Cerebral Hemodynamics in Hypertension: 
A Transcranial Duplex Study

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ABSTRACT

Background: Blood pressure reduction has been shown to be beneficial in both primary and secondary stroke prevention. Objective: To study the effect of hypertension on cerebral blood flow hemodynamics and cerebral hemodynamics in relation to age, duration of hypertension, severity of hypertension and body mass index (BMI) by using transcranial color coded duplex. Methods: This study included 40 patients with hypertension: Classified to (Group Ia) Twenty without a history of cerebrovascular stroke and (Group Ib) twenty with evidence of past cerebrovascular stroke) and 20 healthy controls. Blood pressure and body mass index were measured and extracranial and transcranial duplex was performed for all subjects. Results: Comparison between hypertensive patients without CVS and controls showed no significant differences. Comparison of hypertensive patients with CVS and controls showed statistically significant older age (p=0.009), higher Right IMT (p=0.002), lower PSV (0.018), lower TAP (p=0.003) and higher PI (0.004) in hypertensive patients. Comparison of hypertensive patients without CVS to hypertensive patients with CVS showed higher PI (p=0.037). The only significant finding was the correlation between age and increased left CCA-IMT in hypertensive patients (p=0.033). Conclusion: Hypertension may affect cerebral hemodynamics in stroke patients by an indirect mechanism. Age and obesity may not have a direct effect on cerebral hemodynamics in hypertensive patients. TCD appears to be a suitable method for assessment of cerebral hemodynamics and vasculature in hypertensive patients. [Egypt J Neurol Psychiat Neurosurg. 2011; 48(3): 277-284]

Key Words: Hypertension, Hemodynamics, IMT, PI, PSV, PI, BMI

INTRODUCTION

Stroke is the second most common cause of death worldwide and a complication to many risk factors; one of the commonest is hypertension¹. Blood pressure reduction has been shown to be beneficial in both primary and secondary stroke prevention².

The dynamics of the cerebral vascular response to blood pressure changes in hypertensive humans is poorly understood. Because cerebral blood flow is dependent on adequate perfusion pressure, it is important to understand the effect of hypertension on the transfer of pressure to flow in the cerebrovascular system of elderly people¹. Transcranial Doppler (TCD), is a noninvasive technique to assess cerebral hemodynamics and is now widely available and routinely used for diagnosis and follow-up of neurovascular diseases³.

The aim of this study is to study the effect of hypertension on cerebral blood flow hemodynamics and cerebral hemodynamics in relation to age, duration of hypertension, severity of hypertension and body mass index (BMI) by using transcranial color coded duplex.

PATIENTS AND METHODS

This study is a prospective case-control study: (I) Forty patients with hypertension diagnosed according to the British Hypertension Society guidelines for hypertension management (5) and were further subdivided into 2 groups: (Ia) Twenty hypertensive patients without cerebrovascular insult. (Ib) Twenty hypertensive patients with ischemic cerebrovascular insult whether symptomatic or detected by neuroimaging. (II) Twenty healthy control subjects. All patients were selected from the Neurology department and outpatient neurology & internal medicine clinic at Kasr El Aini University hospitals during the period from May 2009 to October...
2010. Subjects were excluded if they have diabetes mellitus, dyslipidemia, stroke within 1 month from onset, hemorrhagic stroke or extracranial internal carotid artery stenosis causing 50% or more diameter reduction which may significantly affect cerebral hemodynamics.

**Methods:**

**I. Clinical evaluation:** Complete history of hypertension, and measurement of blood pressure and BMI. We classified patients in groups with hypertension to early stage hypertensive patients with duration of hypertension ≤ 5 years and chronic hypertensive patients with duration of hypertension > 5 years.

**II. Laboratory tests:** Measurement of fasting blood sugar and lipid profile (serum triglycerides, cholesterol, HDL and LDL) for all subjects.

**III. Computerized tomography (CT) of the brain:** Axial cuts without contrast were performed for confirming ischemic stroke for hypertensive subjects excluding hemorrhagic stroke.

**IV. Extracranial carotid artery duplex and Transcranial color-coded duplex sonography (TCCS):** This examination was performed at Neurovascular ultrasonographic laboratory, Neurology department, Kasr Al Aini Hospitals using Phillips HDI 5000 ultrasound equipment:

a. **Extracranial vessels:** A high frequency (7 to 10 MHz) linear array transducer was employed to scan the carotid from the most proximal common carotid artery (CCA) to the internal carotid artery (ICA) as far as the mandible permitted. The intima–media complex thickness (IMT) was measured at the far wall. Carotid atherosclerotic disease was considered present if the intima-media complex showed diffuse thickening (≥ 1.0 mm) or if carotid plaques were detected (Figure 1). The degree of stenosis was primarily assessed according to the Doppler information. Hemodynamically insignificant plaque (< 50% stenosis) was diagnosed if plaque was detected on B-mode image and PSV was < 125 cm/s.

b. **Intracranial vessels:** Evaluated by TCCS with the use of 2 MHz phased array transducer. At the start of the examination the transtemporal acoustic bone window was tried to check for adequate ultrasonic beam penetration, if failed, patients were considered inappropriate for the TCCS examination. The patient attained a supine position, examined with the operator at his head and the middle cerebral artery (MCA) on both sides was insonated through the temporal window (Axial plane) (Figure 2). Each MCA was investigated using spectral Doppler sonography with the colour-coded Doppler signal used for the presence of stenosis, occlusions in the MCA measuring: Peak systolic velocity (PSV), End diastolic velocity (EDV), Time average peak (TAP) Resistivity index (RI) and Pulsatility index (PI).

**Figure 1.** Extracranial B-mode of the Common carotid artery (CCA) showing (A) measurement of the IMT. (B) An atheromatous plaque.
**Statistical Analysis:**

Data were statistically described in terms of range, mean±standard deviation (SD), frequencies (number of cases) and percentages when appropriate. Comparison of quantitative variables between the 3 study groups in the present study was done using one way analysis of variance (ANOVA) test with posthoc multiple 2-group comparisons. For comparing categorical data, Chi square ($\chi^2$) test was performed. Exact test was used instead when the expected frequency is less than 5. Correlation between various variables was done using Pearson moment correlation equation for linear relation. A probability value (p value) less than 0.05 was considered statistically significant. All statistical calculations were done using computer programs Microsoft Excel 2007 (Microsoft Corporation, NY, USA) and SPSS (Statistical Package for the Social Science; SPSS Inc., Chicago, IL, USA) version 15 for Microsoft Windows.

**RESULTS**

Characteristics of the study population are shown in Table (1). Comparison between hypertensive patients without cerebrovascular insult and controls showed no significant differences in age, BMI, Right IMT, Left IMT, PSV, TAP and PI (p>0.05) (Table 2).

Comparison of hypertensive patients with cerebrovascular insult and controls showed statistically significant older age (p=0.009), higher Right IMT (p=0.002), lower PSV (0.018), lower TAP (p=0.003) and higher PI (0.004) in hypertensive patients but no significant differences in BMI or Left IMT (p>0.05) (Table 3).

Comparison of hypertensive patients without cerebrovascular insult to hypertensive patients with cerebrovascular insult showed higher PI (p=0.037). Right IMT showed only a trend towards increase in group hypertensive patients with CVS (p=0.067) and no significant differences in age, BMI, MABP, Left IMT, PSV or TAP (p>0.05).

Comparison of patients with early stage to patients with late stage hypertension within each group of hypertensive patients showed no significant differences (p>0.05).

Comparison between obese and non-obese patients within study subgroups showed no statistically significant differences regarding duplex parameters (p>0.05). Comparison between obese patients in group Ia versus obese patients in group Ib: there was a trend towards significant difference regarding PI (p=0.053). Comparison between obese patients in group Ib versus obese controls: there was a statistically significant difference regarding PI (p=0.007).

For each group, the duplex parameters were correlated with the following variables: Age, BMI, and MABP, duration of hypertension and grade of hypertension. The only significant finding was the correlation between age and increased left CCA-IMT in group Ib (p=0.033), otherwise there were no significant correlations (p>0.05).
Table 1. Characteristics of the study population

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group Ia (Hypertensive Without CVS (n=20))</th>
<th>Group Ib (Hypertensive with CVS (n=20))</th>
<th>Group II (Controls n=20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>Mean±SD (30-76)</td>
<td>Mean±SD (40-72)</td>
<td>Mean±SD (44-60)</td>
</tr>
<tr>
<td>Sex (number (percentage))</td>
<td>Males: 10 (50%); females: 10 (50%)</td>
<td>Males: 14 (70%); females: 6 (30%)</td>
<td>Males: 13 (65%); females: 7 (35%)</td>
</tr>
<tr>
<td>BMI</td>
<td>Mean±SD (22.8-35.8)</td>
<td>Mean±SD (19.7-37.6)</td>
<td>Mean±SD (19.6-32.3)</td>
</tr>
<tr>
<td>MABP (mmHg)</td>
<td>Mean±SD (97-147)</td>
<td>Mean±SD (93-123)</td>
<td>Mean±SD (83-102)</td>
</tr>
<tr>
<td>Duration of Hypertension</td>
<td>Mean±SD (1-20)</td>
<td>Mean±SD (1-20)</td>
<td>-</td>
</tr>
<tr>
<td>Stage of Hypertension</td>
<td>Early (&lt;5years): 10 (50%); Chronic (≥5years): 10 (50%)</td>
<td>Early (&lt;5years): 12 (60%); Chronic (≥5years): 8 (40%)</td>
<td>-</td>
</tr>
</tbody>
</table>

BMI: body mass index; CVS: cerebrovascular stroke; MABP: arterial blood pressure; SD: standard deviation

Table 2. Comparison between hypertensive patients without cerebrovascular insult (group Ia) and controls (group II).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group Ia (mean±S.D)</th>
<th>Controls (group II) (mean±S.D)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>55 ± 10.548</td>
<td>51 ± 4.60</td>
<td>0.133</td>
</tr>
<tr>
<td>BMI</td>
<td>28.308 ± 3.8038</td>
<td>26.980 ± 3.9486</td>
<td>0.327</td>
</tr>
<tr>
<td>Rt. IMT</td>
<td>0.081 ± 0.0144</td>
<td>0.0755 ± 0.0143</td>
<td>0.200</td>
</tr>
<tr>
<td>Lt. IMT</td>
<td>0.084 ± 0.0153</td>
<td>0.079 ± 0.0118</td>
<td>0.300</td>
</tr>
<tr>
<td>PSV</td>
<td>100.107 ± 32.987</td>
<td>107.832 ± 23.848</td>
<td>0.361</td>
</tr>
<tr>
<td>TAP</td>
<td>66.66 ± 23.541</td>
<td>75.983 ± 17.769</td>
<td>0.133</td>
</tr>
<tr>
<td>PI</td>
<td>0.8343 ± 0.1621</td>
<td>0.7908 ± 0.1317</td>
<td>0.390</td>
</tr>
</tbody>
</table>

BMI: body mass index; IMT: intima-media thickness; PI: pulsatility index; PSV: peak systolic velocity; SD: standard deviation; TAP: time average peak.

Table 3. Comparison between hypertensive patients with cerebrovascular insult (group Ib) and controls (group II).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group Ib (mean±S.D)</th>
<th>Controls (Group II) (mean±S.D)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>58.05 ± 8.605</td>
<td>51 ± 4.60</td>
<td>0.009 **</td>
</tr>
<tr>
<td>BMI</td>
<td>28.455 ± 4.9155</td>
<td>26.980 ± 3.9486</td>
<td>0.277</td>
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<tr>
<td>Rt. IMT</td>
<td>0.089 ± 0.0111</td>
<td>0.0755± 0.0143</td>
<td>0.002 **</td>
</tr>
<tr>
<td>Lt. IMT</td>
<td>0.0955 ± 0.0208</td>
<td>0.079± 0.0118</td>
<td>0.482</td>
</tr>
<tr>
<td>PSV</td>
<td>87.452 ± 21.226</td>
<td>107.832± 23.848</td>
<td>0.018 *</td>
</tr>
<tr>
<td>TAP</td>
<td>56.858 ± 15.917</td>
<td>75.983± 17.769</td>
<td>0.003 **</td>
</tr>
<tr>
<td>PI</td>
<td>0.9413 ± 0.1788</td>
<td>0.7908± 0.1317</td>
<td>0.004 **</td>
</tr>
</tbody>
</table>

BMI: body mass index; IMT: intima-media thickness; PI: pulsatility index; PSV: peak systolic velocity; SD: standard deviation; TAP: time average peak.

* Statistically significant at p value < 0.05
** Statistically significant at p value < 0.01
Table 4. Comparison between hypertensive patients without cerebrovascular insult (group Ia) and hypertensive patients with cerebrovascular insult (group Ib).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group Ia (mean±S.D)</th>
<th>Group Ib (mean±S.D)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>55 ± 10.548</td>
<td>58.05 ± 8.605</td>
<td>0.250</td>
</tr>
<tr>
<td>BMI</td>
<td>28.308 ± 3.8038</td>
<td>28.455 ± 4.9155</td>
<td>0.914</td>
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<tr>
<td>MABP</td>
<td>114.17 ± 14.137</td>
<td>109.83 ± 9.641</td>
<td>0.192</td>
</tr>
<tr>
<td>Right IMT</td>
<td>0.081 ± 0.0144</td>
<td>0.089 ± 0.0111</td>
<td>0.064</td>
</tr>
<tr>
<td>Left IMT</td>
<td>0.084 ± 0.0153</td>
<td>0.0955 ± 0.0208</td>
<td>0.736</td>
</tr>
<tr>
<td>PSV</td>
<td>100.107± 32.987</td>
<td>87.452 ± 21.226</td>
<td>0.137</td>
</tr>
<tr>
<td>TAP</td>
<td>66.66 ± 23.541</td>
<td>56.858 ± 15.917</td>
<td>0.115</td>
</tr>
<tr>
<td>PI</td>
<td>0.8343 ± 0.1621</td>
<td>0.9413 ± 0.1788</td>
<td>0.037 *</td>
</tr>
</tbody>
</table>

*BMI body mass index; IMT intima-media thickness; MABP mean blood pressure; PI pulsatility index; PSV peak systolic velocity; S.D standard deviation; TAP time average peak.

*Statistically significant at p value < 0.05

DISCUSSION

In the present study, we did not find any significant difference between hypertensive patients without cerebrovascular insult (group Ia) and controls as regards duplex parameters. On the contrary we found lower flow velocities hypertensive patients with cerebrovascular insult (group Ib) when compared to controls. Only PI was significantly changed comparing the two groups of hypertensive patients but there were no significant differences as regards flow velocities.

A reduction of cerebral blood flow (CBF) in hypertension has been repeatedly described. TCD studies, showed both increased and normal flow velocity in the cerebral arteries. In our study, the significantly elevated PI in group Ib patients compared to group Ia patients reflects elevated distal cerebral resistance in group Ib. Infarctions may be associated with an increased Collagen-Elastin ratio and a consequent rise in distal cerebral resistance. These results are further supported by experimental and clinical studies.

The lack of significant differences between two groups of hypertensive patients in our study as regards flow velocities may be due to the fact that patients with acute stroke were excluded from the study. Small brain infarctions in the acute or subacute phase can induce a spreading reduction in cerebral metabolism and a subsequent decrease in CBF because of its efferent effects. However, in the chronic stage the arteriolar conditions rather than the remote effects would be a determinant of CBF and mean flow velocity. Also, all patients in both groups of hypertensive patients (except 2 patients in each group) were under treatment of hypertension which would produce less reduction in CBF than expected which may reflect the role of antihypertensive drugs on the protection of cerebral hemodynamics and may normalize impaired cerebral flow autoregulation in the early stages of hypertension. Moreover, vasoactive substances such as catecholamines, sometimes elevated in essential hypertensive patients, may exert fewer effects on the cerebral vasculature than on other systemic arteries.

We did not find any significant difference between stages of hypertension as regards duplex parameters. Moreover, there were no significant correlations between duration of hypertension and grade of hypertension with duplex parameters. Similarly, Ficzere et al. did not find any difference of resting MCA CBF velocities in patients with chronic severe hypertension compared to healthy subjects. However, some authors have reported some differences in MCA CBF velocities according to the stage of the hypertension.

Our study did not find a significant correlation between age and duplex parameters in all studied groups except for increased left CCA-IMT with age in group Ib patients which indicates that aging have no effect on cerebral hemodynamics but may be responsible for the development of atherosclerosis. Rosengarten et al. using TCD showed unchanged hemodynamics between different age groups but did note a decrease in resting flow velocity with advancing age. An observable effect of aging on carotid artery from children to adults was demonstrated by Vavilala et al., but after adolescence carotid artery remains stable over much of adult life in a healthy person.

In our study only pulsatility was higher in obese patients of group Ib compared to obese patients of...
group Ia and obese controls suggesting that BMI and obesity have an indirect effect on cerebral hemodynamics by increasing distal arteriolar stiffness and resistance. Few studies reported on the relationship between obesity and cerebral blood flow regulation. Selim et al.\textsuperscript{40} found by using TCD that high BMI is associated with impairment of cerebral blood flow and resistance in cerebrovascular bed, independent of diagnosis of type-2 diabetes, hypertension or stroke.

Controversies about cerebral hemodynamics in hypertension may be contributed to studies employing different CBF assessment techniques or due to methodological differences such as the selection of patients.

Some factors may have influenced the results of the present study. Most patients of group Ia (14 patients) had a duration of hypertension < 5 years which is considered within the early stages of hypertension and arteriopathy may not have been severely developed leading to less impaired cerebral vessels. Also, Group Ib had significantly higher mean age when compared to controls which may contribute to lower flow velocities. Furthermore, most of our patients had mild hypertension (50%) which is an indicator to good control of their blood pressure.

Therefore, we conclude that hypertension may affect cerebral hemodynamics in patients with previous stroke only by an indirect mechanism. Hypertensive patients without clinically evident signs of cerebrovascular damage have no detectable impairment of cerebral hemodynamics as detected by TCD. There is no relation between duration or stage of hypertension and cerebral hemodynamics. Age and obesity may not have a direct effect on cerebral hemodynamics in hypertensive patients. TCD appears to be a suitable method for assessment of cerebral hemodynamics and vasculature in hypertensive patients.

[Disclosure: Authors report no conflict of interest]

REFERENCES

الملخص العربي

ديناميكية الدورة الدموية المخية في مرضى ضغط الدم العالي: دراسة باستخدام الدوبلكس

بعد مرشّع ارتفاع ضغط الدم من أكثر أمراض القلب والأوعية الدموية انتشارًا ومسئون عن نسبة كبيرة من حالات الوفاة والإعاقة بالعالم، أجمع. الهدف من هذه الدراسة هو تحديد مدى تأثير مرشّع ارتفاع ضغط الدم على ديناميكية الدورة الدموية المخية وعلاقة ديناميكية الدورة الدموية المخية بالعمر. مدة الإصابة بارتفاع ضغط الدم، درجة الإصابة بضغط الدم، مؤشر كتلة الجسم باستخدام الموجات فوق الصوتية، المولدة عبر الجمجمة.

وقد أجريت الدراسة على 400 من مرضى ارتفاع ضغط الدم بعد استبعاد عوامل الخطر الأخرى خاصة كالسكري وارتفاع نسبة الدهون بالدم.

تم تقسيم المرضى إلى مجموعتين: 200 مريض بارتفاع ضغط الدم بدون الإصابة بسكينة دماغية و200 مريض بارتفاع ضغط الدم وأصيب بسكينة دماغية. تم قياس ضغط الدم وقياس التدفق في الأوعية الدموية وقياس الضغط في الدم. المشاركين في الدراسة من 30 إلى 70 سنة بمتوسط قدره 55%.

أثبت النتائج أن سمنة بطانة الشريان السباتي الأمي كان أكبر في مرضى المجموعة A مقاينة بمجموعة التحكم وليس مرضى المجموعة A أو B، أو لا ينتمون بأي حال من الأحوال بين المجموعتين، بالنسبة لسمك بطانة الشريان السباتي الأمي. و أن نزول السرطان الافراقي ومستوى سرعة التدفق كان أقل في مرضى المجموعة A مقاينة بمجموعة التحكم وليس بمرضى المجموعة A. كان المؤشر البسيط كان أعلى في مرضى المجموعة A، clic على مجموعة اب. لا يمكن أن يكون نقصًا ذو انعكاسية، فيما يتعلق بجميع التغيرات المدوية فيهما، كما تأثر بالمجموعة A و B، وأن هناك فرق ذو دالة إحصائية فيما يتعلق بالنتائج الموجات فوق الصوتية بين المجموعة A ومجموعة التحكم. لم يكن هناك فرق ذو دالة إحصائية فيما يتعلق بنتائج الموجات فوق الصوتية بين المرضى ومجموعة التحكم. ومع ذلك، لا يمكن أن يكون من الممكن إجراء تحليلات ونتائج الموجات الصوتية باستخدام علاقة طرددية إيجابية ذات دالة إحصائية بين العمر وزيادة سمنة بطانة الشريان السباتي الأمي في مرضى المجموعة B.

ومن تلك النتائج أن مرضى ارتفاع ضغط الدم الذين يعانون من عادات سريرية واضحة للسكينة الدماغية لا يوجد لديهم تأثر ملحوظ لتتفق الدم الدماغي. سرعات التدفق الأقل وزيادة المؤشر البسيط لمرضى المجموعة B مقاينة بمجموعة التحكم ليس مرضى المجموعة A تشير إلى أن تأثر ديناميكية الدم الدماغي لدى هؤلاء المرضى قد يكون راجعا إلى آلية أخرى بدلاً من ارتفاع ضغط الدم.