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● *Original Contribution*

ABSENCE OF GRAVITY-DEPENDENT MODULATION OF STRAIGHT SINUS FLOW VELOCITY IN HEALTHY HUMANS

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Abstract—The influence of whole-body positions on the cerebral blood flow in normal subjects is unclear. Blood flow in cerebral veins and sinuses is continuous, pulsatile and proportional to cerebral blood flow. We examined young healthy volunteers to evaluate peak mean flow velocity (vm) in the straight sinus (SS) assessed by transcranial Doppler sonography in predefined variations of the whole-body pitch position relative to gravity in the presence of a normal (normocarbia) and an impaired (hypercarbia) cerebral autoregulation. A 2 MHz ultrasound probe was fixed with a headband nearby the protuberantia occipitalis externa. Fifteen subjects were seated in a motorized three-dimensional turntable. Vm-SS, blood pressure and heart rate were monitored in five whole-body pitch positions from upright (0°) to "20° head-hanging" (110°): 0, 30, 60, 90 and 110°. The experiment was repeated during the inspiration of 5% CO_2. Of 15 subjects, 14 showed reliable ultrasound data; the results of one subject with movement artifacts were excluded. Vm-SS values under normocarbia (hypercarbia) were 23.9 ± 4.2 cm/s (40.9 ± 6.7 cm/s) at 0°, 23.1 ± 5.0 cm/s (38.0 ± 5.0 cm/s) at 30°, 24.9 ± 5.1 cm/s (39.9 ± 3.3 cm/s) at 60°, 29.2 ± 8.5 cm/s (41.0 ± 4.7 cm/s) at 90° and 27.0 ± 11.6 cm/s (43.6 ± 12.1 cm/s) at 110°. Vm-SS measured under normocarbia ($p = 0.09$) and hypercarbia ($p = 0.25$) were not affected while subjects were positioned from upright toward "20° head-hanging", whereas blood pressure and heart rate decreased ($p < 0.01$). Our results suggest that changes of whole-body position from upright to "20° head-hanging" do not alter cerebral blood flow in healthy subjects. (E-mail: Ralf.Baumgartner@usz.ch) © 2008 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Cerebral venous circulation, Ultrasound, Gravity force.**

INTRODUCTION

The management of patients with disease or trauma of the brain causing intracranial hypertension includes moderate (15° to 45°) elevation of the head from the supine position to reduce intracranial pressure (Durward et al. 1983; Feldman et al. 1992; Meixensberger et al. 1997; Schneider et al. 1993). Further head elevation above 45° may be harmful due to a decrease of cerebral perfusion pressure and blood flow (CBF) (Durward et al. 1983). In contrast, the influence of different body positions on CBF in the surrounding normal brain tissue of these patients and in healthy volunteers is unclear.

Studies using magnetic resonance (MR) angiography (Mattle et al. 1990, 1991) and transcranial Doppler sonography (TCD) (Aaslid et al. 1991; Baumgartner et al. 1997a, 1997b; Becker et al. 1995; Stolz et al. 1999) have shown that blood flow in the cerebral veins and sinuses of healthy volunteers is continuous, pulsatile and directed toward the right heart. Furthermore, relative changes of peak mean flow velocities (vm) in the straight sinus (SS) show a linear correlation with relative vm-changes in the middle cerebral artery and, thus, with relative changes of CBF (Aaslid et al. 1991). The walls of cerebral sinuses such as the SS are rigid and fixed at the skull (Kalbag 1972). Therefore, changes of head position relative to gravity do not modify the diameter of the SS or its position with respect to a TCD probe, which is fixed with a headband to the scull. Consequently, it is fair to assume that relative changes of SS flow velocity induced by alterations of the head position would reflect relative changes of CBF.

The aim of our study was to evaluate whether SS-vm in healthy subjects is modified as a function of predefined whole-body pitch orientation in a range from upright (0°) to supine (90°) and "20° head-hanging"

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(110°). Subsequently, the experiments were repeated during the inhalation of CO_2. Hypercarbia may enhance possible cerebrovascular effects of body position changes because it impairs cerebral autoregulation by dilating the resistance vessels of the brain (Markwalder et al. 1984). The rationale for measuring SS-vm also under hypercarbia is that cerebral autoregulation is frequently impaired in patients with cerebral disease or trauma.

MATERIALS AND METHODS

Subjects

Fifteen healthy volunteers (10 women) with a mean age of 33 ± 4 y (range, 25 to 39) were recruited among the employees and students of the Department of Neurology, University Hospital of Zurich, Switzerland. The study protocol was reviewed and approved by the local ethical committee. Written informed consent was obtained from all subjects.

The subjects had (1) no history of nervous system disease including seizure disorder, psychiatric disease including substance and drug abuse and medical disease including coryza and bronchitis; (2) an occipital acoustic window providing adequate spectral Doppler signals from the SS and (3) normal findings in the extra- and intracranial cerebral arteries at color duplex sonography. One subject with recurrent displacement of the ultrasound probe during experiments was excluded from the final analysis, *i.e.*, the statistical analysis is based on 14 subjects.

Color Duplex Sonography of the Cerebral Arteries

Color duplex ultrasound studies were performed with an Acuson Sequoia, Mountain View, CA, USA. A linear 4 to 8 MHz probe was used for extracranial and a 2.0 to 3.5 MHz sector probe for transcranial insonation.

Experimental Protocol

Subjects were seated in a three-dimensional (3D) turntable with three servo-controlled motor-driven axes (prototype built by Acutronic, Jona, Switzerland). Subjects were rotated about their interaural axis backward from upright to five consecutive static whole-body pitch positions. These rotations imply reorientations of the gravity vector in the midsagittal plane of head and trunk. Each whole-body pitch position was kept for a period of 6 min, while SS flow velocity, blood pressure (BP) and heart rate (HR) were monitored (Fig. 1): exam 1, 0° = upright; exam 2, 30°; exam 3, 60°; exam 4, 90° (= supine) and exam 5, 110° (= "20° head-hanging"). Further increases of backward whole-body pitch could not be performed because of a displacement of the ultrasound probe. In each whole-body pitch position, subjects

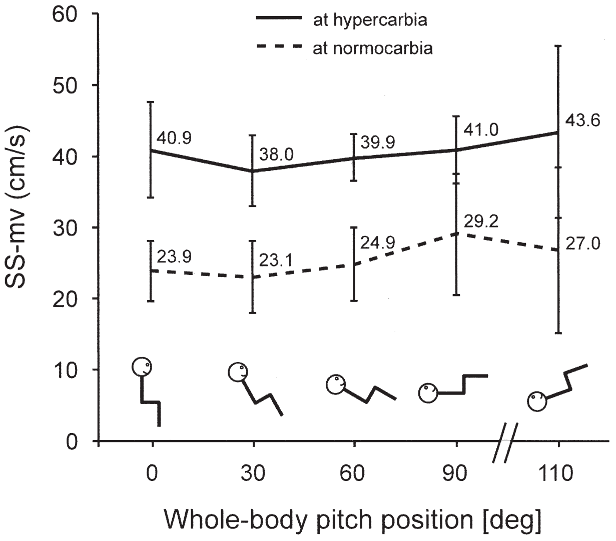

Fig. 1. Straight sinus flow velocities during variations of the whole-body pitch position. Average flow velocities in 14 straight sinuses as function of whole-body pitch position at normocarbia (dashed connecting lines) and hypercarbia (solid connecting lines). Error bars: ± 1 SD.

were kept in normocarbic condition during the first 3 min, and in hypercarbic condition, by inhalation of 5% CO_2 through a mask, during the subsequent 3 min. Thereafter, the whole-body was rotated into the next position. The rotation maneuver lasted for about 10 s and allowed together with the following 2 min of normocarbia the normalization of arterial pCO_2 values and SS flow velocities. Arterial pCO2 was not monitored because hypercapnia was used to measure the influence of different body positions on SS blood flow velocity but not to assess vasomotor reactivity.

The SS was insonated through the occipital acoustic window with a 2 MHz transducer using a pulsed-wave Doppler machine (Multi-Dop X-4; DWL, Sipplingen, Germany). The transducer was positioned about 1 cm above the external occipital protuberance and fixed on the skull with an elastic band to avoid movement artifacts. Peak mean flow velocities (Vm) of the SS were measured in its proximal part providing the smallest insonation angle possible at an insonation depth of about 50 mm according to the technique described by Aaslid et al. (1991). Mean depth of insonation of the SS was 50 ± 3 mm (range, 46 to 56 mm). Special attention was paid to obtain a venous Doppler signal directed toward the transducer without superposition of spectra resulting from neighboring branches of the posterior cerebral artery. To make sure that flow velocity measurements were performed in a steady state, subjects were exposed for 3 min to normocarbia and, subsequently, another 3 min to hypocarbia and only Vm-SS acquired in the last of the 3

Table 1. Straight sinus flow velocities, blood pressure and heart rate in 14 subjects during different pitch-body positions

Exam	Position [deg]	Peak mean straight sinus flow velocity* (range) [cm/s]		Mean blood pressure (range) [mm Hg]		Mean heart rate (range) [beats per min]
		Normal air	5% CO_2	Systolic	Diastolic	
1	0	23.9 ± 4.2 (18.1 - 30.4)	40.9 ± 6.7 (30.8 - 55.8)	119 ± 6 (110-130)	76 ± 5 (65-80)	74 ± 8 (56-88)
2	30	23.1 ± 5.0 (13.3 - 30.4)	38.0 ± 5.0 (30.6 - 47.0)	119 ± 5 (110-130)	76 ± 5 (65-90)	72 ± 8 (60-84)
3	60	24.9 ± 5.1 (16.3 - 31.7)	39.9 ± 3.3 (33.9 - 45.4)	119 ± 5 (110-130)	76 ± 6 (65-90)	71 ± 7 (60-80)
4	90	29.2 ± 8.5 (19.0 - 50.0)	41.0 ± 4.7 (35.5 - 51.6)	116 ± 5 (110-130)	73 ± 8 (60-80)	69 ± 5 (64-80)
5	110	27.0 ± 11.6 (14.4 - 61.0)	43.6 ± 12.1 (35.1 - 81.8)	115 ± 3 (110-120)	72 ± 7 (60-76)	68 ± 7 (56-80)

CO_2 denotes carbon dioxide
* Reported values were obtained after 121to180 seconds of recording

monitoring min were used for analysis. Accordingly, the mean BP (two measurements) and HR values obtained during the last minute of monitoring were used for final analysis.

BP was determined with a pneumatic cuff and HR was calculated using the Doppler spectra.

Statistical Analysis

Flow velocities, systolic and diastolic BP, as well as HR obtained at normo- and hypercarbia in different whole-body pitch positions were compared by nonparametric analysis of variance according to Friedman followed by post hoc testing according to Wilcoxon and Wilcox in the case of overall significance. As all variables were normally distributed, we report mean values and standard deviations unless otherwise stated. *P* values of less than 0.05 were considered significant.

RESULTS

Figure 1 and Table 1 show vm-SS, BP and HR values assessed in different whole-body pitch positions.

Vm-SS did not change with whole-body pitch position ($p > 0.05$), both under normocarbia (Fig. 1, dashed line) and hypercarbia (Fig. 1, solid line). Vm-SS was higher under hypercarbia than normocarbia ($p < 0.0001$).

Systolic and diastolic BP as well as HR (pooled data of normo- and hypercarbia) progressively decreased from exam 1 to 5 with significant differences in various whole-body pitch positions (for all: $p < 0.01$). Specifically, systolic BP decrease was significant ($p < 0.05$) for the comparisons 30 versus 90°, 30 versus 110°, 60 versus 90° and 60 versus 110°; diastolic BP decrease was significant for the comparisons 30 versus 60° and 30 versus 110°; HR decrease was significant for the comparisons 0 versus 60°, 0 versus 90°, 0 versus 110°, 30 versus 90°, 30 versus 110° and 60 versus 110°. Systolic and diastolic BP and HR were similar at normocarbia and hypercarbia ($p > 0.05$).

DISCUSSION

The main result of this study is that SS flow velocity did not change during stepwise variation of the whole-body pitch position from the upright to the supine (90°) and "20° head-hanging" (110°) in healthy subjects. The absence of gravity-dependent modulation of SS flow velocity was even observed during hypercarbia, which partially impairs cerebral autoregulation.

The walls of cerebral sinuses, which consist of a thin endothelium and two layers of dura mater, are rigid and fixed at the skull (Kalbag 1972). Therefore, changing the head position relative to gravity does neither modify the diameter of the sinuses nor their position relative to the scull-fixed ultrasound transducer. It is thus fair to assume that relative changes of SS flow velocity would reflect relative changes of CBF. Since SS flow velocity remained stable during all whole-body pitch positions, we conclude that sinovenous blood flow and, consequently, CBF is relatively insensitive to gravity changes in healthy subjects. In the absence of intracranial hypertension, our findings may also apply to the healthy cerebral areas of patients with disease or trauma of the brain. However, further studies are needed to examine this hypothesis.

Previous TCD studies have investigated alterations of blood flow velocity in the middle cerebral artery (MCA) during different body positions of healthy volunteers (Bondar et al. 1999; Serrador et al. 2000). In this study, vm-SS showed a nonsignificant trend during normocarbia (but not hypercarbia) to increase by 22%, which differs from the results of two TCD studies performed under normocarbia that observed nonsignificant decreases of vm-MCA (Serrador et al. 2000; Bondar et al. 1999). Vm-MCA decreased by 8% in the upright compared with the supine position in one study (Serrador et al. 2000) and by 10% to 12% during the last 60 s of 5 min head-up tilts of 60° and 90° in the other investigation (Bondar et al. 1999). In contrast to TCD monitoring of the SS, transcranial insonation of the MCA has the disadvantage that the position of the artery with respect to the fixed ultrasound probe may change during alterations of the body position, which may lead to inappropriately slow velocity measurements. Furthermore, it is unknown whether altered body positions change the diameter and, thus, flow velocities of the MCA. Thus, methodological inaccuracies may explain the aforementioned MCA flow velocity decrease observed during changes of body position. Another cause of the different findings in this compared with the two aforementioned TCD studies might be the low number of investigated subjects.

Autoregulation maintains CBF at a near-constant level for cerebral perfusion pressure values ranging between 60 and 150 mm Hg (Strandgaard et al. 1973). In our study, systolic and diastolic BP decreased significantly with increasing whole-body pitch from upright to "20° head-hanging" but remained within the normal limits of cerebral autoregulation. The absence of SS flow velocity decrease in this study suggests that the observed BP drop was successfully counteracted before and during the administration of CO_2 by cerebral autoregulation.

It is important to note that the aim of this study was to measure SS-vm in predefined whole body positions but not to investigate alterations of SS-vm after alterations of the whole-body position.

One limitation of the present study is the low number of examined subjects. To demonstrate significant changes of SS-vm ($p < 0.05$), 142 patients would be needed during normocarbia and 186 patients during hypercarbia. This number of patients, however, would have surpassed the financial resources that were available for this study. Another drawback is that we studied just the SS, which drains only the deep sinovenous system. However, the authors are not aware of any report suggesting that changes of body position are associated with changes of the drainage territories of cerebral veins and sinuses. Thus, the authors assume that the findings observed in the SS are similar in other cerebral sinuses.

CONCLUSION

Our results suggest that the cerebral sinovenous drainage and, consequently, CBF remain unaffected by changes of whole-body position ranging from upright to "20° head-hanging" in healthy young adults.

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