Effects of transient intrathoracic pressure changes (hiccups) on systemic arterial pressure

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Mathew, Oommen P. Effects of transient intrathoracic pressure changes (hiccups) on systemic arterial pressure. J. Appl. Physiol. 83(2): 371–375, 1997.—The purpose of the study was to determine the effect of transient changes in intrathoracic pressure on systemic arterial pressure by utilizing hiccups as a tool. Values of systolic and diastolic pressures before, during, and after hiccups were determined in 10 intubated preterm infants. Early-systolic hiccups decreased systolic blood pressure significantly (P < 0.05) compared with control (39.38 ± 2.72 vs. 46.46 ± 3.41 mmHg) and posthiccups values, whereas no significant change in systolic blood pressure occurred during late-systolic hiccups. Diastolic pressure immediately after the hiccups remained unchanged during both early- and late-systolic hiccups. In contrast, diastolic pressure decreased significantly (P < 0.05) when hiccups occurred during diastole (both early and late). Systolic pressures of the succeeding cardiac cycle remained unchanged after early-diastolic hiccups, whereas they decreased after late-diastolic hiccups. These results indicate that transient decreases in intrathoracic pressure reduce systemic arterial pressure primarily through an increase in the volume of the thoracic aorta. A reduction in stroke volume appears to contribute to the reduction in systolic pressure.

Methods

Fourteen episodes of hiccups in 10 preterm infants formed the basis of this study. These infants had a birth weight of 1,291 ± 455 g; their mean gestational age at birth was 29.2 ± 2.7 wk. Nine infants were appropriate for gestational age, and one infant was small for gestational age. All infants, except one, were intubated at the time of the study. Six infants required relatively low ventilator support with peak pressures of <20 cmH2O and ventilatory rate <15 breaths/min. The infants were evaluated during their first week of life (mean 3.1 ± 1.5 days; range 1–6 days). The primary diagnosis was respiratory distress syndrome in six, transient tachypnea of the newborn in two, and respiratory depression in the remaining two. The study protocol was approved by the institutional review boards of East Carolina University and Pitt County Memorial Hospital.

Respiration, electrocardiogram (ECG), and systemic arterial blood pressure were being monitored and displayed on the bedside monitor as a part of clinical care. Arterial blood pressure was monitored through a pressure transducer attached to an umbilical arterial catheter (3.5- or 5-Fr) with its tip in the abdominal aorta. During hiccups, ECG signals and respiratory and blood pressure waveforms were downloaded from the bedside monitor, by using custom-made software, to a bedside personal computer (IBM PS/2). Respiratory rates and blood pressure waveforms were sampled at 125 Hz and ECG at 500 Hz.

Data analysis. The data acquired were redisplayed as a waveform and analyzed off-line by using custom-made software. Hiccups introduce a high-frequency spike and a low-frequency-wave artifact on the ECG channel (2). They also can be distinguished on the respiratory channel as a sharp signal on the respiratory waveform. These cardiorespiratory markers were used to identify individual hiccups. Hiccups were defined as occurring during diastole if they began after the dicrotic notch and before the beginning of the next cardiac cycle; otherwise, the hiccups were defined as occurring in systole. Hiccups occurring in systole were further subdivided into early and late on the basis of their onset in relation to peak systolic pressure. Hiccups occurring in diastole were defined to be late if they extended into the systole of the next cardiac cycle. Values of systolic and diastolic pressures of two to three cycles immediately preceding hiccups were determined by using custom-made software; these values served as control. Values of blood pressure waveforms during hiccups and the next two phases of the cardiac cycle immediately after hiccups were also determined. These values were compared by using analysis of variance and t-tests and were considered significant if the P values were <0.05.

INTRATHORACIC PRESSURE (ITP) decreases during spontaneous breathing. Hemodynamic consequences of ITP changes have been the focus of many investigations (1, 3, 8, 10, 11, 14–16). Acute effects of ITP changes on cardiac output and arterial blood pressure depend on the mechanical effects of respiratory-circulatory interaction, reflex responses to these interactions, and consequences of altered blood-gas tensions. Although the effects of tidal breathing on circulation are relatively small, augmented respiratory efforts induce significant changes in systemic and pulmonary arterial pressures (1, 3, 8, 9, 11, 14, 15, 17). Inspiratory decrease in systemic arterial blood pressure has been primarily attributed to a decrease in stroke volume by some investigators (8, 11, 14), whereas others have implicated direct transmission of ITP to the vascular tree as the dominant mechanism (10, 15, 22).

ITP changes associated with breathing are exaggerated in a number of conditions such as loaded breathing, airway obstructions, snoring, and obstructive sleep apnea (1, 9, 16, 17). It is often difficult to determine with certainty the primary mechanism(s) responsible for the reduction in systemic arterial pressure because the effects of normal, and especially exaggerated, inspiratory efforts span several cardiac cycles. ITP changes associated with hiccups, on the other hand, are very brief. Although the respiratory effects of hiccups have been reported, the cardiovascular effects of hiccups have not been investigated. The increased frequency of hiccups in neonates (2) provided an excellent opportunity to document the hemodynamic effects of transient ITP changes.
RESULTS

One hundred and eighty-five hiccups were analyzed. Of these, 69 occurred during systole and 116 during diastole. The effects on blood pressure varied depending on the time of occurrence of hiccups during the cardiac cycle.

Hiccups in systole. When hiccups occurred during early systole, the systolic pressure decreased compared with the preceding control value (39.38 ± 2.72 vs. 46.46 ± 3.41 mmHg). The corresponding value for systolic pressure immediately after hiccups was 47.65 ± 3.68 mmHg. The decrease in systolic pressure during the hiccups was significant compared with control and posthiccups values (P < 0.05; Fig. 1). A representative episode is illustrated in Fig. 2. Systolic pressure values immediately preceding and after hiccups were 26.64 ± 1.31 and 27.49 ± 1.32 mmHg, respectively.

No significant change in systolic pressure was observed when hiccups occurred in late systole (Fig. 1; P > 0.05). The dicrotic notch was not identifiable in these episodes and the fall in blood pressure was more steep compared with control, as shown in Fig. 3. No change in diastolic pressure was seen overall (27.66 ± 1.11 vs. 27.59 ± 1.31 mmHg). The lowest values were generally seen in early diastole; increases in diastolic pressure, instead of the normal slow decrease, were often seen immediately after the completion of the hiccups.

Hiccups in diastole. Control diastolic pressure of early-diastolic hiccups was 28.69 ± 1.25 mmHg. Corresponding values during and immediately after hiccups were 24.59 ± 1.34 and 29.10 ± 1.13 mmHg, respectively. The decrease in diastolic pressure was significant compared with control and posthiccups values (P < 0.05; Fig. 4). An example of one such episode is shown in Fig. 5. Systolic pressure values of the cycles immediately preceding and after hiccups did not change (48.99 ± 3.33 vs. 48.73 ± 3.30 mmHg; P > 0.05).

As in early-diastolic hiccups, diastolic pressure of late-diastolic hiccups decreased significantly compared with control (21.02 ± 1.14 vs. 27.89 ± 1.19 mmHg; Figs. 4 and 6). However, the effect on subsequent systolic pressure was different. A significant decrease in systolic pressure was observed for one cardiac cycle whenever hiccups began in late diastole and extended into early systole (47.41 ± 2.20 vs. 42.15 ± 1.58 mmHg; P < 0.05).

DISCUSSION

Results of the present study clearly demonstrated that systemic arterial pressure decreased during hiccups. The effect of hiccups on arterial pressure depended on the time of occurrence of hiccups during the cardiac cycle.

Systemic arterial blood pressure depends on heart rate, stroke volume, and total peripheral vascular resistance. A greater inspiratory decrease in systemic arterial pressure occurs during augmented respiratory efforts such as loaded breathing, snoring, and obstructive sleep apnea (1, 3, 8, 9, 11, 17). Our finding of decreased arterial pressure during hiccups is consistent with this concept, because large decreases in ITP occur in all these conditions. The reasons for the decrease in systemic arterial pressure during inspiratory efforts are less clear. The time constant for baroreceptor-mediated reflexes is too long to account for the phasic changes in blood pressure during respiration (5). Inspiratory decreases in stroke volume have been documented in both animals and humans (3, 7, 15, 20). Inspiratory decrease in ITP decreases right atrial pressure and increases venous return (6). Increased venous return, in turn, increases the right ventricular (RV) preload and stroke volume. During exaggerated inspiratory efforts, as a result of ventricular interdependence, RV distension decreases left ventricular (LV) compliance, resulting in increased impedance to inflow from the left atrium (4). Consequently, the LV preload decreases.

The role of other factors in the decrease of LV stroke volume is less clear. Available evidence on the effect of ITP changes on LV afterload is conflicting (7, 17, 20). Previous studies (utilizing esophageal pressure measurements to estimate transmural pressure changes) have suggested that a decrease in ITP during systole
increases the transmural pressure and constitutes an increased LV afterload (17, 20, 21). In contrast, Scharf et al. (19), who used direct pericardial measurements, showed that LV transmural pressure decreases in inspiration. Other factors that could alter LV stroke volume are changes in lung volume and abdominal pressure, but these factors do not appear to play any significant role (12, 13, 18).

Usefulness of hiccups as a tool. One major problem in utilizing the decrease in ITP associated with inspiratory effort to study hemodynamic changes is that each inspiratory effort lasts two to five cardiac cycles. We have utilized hiccups, a naturally occurring event, to investigate the effect of transient changes in ITP on systemic arterial pressure. Inspiratory duration of hiccups is <150 ms (2), which is less than one-half of a cardiac cycle in the preterm infant. Because the duration of hiccups is brief, it eliminates changes in blood-gas tensions as a confounding variable. Esophageal pressure changes, which reflect ITP changes, during hiccups range from 20 to 25 cmH₂O in neonates (2). Hence, hiccups appear to be an ideal tool in the investigation of the hemodynamic effects of brief decreases in ITP.

In the present study, we observed a decrease in systemic arterial pressure during hiccups. The decrease in systolic pressure observed during hiccups occurring in ventricular systole can only be attributed to a decrease in stroke volume and/or vascular resistance because venous return and ventricular preload of the previous cardiac cycle remain unchanged. Both the heart and intrathoracic aorta are compliant structures, and, therefore, the primary factor responsible for the decrease in systolic pressure cannot be determined with certainty from the above observations during systole. However, the decrease in diastolic pressure during diastolic hiccups cannot be attributed to a decrease in stroke volume because hiccups occurred after LV ejection and aortic valve closure. The intrathoracic aorta is the only part of the vascular tree that can be affected by ITP to have an immediate effect on systemic arterial pressure. Therefore, the decrease in diastolic pressure is the result of distension of the thoracic aorta. The decrease in systolic pressure during early-systolic hiccups was only modestly greater than the decrease in diastolic pressure when hiccups occurred during ventricular diastole. However, on a percent basis the changes were similar. I interpret this finding to indicate that most of the observed effects of brief ITP changes reflect a compliant thoracic aorta. Decreases in LV stroke volume may play a modest role in the observed effect during systole.

Results of the present study are in general agreement with the findings of Peters et al. (12, 13) in anesthetized dogs. By utilizing ECG-triggered phrenic nerve stimulation, these investigators studied the hemodynamic effects of transient decreases in ITP. Decreases in ITP during diastole increase both anteroposterior and lateral dimensions of intrathoracic aorta and reduce antegrade flow through the descending aorta and the carotid arteries. Rapid return of ITP toward the baseline is associated with simultaneous decrease in the volume of intrathoracic aorta and an increase in antegrade flow. Additionally, a reduction in LV stroke volume of the ensuing systole is seen, especially when the ITP changes occur in late diastole. Decreased systolic pressure seen after late-diastolic hiccups in the present study is in agreement with this observation. Decreased LV preload due to ventricular interdependence is presumed to be responsible for both observations. Phrenic nerve stimulation in systole reduces LV stroke volume and increases intrathoracic aortic volume without altering LV preload. These findings indi-

![Fig. 2. Effect of hiccups during systole. Traces are (from top to bottom) ECG (A), systemic arterial blood pressure (ABP; B), and respiration (Insp; C). Onset of hiccups can be seen as an artifact on ECG trace and as sharp waveform on respiration. Note decrease in peak systolic pressure as well as change in systolic waveform during hiccups.](http://jap.physiology.org/)

![Fig. 3. Effect of late-systolic hiccups on systemic arterial pressure. Traces are as in Fig. 2. Steep decline in systolic pressure after peak and absence of dicrotic notch can be noted.](http://jap.physiology.org/)
cate that compliance of the thoracic aorta and afterload of the LV contribute to the decreased arterial flow and pressure (pulsus paradoxus) seen during augmented inspiratory efforts.

Some hiccups occurred during the transition from systole to diastole, whereas others occurred during the transition from diastole to systole. These events provided additional insights into the interaction between ITP and arterial blood pressure. The former, by definition, began after the peak systolic pressure and extended into early diastole. The normal decrease in pressure was exaggerated compared with control cardiac cycles, and the dicrotic notch was not clearly identifiable. At the end of hiccups, an increase in antegrade flow in the descending aorta when ITP returned rapidly toward control values. When hiccups occurred during diastolic-systolic transition, both diastolic and systolic pressures generally decreased. The decrease in peak systolic pressure suggests that ITP plays a role in decreasing LV stroke volume. A reduction in preload (through ventricular interdependence) and an increase in LV afterload account for this reduction in stroke volume, as suggested by the findings of Peters et al. (12, 13).

In conclusion, a decrease in systemic arterial pressure was observed during the phase in which hiccups occurred. The primary mechanism for the reduction in systemic arterial pressure appears to be the effect of decreased ITP on a compliant thoracic aorta. In fact, Peters et al. (12) documented an increase in antegrade flow in the descending aorta when ITP returned rapidly toward control values. When hiccups occurred during diastolic-systolic transition, both diastolic and systolic pressures generally decreased. The decrease in peak systolic pressure suggests that ITP plays a role in decreasing LV stroke volume. A reduction in preload (through ventricular interdependence) and an increase in LV afterload account for this reduction in stroke volume, as suggested by the findings of Peters et al. (12, 13).

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REFERENCES


