EFFECTS OF RAPID ONSET ACCELERATION ON CEPHALIC PULSATILE BLOOD VOLUME IMPEDANCE WAVEFORMS IN HUMANS

Barry S. Shender, Ph.D.
Naval Air Development Center, Code 6023, Warminster, PA 18974-5000

ABSTRACT

Electrical impedance plethysmographic measurements of the relative changes in cephalic pulsatile blood volume (Rheoencephalography, or REG) have been performed clinically for many years. REG indices provide information about cerebral vascular resistance (CVR). This technique has been used to noninvasively monitor real-time cephalic pulsatile blood volume changes in humans exposed to acceleration stress in the head-to-foot direction (+Gz) on the Naval Air Development Center (NADC) human centrifuge. Changes in the REG waveform occurring with increasing +Gz load have been characterized.

INTRODUCTION

Advanced aerospace vehicles are capable of rapidly generating and sustaining acceleration forces at magnitudes and durations exceeding the unprotected tolerance limits of their human operators. The primary effect of +Gz stress is a reduction in blood flow to the brain and blood pooling in the extremities and abdomen. It has been shown that under acceleration stress cranial vasoconstriction decreases, particularly in the pial system.

Rheoencephalography is a plethysmographic technique which relates changes in the volume and/or conductivity of the head to changes in electrical impedance. It has been shown that these pulsations depend upon integrity of cephalic blood flow.

The form of the pulsatile REG waveform (Zp) is quite variable and may change depending on the state of the cephalic vasculature. The size and timing of its prominent features can give an indication of the state of the cephalic circulation (see Figure 1). The 'A' wavelet occurs with the systolic phase of the cardiac cycle and its peak follows the R wave of the ECG (under normal conditions) by about 0.3s. The 'C' wavelet is associated with overall venous pressure and the relative amount of impedance to venous outflow. It is usually smaller in magnitude than 'A'. Following 'C' there can be a number of smaller inflections. The ratio B/A gives an indication of arteriolar tone. Changes in the ratio C/A indicate alterations in blood outflow and venous tone. The REG period, 'T', is the same as the ECG R-R interval. A reduced value of the REG peak time, 'a', indicates decreased vascular tone. The ratio a/T provides information as to the elasticity and tone of large and intermediate size vessels, i.e. CVR. It is important to remember that REG is a relative measure of the state of the cephalic circulation. As such, the REG is most useful when comparing unstressed waveforms to those measured during acceleration stress.

METHODS

Relaxed G-tolerance levels (Gtol) were determined for 20 volunteer male subjects during exposures to rapid onset (2 G/s), 15 second +Gz plateau runs on the NADC human centrifuge. G levels ranged from +2.5 to +5Gz. Relative changes in cephalic blood volume were obtained using REG. Calculations of various REG indices were performed and expressed as a percentage change between prestress (+1.03Gz) and stressed values for 40 high G exposures.

RESULTS

Figure 2 contains a strip chart showing the effects of +5Gz on Zp. Zp wavelets A, B, and C all increase in magnitude under acceleration stress. Typically, 'B' is less pronounced and the difference in magnitude between 'A' and 'C' is reduced. As the level of stress rises more and more of the relatively highly conductive blood plasma and cerebrospinal fluid is redistributed within the skull or is drained out of the cephalic space. Therefore, the impedance of the head rises as acceleration stress increases.

For each index, five waveforms were averaged to eliminate the effects of random noise. While there was some variability among subjects, data points were averaged together since the overall trend in their indices was the same for each +Gz level and point in time during the runs. The relative change in impedance was then expressed as the percent change between prestress and stressed values. The prestress period is defined as five seconds prior to acceleration onset. Exposure time is broken down as follows: 0-5s, 5-10s, and 10-15s at +Gz plateau, 20-25s and 30-35s after acceleration onset. In this way any effects of cardiovascular (CV) compensation which may occur after ten seconds of high +Gz exposure may be seen. No effects of CV compensation were seen with 'A'. After 10s at +3.5 and +4Gz, changes in 'C' indicate that compensation may have begun. Note that there is great variability within individuals as to when their CV compensatory responses may begin.
nature of this response also depends upon the rate of onset and level of acceleration stress. By 15s after offloading from plateau, all wavelets returned to within about 15% of the prerun levels. Figure 3 contains the results for the 'A' wavelet.

One way ANOVA tests comparing the means of the percent changes in 'A', 'B', and 'C' with respect to run time show that Zp changes significantly (p<0.001) as the length of time under acceleration stress continues. The results of two way ANOVA comparisons between percent changes in 'A', 'B', and 'C' with respect to run time and +Gz level indicate significant differences between calculated impedance values and run time. However, only 'A' and 'C' demonstrate a significant difference between impedence, run time, and stress (p<0.001 and p<0.005, respectively). One cannot state that changes in 'B', as analyzed under conditions of this test, did not occur due to chance alone.

The changes in B/A during relaxed +Gz runs were quite variable. For all +Gz levels, during the first five seconds at plateau, arteriolar tone decreased. Beyond this time at plateau and during recovery, arteriolar tone either rose or fell depending upon the acceleration load, though not in any particular pattern. Results of a two way ANOVA comparing these values to run time and acceleration level show that there was no significant change in B/A with respect to +Gz levels during relaxed acceleration exposures.

The results determining the effects on changing venous tone, C/A, under high +Gz were quite different (see Figure 4). With each +0.5 Gz increase, C/A indicated a decrease in tone, except for the first run at +2.5 Gz. Results of a two way ANOVA comparing these values to run time and acceleration level indicate that there was a highly significant change in percent change of C/A with respect to acceleration levels (p<0.001).

Analysis of the ratio a/T was difficult to interpret in the classical fashion. 'a' decreases with increasing stress indicating reduced tone. However, heart rate concurrently increases. Therefore, there is a tendency for a/T to either rise or fluctuate. One sample t tests performed comparing prestress levels to stressed levels showed highly significant differences (p < 0.01 or better) at +3.5 Gz and above. By 15 seconds after onset of acceleration, a/T returned to prestress values.

CONCLUSIONS

A real-time method to non-invasively monitor pulsatile changes in cephalic blood volume under +Gz stress has been demonstrated. This method has the potential to increase our fundamental understanding of the effects of +Gz stress on the central nervous system.

LIST OF REFERENCES