APG® Air Plethysmograph on the Mir Space Station

Under contract to CNES, the APG® was part of the PHYSIOLAB project on the Mir Space Station. The APG® was used to assess cardiovascular deconditioning in cosmonauts during spaceflights.

Use of air plethysmography during the French-Russian mission EO 22 on board the Mir Space Station.
F. Louisy, C. Andre-Deshays, D. Cauquil, M. Lazerges, C. Lafaye, A.L. Camus, P. Schroiff, and G. Gallina.

Frontiers in computed-aided visualization of vascular functions, Blazek V and Schulz-Ehrenburg U (Eds.). Proceedings of the Seventh International Symposium CNVD 97, Jan 10-12, Paris, France, pp 153-159.

Introduction

Air plethysmography has been implemented during the last French-Russian mission CASSIOPEE EO 22 on board the MIR Space station within the framework of the PHYSIOLAB project.

PHYSIOLAB consists of a cardiovascular functional exploratory laboratory aimed at assessing cardiovascular deconditioning in cosmonauts during spaceflights. The goals of PHYSIOLAB are dual: 1) to provide a better understanding of mechanisms underlying arterial pressure dysregulation (i.e. orthostatic intolerance) occurring during exposure to microgravity and 2) to allow medical and physiological monitoring of cosmonauts in the prospect of improving medical countermeasures to implement before return to earth. PHYSIOLAB is composed of a set of instruments including:

- a Holter EKG/AP for the monitoring of circadian profiles of heart rate and arterial pressure,
- a Portapres for spectral analysis of arterial pressure and heart rate,
- a Doppler ultrasound for the investigation of arterial peripheral flows and resistances,
- an Air Plethysmograph for assessing changes in peripheral venous hemodynamics.

We believe it was important to assess peripheral venous hemodynamics during spaceflights for several reasons:

1. we believe that alterations of lower limb venous distensibility (i.e. increase in venous distensibility) are one of the factors inducing the orthostatic intolerance syndrome occurring in astronauts, because of the resulting pooling of blood in the lower part of the body,
2. to date, we have only few data about alterations of lower limb venous hemodynamics during spaceflights and data currently available have mainly been collected during ground simulation studies (bedrests) (Bonde-Petersen et al. 1994, Buckey et al. 1992, Convertino et al. 1989 a and b, Louisy et al. 1990, 1995, 1997),
3. until now, alterations of venous hemodynamics have always been described in terms of venous compliance or distensibility (Bonde-Petersen et al. 1994, Buckey et al. 1992, Convertino et al. 1990 a and b, Johnson et al. 1977, Louisy et al. 1990, Thornoton and Hoeffler 1977) and we believe that to have a complete understanding of venous alterations, we also have to consider other parameters such as venous filling, venous emptying, the pumping role of muscles and parameters of capillary filtration.

Therefore, venous hemodynamics was assessed by air plethysmography with venous occlusion during the French-Russian space mission EO 22 on board the MIR Space station.

Material and Methods

Subjects - Plethysmographic measurements were performed on two members of the mission, the French scientist cosmonaut Claudie Andre-Deshays and the Russian engineer cosmonaut Alexandre Kalieri. Neither had a history of cardiovascular disease and, evidently, as cosmonauts they were healthy. The French cosmonaut flew on board MIR for 16 days while Kalieri remained in Space for approximately 8 months.

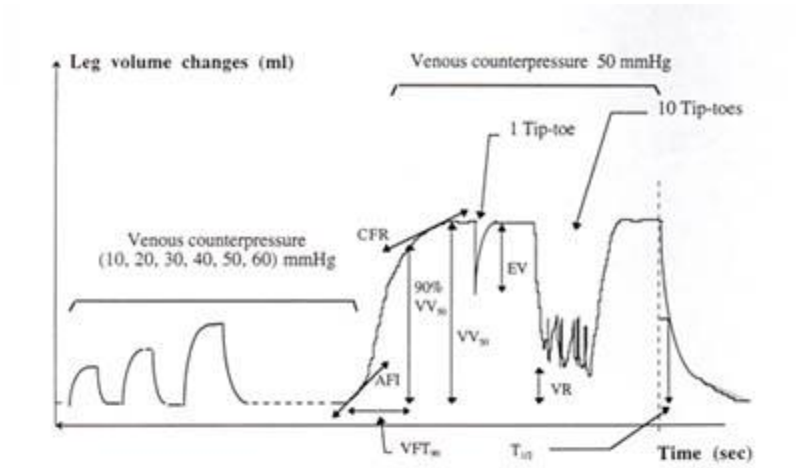
Methods - Venous hemodynamics was assessed by air plethysmography with venous occlusion. The method consisted in measuring absolute leg volume changes under the influence of several levels of venous occlusion.

The apparatus is derived from the Air Plethysmograph APG® 1000 (ACI Corporation, San Marcos, CA, USA) adapted for space utilization. It is composed of an air pump that inflates a long tubular air cuff (to a selected pressure of about 6 mmHg), applied to the leg to be measured. A pressure sensor reads the pressure in the cuff, displays the data on a bar graph on the front panel, and sends the pressure signal to a computer. This computer, the central processing unit (PMU), also provides measurement session management, data registration and processing, and downlink transmission of experimental and medical data.

The measurement protocol (figure 1) is partly derived from the protocol implemented at the St Mary's Hospital Medical School (by Nicolaides et al.). Several couterpressures (10, 20, 30, 40, 50, and 60 mmHg) are applied at the thigh and corresponding leg volume changes are recorded. A pressure-volume curve is then drawn by plotting leg volume changes (venous capacities) against occlusion pressures. This pressure-volume curve allows the determination of leg compliance, which mainly depends upon compliance of deep leg veins. Other parameters are measured and calculated with a counterpressure of 50 mmHg applied at the thigh:

- AFI corresponds to the slope of the plethysmograph curve during the first 20 seconds after application of counterpressure,
- VV50 corresponds to the volume increase of the leg at the considered counterpressure (the functional venous volume at 50 mmHg counterpressure),
- VFI is calculated and represents the ratio 90% VV50/VFT90 (time for 90% VV50 venous filling),
- CFR is measured as the slope of the plethysmographic curve between minutes 3 and 4 before the plateau,

- EV represents the absolute volume ejected from the calf after one tip-toe. EF is calculated as the ratio (EV/VV50) *100,
- RV represents the residual volume, i.e. the volume of blood remaining in the leg after 10 tip-toes. RVF is calculated as the ratio (RV/VV50) *100,
- T1/2 represents the half-emptying time.



In the French cosmonaut Claudie Andre-Deshays, measurements were performed before flight at D-60 and D-30, during flight at D5, D12, and D15 and after flight at R+1, R+3 and R+5. In the Russian cosmonaut, measurements were only made in flight since at the moment of data handling, this cosmonaut still remained in the MIR station.

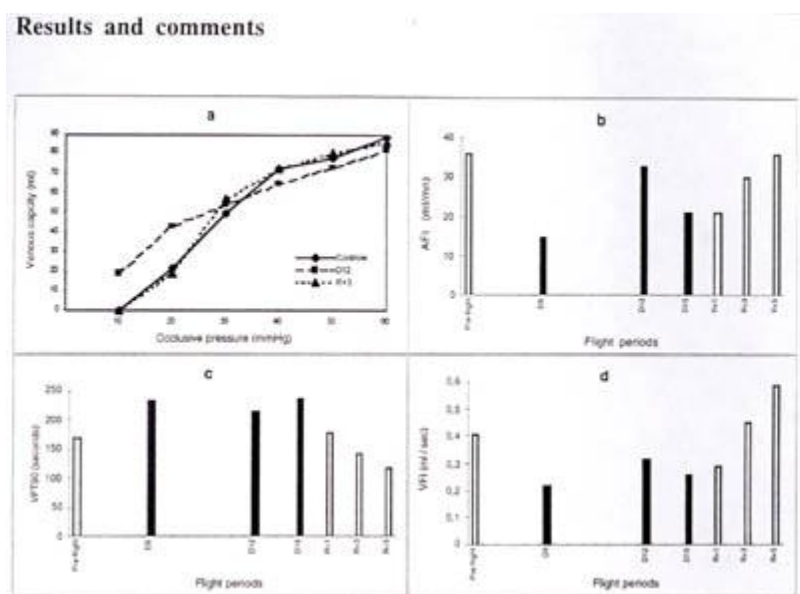


Figure 2. Changes in venous compliance (pressure-volume curve, a), arterial flow index AFI (b), venous filling time for 90% VV50, VFT90 (c) and venous filling index VFI (d) during and after spaceflight as compared to pre-flight, in the French cosmonaut.

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Results

Results achieved on the French cosmonaut before, during, and after flight are shown on figures 1 and 2. The pressure-volume curve during flight (figure 1, a) is characterized by an increase in venous capacities for lower occlusive pressures (10, 20 mmHg), with venous compliance being unchanged for higher counterpressures (30, 40 50 and 60 mmHg). This probably corresponded to an increase in the zone of free distensibility as was previously hypothesized (Thornton and Hoeffler 1977), because of fluid translocation towards the upper part of the body in microgravity and the consecutive decrease in basal venous pressure in lower limbs.

AFI tended to decrease during flight (figure 1, b) (39 ml. mn-1 at pre-flight vs 15 and 21 ml. mn-1 at D5 and D15, respectively) with a progressive return to normal (and even a higher value) during recovery (21, 30 and 36 ml. mn-1 at R+1, R+3 and R+5, respectively).

Venous filling parameters are represented by VFI. VFI tended to decrease during flight (0.32, 0.22 and 0.26 ml.sec-1 at D5, D12 and D15, respectively vs 0.41 ml.sec-1 at pre-flight) with a progressive normalization after flight (0.29, 0.45 and 0.49 ml.sec-1 at R+1, R+3 and R+5, respectively). As VFI represents the ratio 90% VV50/VFT90 and, apparently, VV50 (in absolute value) does not change during flight as compared to pre-flight, the decrease in VFI may necessarily be due to an increase in VFT90, as confirmed in figure 1, c (for VFT90, 171 sec. at pre-flight vs. 232, 215 and 238 sec. at D5, D12 and D15, respectively and 181, 143 and 199 sec. at R+1, R+3 and R+5 respectively).

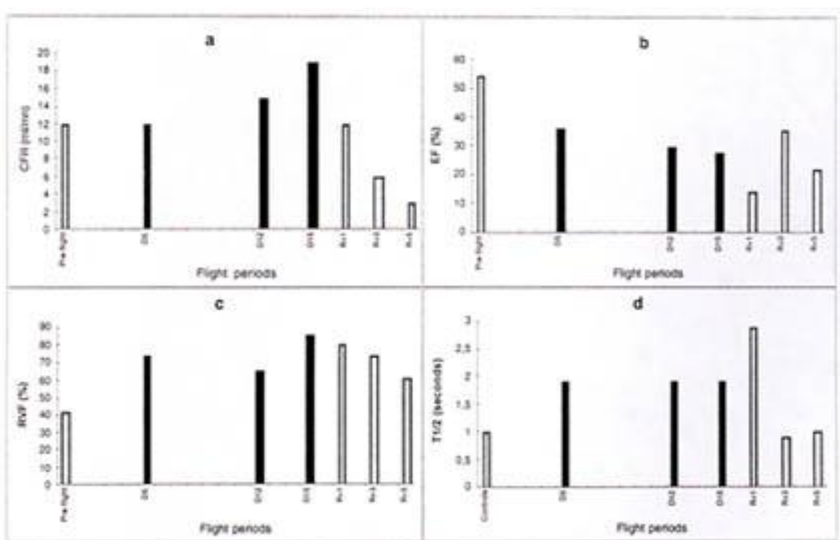

Figure 1. Changes in capillary filtration rate CFR (a), ejection fraction EF (b), residual volume fraction RVF (c) and half-emptying time T1/2 (d) during and after spaceflight as compared to pre-flight in the French cosmonaut.

Capillary filtration rate tended to increase during flight (12 ml.mn-1 at pre-flight vs 12, 15 and 19 ml.mm-1 at D5, D12 and D15, respectively) with a rapid return to normal or even to lower values during recovery (12, 6 and 3 ml.mn-1 at R+1, R+3, R+5, respectively).

EF had a sharp tendency to decrease during flight (54% at pre-flight vs 36.2, 29.5 and 27.5 % at D5, D12 and D15, respectively). On recovery, EF did not return to baseline throughout the first week, and even dropped to its lowest level at R+1, i.e. just after landing. RVF also tended to increase during flight (42.5% at pre-flight vs 74.1, 65.4 and 85% at D5,

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D12 and D15, respectively). During recovery, RVF returned to normal only at Day 5 but it remined higher than baseline values at R+1 and R+3.

Finally, half emptying time T1/2 also increased during exposure to microgravity (1 sec. at pre-flight vs 1.9 sec. at D5, D12 and D15), with a greater increase at Day 1 of recovery, followed by a rapid return to normal at R+3 and R+5.

Air plethysmography was used for the first time during spaceflight on board the MIR station. Results achieved within the framework of the mission CASSIOPEE which lasted 16 days for the French cosmonaut Claudie Andre-Deshays demonstrate the usefulness of air plethysmography during spaceflight. Until now, venous hemodynamics during ground-based studies or experiments on board Space stations has been assessed only in terms of venous compliance (Bonde-Petersen et al.1994, Buckey et al.1992, Convertinal et al.1990 a and b, Johnson et al.1977, Louisy et al. 1990, Thornton and Hoeffler 1977). These studies were performed using impedance, ultrasound or strain gauge plethysmography. However, by itself venous compliance is not sufficient to characterize venous hemodynamics. In our opinion, venous hemodynamics also has to be defined by filling parameters (venous filling index, venous filling time, venous compliance or distensibility, arterial inflow), emptying parameters (half emptying time) and parameters characterizing the efficiency of the venous muscle pump (calf muscle pump for legs). All these parameters could be assessed by using air plethysmography. This method therefore proves to be appropriate the evaluation of venous hemodynamics changes during exposure to microgravity.

Results reported above demonstrate alterations of venous filling as well as venous emptying parameters and changes in efficiency of calf muscle pump. These changes, which are part of the cardiovascular deconditioning syndrome, may account, at least partly, for the orthostatic intolerance developing after flight. We also have to refer to outstanding changes in some venous parameters immediately post-flight (R+1) (i.e. half emptying time T1/2, ejection fraction EF, and residual volume fraction RVF), which are compatible with the specific alteration of orthostatic tolerance, usually maximum at this period of recovery. Also, it is interesting to note that capillary filtration was modified during flight. This may contribute to the complexity of vascular deconditioning, showing an alteration of the full vascular system, i.e. physiologic disturbances taking place in the high and low pressure systems as well as in the capillary network.

Measurements made in the Russian cosmonaut during flight are thoroughly consistent with those made in the French cosmonaut, which emphasizes the reproducibility and reliability of the technique used. Further examinations performed on next French cosmonauts as well as Russian cosmonauts (until 1999) will allow us to have a more complete understanding of venous alterations in microgravity, and to implement more efficient countermeasures to prevent human post-flight orthostatic intolerance and decrements in work capacity alterations.

References available upon request.