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Normal Diaphragmatic and Rib Cage Breathing: Effects on Venous Return Patterns in Monitored Human Subjects

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Abstract

Objective: To measure the natural prevalence of diaphragmatic (DB) and rib cage breathing (RCB) and their respective effects on venous return in human subjects.

Methods: Sixteen subjects (9 men, 4 women, and 3 boys, aged 10 to 83) were monitored for breathing patterns with stretch transducers on the upper chest, the mid chest, and the abdomen at the umbilicus. Monitoring for venous flow patterns was carried out with infrared transducers on the forehead, sampling superior vena cava (SVC) volume, and with leg electrodes, sampling leg blood volume (LBV) by electrical impedance. Recordings were made during 3 minute periods of sitting and standing after knee bending exercise.

Results: DB, indicated by inward movement of the mid chest with breathing, accounted for 0 - 46% of breathing activity in all positions (One subject had no DB) this breathing pattern correlated with an overflow of venous volume into the SVC. RCB, consisting of upper chest expansion, mid chest constriction, and inward abdominal movement at the umbilicus - accounted for 9 - 37% of breathing activity. This breathing pattern correlated with extraction of LBV, superimposed on an underlying sinusoidal fluctuation of LBV.

Conclusions: DB and RCB are normal, prevalent breathing patterns augmenting venous return to the heart. SVC backflow and rhythmic LBV were observed for the first time.

Keywords: Ribcage breathing; Diaphragmatic breathing; Superior vena cava; Leg veins

Introduction

The dependence of cardiac output on venous return that is dependent in turn on breathing has long been established in animal experiments [1-3]. Inspiration enhances venous return to the right side of the heart and this in turn affects cardiac output, proportionately. In addition, two distinctive breathing patterns, diaphragmatic (DB) and rib cage breathing (RCB) [4,5] as they relate to venous return, have been described in both animal and human experiments [6-8]. DB compresses abdominal contents and the splanchnic bed and pushes venous blood volume into the chest. RCB reduces intrathoracic pressure and pulls venous blood into the chest. Thus the mechanics of breathing that induce venous return to the heart have been described.

With these experimental observations in place the purpose of this paper is to demonstrate the natural distribution of these major breathing and venous return patterns in human subjects. Potentially, attention to breathing patterns might be useful in such clinical disorders as tetraplegia, in which chest expansion is impaired and cardiac output reduced proportionately, or orthostatic hypotension, in which breathing efforts are enhanced but breathing mechanics may be inefficient [9-12].

Materials and Methods

Subjects

Volunteers of various ages and both sexes were recruited with informed, written consent, including a parent's consent in the case of underage subjects. There was no monetary compensation.

Each subject was monitored during consecutive sitting, standing, standing with knee bends, and standing after exercise for 3 minutes each. The speed and depth of the knee bends were selected by the subject based on ease of performance. No attempt was made to standardize this exercise. Measurements of breathing and venous volume were taken continuously during the sitting, standing, knee bending, and standing after knee bends. There were no intervals between these positions and movements. The duration of the test for each subject was 12 minutes.

Monitors

A cutaneous blood flow transducer (Model 1020, UFI, Morrow Bay, CA) was held onto the mid forehead above the level of the eyes with an elastic band. This transducer measured reflectance of a 950 nm infrared probe, with a 50% penetrance of 6 mm into soft tissue. This probe recorded forehead blood volume, predominantly venous blood, and, as such, sampled the tributaries of the superior vena cava (SVC).

A stretch transducer (Pneumobelt, UFI) was wrapped around the chest at the fourth costal interspace to measure upper chest expansion or rib cage breathing (RCB), another at the level of the xyphoid cartilage and the sixth costal interspace to measure mid chest movement or diaphragmatic breathing (DB), and another at the level of the umbilicus to measure abdominal movement (AM).

Leg blood volume (LBV) was determined by electrical impedance, snap electrodes (Red Dot, 3 M) being placed on the lateral side of the thigh opposite at the proximal edge of the patella and onto the medial side of the mid-calf, grounding to the opposite calf. LBV was substituted for the AM monitor in 10 of the 16 subjects studied.

In all of these tests the upward deflection of the signal was set to indicate increased blood volume of the forehead, outward movement of the upper or mid chest, expansion of the abdomen, or increased blood volume of the calf. The upward signal direction for the calf was set to indicate venous filling. This was done by passively lifting the leg to drain the veins and then returning the leg to the dependent position for venous filling.

All transducer signals were conditioned through a polygraph (Model 79E polygraph with P122 low level amplifiers, Grass Instruments Company). These signals were carried to an analog to digital card (DAQCard-1200, National Instruments), and processed in a laptop computer (Satellite Model M20, Toshiba) using proprietary software (Polyview, Grass Instruments Company).

Analysis

Breathing and venous patterns were printed on paper in 3 minute segments, corresponding to the sitting, standing, exercise, and standing-after-exercise positions tested. The printouts were read for patterns of breathing and venous volume and their correlations. By use of calipers the duration of each breathing pattern could be transferred to the time line and expressed in seconds.

The prevalence of each kind of breathing pattern for each individual could be calculated as a percentage of time in the sitting and standing positions. Likewise, by the use of calipers, the onset and duration of changes in the venous return patterns could be determined and compared with the onset and duration of breathing patterns. However, breathing and venous return patterns during knee bends were usually unreadable since excursions in all channels were maximal. These patterns were not assessed.

Results

Subjects

Sixteen subjects were studied - 9 men, 4 women, and 3 boys. The age range was 10 to 83, median 55 years. Body mass index ranged 17- 29, median 22. One man and 1 woman had diabetes mellitus without vascular complications; one woman had hypertension with history of stroke; one man was a recent smoker. Six subjects were assessed for SVC, RCB, DB, and AM. Ten subjects were assessed in the same way but with LBV substituting for AM.

Breathing patterns

Three breathing patterns, occurring sequentially, were recognized. Non-specialized breathing (NSB) consisted of even, unchanging excursions of the chest and abdomen (Figure 1). The second pattern of breathing, DB, consisted of an isolated constricting movement of the mid chest without change in the pattern of the upper chest or abdominal movement (Figure 1).

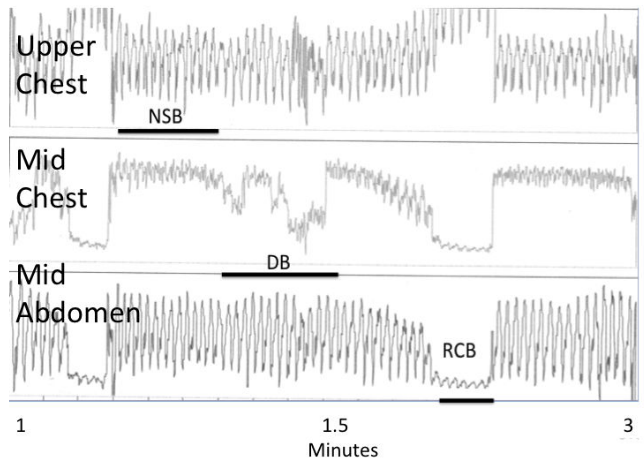

Figure 1: Three typical breathing patterns at rest. NSB, nonspecific breathing pattern, is underlined in the top tracing. DB, diaphragmatic breathing, identified by constricting movements of the mid chest, is underlined in the middle tracing. RCB, rib cage breathing, features 3 parts - expansion of the upper chest, constrictive movement of the mid chest, and abdominal movement, AM. These are indicated by the underlining at the bottom of the tracing.

The third pattern, RCB, consisted of an abrupt onset of expanded upper chest movements, constricting mid chest movements as for DB, and extreme inward AM. This breathing pattern appeared to correspond to the RCB previously described experimentally (Figure 1). NSB followed each of the specialized breathing patterns DB and RCB.

DB and RCG were found in both the sitting and standing postures. They occurred alternately, except for the single subject who did not demonstrate the DB pattern. The fraction of breathing time due to DB breathing was 0 - 46%, that due to RCB was 9 - 37%. These patterns together ranged from 7 to 52, median of 27% of recorded breathing time.

Venous return patterns

The baseline of the forehead pulse, representing SVC volume, periodically rose and fell in clusters of 2 or 3 "humps", interrupting a steady baseline. These hump patterns corresponded with DB (Figure 2). In addition, smaller fluctuations in the SVC volume occurred in concert with RCB (Figure 2). Impedance of the calf, representing LBV, waxed and waned in a sinusoidal pattern. This venous pattern was periodically broken by a depression of varying degrees. These interruptions corresponded with RCB, indicating removal of venous volume, Figure 3.

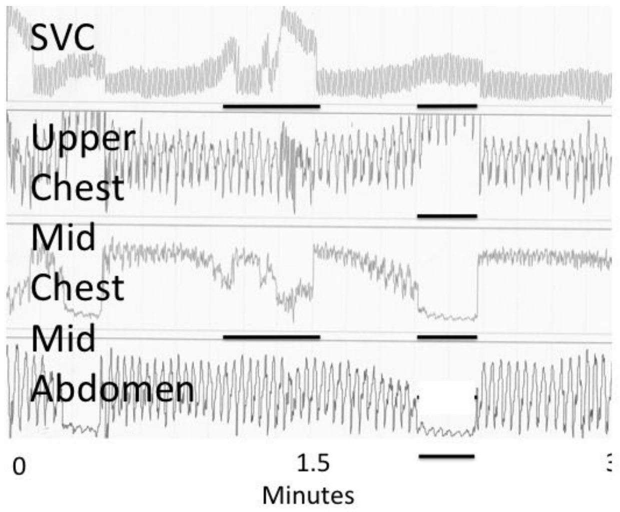

Figure 2: Effects of breathing on the superior vena caval volume, top tracing. Diaphragmatic breathing and its effects are indicated by underlining at the first and third tracings. Rib cage breathing and its effects are indicated by the stacked underlining on the right side of the graph.

In 6 subjects LBV was depleted by Type 3 breathing at the peak of the sinusoidal filling pattern; in 3 the depletion was at the nadir. (A tenth subject had a flat baseline LBV tracing.) These two patterns accounted for all abrupt changes in venous return.

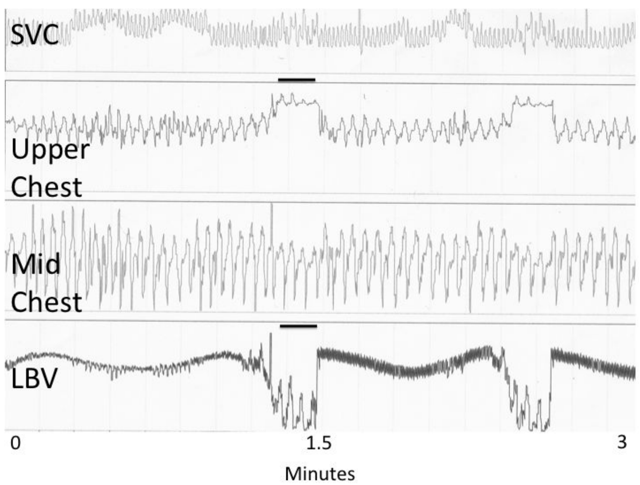

Figure 3: Effect of rib cage breathing on leg blood volume. Upper chest expansion correlated with LBV depletion. Note the line over the upper chest expansion and the correlating line over the deep depression of LBV. The underlying sinusoidal fluctuation of the LBV is also apparent.

The abdominal constriction, key part of rib cage breathing and not shown in this figure, does not prevent the aspiration of venous blood from the legs, despite the implied increased intra-abdominal pressure.

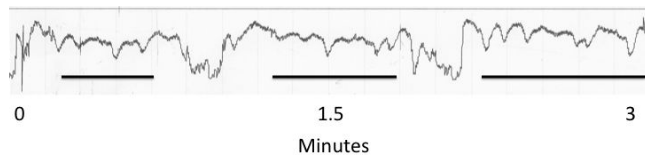

Figure 4: Abnormal pulsation of leg blood volume, underlined. The rate of this pulse is slower than either arterial pulse or respiratory rate.

One subject demonstrated pulsation of the LBV superimposed on a sinusoidal pattern, Figure 4. The rate of this pulsation was slower than arterial pulse or breathing rates, as evident in the figure. This subject was the only smoker in the group tested. The major observations made in these studies are summarized in Table 1.

Breathing type	Diaphragmatic	Ribcage
Fraction of total breathing	0-46%*	9-37%
Superior vena cava reflux	100% (large)	100% (small)
Extraction of leg vein volume	0%	100% (large)
*Except for the single subject without diaphragmatic breathing, these breathing patterns occurred alternately.		

Table 1: Frequency of correlations of breathing and venous return patterns in unselected subjects.

Discussion

This survey of human subjects during normal activities revealed three types of breathing-the NS pattern, the most common and least distinctive in shape; the DB pattern, characterized by mid chest constriction in this study, and the RCB pattern, characterized by expansion of the upper chest, constriction of the mid chest, and constriction of the abdomen at the level of the umbilicus. The significance of DB and RCB is their exceptional ability to move venous blood.

The patterns of DB and RCB suggest the mechanisms of augmented venous return, previously demonstrated experimentally [6-8]. In DB the narrowing of the mid chest, Figure 1 suggests that the oblique abdominal musculature with origins in the flexible lower ribs pulls them toward the abdominal cavity in coordination with the contraction and descent of the diaphragm. The resulting compression of venous contents of the upper abdominal cavity, mainly the splanchnic bed and the inferior vena cava, forces blood into the thorax [8,13]. Retrograde flow in the vena cava is prevented by the valve structure of the venous system of the lower extremities. The volume of venous blood being pushed into the thorax overcomes the capacity of the right atrium, right ventricle, and pulmonary vasculature as evidenced by the volume increase in the SVC. There are no valves in the SVC to impede retrograde flow. Although retrograde flow into the SVC can be demonstrated with a valsalva maneuver [14] the consistent retrograde flow with one form of normal breathing, DB, does not seem to have been reported.

In contrast to DB, RCB creates negative intrathoracic pressure and draws blood into the chest [7,15]. The upper chest is expanded, the lower chest constricted as for DB, but in addition, the abdomen is fully constricted, evidenced by the inward movement of abdomen at the level of the umbilicus. This is in contrast to DB when the mid abdomen is not constricted. The difference appears to be that in RCB the fully contracted abdomen serves as a fulcrum for the descending diaphragm on which it can lift the rib cage, and therefore expand the chest [15]. The negative thoracic pressure of RCB induces venous return from the lower extremities and inferior vena cava [16]. In contrast to DB, however, there is only slight spillover of venous return into the SVC. It can be suggested that with RCB a greater portion of venous return is more quickly shunted into the pulmonary vasculature due to the negative intrathoracic pressure of RCB and consequently the reduction of pulmonary vascular resistance.

That the abdominal musculature is important in both diaphragmatic and rib cage breathing can be emphasized. A clinical example is the tetraplegic subject. In this condition the abdomen and chest are both paralyzed; the abdomen cannot contract and the chest cannot expand on breathing, markedly reducing the vital capacity, venous return, and cardiac output [12,17]. With the application of a tight abdominal binder, diaphragmatic pressure production and left ventricular function are both improved [18].

Aside from the effects of breathing on venous return, however, none of the breathing patterns described accounted for the underlying sinusoidal venous pattern found in the leg. An intrinsic venous tone with periodicity was apparent. The effect of the observed change in the venous tone of the legs on venous return has not been measured.

Finally, it should be mentioned that a single subject demonstrated pulsation of leg veins superimposed on the phasic pattern of leg vein volume. This subject was the only smoker in the test group. A similar report has not been found.

Limitations of this survey can be described. The possibility that extension of the thoracic spine is important as a mechanism is breathing with chest expansion. This was not measured directly but paraspinal musculature might have supplemented the action of the diaphragm in RCB. The splanchnic venous bed and the inferior vena cava were not monitored for volume or flow.

In summary normal breathing includes DB and RCB patterns. These patterns vary in duration, occur alternately, and account for approximately a quarter of breathing activity. The onset of either of these breathing patterns abruptly increases venous return to the chest - DB by compressing venous reserves in the abdomen and RCB by aspirating venous reserves from the legs and abdomen. DB and RCB also cause a reflux of venous return into the SVC. Finally, an underlying phasic change in the tone of leg veins has been noted.

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