in normal pregnancy during middle and late stage]. Zhong Nan Da Xue Xue Bao Yi Xue Ban. 2018;43(8):886-891.
8. Nevo O, Soustiel JF, Thaler I. Maternal cerebral blood flow during normal pregnancy: a cross-sectional study. Am J Obstet Gynecol. 2010;203(5):475.e471-476.
9. Vavilala MS, Newell DW, Junger E, Douville CM, Aaslid R, Rivara FP, Lam AM. Dynamic cerebral autoregulation in healthy adolescents. Acta Anaesthesiol Scand. 2002;46(4):393-397.
10. Bergman L, Cluver C, Carlberg N, Belfort M, Tolcher MC, Panerai RB, van Veen T. Cerebral perfusion pressure and autoregulation in eclampsia-a case control study. Am J Obstet Gynecol. 2021;225(2):185.e181-185.
11. Cunningham FG, Twickler D. Cerebral edema complicating eclampsia. Am J Obstet Gynecol. 2000;182(1 Pt 1):94-100.
12. Bergman L, Acurio J, Leon J, Gatu E, Friis T, Nelander M, Wikstrom J, et al. Preeclampsia and increased permeability over the blood-brain barrier: a role of vascular endothelial growth receptor 2. Am J Hypertens. 2021;34(1):73-81.
13. Kozlowski S, Stelmaszczyk-Emmel A, Szymusik I, Saletra-Bielinska A, Brawura-Biskupski-Samaha R, Pietruski P, Osinska A, et al. sFlt-1, Not PlGF, is related to twin gestation choronicity in the first and third trimesters of pregnancy. Diagnostics (Basel). 2021;11(7):1181.
14. Goulopoulou S. Maternal vascular physiology in preeclampsia. Hypertension. 2017;70(6):1066-1073.
15. Xiao J, Shen F, Xue Q, Chen G, Zeng K, Stone P, Zhao M, et al. Is ethnicity a risk factor for developing preeclampsia? An analysis of the prevalence of preeclampsia in China. J Hum Hypertens. 2014;28(11):694-698.
16. Shi P, Zhao L, Yu S, Zhou J, Li J, Zhang N, Xing B, et al. Differences in epidemiology of patients with preeclampsia between China and the US (Review). Exp Ther Med. 2021;22(3):1012.
17. Gestational Hypertension and Preeclampsia: ACOG Practice Bulletin Summary, Number 222. Obstet Gynecol. 2020;135(6):1492-1495.
18. Serra-Serra V, Kyle PM, Chandran R, Redman CW. Maternal middle cerebral artery velocimetry in nor-

mal pregnancy and postpartum. Br J Obstet Gynaecol. 1997;104(8):904-909.
19. Batur Caglayan HZ, Nazliel B, Cinar M, Ataoglu E, Moraloglu O, Irkec C. Assessment of maternal cerebral blood flow velocity by transcranial Doppler ultrasound before delivery and in the early postpartum period. J Matern Fetal Neonatal Med. 2019;32(4):584-589.
20. van Veen TR, Haeri S, Sangi-Haghpeykar H, Belfort MA. Changes in maternal posterior and anterior cerebral artery flow velocity during pregnancy and postpartum—a longitudinal study. J Clin Ultrasound. 2013;41(9):532-537.
21. Zeeman GG, Hatab M, Twickler DM. Maternal cerebral blood flow changes in pregnancy. Am J Obstet Gynecol. 2003;189(4):968-972.
22. Euser AG, Cipolla MJ. Cerebral blood flow autoregulation and edema formation during pregnancy in anesthetized rats. Hypertension. 2007;49(2):334-340.
23. Sharara HA. A review of eclampsia in Qatar: A twenty-year study (from January 1991-December 2009). Qatar Med J. 2012;2012(2):7-15.
24. Sifakis S, Pharmakides G. Anemia in pregnancy. Ann N Y Acad Sci. 2000;900:125-136.
25. Johnson AC, Cipolla MJ. The cerebral circulation during pregnancy: adapting to preserve normalcy. Physiology (Bethesda). 2015;30(2):139-147.