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Importance of angle correction in transcranial color-coded duplex insonation of arteries at the base of the brain

Značaj korekcije ugla insonacije u transkranijalnom kolor dupleks ispitivanju krvnih sudova na bazi mozgu

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Abstract

Background/Aim. Transcranial color-coded duplex (TCCD) sonography allows visualization of the vessels being examined and measurement of the angle of insonation. The published literature suggests that blood vessels are insonated at the angle lower than 30 degrees, hence no correction for the angle is necessary. The aim of this study was to determine the availability of intracranial blood vessels for insonation, and the percentage of arteries and their segments which can be insonated at the angles lower than 30 degrees. **Methods.** The study included 120 patients (mean age 51). For each of the segments the angle of insonation was registered based on TCCD vizualization, and hemodynamic parameters were measured. The angle of insonation was measured using combined B-mode and color Doppler vizualization, as the angle between the direction of the ultrasound beam and the axis of the shown arterial segment. **Results.** The total success rate of insonation was 86.33% (1,554 out of 1,800). The mean angle of insonation value in all the examined arterial segments was 42 degrees. The insonation angle was higher than 30 degrees in about three quarters of the examined segments, especially in the A2 segment of the anterior cerebral artery (98%), the P1 segmet of the posterior cerebral artery (87%) and in the terminal internal carotid artery (83%). The A1 segment of the anterior cerebral artery showed the best insonation conditions with the angle of insonation lower than 30 degrees in 53% of the cases. **Conclusion.** The presented results of angles of insonation measurements for the anterior, middle and posterior cerebral arteries and their segments, as well as the terminal portion of the internal carotid artery clearly indicate that their average values in tested segments were very often higher than 30 degrees, which can cause an error in blood flow velocity measurement that cannot be ignored. The results confirm the necessity of correcting flow velocity values on the basis of the angle of insonation in TCCD sonography.

Key words:
ultrasonography, doppler, transcranial; ultrasonography, doppler, duplex; blood flow velocity; carotid artery, internal; anterior cerebral artery; middle cerebral artery

Apstrakt

Uvod/Cilj. Transkranijalna kolor kodirana dupleks (TCCD) sonografija omogućuje prikaz ispitivanih krvnih sudova i merenje ugla insonacije. Literatura govori u prilog tome da su uglovi insonacije uglavnom ispod 30 stepeni i da zbog toga nije potrebno raditi korekciju brzine. Cilj rada bio je da se utvrdi dostupnost intrakranijalnih krvnih sudova za insonaciju i procenat arterija i njihovih segmenata koji se mogu insonirati pod uglom manjim od 30 stepeni. **Metode.** Ispitivanjem je obuhvaćeno 120 bolesnika (srednje starosti 51 godine). Za svaki od segmenata registrovan je ugao insonacije na osnovu TCCD prikaza i merene su hemodinamske karakteristike. Ugao insonacije meren je kombinovanim B-mod i kolor doppler prikazom, kao ugao između pravca ultrazvučnog talasa i osovine prikazanog arterijskog segmenta. **Rezultati.** Insonacija je bila uspešna kod 86,33% insoniranih segmenata (1 554 od 1 800). Srednja vrednost ugla insonacije svih arterijskih segmenata bila je 42 stepena. Ugao insonacije bio je veći od 30 stepeni kod oko tri četvrtine ispitivanih segmenata, a naročito u A2 segmentu prednje moždane arterije (98%), P1 segmentu zadnje (87%) i u terminalnoj unutrašnjoj karotidnoj

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arteriji (83%). Segment A1 prednje moždane arterije pokazao je najbolje uslove za insonaciju, sa uglom manjim od 30 stepeni kod 53% bolesnika. **Zaključak.** Prikazani rezultati merenja uglova insonacije za prednju, srednju i zadnju moždanu arteriju i njihove segmente, kao i terminalnu unutrašnju karotidnu arteriju, jasno pokazuju da su njihove srednje vrednosti često veće od 30 stepeni, što može uzrokovati grešku u merenju brzine protoka koja se ne može zanemariti. Rezultati potvrđuju potrebu za korekcijom vrednosti brzine protoka u odnosu na ugao insonacije u TCCD sonografiji.

Ključne reči:
ultrasonografija, dopler, transkranijumska; ultrasonografija, dopler, dupleks; krv, brzina protoka; a. carotis interna; a. cerebri anterior; a. cerebri media.

Introduction

Modern neurosonological examination consists of Doppler sonography of cervical blood vessels and transcranial Doppler sonography of intracranial blood vessels. Although transcranial examination was one of the first attempts of medical use of ultrasound, it became a routine neurological diagnostic tool only since 1982 [1]. Transcranial Doppler sonography is performed by two types of devices, standard (blind) transcranial Doppler (TCD) and transcranial color-coded duplex (TCCD) sonography [2, 3]. Standard TCD does not show a live image of the structures being examined, but displays only the Doppler signal, therefore intracranial arteries are identified by indirect parameters such as: depth of the sample volume, position of the probe, flow direction and the reaction to the compression tests [4]. TCCD displays the image of blood vessels and measurement of the blood flow velocity. There is also the possibility to correct for the angle of insonation. The approaches to insonation for TCCD are not different from the standard TCD. The most important approach to displaying the anterior circulation, posterior cerebral arthery and veins is the transtemporal acoustic window [5]. Insonation approach to vertebrobasal structures is the transforaminal window [6].

Blood flow velocity and its changes during the cardiac cycle represent the basic data which are analyzed by Doppler sonography. Blood flow velocity is determined using a Doppler sonography computer, by processing the of differences frequency in emitted and received ultrasound waves which are reflected from erythrocytes in blood vessels (Doppler shift) using the Doppler formula. It is important to have in mind that the calculated velocity of blood flow can be accurate only if the Doppler probe is placed in such a way that the ultrasound beam is in the direction of blood flow. If the ultrasound beam is directed at the angle wider than 0 degree to a blood vessel, real blood flow velocity is equal to the measured velocity divided by the cosine function of the angle between the ultrasound beam and the long axis of a blood vessel. The cosine function ranges from 1 (when the angle of insonation is zero) to 0 (when the angle of insonation is 90 degrees).

Based on radiological and anatomical considerations, when TCD was introduced, it was assumed that the angle of insonation of the arteries at the base of the brain is similar and relatively small, so the normal values of flow rate were defined accordingly [7]. Given the lack of visual control, identification of certain vessels, and in particular their specific segments depends mostly on the experience of the examiner. The possibility of doing angle correction was available only for extracranial blood vessels with duplex ultrasound examination. With the introduction of TCCD, which involves the simultaneous use of the B-mode and color Doppler image and pulse wave Doppler signal, the possibility of measuring the insonation angle became available also in transcranial examination. Since then several works showing the importance of correcting the velocity by the angle of insonation have been published [8–10], including a smaller number of articles outlining the angle of insonation values for particular artery [usually only for the middle cerebral artery (MCA) and on a relatively small number of respondents)] [7].

Having in mind importance of transcranial ultrasound examination, and the significance of correct blood flow velocity measurements for evaluation of many pathological states, the possibility of using angles of insonation greater than 30 degrees, which largely alter the real blood velocity measured, cannot be ignored.

The aim of this study was to determine the availability of intracranial blood vessels for insonation, and the percentage of areteries and their segments which are insonated at angles lower than 30 degrees.

Methods

This study was conducted from March 2004 to March 2005 at the Clinic of Neurology the Military Medical Academy in Belgrade, Serbia. Inclusion criterion for the patients was that the neurological finding was negative for any pathological process of any origin in the brain, or significant heart disease. The subjects in which examination revealed hemodynamically significant stenotic or occlusive changes either in precranial, or intracranial arterial segments, as well as patients who did not have a sufficient temporal acoustic window were excluded from the study.

All the patients accepted precranial and transcranial Doppler sonography examination to be done, and signed the informed consent form.

Examination of patients was performed using a "Toshiba SSA 370A, Power Vision 6000" ultrasound, in the supine position after taking basic personal and medical history, blood pressure and pulse measurements.

Doppler sonography of blood vessels was done using a 7.5 to 11 MHz probe in B-mode and color Doppler mode to establish morphological abnormalities (if present), degree of lumen reduction, and the flow characteristics in the carotid and vertebral arteries: systolic [peak systolic velocity (PSV)] and diastolic flow velocity [end diastolic velocity (EDV)] and the diameter of the vessel from which the machine calculates the mean flow velocity (MEANV), resistance index (RI), cross sectional area (AREA) and cardiac output flow (FLOW) [11].

Transcranial examination of the arteries at the base of the brain was carried out with a 2 MHz probe through the temporal and occipital acoustic window [6]. Figure 1 shows the Willis arterial polygon and in particular its components and branches: the distal portion of the internal carotid artery (ICA), anterior cerebral artery (ACA), MCA and posterior cerebral artery (PCA), which is a typical image in TCCD examination of intracranial arteries through the temporal window. The examination through temporal a window was carried out in the axial plane, usually through the middle and posterior part of this window.

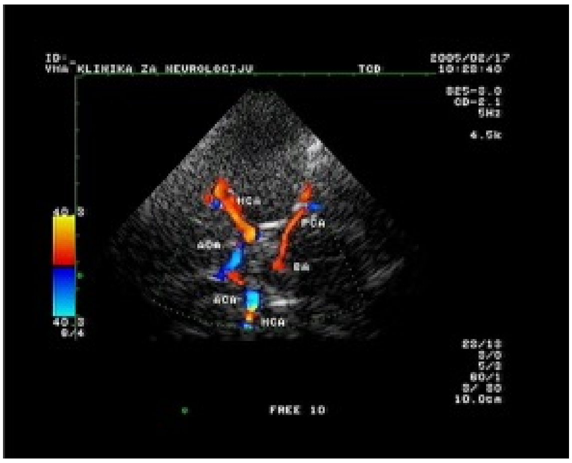

Fig. 1 – The Willis arterial polygon as can be seen by transcranial color-coded duplex sonographic examination of intracranial arteries through the temporal window.

It began with B-mode presentation of brain structures in mesencephalic plane and continued with color Doppler in order to obtain a better view of the terminal internal carotid artery (TICA), proximal precommunicating (A1) and post-communicating (A2) segments of the ACA, the horizontal sphenoid (M1) and insular (M2) segments of MCA and the proximal precommunicating (P1) and distal mesencephalic (P2) segments of PCA [10]. For each of the registered segments angle of insonation based on TCCD, visualization and hemodynamic parameters (PSV, EDV, MEANV and RI) were measured. The angle of insonation was measured using combined B-mode and color Doppler visualization, as the angle between the direction of the ultrasound beam and axis of the shown arterial segment.

Statistical analysis was performed using the free PSPP Software version 0.8.4.

In order to determine the significance in the difference of the distribution of age between male and female patients, as well as the distribution of insonation angles between the left and right intracranial blood vessels *t*-test was used. Continous variables were summarized as mean ± standard deviation. The angle measurement results of the examined arteries and their segments were grouped by the angle of insonation into those less than and equal to 30 degrees, and those above 30 degrees.

Results

A total of 120 patients were examined. Sixty five (54%) were men, and fifty five (46%) women. The mean age of the patients was 51 ± 16 years. There was no statistically significant difference between the age of men and women (data not shown).

A total of 1,800 insonations were attempted. The rate of success of insonation of different arteries and their segments during the transcranial ultrasound examination is shown in Table 1. The total success rate of insonation was 86.33%. In almost all the patients (97.08–99.16%) arteries were insonated successfully. Their segments had lower insonation rates, ranging from 70% for the P1 segment of the PCA, to 82.50% for the A2 segment of the ACA.

Table 1

The success rates of transcranial insonation of different arteries and their segments

Artery/Segment	Right (n)	Left (n)	Total n (%)
Terminal ICA	118	119	237 (98.75)
ACA	116	117	233 (97.08)
ACA A1	97	100	197 (82.08)
ACA A2	99	99	198 (82.50)
MCA	119	119	238 (99.16)
PCA	118	116	234 (97.50)
PCA P1	89	79	168 (70.00)
PCA P2	86	84	170 (70.83)
BA	117		117 (97.50)
Intracranial VA	116	117	233 (97.08)
Total	721	833	1554 (86.33)

ICA – internal carotid artery; ACA – anterior cerebral artery; A1 – precommunicating, and A2 – postcommunicating segments; MCA – middle cerebral artery; PCA – posterior cerebral artery; P1 – proximal precommunicating, and P2 – distal mesencephalic segments; BA – basilar artery; VA – vertebral artery.

The mean angle of insonation value in all the examined arterial segments was 42 degrees. The proportion of insonation angles lower than 30 degrees and higher than 30 degrees for all the examined arteries and their segments is shown in Table 2. TICA was insonated at the angles less than and equal to the 30 degrees in only 17% of cases, while in 83% of cases the angle of insonation was higher than 30 degrees.

Table 2

Proportions of arteries and their segments insonated at angles below or above 30 degrees

Artery/Segment	Angle of insonation (%)	
	≤ 30°	> 30°
TICA	17	83
ACA A1	53	47
ACA A2	2	98
MCA	21	79
PCA P1	13	87
PCA P2	49	51
Total	25	75

TICA – terminal internal carotid artery; ACA – anterior cerebral artery; A1 – maximal precommunicationg, and A2 – post-communicating segments; MCA – middle cerebral antery; PCA – posterior cerebral artery; P1 – proximal precommunicating, and P2 – distal mesencephalic segments.

The A1 segment of the ACA was insonated at the angle lower than 30 degrees in 53% of the cases, while the A2 segment of the same artery was insonated at the angle lower than 30 degrees in only 2% of the cases. In approximately 75% of the respondents, the angle of insonation of the proximal A1 segment of the ACA was less than 45 degrees, while for the A2 segment about 80% of respondents were examined at an angle greater than 45 degrees, and in 23% the angle was greater than 60 degrees.

In 21% of cases the MCA was insonated at the angle lower than 30 degrees.

The PCA was examined under various conditions depending on the segment. P1 and P2 segments of the PCA were insonated at angles lower than 30 degrees in 13 and 49% of the cases, respectively. In approximately 58% of respondents the angle of insonation in the P1 segment was greater than 45 degrees. The postcommunicating segment P2 was insonated at a more favorable angle at about 30 degrees where the noted flow velocity was higher and the flow direction was away from the transducer. In about 78% of the patients the angle of insonation was less than 45 degrees.

In around three quarters of examined segments, the angle of insonation was higher than 30°.

Discussion

This study examined 120 patients without any cerebral pathologies to measure the angles of insonation while evaluating blood flow through cerebral blood vessels. Out of 1,800 potential insonations, 1,554 were successful, and the angles, ranging from 1 to 80 degrees, were obtained.

The average value was about 42 degrees. The literature generally considers the values of the angle of insonation to be less than 30˚, which was presented by Eicke et al. [8]. The range in their results, which was 0–70 degrees, is similar to the results of this study. The basic assumption of the authors that spoke in favour of these results was that the angle of insonation was usually less than 30˚ thereby the error in measuring the velocity does not exceed the value of around 15%. According to the presented results: $\cos 42^\circ = 0.74$, which makes the error of about 25% in measuring the velocity without corrections. The results of measurements of the angles of insonation of intracranial arteries show that they were greater than 30˚ in 75% of the examined segments.

Only in 17% of the cases, the angle of insonation of the terminal segment of the ICA was smaller than 30˚ and higher than 60˚ in the same percentage. It is a short arcuate segment of the ICA syphon in which the flow direction was toward the probe in one part, and away from the probe in another one. No data on the angles of insonation in this segment was found in the literature.

The ACA was insonated under different circumstances depending on the segment. The proximal A1 segment with excellent insonation conditions was insonated at the angle lower than 30 degrees in 53% of the patients. According to our results, this segment had the most favourable insonation conditions. Our results are similar to those presented by Bartels et al. [10] and Martin et al. [12], and differ significantly from the results of Baumgartner et al. [9]. The segment A2 was examined under a very unsatisfying angle in most cases. In 98% of the cases the angle of insonation was higher than 30˚. In the literature, no data on the insonation conditions of this segment through temporal window was found. More favorable conditions could be reached through the frontal acoustic window that has been described previously [13].

The MCA is the artery that is the most studied, using both conventional TCD, as well as more contemporary TCCD sonography. The results obtained by measuring the angles of insonation using this method can vary depending on the author. The most favorable results were measured by Baumgartner et al. [9], while Krejza et al. [14] and Tsuchiya et al. [7] obtained significantly higher values. About 20% of the examined segments of the MCA were lower than 30 degrees, and other 80% were greater, although in only 5% the angle was higher than 60 degrees. The PCA insonation conditions differ significantly in proximal and distal segments, which is consistant with its anatomical course. Segment P1, P2a and P2P and P3 segment in part are accessible to Doppler sonographic examination. In Doppler sonographic terminology two segments of PCA are present: P1 in which blood flow is directed towards the probe and P2 where flow direction is away from the probe. The segment P1 corresponds to precommunicating and anterior mesencephalic segments. It is usually insonated in a more distal part, close to the point where flow of blood changes direction in relation to the probe. The result obtained by Bartels et al. [10] was close to this while the angles received by Baumgartner et al. [9] and Martin et al. [12] were significantly lower. The results of the two authors are close to those obtained in the distal P2 segment, which has much more favorable insonation conditions, in about 49% of the segments the angle was lower than 30 degrees. The authors whose results can be found in the available literature did not specifically analyze the insonation conditions of the segments P1 and P2.

Conclusion

The presented results of the angles of insonation measurements for the anterior, middle and posterior cerebral arteries and their segments, as well as the terminal portion of the internal carotid artery clearly show the values which are very often higher than 30 degrees. This situation can cause an error in blood flow velocity measurement that should not be ignored. The results confirm the necessity of correcting flow velocity values on the basis of the angle of insonation in transcranial color-coded duplex sonography.

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