POSTURAL STRESS TESTS FOR THE CLINICO-PHYSIOLOGICAL EVALUATION OF CARDIOVASCULAR REFLEXES

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Summary: Postural stress tests are useful in the assessment of cardiovascular reflex response of normal subjects who may be involved in specialised occupations such as flying; in order to study the effects of physiological stresses such as heat stress, hypoxia, simulation of weightlessness; physiological evaluation of cosmonaut candidates, in patients who may have autonomic neuropathy. Most commonly quiet standing is used but head-up tilt table test and the application of lower body suction may provide a better method of evaluation. These three tests for assessing reflex cardiovascular function are discussed.

Key words: blood pressure, head-up tilt, heart rate, postural hypotension

The maintenance of normal blood pressure and the limitation of the peripheral blood pooling (which occurs because of a shift of blood into the legs) during postural stress is a function of cardiovascular reflexes. In certain work situations for example in aviation (during the application of exaggerated postural stress produced by radial accelerations) inadequacy of these reflexes can cause hypotension which may be severe enough to produce episodic unconsciousness. Other physiological stresses such as hypoxia (12, 24), exercise (30), space flight (31) and heat exposure (32) may alter tolerance to postural stress and may need investigation. In clinical situations an abnormality of cardiovascular reflex response during postural stress may indicate the presence of neurological disorder (4) or adverse effects of a drug. It may therefore become necessary to evaluate the integrity of the cardiovascular reflexes in apparently healthy individuals (such as aircrew) who may present with a clinical history suggestive of intolerance to postural stress (15), for assessing a subject's cardiovascular function during various physiological stresses, or in the clinical evaluation of patients with neurological disorders (4). Such an assessment can be done using postural stress tests in the field, by the bedside, or in the laboratory.

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Postural stress reduces the intra-thoracic blood volume and shifts it into the legs where it forms a pool, thereby producing a fall in blood pressure and a reduction in the circulating blood volume (40). Compensation to this is brought about by (i) a reflex tachycardia and (ii) arteriolar constriction which are aimed at maintenance of the arterial blood pressure and, (iii) venoconstriction which helps to limit the expansion of the blood pool in the legs, keeps up the pre-load, and is helped by the increased activity of the abdomino-thoracic respiratory pump, the pumping action of the leg muscles and the venous valves (40). The details of the physiological mechanisms involved in bringing about the cardiovascular effects are not in the purview of this paper and can be found elsewhere (1, 4, 22).

Heart rate and arterial blood pressure are the variables commonly measured to assess the reflex integrity (13, 15), and if facilities permit peripheral vascular resistance may be measured.

Various methods can be employed to give the postural stress and can involve quiet standing, head-up tilting (both of which produce a change in posture from the supine to the erect) and the application of lower-body subatmospheric pressure (LBSP).

Quiet standing: By far the simplest test for eliciting cardiovascular response to postural stress is quiet standing for 5-20 minutes after the heart rate and blood pressure have stabilised while supine. The change of posture displaces about 600 ml of blood from the thorax into the legs (44), deactivates arterial baroreceptors to produce a reflex tachycardia (2) which is mediated mostly by vagal tone withdrawal (20), produces a slight fall in the systolic blood pressure, and a slight increase in the diastolic blood pressure.

The immediate heart rate increase on standing in healthy young subjects is seen by about the 15th beat (20), and this later settles down to a steady state value which is about 10-15 beats min⁻¹ higher than the supine value. In the elderly (65 years and above) (10) and in patients with autonomic neuropathy (4) the tachycardia response is markedly attenuated and may be accompanied by postural hypotension.

The immediate cardiovascular changes are difficult to demonstrate unless continuous instant heart rate and intra-arterial blood pressure monitoring are available. The blood pressure can be measured by an independent observer using a sphygmomanometer while it is best to monitor ECG for heart rate. Instant heart rate measurement by a rate-meter is the method of choice if the equipment is available but in the absence of any recording
facilities, counting of the apex beat by an independent observer using a stethoscope may be resorted to. Palpating a peripheral artery may be confusing. If available, a random-zero sphygmomanometer which eliminates observer bias (39) should be used for blood pressure measurements which can be made comfortably at 1 minute intervals. The sphygmomanometer cuff is inflated above the resting systolic blood pressure level before the subject stands up so as to enable the observer to make the earliest possible measurement after the stress is given in order to reduce the disadvantage of not having an on-line blood pressure record from an indwelling arterial catheter.

The passive standing test recommended by Hyatt et al. (26) may also be used. In this the subject on rising from the supine position, leans his back against a wall with his heels 6 inches in front of the wall, and relaxes in this position for the duration of the test.

One of the criticisms of the standing test is that calf muscles are activated while standing and aid venous return, and that this may modify the cardiovascular response (36), but this drawback is offset by the simplicity of the test which can be given in the field, by the patient’s bedside and in the laboratory with equal ease and with minimum equipment.

**Head-up tilt test**: The head-up tilt (HUT) is used extensively as a postural stress test in physiological (12, 13, 14, 15, 48), and in clinical investigations (4, 11, 27, 28) where reflex cardiovascular response may be affected.

To carry out the test, the subject is strapped supine on to a tilt table which can be rapidly tilted to the required head-up position mechanically or manually. Physiological measurements are made while the subject is supine, immediately on tilting, and thereafter at suitable intervals up to 20 minutes. The heart rate however should be monitored continuously using a cardiac monitor as far as possible in order to detect adverse reactions at an early stage. Otherwise the method can be the same as that used in the standing test. The test is normally performed in a thermally controlled laboratory at about 25°C, and at fixed time of the day to avoid circadian variations (3, 29). The subject is normally supported by a torso harness and by a soft saddle in the tilted position. These device are comfortable (15). The presence of a foot-board during tilt is likely to activate the muscles because of weight bearing, and in turn promote muscle pumping which may affect the cardiovascular response because of an increase in the venous return but others suggest that the foot board does not affect the results (36). It is our practice to avoid the foot
support. After the subject’s blood pressure and heart rate stabilize, he is tilted rapidly (< 5 sec) head-up. Various degrees of tilt ranging from 30° to 90° have been used (15, 21, 35, 47), but 70° head-up has been most common as the cardiovascular effects produced using this angle are similar to those produced with 90° HUT (sine angle 70° = 0.94 and sin 90°=1; (21, 35)), but without the attendant discomfort. The rate of tilt is important as it affects the reflex response of the cardiovascular system (36).

The normal cardiovascular response to HUT is a reflex increase in heart rate, an increase in the diastolic blood pressure, little or no change in the systolic blood pressure (Fig. 1) and an increase in the mean arterial pressure (15). The tachycardia seen during

![Diagram showing the changes in blood pressure and heart rate during HUT.](image)

Fig. 1: Mean and SE values for the diastolic (DBP), mean arterial (MAP) and systolic (SBP) blood pressure (mmHg), and heart rate beats/min (HR) while supine (S), immediately on 70° head-up tilt (0 min) and at 3 min intervals during the 20 min of HUT (lung stripped area) and during 4 min of post-tilt recovery in the supine posture (short stripped area) in 20 normal young males. Time periods from supine to 0 min HUT to 0 min recovery are not to scale.
HUT differs slightly from that seen with standing because the relative vagotonia after about the initial 30 beats seen with the latter is not observed with the former. The cardiac and stroke volume indices calculated from the left ventricular ejection time (23) reduced by about 17% and 35% respectively (16), and the myocardial contractility measured from the systolic time intervals (49) is significantly compromised even in normal subjects (17).

Head-up tilt table test, though a good technique for assessing cardiovascular response to postural stress, is not always found comfortable by all the subjects. Vestibular stimulation may occur during the rapid change in body position (1). In case of a syncope, reverting to the supine posture can take time. Its main advantage over the standing test is that to an extent the central blood volume content can be depleted in a graded manner by giving the subject increasing degree of HUT. However in both these tests the physiological effects produced by the low-pressure cardio-pulmonary receptor and the arterial baroreceptors can not be separately studied.

Lower-body subatmospheric pressure: The application of lower-body subatmospheric pressure (LBSP or lower body suction) at the level of the iliac crests produces a central hypovolaemia without a change in posture (9) because the blood is shifted from the chest in to the lower limbs by the pressure gradient created by the suction between the upper and lower regions of the body (51).

Lower-body suction is applied using a domestic vacuum cleaner connected to the suction box via an adjustable leak. A foot plate prevents a downward shift of the subject during suction. A seal must be applied around the waist in order to prevent a loss of the desired suction pressure. Various methods of doing this have been advocated (51). One of the simpler ones get the subject to wear a plastic "skirt" tightly around the waist and then mount its free end over the box edges (5, 18). A pressure transducer, or more simply, a mercury or water manometer is used to monitor the degree of suction. Electrical controls should include an on/off switch for instantaneous termination of the suction and a rheostat control to regulate the rate of application.

At suction pressures below 30 mmHg, there is no change in heart rate or blood pressure despite a reduction in the central venous pressure, but the forearm blood flow decreases because of a sympathetic vasoconstriction mediated by the low-pressure cardio-vascular receptors (1, 22). At higher suction pressures the heart rate increases the systolic blood pressure falls and the diastolic BP increases slightly (18, 37), but there is no further
significant change in the forearm vasoconstriction (Fig. 2). The mean arterial pressure is not affected until a suction of 60 mmHg and above is applied (37). When applied in a graded manner, LBSP produces incremental central hypovolaemia and progressive increase in the heart rate (37). Normal subjects may suffer a vaso-depressor syncope at a LBSP of 50-60 mmHg applied for 10 min while at even higher degree of suction, the syncope may occur sooner (37). The cardiovascular effects of standing and LBSP of 40 mmHg are equivalent because an equal volume of blood (about 600 ml) is displaced peripherally in both the conditions (38, 44).
Lower-body suction can be applied in a controlled manner to selectively deactivate low-pressure cardiovascular receptors (at pressures between 10-30 mmHg), and then to deactivate the arterial baroceptors at suction pressures above 30 mmHg (2). In this manner the reflex effects mediated by the low-pressure and the high pressure baroreceptors can be separately investigated. The procedure can be safely used to induce postural hypotension in a controlled manner (37). Further this method of simulating postural stress eliminates some inherent disadvantages of head-up tilt, the interruption which occurs while making physiological measurements in the process of tilting, and also the setting-up of gravity induced hydrostatic pressure gradients in the cardiovascular system, making it an excellent technique for assessment of cardiovascular reflexes in human subjects in health and disease.

Variability of cardiovascular response to postural stress tests: Inter individual variability of the response of the cardiovascular variables to postural stress is high for tilt heart rate and diastolic blood pressure, but comparatively low for systolic blood pressure (43, 46). In a large series of 166 head-up tilt tests in normal young males, the coefficient of variation of the systolic blood pressure, diastolic blood pressure, the mean arterial pressure and the heart rate was 6.8%, 9%, 7.5% and 14% respectively (15). Similar pattern of variability was observed during LBSP (50). Smith et al. (46) concluded that the heart rate was the most sensitive index of postural stress as it correlated well with the reduction in the intra-thoracic blood volume, but was the least reliable because of its high variability while the systolic blood pressure was the most reliable as it showed the least variability.

The overall intra-individual variability for the cardiovascular variables on the other hand is comparatively less (46, 50). Nevertheless some subjects may show greater consistency than others during postural stress, and it is suggested that while interpreting an individual response during the stress, an average of about 2-3 values for each variable during the test is taken into consideration. Averaging more data has no added advantage as it has no further effect on variability (52). It has been our practice to base the assessment of patients with a past history of syncope/pre-syncope on at least 3 stress tests (15).

Abnormal response to postural stress tests: A systolic hypotension (20 mmHg or more) with or without an episodic loss of consciousness constitutes the main abnormal response to postural stress. This has been reported in apparently normal healthy young adults (25,30), and in patients with autonomic neuropathy (4) who are subjected to postural stress. We however did not find any incidence of postural hypotension in a
large series of tilt tests in normal military personnel (15). This difference in finding could be attributed the difference in the methods used in applying the postural stress; to the better tolerance of heat adapted subjects to the stress; or to ethnic differences.

In the common variety of the abnormal response which may be seen in apparently normal individuals, the sequence of events which culminates in postural hypotension consists of tachycardia, fall in systolic blood pressure, a narrowing of the pulse pressure followed abruptly by a precipitous fall in the systolic BP and a bradycardia. This sequence of events has been described as the sympathicotonic response (41) and is often accompanied by restlessness, sighing respirations, sweating, nausea and a feeling of light-headedness. The reaction usually interrupts a normal reflex response and may occur when the compensatory activity which is aimed at maintaining arterial blood pressure and limit the peripheral blood pool formation is inadequate. This may happen because of prolongation of the stress, dilatation of skin blood vessels during heat exposure, and a sympathetic cholinergic vasodilatation of the muscle resistance vessels brought about by emotional distress, fear, anxiety, pain and discomfort (7, 42), or by standing in the hyperlordotic posture (as on parade) (8). A pre-existing reduction in circulating fluid volume because of dehydration (as in heat exposure) and haemorrhage can further aggravate the situation. The hyper-excitation of the sympathetic nervous system that ensues is accompanied by pre-syncopal symptoms, and signs which include marked tachycardia, falling systolic blood pressure, sweating and pallor. Th profound bradycardia and the precipitous fall in systolic and diastolic blood pressure that may follow have been attributed to a vaso-depressor reflex activated by the stimulation of ventricular wall pressure receptors (42, 45). There is evidence that the sympathetic vasoconstriction is unaffected during the syncopal reaction (19). The subject recovers rapidly on cessation of the postural stress when the temporarily sequestered circulating blood volume is rapidly restored to normal.

In the more serious variety of postural hypotension [the asympathicotonic reaction (41)] there is a progressive fall in the arterial blood pressure without a change in the heart rate. It is usually found in patients with neurological disorders such as diabetic autonomic neuropathy, Shy-Drager's syndrome, and tabes dorsalis (4, 6, 33) but may also be seen in normal elderly individuals (> 65-70 years of age) as a result of structural changes in the vascular tree or autonomic dysfunction (10, 34).

In conclusion, cardiovascular reflex effects can be assessed using various postural stress tests effectively for physiological and clinical investigations in the field, by the patient's bedside, or in the laboratory using more elaborate equipment. Physiologists, clinicians and medical students can make use of these tests to assess or understand cardiovascular reflex response in man in health or disease.
REFERENCES


