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The Concordance of Respiratory Fluctuations in Oesophageal and Central Venous Pressures

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ABSTRACT

Respiratory fluctuations in oesophageal and central venous pressures were recorded in 13 healthy subjects and compared with respect to phase and amplitude concordance. An average divergence in phase of nearly 180° was obtained, with large inter- and intra-individual variations. Disregarding phase the amplitude of the respiratory central venous pressure was found to be, on the average, a good 1/4 of that of the oesophageal pressure in the supine posture, and a good 2/3 while the subjects were sitting. These figures also varied considerably. It is suggested that the findings might be referred to competition between a central venous pressure raising effect of inspiration enhanced venous return, and a central venous pressure depressing effect of the inspiratory fall in intrathoracic pressure. The partitioning of costal and abdomino-diaphragmatic breathing is considered of great significance to the outcome of this competition. It is concluded that the oesophageal balloon catheter technique for estimation of transpulmonary pressure cannot simply be replaced by the central venous catheter technique in healthy subjects. Its application in patients with certain pulmonary disorders, however, might be more successful.

INTRODUCTION

The oesophageal balloon catheter technique is well established for estimation of respiratory fluctuations in intrathoracic pressures. Unfortunately, it can cause some discomfort, especially when used for repeated or long-term recordings, e.g. in monitoring of pulmonary mechanics in intensive care patients. These patients, however, often have a central venous catheter *in situ* and some reports have been made of good conformity between respiratory fluctuations in oesophageal and central venous pressure curves (5, 6, 7, 8). It has also been suggested that fluctuations in central venous pressure due to respiration be combined with the spirogram to form an index of pulmonary compliance (10). Since there appear to be no detailed descriptions of the conditions for making use of central venous pressures in this way, the present investigation was undertaken with the aim of determining how the respiratory fluctuations in central venous pressure accorded with those in oesophageal pressure in healthy subjects.

MATERIAL AND METHODS

The investigation was performed on 13 volunteers, 7 women and 6 men. They were all of ordinary physical constitution and apparently healthy, to judge from their history, the findings at physical examination and chest roentgenograms. Their ages varied between 21 and 34 years.

Three variables were recorded: oesophageal pressure (P_{oe}), central venous pressure (P_{cv}) and respiratory airflow at the mouth. Oesophageal and central venous pressures were measured relative to atmospheric pressure with differential pressure transducers (EMT 33, Siemens-Elema, Solna, Sweden). The oesophageal catheter, which was of polyethylene (PE 240), was 100 cm long and had an inner diameter (i.d.) of 1.7 mm, one end-hole and several side-holes. The holes were covered by a 10 cm long latex balloon, 2.6 cm in perimeter. The balloon catheter was inserted nasally to the lower part of the oesophagus, the tip being placed about 45 cm from the nostril. The balloon was deflated and refilled with 0.2 ml air. The central venous catheter, which was made of radiopaque PVC, was 60 cm long and had an i.d. of 1.3 mm. It had an end-hole but no side-holes (Bardic I-catch 1914, SR Bard International Ltd., Clacton, Essex, England). The catheter, filled with saline, was introduced percutaneously to a cubital vein and advanced to the superior vena cava and right atrium. Its position was checked by X-ray.

The transducers, which were calibrated in parallel against a water column, were always placed at the level of the 6th intercostal space in the mid-axillary line.

The subject breathed through a mouth-piece with nose-clips applied. The air flow through the mouth-piece was measured with a pneumotachograph (Fleisch No. 1, Godart, Bilthoven, Netherlands) connected to a differential pressure transducer (EMT 32, Siemens-Elema).

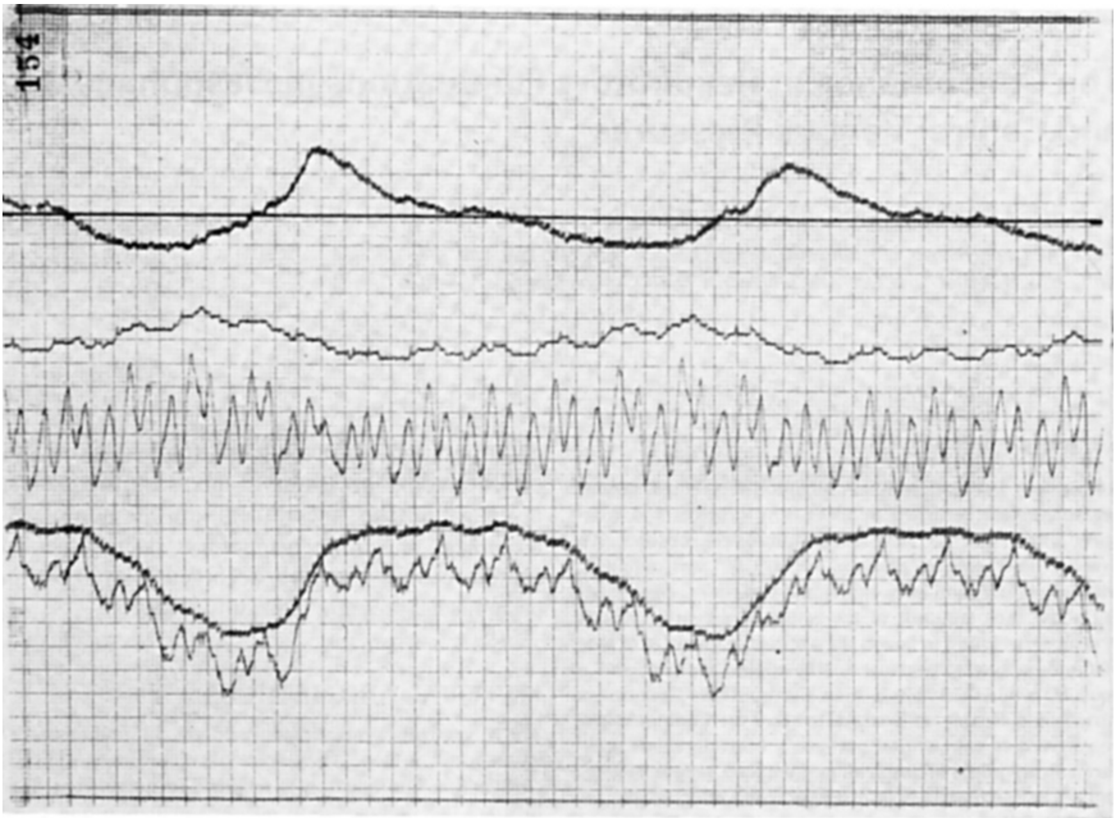

Fig. 1. Example of a digital-to-analogue converted display, obtained from the computer. Top to bottom: air flow (downward deflexion from indicated zero flow means inspiration); filtered and non-filtered P_{cv}, filtered and non-filtered P_{oe}.

The investigation programme included the following variations:

1. All 13 subjects were investigated in the supine, semi-recumbent (elevated 30° from the horizontal plane) and sitting positions.
2. In 6 of the subjects the respiratory frequency was varied (10, 20 and 40 breaths per min). The tip of the central venous catheters was placed at the level of the lower part of the superior vena cava (SCV_I). At 40 breaths per min, however, it was impossible to decipher two of the central venous pressure records from the supine and semi-recumbent positions and one from the sitting position. This was mainly due to interference between the effects of respiratory and cardiac activity on the central venous pressure at this respiratory frequency.
3. In 4 of them external airway resistances were increased stepwise from 0 (R_0) to about 35 cm $H_2O/l \cdot sec^{-1}$ (R_{III}) by adding pieces of foam rubber to the mouth-piece. The respiratory frequency was 15 breaths per min and the tip of the central venous catheter was placed at the level of SCV_I.
4. In the remaining 3 subjects the tip of the central venous catheters was placed at different levels. The tip was stepwise withdrawn from the right atrium (RA) to the level of SCV_I and then to the level of the upper part of the superior vena cava (SCV_{II}) and the subclavian vein. The respiratory frequency was 15 breaths per min.

Signals were recorded on analogue tape and digitized at a sampling frequency of 50 Hz for the smoothing of oesophageal and central venous pressure signals with a digital, non-recursive low-pass filter.

After digital computation, the values were reconverted to analogue signals and recorded graphically with a multi-channel ink-jet recorder (Minograf 800, Siemens-Elema), for further manual processing. An example of such a recording is given in Fig. 1.

The beginning and end of a breath were demarcated where the air flow signal crossed the zero-flow reference. For the calculation of phase difference between oesophageal and central venous pressure curves, each breath was considered to be 360°. During inspiration there was always a fall in the oesophageal pressure curve and its minimum was marked. In the central venous pressure curve there was either an increase or a decrease during inspiration and the maximum or the minimum, as the case may be, was marked. The time-based distance between marks in the two different pressures was calculated (in degrees) and considered as the phase difference between

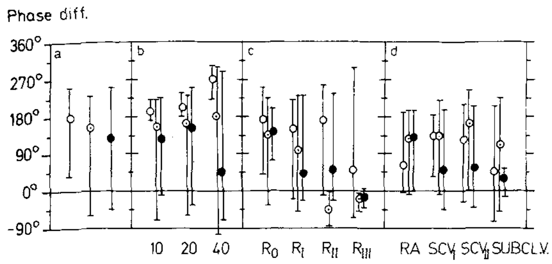

Fig. 2. Phase differences between P_{cv} and P_{oe}. Group mean value and ranges. ○, supine; ⊙, semi-recumbent; ●, sitting. Positive values when P_{oe} curve precedes P_{cv} curve. (*a*) All 13 subjects, with a respiratory frequency of 15–20 breaths per min and with P_{cv} catheter at SVC_I. (*b*) Six subjects with different respiratory breathing frequencies. Note that at 40 breaths/min the number of sujects in supine and semi-recumbent positions was 4, and in the sitting position, 5. (*c*) Four subjects in whom increasing external airway resistances were applied. (*d*) Three subjects with different tip positions of P_{cv} catheter.

the two curves. Regarding the oesophageal pressure curve as a reference, the phase difference was given a positive sign when the oesophageal pressure mark preceded the mark of the central venous pressure, and a negative sign for the reverse. When an increase took place in central venous pressure during inspiration, the mark for this pressure was considered to be about 180° out of phase, compared with the oesophageal pressure mark. The 'exact' figure was calculated by adding the measured phase difference, with its appopriate sign, to 180°.

The pressure difference between maximum and minimum levels within a breath was calculated as the respiratory pressure amplitude, (i.e. ΔP_{oe} and ΔP_{ev} respectively). The phase shape was disregarded. In order to make the values inter-individually comparable, the quotient $\Delta P_{cv}/\Delta P_{oe}$ was taken as an index of their amplitude correlation.

RESULTS

The phase differences are presented in Fig. 2. In Fig. 2*a* all 13 subjects are presented as a group for investigations at respiratory frequencies of 15 to 20 breaths per min and with the tip of the central venous catheter at the level of SCV_I. The influence of body position on the phase differences can be seen. The mean difference for the 13 subjects when supine was 175° (range +35° to +250°), when semi-recumbent 150° (range −60° to +230°) and when sitting 126° (range −45 to +250°). Student's *t*-test was applied to paired differences between values from the supine and sitting positions, and these were found to be not statistically significant ($P>0.05$).

An increase in respiratory frequency from 10 to 20 or even to 40 breaths per min did not change the phase differences appreciably (Fig. 2*b*).

When external airway resistances were applied, this tended to delete the phase differences (Fig. 2*c*). When the group mean values with no external resistances (R_0) were compared with those with the highest external resistance (R_{III}), a decrease in phase difference from 172° tp 52° was found for the supine position, from 136° to −21° for the semi-recumbent position and from 144° to −15° for the sitting position. However, when Student's *t*-test was applied to paired differences between R_0 and R_{III}, the decrease was statistically significant ($P<0.05$) only for the sitting position.

Alterations in the position of the central venous catheter tip did not systematically change the phase differences (Fig. 2*d*).

The $\Delta P_{cv}/\Delta P_{oe}$ quotients are presented in Fig. 3. In Fig. 3*a* all 13 subjects are presented as a group for investigations at respiratory frequencies of 15 to 20 breaths per min and with the tip of the central venous catheter at the level of SCV_I. The influence of body position on these quotients can be seen. The mean quotient for the 13 subjects when supine was 0.28 (range 0.12 to 0.44), when semi-recumbent 0.42 (range 0.25 to 0.56) and when sitting 0.68 (range 0.34 to 1.40). When Student's *t*-test was applied to paired differences between values from the supine and sitting positions, these were found to be statistically significant ($P<0.05$).

There were no systemic differences between quotients at 10, 20 and 40 breaths per min (Fig. 3*b*).

The application of external airway resistances did not notably alter the amplitude quotients (Fig. 3*c*). Neither were there any noteworthy changes of the quotients when the position of the central venous catheter tip was altered (Fig. 3*d*).

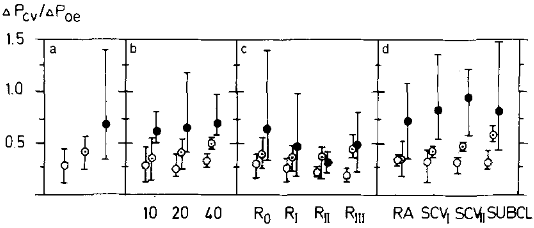

Fig. 3. $\Delta P_{cv}/\Delta P_{oe}$ quotients. Group mean values and ranges. For further explanation, see caption to Fig. 2.

DISCUSSION

Opdyke & Brecher (9) found that the effective right atrial pressure increased during inspiration in dogs, and Nakhjavan et al. (8) obtained the same result in humans, the effective pressure being the algebraic difference between right atrial (or central venous) pressure and intrathoracic (or oesophageal) pressure. According to the recordings illustrating their reports, however, there was good phase conformity between pressures, which means that there was a drop during inspiration in right atrial (or central venous) pressure relative to atmospheric pressure. Our results are in agreement with this with respect to effective right atrial (or central venous) pressure. We did not obtain the same good phase conformity between respiratory fluctuations in central venous and oesophageal pressures. In our group of 13 healthy subjects the respiratory fluctuations in central venous pressure differed in phase by almost 180°, on the average, from those in oesophageal pressure. Furthermore, bot the inter- and intra-individual variations around this mean were considerable, which was mainly due to phase shifts in the central venous pressure curve. The oesophageal pressure curve appeared quite constant throughout, with its minimum at about 125° from the start of the breath, except that it dropped to 90° when the largest external airway resistance was added.

The following interpretation of our results is suggested. An inspiration has at least two—oppositely oriented—effects on central venous pressure. The intrathoracic pressure becomes more negative during inspiration and causes the central venous pressure to follow the same direction. However, it also enhances venous return to the heart (2). The blood volume in the central veins and right atrium increases, which in turn increases the central venous pressure. During normal breathing in healthy individuals it would seem, according to our results, that the pressure-raising effects from inspiratory increased venous return predominates. The only thing which significantly influenced the phase differences in our investigation was the addition of an external airway resistance, which tended to delete them. Here the effect of a heavy fall in intrathoracic pressure during inspiration overwhelmed the central venous pressure increasing effect of venous return, which under these circumstances may even be obstructed, according to the 'collapse' theory (2, 3, 4).

The large inter- and intra-individual variations in phase difference might be explained by changes in the partitioning of costal and abdomino-diaphragmatic breathing. An important contributor to the increase of venous return into the chest during inspiration is a simultaneous increase in intra-abdominal pressure, which squeezes blood from the abdominal towards the thoracic part of the inferior vena cava (1, 6). This may be illustrated by the following. In a healthy subject, we measured the central venous, oesophageal and intra-gastric (as an estimate of the intra-abdominal) pressures simultaneously with the respiratory air flow. Recordings were made during normal, predominantly costal and predominantly abdomino-diaphragmatic breathing. As can be seen in Fig. 4, costal breathing (*b*) proved to give good phase conformity between the central venous and oesophageal pressures. There was no noteworthy deflexion in intra-gastric pressure during inspiration. A possible reason for this is that when there was no increase in intra-abdominal pressure during inspiration, the venous return to the chest during inspiration was not sufficiently accelerated to raise the central venous pressure. During predominantly abdomino-diaphragmatic breathing (*c*), the central venous and oesophageal pressures were almost 180° out of phase. There was also a considerable increase in intra-gastric pressure. Analogously to the above reasoning, it is conceivable that when there was an increase in intra-abdominal pressure, the venous return to the chest was accelerated to a sufficient extent to increase the central venous pressure during inspiration.

Concerning the pressure amplitude quotients ($\Delta P_{cv}/\Delta P_{oe}$), their fairly good constancey on application of external airway resistances may indicate some interrelationship. Again, however, there was a considerable variation. Furthermore, the quotient often expressed an increase in central venous pressure divided by a decrease in oesophageal pressure. The only factor which significantly influenced the quotients in our experimental design was body position. The quotients increased when the position was changed from supine to sitting due to an increase in central venous pressure amplitude (ΔP_{cv}). As body position did not significantly influence the phase differences, the reason for its effect on the quotients might be that the difference between inspiratory and expiratory rate of venous return is greater in the sitting than in the supine posture. This means that the expiratory rate of venous return is presumed to

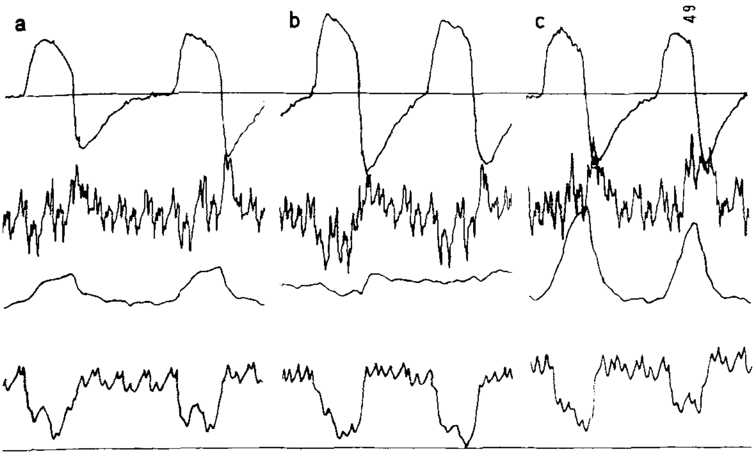

Fig. 4. Recording of air flow (upward deflexion from indicated zero flow means inspiration), P_{cv}, intragastric pressure and P_{oe} during (*a*) normal breathing, (*b*) predominantly costal breathing, (*c*) predominantly abdomino-diaphragmatic breathing.

fall when the subjects are sitting, the inspiratory rate of venous return remaining at the same level in spite of changes in body position.

In summary, the results of this study imply that the oesophageal balloon catheter technique cannot simply be replaced by a central venous catheter technique for estimation of variations in transpulmonary pressures due to respiration in healthy subjects. However, when simulating pulmonary disorders by applying external airway resistances, the successively increased oesophageal pressure amplitudes were paralleled by increases in the central venous pressure amplitudes. Their phase differences also tended to diminish. This indicates that the technique might be useful in some clinical situations.

Finally, it should be pointed out that statements on venous return were estimated from pressure recordings. They should in fact be based on flow recordings, but such parameters were not within the primary aims of this investigation.

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