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Elasticity/distensibility of the ascending aorta: basal conditions and simulated conditions from space flights

N. ALESSANDRI, F. TUFANO, M. PETRASSI, C. ALESSANDRI, L. LANZI, L. FUSCO, F. MOSCARIELLO, C. DE ANGELIS*, E. TOMAO*

Department of Cuore e Grossi Vasi "A. Reale", polo pontino, University "Sapienza", Rome (Italy)
*Flight Sperimental Center, Military Airport, Pratica di Mare, Rome (Italy)

Abstract. – ***Introduction:*** **The hysto-morfological composition of the ascending aorta wall gives to the vessel its characteristic elasticity/distensibility, which is deteriorated due to both physiological (age) and pathological events (hypertension, diabetes, dyslipidemia). This contributes to reduce the wall elasticity and to occurrence of cardiovascular events.**

Matherials and Methods: **Thirty young healthy subjects (20 males, 10 females, age <30 yr), were subjected to different postural conditions with and without Lower Body Negative Pressure (LBNP) with conventional procedures, to simulate the microgravity conditions in space flight. During this procedure the cardiovascular parameters and the aorta elasticity were assessed with ecocardiography.**

Results: **The observation of results and statistical comparison showed that despite different hemodynamic conditions and with significant variation of blood pressure related to posture, elasticity/distensibility did not change significantly.**

Discussion: **The elasticity/distensibility of arterial vessels is the result of two interdependent variables such as blood pressure and systolic and diastolic diameters. While blood pressure and heart rate vary physiologically in relation to posture, the compensation of the vessel diameters modifications maintains the aortic compliance invariate. Therefore, in young healthy people, despite the significant postural and the sudden pressure changes (equivalent to parietal stress) aortic compliance does not alter. This behavior might be related to the low rate of cardiovascular events that are present in healthy people aged under 30 yrs.**

Key Words:

Elasticity/distensibility of the ascending aorta, Windkessel function, Simulate the microgravity conditions.

Introduction

Large arteries of caliber, and the ascending aorta (Asc Ao) in particular, play a key role in cardiovascular hemodynamic. The "pump function" of Asc Ao, connected in series with the heart, enables the aorta to expand during ventricular systole thanks to the systolic output. During diastole the aorta returns to its original size. This is the consequence of the physical conversion Pe → Ke, Ke → Pe, (where Pe is potential energy and Ke is kinetic energy).

The accumulated elastic potential energy accumulated, contributes to transform the blood flow from pulsed to continue, in accordance with the "Windkessel" function[1].

The aorta elasticity/distensibility is due to the morphological characteristics of the wall, with a directly proportional relationship.

For physiological events and pathological factors (increased biological age, hypertension, atherosclerosis, diabetes, dyslipidemia, etc.) the vessel wall morphology, undergoes to structural changes. This produces a progressive reduction of vessel elasticity/distensibility and thus, a loss of capacity to fulfill its duty of hemodynamic support.

Recently some Authors have observed that an increase of arterial stiffness is associated with an increased risk of cardio and cerebrovascular diseases and it should constitute an independent risk factor[2,3].

The force of gravity exerts a predominant role in countering the postural hemodynamic changes in humans. The directional variation of the force of gravity (±Gz), with an average acceleration of 9.8 m/sec^2, is the main responsible of the mass redistribution of circulating blood.

Corresponding Author: Nicola Alessandri, MD; e-mail: nicola.alessandri@uniroma1.it

The simple change in posture from clinostatism to orthostatism and viceversa, confirms the variation in venous return and cardiac output, and the effect of gravity is neutralized by a physiological mechanisms of compensation[4].

Studies on the behavior of the astronauts during the flight in microgravity, show significant cardiovascular changes. In particular, the most important effects are the redistribution of blood from the supra and sub-diaphragmathic compartments and the activation of important regulatory systems (sympathethic system, natriuretic hormones secretion, renin-angiotensin system, etc.) with modifications in vestibular and baroceptorial reflexes[5,6].

In astronauts returned to earth from space flights, the cardio-thoracic-vascular system is able to compensate gravitational variations so much to cause orthostatic intolerance[7].

Our interest is to assess the contribution of the great vessels in postural changes and thus in the force of gravity, maintaining the flow and cardiac blood pressure.

The aim of this study is to evaluate the variations of elasticity/distensibility of the ascending aorta in response to postural changes in basal conditions and simulated conditions through use of the Lower Body Negative Pressure (LBNP).

Materials and Methods

In 12 months 30 young healthy subjects (20 males and 10 females) were processed to observation during Tilt-Test. The first observation was made at the Tilt-Test Laboratory of the U.O.C. of Cardiology, University of Rome "Sapienza", polo pontino.

The second one, was conducted at the Flight Sperimental Center, at the Military Airport "Mario De Bernardi", Pratica di Mare, Rome, Italy.

All the enrolleds were volunteers, in good health and they weren't assuming any drugs. The equipment used for the study was an automatic up Tilt-test "Gardhen Bilance" and the and the ACUSON Sequoia C512 Echocardiography System (Siemens, Milano Italy). The blood pressure and the heart rate values were obtained with the "Vasotrac MedWave" non invasive blood pressure monitor (registration every 5 seconds). The first exercise consisted in subjecting the 30 young people to Tilt-test with the following sequence: head-up position (+60°) for 40 minutes, corresponding to a gravitational stress +Gz, and then for 20 minutes in head-down (–15°) position, corresponding to a gravitational stress –Gz.

In the second approach, performed in the Military Airport a few days later, young people were exposed to Tilt-test by wearing a device to achieve a state of the Lower Body Negative Pressure (LBNP) at –20 mmHg. The program used for Tilt-test was: 40 minutes in head-up (+60°) with LBNP off, then for 20 minutes in Head Down (–6°) and for 20 minutes in Head Down (- –15°) with activated LBNP.

During the test the values of blood pressure (BP) and heart rate (HR) were monitored and recorded every 15 seconds. A color Doppler transthoracic echocardiogram (TTE) (devices: ACUSON Sequoia C512 Echocardiography System [Siemens, Milano Italy]) was made at the beginning (baseline) and during each change of posture.

Color-Doppler Echocardiography

A TTE was executed using standard projections and the measures were identified following the criteria of the American Society of Echocardiography.

The telediastolic (TDD Asc Ao) and telesystolic (TDD Asc Ao) diameters were measured at 3 cm above the aortic valvular plane in order to evaluate the elasticity/distensibility of ascending aorta.

The systo-diastolic blood pressure values were also used to calculate the classical formulas: Peterson's Modulus (Ep), Young's Modulus (Es), β-stiffness (β-stiff) Compliance (CompAo), Distensibility (Dist). The same measurements were made in each different posture, in basal conditions, after 35 minutes in orthostatic position (+60°), and after 15 minutes in Trendelenburg position. 15 minutes after the beginning of the lower body negative pressure (–20 mmHg), the color-Doppler echocardiogram was made. All measurements were assessed by two different operators independently.

Statistical Analisys

Mean values and the relative SD have been evaluated in statistical data processing. For not paired data the Student's *t*-test was used for the comparison of the mean values. Parameters were observed in clinostatic conditions (Base Gr.), in head-up Tilt test (+60°) (Gr. 60°) and in head down Tilt-test (–15°) (Gr. –15°). The same measurements have been repeated after application of LBNP (–20 mmHg) and in head down tilt-test (–6° and –15°) (Gr. LBNP –6° and Gr. LBNP –15°).

Statistical comparisons have been made between the values obtained from the same group in all phases of the study. This procedure permits to observe the possible presence of changes in the parameters used for the evaluation of ascending tract properties of the aorta.

Results

Thirty subjects have been examinated. 20 were male and 10 female, average age was 27 ± 2.7 years, (M 26 ± 1.6, F 29 ± 1), height: 1.77 ± 0.08 cm, weight: 74.17 ± 10.45 kg and BMI 23.68 ± 2.18.

In Tables I-IV all the data are reported. Tables I and II show mean values and ΔS in each postural condition (Basal Gr, Gr +60°, Gr –15°, Gr. LBNP –6° Gr. LBNP –15°). The significance and statistical analysis of the comparison between the results obtained in various positions are reported in Tables III and IV. In basic conditions and without the LBNP, the transition from basal position to orthostatism (+60°) determines a variation of the systolic BP, the diastolic BP and HR values (statistical significative difference $p < 0.01$). From basal to Trendelenburg position (–15°), there is only a significant change in systolic ($p < 0.01$) and diastolic arterial pressure ($p < 0.01$), but not in HR ($p > 0.05$). From the Trendelenburg (–15°) to orthostatic position (+ 60°), there is significance variation in the values of BP and HR ($p < 0.01$).

Telediastolic (TDD Asc Ao) and telesystolic diameters (TSD Asc Ao) measurement, performed three cm above the valvular plane, aren't affected by a significant modification of their average values ($p > 0.05$) during the various positions.

The evaluation of the aortic elasticity/distensibility (Table III), doesn't show any statistically significant changes ($p > 0.05$) in all parameters used to determine this characteristics (Ao Dist, β-stiff, Ao Comp., Ep, Es). The same calculations were performed with active LBNP (–20 mmHg) (Table IV). There are no statistically significant changes ($p > 0.05$), in blood pressure (systolic and diastolic), heart rate, telediastolic and telesystolic diameters of ascending aorta and in all other parameters for elasticity/distensibility evaluation.

In the Tables I and II, are reported the mean values and the standard deviation (ΔS) of the parameters in each postural condition. In the Tables III and IV the statistical significance is shown ($p < 0.05$).

SBP = systolic blood pressure (mm of mercury), DBP = diastolic blood pressure (mm of mercury), HR = heart rate (beat per min), TDDASCAo = telediastolic diameter of Ascending Aorta (mm), TDDASCAo = telediastolic diameter of Ascending Aorta (mm), B-stiffness = beta-stiffness index, Ep = Peterson's module, Es= Young's module, LBNP (lower body negative pressure).

Table I. Mean values and ΔS. Data are means ± SD.

Parameters	Values Basal Gr.	Values Gr. +60°	Values Gr. –15°
SBP (mmHg)	113.06 ± 6.64	107.22 ± 6.47	118.46 ± 5.30
DBP (mmHg)	71.39 ± 3.76	73.06 ± 3.76	75.77 ± 4.39
HR (bpm)	68.83 ± 10.16	78.22 ± 10.16	66.00 ± 8.99
TDDAscAo (mm)	30.28 ± 2.22	30.17 ± 1.56	31.50 ± 1.99
TDDAscAo (mm)	27.72 ± 2.11	27.83 ± 1.62	28.70 ± 1.69
B-stiffness	5.36 ± 1.49	4.77 ± 1.93	4.90 ± 1.46
Ep	3.23 ± 0.88	2.83 ± 1.13	3.15 ± 0.96
Es	0.48 ± 0.13	0.43 ± 0.17	0.47 ± 0.15
Aortic distensibility	0.0045 ± 0.0015	0.0053 ± 0.0018	0.0047 ± 0.0012
Aortic compliance	3.39 ± 0.9	4.00 ± 1.33	3.55 ± 1.59

Table II. Mean values and ΔS with activated LBNP (–20 mmHg). Data are means ± SD.

Parameters	Values (–15° LBNP)	Values (–6° LBNP)
SBP (mmHg)	119.44 ± 5.27	119.44 ± 6.35
DBP (mmHg)	76.67 ± 3.54	78.89 ± 2.20
HR (bpm)	66.00 ± 10.48	66.11 ± 11.69
TDDAscAo (mm)	31.28 ± 1.99	31.67 ± 2.18
TDDAscAo (mm)	29.11 ± 1.69	29.00 ± 2.15
B-stiffness	5.15 ± 1.46	5.05 ± 1.50
Ep	3.23 ± 1.02	3.30 ± 1.04
Es	0.50 ± 0.12	0.50 ± 0.16
Aortic distensibility	0.0043 ± 0.0012	0.0045 ± 0.0018
Aortic compliance	3.27 ± 0.96	3.39 ± 1.39

Discussion

The histo-anatomic structure of aortic wall varies in the number and location of the "elastic unit" along the course (ascending tract, arch, thoracic and abdominal) even if it has the same composition. There are 60 "elastic units" in ascending aorta and 40 in the thoraco-abdominal tract[8]. Different number of "elastic units" causes a progressively decrease of elastic properties[9,10].

The ascending aorta is the most elastic portion, with the most favorable values of elasticity/distensibility. The values of elasticity/stiffness in young healthy people (average age 20 years), at the end of biological development, are considered normal benchmarks. Our data show that the vessel diameter increases with age and elasticity is reduced proportionately as expressed in mathematical formula[11,12]. The elasticity/stiffness of the vessels changes in relation to the degree of atherosclerosis developed, until parietal rigidity[13,14].

A good availability of young volunteers has been observed during the test. Abnormal responses to suspend or to stop the test were not observed. Only four young men have complained about a slight tension on the head (fronto-temporal area or general "discomfort") in head-down position (–15°), probably due to overflow in the supra diaphragmatic portion of the body. No symptoms were observed during testing at –15° with the use of LBNP.

Initially the observation of these parameters during the orthostatic position +60° with active LBNP was included in the program. The detection of hemodynamic values even in the preclinical phase (reduction of BP, rapid increase of HR) permit to suspend the observation.

Changes in blood pressure and heart rate after changes in posture (from clino to orthostatism), were observed in this study. These variations did

Table III. *t*-test.

Parameters	Basal vs. +60	Basal vs. –15°	–15° vs. +60°
SBP (mmHg)	< 0.01	< 0.01	< 0.01
DBP (mmHg)	< 0.01	< 0.01	< 0.01
HR (bpm)	< 0.01	> 0.05	< 0.01
TDDAscAo (mm)	> 0.05	> 0.05	> 0.05
TDDAscAo (mm)	> 0.05	> 0.05	> 0.05
B-stiffness	> 0.05	> 0.05	> 0.05
Ep	> 0.05	> 0.05	> 0.05
Es	> 0.05	> 0.05	> 0.05
Aortic distensibility	> 0.05	> 0.05	> 0.05
Aortic compliance	> 0.05	> 0.05	> 0.05

Table IV. *t*-test.

Parameters	(Basal) vs. (–15° LBNP)	(–15) vs. (–6° LBNP)	(–15°) vs. (–15° LBNP)
SBP (mmHg)	> 0.05	> 0.05	> 0.05
DBP (mmHg)	> 0.05	> 0.05	> 0.05
HR (bpm)	> 0.05	> 0.05	> 0.05
TDDAscAo (mm)	> 0.05	> 0.05	> 0.05
TDDAscAo (mm)	> 0.05	> 0.05	> 0.05
B-stiffness	> 0.05	> 0.05	> 0.05
Ep	> 0.05	> 0.05	> 0.05
Es	> 0.05	> 0.05	> 0.05
Aortic distensibility	> 0.05	> 0.05	> 0.05
Aortic compliance	> 0.05	> 0.05	> 0.05

not exceed 15% and can thus be considered in the physiological range[15].

An important observation is the significant reduction of fluctuations (from 15% to about 2%) of both the BP and the HR in relation to posture with the use of LBNP[16,17]. This confirms the importance in the use of LBNP in specific work situations.

A relevant observation was carried out in young healthy subjects, free from drugs assumption, not trained in this kind of stimulation. Statistically significant changes in the functional behavior of ascending aorta didn't occur. This trend is found both under the influence of gravitational force of the earth, and when gravity is contrasted by a system of LBNP (–20 mmHg). The elasticity/distensibility function of arterial vessels is a consequence of two interrelated variables: blood pressure and the systo-diastolic diameter. It was noted that the BP and HR vary physiologically in relation to posture, thus, the compensation of the diameter variation of vessel was responsible to maintain the aortic compliance.

In conclusion, the results of this work evidence that, despite significant postural variations, the aortic compliance does not change in young healthy people. Further studies are necessary to assess the effect of gravity or simulated microgravity on ascending aorta, to better understand how the human cardiovascular system responds to these situations.

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