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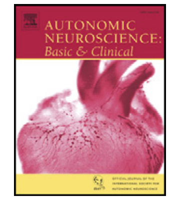

Effects of trunk posture in Fowler's position on hemodynamics

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ABSTRACT

We speculated that stroke volume would be higher and heart rate would be lower when the head and upper trunk were mainly upright in the Fowler's position. We therefore analyzed the effects of three trunk postures in Fowler's position on heart rate, blood pressure and circulatory volume.

Heart rate (HR), blood pressure (BP), stroke volume (SV), cardiac output (Q), systemic vascular resistance (SVR), ejection time (ET) and pre-ejection period (PEP) were measured in 10 healthy male volunteers (mean age ± SEM, 20.7 ± 0.5 y; range, 19–23 y) while in three trunk postures in Fowler's position. Stroke volume and Q were measured using impedance cardiography. The three trunk postures were 30° of lower and upper trunk inclination (WT30°), 30° and 60° of lower and upper trunk inclination (UT 60°), respectively and 60° of upper and lower trunk inclination (WT60°).

Both SV and ET were significantly higher and HR and PEP were lower at UT60° than at WT60° ($p < 0.01$) whereas these values did not significantly differ between WT30° and UT60° ($p > 0.05$). None of Q, SVR and BP significantly differed among the three conditions ($p > 0.05$).

These findings suggested that SV and preload are higher when the upper trunk is upright (UT60°) than when the entire trunk is upright (WT60°) while in Fowler's position. In addition, Q might be maintained without increasing HR through vagal withdrawal when only the upper trunk is upright in healthy young males in Fowler's position.

1. Introduction

Studies of cardiovascular regulation in humans with the head tilted up (HUT) and down (HDT) have found that posture influences hemodynamics and the autonomic nervous system. Standing or HUT decreases ventricular filling pressure and stroke volume (SV) according to a shift in the distribution of blood volume to the lower extremities. Consequently, sympathetic nerve activity is activated, heart rate (HR) increases and vascular contraction maintains circulatory volume. Conversely, SV increases, sympathetic nerve activity and HR decrease and vagal nerve activity increases in the supine, compared with an upright position (Pagani et al., 1986; Pomeranz et al., 1985; Rowell, 1993; Saul et al., 1991; Shoemaker et al., 2001). These findings were determined by analyzing heart rate and blood pressure fluctuations, circulatory volume, systolic time intervals and muscle sympathetic nerve activity (Pagani et al., 1986; Rowell, 1993; Saul et al., 1991; Shoemaker et al., 2001).

Fowler's position or the semi-seated position is often clinically applied as well as standing and supine positions. Fowler's position is achieved by inclining the backrest of a bed upwards from the supine position with flexed or straight knees unlike HUT and HDT which the whole body is inclined (Potter, 2009). The upright head and trunk in Fowler's position are more essential for the quality of life of patients who are confined to bed or frail and it is clinically applied most frequently at inclinations between 30° and 60° (Carol et al., 2008; Potter, 2009). Patients who are confined to bed or frail are frequently placed in Fowler's position instead of remaining supine to assist ambulation, monitor hemodynamics and facilitate breathing as well as routine activities such as eating or conversation (Carol et al., 2008; Her and Frost, 1999; Metzler and Harr, 1996; Potter, 2009; Rauen et al., 2009). On the other hand, such patients develop orthostatic hypotension because they cannot physically compensate quickly for the downward fluid shift caused by assuming an upright position (Bundgaard-Nielsen et al., 2009; Cowie et al., 2004; Metzler and Harr, 1996; Steinberg, 1980). Thus, to understand the most effective posture required to counteract the downward fluid shift while in Fowler's position should be clinically meaningful. Some studies have described a relationship between the angle of Fowler's position and the accuracy of hemodynamic measurements among patients in intensive care units (Driscoll et al., 1995; Shih, 1999; Wilson et al., 1996) and Driscoll et al. (1995) reported

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that cardiac output is decreased in patients under intensive care who are in the Fowler's position, compared with those who are supine. A study of young healthy individuals has shown that blood pressure in Fowler's position is intermediate between the seated and supine positions (Cicolini et al., 2010) and a cross-sectional study of hypertensive patients found the same tendency (Cicolini et al., 2011). However, the most appropriate posture required to counteract the downward fluid shift while in Fowler's position has not been investigated as far as we can ascertain.

We speculated that stroke volume would be higher and heart rate would be lower when the head and upper trunk are mainly upright compared with when the head and the whole trunk are upright in Fowler's position, because most body segment positions remain lower when the head and upper trunk are upright. We tested this hypothesis in a fundamental study of the effects of three trunk postures in Fowler's position on heart rate, blood pressure and circulatory volume in healthy young men.

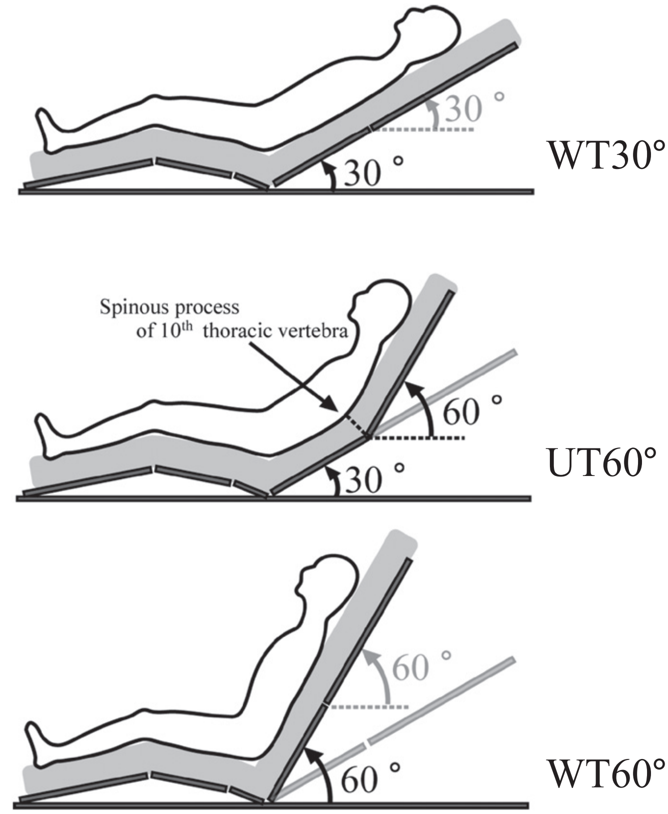

Fig. 1. Bed positions for each condition. A. Lower and upper trunk inclined at 30° (WT30°). B. Lower and upper trunk inclined at 30° and 60°, respectively (UT60°). Upper and lower segments were subdivided based on the spinous process of 10th thoracic vertebra. C. Lower and upper trunk inclined at 60°, respectively (WT60°).

2. Methods

2.1. Study participants

We assessed hemodynamics in 10 male university students (mean age ± SEM, 20.7 ± 0.5 y; range, 19–23 y; weight, 56.7 ± 1.2 kg; height, 170.6 ± 1.5 cm). All were free of chronic or acute cardiovascular, respiratory or other chronic diseases. Beverages containing caffeine or alcohol were not consumed for 24 h before starting the study. All participants refrained from eating and drinking after 2200 h on the evening before the experiments that started in the morning or consumed a light breakfast before experiments that proceeded in the afternoon. All participants were clothed only in shorts.

All experiments were implemented between 1100 and 1400 h. The Ethics Commission of the International University of Health and Welfare approved the study and all recruits provided voluntary written consent to participate after being fully informed about the procedure, risks and protocol.

2.2. Procedure

The participants rested in a thermoneutral room at 28 °C for 15 min and were then prepared for electrocardiography (ECG), continuous measurements of arterial blood pressure and impedance cardiography (ICG). After 5 min resting, data were recorded for 5 min under each condition in all experiments.

The participants were placed in Fowler's positions on a bed at 30° of whole trunk inclination (WT30°), 30° of lower trunk inclination and 60° of upper trunk inclination (UT60°) and 60° of whole trunk inclination (WT60°) (Fig. 1). The upper and lower segments at UT60° were defined by the spinous process of the 10th thoracic vertebra. The height of the bottom of the upper and lower trunk was adjusted according to individual trunk size. All seated positions allowed slight hip and knee joint flexion. All analyses proceeded randomly and were repeated three times in all positions on the same day.

2.3. Instrumentation

Continuous arterial blood pressure was measured at the radial artery by tonometry using a noninvasive arterial blood pressure monitor at the level of the heart. Continuous arterial blood pressure was calibrated using oscillometric sphygmomanometry to measure intermittent cuff blood pressure. Eight Vitrode M spot electrodes (Nihon Kohden, Tokyo, Japan) were attached to the neck and lower thorax of each participant for ICG based on a previous study (Bernstein and Lemmens, 2005). Data from an ECG 100C electrocardiographic lead II (BIOPAC Systems, Goleta, CA, USA) and from impedance cardiography using a NICO 100C instrument (BIOPAC) as well as continuous arterial blood pressure measured using a BP-608EV (Omron Colin, Tokyo, Japan) were recorded on a personal computer using the MP150 data acquisition system (BIOPAC) at a sampling rate of 1 kHz throughout all experiments.

2.4. Data analysis

Heart rate was determined from ECG data in all experiments. Systolic (SBP) and diastolic (DBP) blood pressure was determined from continuous arterial blood pressure. Mean blood pressure (MBP) was calculated as [1/3(SBP − DBP) + DBP)].

We assessed SV, stroke index (SI), cardiac output (Q), cardiac index (CI) and systemic vascular resistance (SVR) using ICG that calculates SV based on thoracic bioimpedance as described (Bernstein and Lemmens, 2005). Q was calculated from product result of SV and HR. Both SI and CI were normalized by SV and Q for the body surface area of each participant (SI = SV/body surface area; CI = Q/body surface area) and SVR was calculated as 80 MBP/Q. Five-minute means of all values were calculated.

We determined the pre-ejection period (PEP) and left ventricular ejection time (ET) from the ECG findings and the derivative signal of ICG for systolic interval analysis (Cybulski, 2011). The PEP was determined as the interval between the Q waves on ECG to point B which is associated with opening of the aortic valve at the first derivative thoracic bioimpedance. Ejection time was determined as the time from point B to point X which is associated with closure of the aortic valve at the first derivative thoracic bioimpedance.

2.5. Statistical analysis

We determined the effects of three postures in Fowler's position upon physiological variables using a repeated measures multivariate analysis of variance (MANOVA) with Pillai's trace statistic. Differences between the two conditions were evaluated using a paired t-test with Bonferroni correction when a main group effect was significant. Statistical significance was established at $p < 0.05$. All values are expressed as means ± SEM. Data were statistically analyzed using R for Windows version 2.13 (www.r-project.org) and the car 2.0-11 package for MANOVA.

3. Results

Table 1 shows the results of all experiments. Although HR and SV were equal at WT30° and UT60°, HR was lower at WT30° and UT60° than at WT60° and SV was higher at WT30° and UT60° than at WT60°. Cardiac output was equal under all tested conditions. Significant main effects were found in HR, SV, SI, PEP and ET (HR, $F (2,8) = 197.0$, $p < 0.01$; SV, $F (2,8) = 94.0$, $p < 0.01$; SI, $F (2,8) = 86.5$, $p < 0.01$; PEP, $F (2,8) = 13.4$, $p < 0.01$ ET, $F (2,8) = 85.1$, $p < 0.01$ MANOVA) at all three angles. Multiple comparisons showed that HR was significantly lower at WT30° and UT60° than at WT60°. All of SV, SI and ET were significantly higher at WT30° and UT60° than at WT60° ($p < 0.01$) and PEP was significantly lower at UT60° than at WT60° ($p < 0.01$). None of HR, SV, SI or ET significantly differed between WT30° and UT60° ($p > 0.05$) and PEP did not significantly differ between WT30° and UT60° or WT60° ($p > 0.05$).

The effects of Q, CI, SBP, MBP, DBP and SVR did not significantly differ (Q, $F (2,8) = 0.45$, $p > 0.05$; CI, $F (2,8) = 0.42$, $p > 0.05$; SBP, $F (2,8) = 0.77$, $p > 0.05$; MBP, $F (2,8) = 0.41$, $p > 0.05$; DBP, $F (2,8) = 0.35$, $p > 0.05$; SVR, $F (2,10) = 0.52$, $p > 0.05$; all MANOVA) among the three angles.

The results of multiple comparisons of conditions between two angles that significantly differed for each physiological variable in each individual tended to be the same.

4. Discussion

Heart rate and PEP were lower and SV, SI and ET were higher at UT60° than at WT60° (Table 1) and HR, SV, SI, PEP and ET were equivalent at UT60° and WT30°. These findings suggested that UT60° did not increase HR or decrease SV and preload compared with WT60° and that hemodynamics and left ventricular function were equal at UT60° and WT30° in young healthy adult males.

Table 1
Hemodynamic values associated with all conditions.

	WT30°	UT60°	WT60°	
	Mean ± SEM	Mean ± SEM	Mean ± SEM	
HR (bpm)	66.2 ± 2.2	65.7 ± 2.7	74.3 ± 2.4*,**	
SBP (mm Hg)	109.3 ± 3.7	114.5 ± 2.9	112.1 ± 3.9	ns
DBP (mm Hg)	55.8 ± 2.5	57.2 ± 2.3	59.1 ± 3.4	ns
MBP (mm Hg)	73.6 ± 2.7	76.3 ± 2.4	76.8 ± 3.5	ns
SV (mL)	90.7 ± 3.8	92.7 ± 4.7	81.1 ± 4.3*,**	
SI (mL/m^2)	55.7 ± 2.7	56.9 ± 3.2	50.1 ± 2.7*,**	
Q (L/min)	5.9 ± 0.2	6.0 ± 0.2	6.0 ± 0.2	ns
CI (L/min·m^2)	3.6 ± 0.1	3.7 ± 0.1	3.7 ± 0.2	ns
SVR (dyne·s/cm^2)	1018.3 ± 39.3	1065.2 ± 48.7	1048.9 ± 42.2	ns
PEP (ms)	111.2 ± 4.2	104.0 ± 4.2	116.7 ± 3.8**	
ET (ms)	301.6 ± 8.8	307.2 ± 10.4	274.2 ± 9.5*,**	

Values are shown as means ± SEM. Q, cardiac output; CI, cardiac index; DBP, diastolic blood pressure; ET, ejection time; HR, heart rate; MBP, mean blood pressure; PEP, pre-ejection period; SBP, systolic blood pressure; SI, stroke index; SV, stroke volume; SVR, systemic vascular resistance. ns, no significant difference among all conditions.
* $p < 0.01$ between WT30° and WT60°.
** $p < 0.01$ between UT60° and WT60°.

4.1. Hemodynamics

The distribution of blood volume generally shifts to the lower extremities according to orthostatic stress and stroke volume decreases as described above. Thus, HR increases through autonomic regulation to maintain circulatory volume (Rowell, 1993). The present study found that SV and SI were lower at WT60° than at UT60° and WT30°, meaning that the effect of gravity was larger at WT60° than at UT60° and WT30° because the lower trunk at UT60° was not upright, whereas the entire trunk was upright WT60°. Heart rate was faster at WT60° than at UT60° and WT30°, indicating that HR adjusted the circulatory volume through autonomic regulation. The HR was <100 bpm at all three angles, and was probably caused by vagal withdrawal (Rowell, 1993). Furthermore, the vagal withdrawal might have been more evident at WT60° than at either WT30° or UT60°. Regardless, these results are in agreement with previous findings of postural change (Cybulski et al., 2004; Rowell, 1993; Shoemaker et al., 2001).

Cardiac output at WT60° did not significantly decrease compared with the other two positions. Cardiac output decreases while upright compared with the supine position in the same manner as SV in healthy persons even if HR increases. Dynamic changes between supine and upright positions such as standing or HUT have been investigated in detail (Fu et al., 2005; O'Leary et al., 2003; Rowell, 1993). However, we evaluated hemodynamics at slight angular differences of the trunk in Fowler's position. The difference in SV among three trunk angles was about 10 mL (between WT30° or UT60° and WT60°) which was smaller than that previously reported. One study found a mean difference in SV of about 30 mL between the supine position and 60° HUT in healthy male and female individuals (Fu et al., 2005). Furthermore, Q was maintained since the decreases in SV compensated for the increase in HR at WT60°.

At UT60° the upper trunk was upright from WT30° although the inclination of the lower trunk was the same. Values for HR, SV, SI, Q and CI did not significantly differ between WT30° and UT60°. Our previous preliminary findings suggested that SV and Q do not differ between WT30° and UT60° under fixed breathing in five healthy individuals (Kubota et al., 2013) and the present results supported our findings. At UT60°, the upper trunk was raised to center at the bottom of the dorsal thorax from WT30°. Since the heart is located close to the rotational center of the bottom of the dorsal thorax, even if the inclination angle of the upper trunk increases, the level of heart at UT60° hardly changed compared with WT30°. Therefore, the effect of gravity on circulatory volume did not essentially differ between the WT30° and UT60° angles of the upper trunk and the blood volume distribution at UT60° probably did not clearly differ from that at WT30°.

Thus, blood volume probably did not shift to the lower body and HR did not increase through vagal withdrawal when only the upper trunk, rather than the entire trunk, was raised in Fowler's position.

4.2. Systolic time intervals

Blood volume shifts from the heart to the lower extremities and venous return and ventricular filling pressure decrease; hence, preload and stroke volume diminish in the upright position (Rankin et al., 1975; Rowell, 1993). The PEP describes the sum of the electromechanical delay and isovolumetric contraction and ET describes the interval between the opening and closing of the aortic valve (Boudoulas, 1986; Cybulski, 2011). Previous findings have shown that PEP is prolonged and ET is shortened in the upright position (Chan et al., 2007; Cybulski et al., 2004; Lewis et al., 1977; STAFFORD et al., 1970). Thus, isovolumetric contraction time is increased because of reduced ventricular filling and a consequently reduced preload (Boudoulas, 1986; Guazzi et al., 1995; Reesink et al., 2007; STAFFORD et al., 1970). Here, PEP was significantly shorter at UT60° than at WT60° and ET was significantly longer at UT60° and WT30° than at WT60°. The prolonged PEP, shortened ET and reduced SV at WT60°

would reflect reduced preload compared with UT60° and WT30° because orthostatic stress might be higher at WT60° than at UT60° and WT30° (WT60° being an upright upper and lower trunk).

Although the upper trunk was upright at UT60° compared with that at WT30°, PEP and ET did not significantly differ between the two positions. The upright upper trunk angle of UT60° might be insufficient to affect blood volume compared with WT30° because the level of heart at UT60° and WT30° was essentially the same and gravity did not differentially affect circulatory volume between the two positions; that is, ventricular filling probably did not differ, and PEP and ET in fact did not significantly differ between WT30° and UT60°.

These findings suggested that preload is higher at UT60° than at WT60° and similar at WT30°.

4.3. Limitations

All of our participants were young and healthy males. Fowler's position is used for patients of all ages, and we intend to analyze the effects of trunk angles in Fowler's position among elderly persons, patients who are confined to bed or frail and those with cardiovascular disease. Considering that Fowler's position is clinically applied, we also plan to compare hemodynamics between Fowler's and supine positions. We will also investigate combinations of various angles of upper trunk inclination to determine the optimal position for patients in the clinical environment.

4.4. Clinical implications

We studied the effects of slight differences in trunk posture during Fowler's position on hemodynamics and left ventricular function. Although trunk posture is defined without dividing the upper and lower segments in Fowler's position during clinical practice, we found that some physiological values significantly differed between the upright upper and upright whole trunk positions. That is, our findings suggested that trunk posture should be subdivided into upper and lower segments. Ventricular filling, SV and Q were easier to maintain without increases in HR via vagal withdrawal when only the upper trunk was upright (UT60°) compared with the whole trunk (WT60°) while in Fowler's position. Hence, an upright upper trunk in Fowler's position might help to maintain circulatory volume and allow patients to raise their head and neck area to participate in routine activities and conversation. In addition, controlling upper trunk posture is important when evaluating the effects of clinical or experimental therapies using hemodynamic measurements.

5. Conclusions

We found that slight differences in trunk posture while in Fowler's position affect hemodynamics. An upright upper trunk results in higher stroke volume and preload and a lower heart rate compared with an upright whole trunk in Fowler's position.

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References

Bernstein, D., Lemmens, H.J.M., 2005. Stroke volume equation for impedance cardiography. Med. Biol. Eng. Comput. 43, 443–450.
Boudoulas, P.F.B.a.H., 1986. Measurement of myocardial inotropy. In: Leier, C.V. (Ed.), Cardiotonic Drugs: A Clinical Survey, Vol. 7. Dekker, New York, pp. 5–48.
Bundgaard-Nielsen, M., Jørgensen, C.C., Jørgensen, T.B., Ruhnau, B., Secher, N.H., Kehlet, H., 2009. Orthostatic intolerance and the cardiovascular response to early postoperative mobilization. Br. J. Anaesth. 102, 756–762.
Carol, T., Carol, L., Priscilla, L., Pamela, L., 2008. Chapter 39. Activity, Fundamentals of Nursing: The Art and Science of Nursing Care, Sixth edition Lippincott Williams & Wilkins, Philadelphia, pp. 1290–1293.
Chan, G.H., Middleton, P., Celler, B., Wang, L., Lovell, N., 2007. Change in pulse transit time and pre-ejection period during head-up tilt-induced progressive central hypovolaemia. J. Clin. Monit. Comput. 21, 283–293.
Cicolini, G., Gagliardi, G., Ballone, E., 2010. Effect of Fowler's body position on blood pressure measurement. J. Clin. Nurs. 19, 3581–3583.
Cicolini, G., Pizzi, C., Palma, E., Bucci, M., Schioppa, F., Mezzetti, A., Manzoli, L., 2011. Differences in blood pressure by body position (supine, Fowler's, and sitting) in hypertensive subjects. Am. J. Hypertens. 24, 1073–1079.
Cowie, D.A., Shoemaker, J.K., Gelb, A.W., 2004. Orthostatic hypotension occurs frequently in the first hour after anesthesia. Anesth. Analg. 98, 40–45.
Cybulski, G., 2011. Impedance Cardiography, Ambulatory Impedance Cardiography, Vol. 76. Springer, Berlin Heidelberg, pp. 7–37.
Cybulski, G., Michalak, E., Koluk, E., Pitkowska, A., Niewiadomski, W., 2004. Stroke volume and systolic time intervals: beat-to-beat comparison between echocardiography and ambulatory impedance cardiography in supine and tilted positions. Med. Biol. Eng. Comput. 42, 707–711.
Driscoll, A., Shanahan, A., Crommy, L., Foong, S., Gleeson, A., 1995. The effect of patient position on the reproducibility of cardiac output measurements. Heart Lung 24, 38–44.
Fu, Q., Witkowski, S., Okazaki, K., Levine, B.D., 2005. Effects of gender and hypovolemia on sympathetic neural responses to orthostatic stress. Am. J. Physiol. Regul. Integr. Comp. Physiol. 289, R109–R116.
Guazzi, M., Pepi, M., Maltagliati, A., Celeste, F., Muratori, M., Tamborini, G., 1995. How the two sides of the heart adapt to graded impedance to venous return with head-up tilting. J. Am. Coll. Cardiol. 26, 1732–1740.
Her, C., Frost, E.A.M., 1999. Assessment of right ventricular function by right ventricular systolic time intervals in acute respiratory failure. Crit. Care Med. 27, 2703–2706.
Kubota, S., Endo, Y., Kubota, M., 2013. Effect of upper torso inclination in Fowler's position on autonomic cardiovascular regulation. J. Physiol. Sci. 63, 369–376.
Lewis, R.P., Rittogers, S.E., Froester, W.F., Boudoulas, H., 1977. A critical review of the systolic time intervals. Circulation 56, 146–158.
Metzler, D.J., Harr, J., 1996. Positioning your patient properly. AJ. Am. J. Nurs. 96, 33–37.
O'Leary, D., Kimmerly, D., Cechetto, A., Shoemaker, J., 2003. Differential effect of head-up tilt on cardiovagal and sympathetic baroreflex sensitivity in humans. Exp. Physiol. 88, 769–774.
Pagani, M., Lombardi, F., Guzzetti, S., Rimoldi, O., Furlan, R., Pizzinelli, P., Sandrone, G., Malfatto, G., Dell'Orto, S., Piccaluga, E., 1986. Power spectral analysis of heart rate and arterial pressure variabilities as a marker of sympatho-vagal interaction in man and conscious dog. Circ. Res. 59, 178–193.
Pomeranz, B., Macaulay, R.J., Caudill, M.A., Kutz, I., Adam, D., Gordon, D., Kilborn, K.M., Barger, A.C., Shannon, D.C., Cohen, R.J., 1985. Assessment of autonomic function in humans by heart rate spectral analysis. Am. J. Physiol. Heart Circ. Physiol. 248, H151–H153.
Potter, P.A., 2009. Chapter 39 Hygiene & Chapter 47 Mobility and Immobility, Fundamentals of Nursing. 7th edition, pp. 898–1253 (Mosby, St. Louis).
Rankin, L.S., Moos, S., Grossman, W., 1975. Alterations in preload and ejection phase indices of left ventricular performance. Circulation 51, 910–915.
Rauen, C.A., Makic, M.B.F., Bridges, E., 2009. Evidence-based practice habits: transforming research into bedside practice. Crit. Care Nurse 29, 46–59.
Reesink, K.D., Hermeling, E., Hoeberigs, M.C., Reneman, R.S., Hoeks, A.P.G., 2007. Carotid artery pulse wave time characteristics to quantify ventriculoarterial responses to orthostatic challenge. J. Appl. Physiol. 102, 2128–2134.
Rowell, L.B., 1993. Reflex Control During Orthostasis, Human Cardiovascular Control. Oxford University Press, USA, New York, pp. 3–203.
Saul, J.P., Berger, R.D., Albrecht, P., Stein, S.P., Chen, M.H., Cohen, R.J., 1991. Transfer function analysis of the circulation: unique insights into cardiovascular regulation. Am. J. Physiol. Heart Circ. Physiol. 261, H1231–H1245.
Shih, F.J., 1999. Patient positioning and the accuracy of pulmonary artery pressure measurements (180f). Int. J. Nurs. Stud. 36, 497–505.
Shoemaker, J.K., Hogeman, C.S., Khan, M., Kimmerly, D.S., Sinoway, L.I., 2001. Gender affects sympathetic and hemodynamic response to postural stress. Am. J. Physiol. Heart Circ. Physiol. 281, H2028–H2035.
Stafford, R.W., Harris, W.S., Weissler, A.M., 1970. Left ventricular systolic time intervals as indices of postural circulatory stress in man. Circulation 41, 485–492.
Steinberg, F., 1980. The effects of immobilization on circulation and respiration. The Immobilized Patient. Springer, US, pp. 11–32.
Wilson, A.E., Bermingham-Mitchell, K., Wells, N., Zachary, K., 1996. Effect of backrest position on hemodynamic and right ventricular measurements in critically ill adults. Am. J. Crit. Care 5, 264–270.