Biphasic Carbon Dioxide Excretion Waveform from a Patient with Severe Kyphoscoliosis

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A CO2 excretion waveform is a time versus CO2 concentration history of exhalation. Ordinarily, well-ventilated regions of the lung (high V/Q ratio) have a relatively low CO2 concentration, low airway resistance, and exhaled gas from this region reaches the CO2 analyzer first, whereas poorly ventilated regions of the lung (low V/Q ratio) have a relatively high CO2 concentration, high airway resistance, and exhaled gas from this region reaches the CO2 analyzer last. The continuum of V/Q ratios between high and low V/Q areas creates a positive (upward to the right) slope to the alveolar plateau (phase III) part of the CO2 excretion wave form.1 Theoretically, if the continuum of V/Q ratios is broken into two distinctly different lung regions (a high and a low V/Q region), which have different exhalation time constants, then a biphasic CO2 excretion wave form might be expected. We herein describe a supine patient with severe rotary kyphoscoliosis of the thoracic and lumbar vertebral column, causing severe compression of one lung. The intraoperative capnographic pattern displayed a biphasic or double-humped appearance; the biphasic pattern was probably caused by two lungs that had very different V/Q relationships and exhalation rates.

REPORT OF CASE

A 45-yr-old male with a history of childhood polio and subsequent severe kyphoscoliosis presented to the operating room for rigid bronchoscopy and laser treatment of tracheal granulomata. He had undergone anterior and posterior fusion of the midthorax 7 yr previously. In the interim he had experienced respiratory failure on three separate occasions and had a tracheostomy placed 5 months prior to operation. Two months later tracheal granulomata caused obstruction of the tracheostomy tube, necessitating the laser resection. His past medical history was also significant for right-sided heart failure well-controlled with digoxin and diet-controlled hypertension. His only other medication was a stable dose regimen of aminophylline.

Preoperative evaluation included a room air arterial blood gas with pH = 7.39, PaO2 = 59 mmHg, PaCO2 = 58 mmHg, and HCO3 = 34.1 mEq/L. Breath sounds were markedly diminished over the right lung and normal over the left lung. A posterior-anterior chest roentgenogram showed severe rotokyphoscoliosis of the thoracolumbar spine (fig. 1). Flexible bronchoscopy one day prior to operation revealed approximately 75% tracheal obstruction secondary to a large area of granulation tissue on the anterior and right lateral tracheal walls.

Following placement of monitors the patient breathed oxygen and received d-tubocurarine 3 mg iv. Anesthesia was induced with iv sodium thiopental 500 mg, and lidocaine 80 mg, and was maintained with inhalation of isoflurane 1.5–2.5% in 45% oxygen, balance nitrogen, and an iv infusion of lidocaine 3 mg·kg−1·h−1. Following succinylcholine 80 mg iv, direct laryngoscopy, and laryngotraacheal spray with 4% lidocaine, a standard, uncuffed, ventilating (sidearm), rigid bronchoscope was inserted into the proximal trachea (per os) without difficulty. The tracheostomy tube was then removed and the stoma externally sealed to prevent a gas leak. Bronchoscopic examination and laser excision of the large tracheal, as well as a right mainstem anterolateral wall granuloma, proceeded uneventfully. Ventilation was controlled with manual intermittent positive pressure ventilation for the duration of the surgical procedure. During the intermittent positive pressure ventilation no spontaneous ventilation occurred as judged by a complete lack of spontaneous movement of the chest, abdomen, reservoir bag, airway pressure manometer needle, ventilator bellows, and pressure derivative monitor.

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FIG. 1. Preoperative posterior-anterior chest roentgenogram of the patient showing severe kyphoscoliosis, compression of the right lung, and hyperexpansion of the left lung.
anesthesia circle system valves, and lack of spontaneous breath sounds. Throughout the intraoperative period, a biphasic capnography wave form was present consisting of a distinct early 18–23 mmHg peak and a distinct late 43–48 mmHg peak (fig. 2). The biphasic pattern remained constant for the duration of the procedure (before and after the resection of the granulomata), was unaffected by variations in tidal volume, minute ventilation or I:E ratio, and was present after the resumption of spontaneous ventilation (during emergence). The patient emerged from anesthesia uneventfully, the postoperative course was unremarkable, and the patient was discharged on the second postoperative day.

DISCUSSION

We observed a biphasic CO₂ excretion waveform in a patient who by physical and radiographic examinations had one of the two lungs severely compressed. We hypothesized that the compressed right lung had a relatively high airway resistance, was poorly ventilated, and was relatively hypercapnic, whereas the left lung had a relatively low airway resistance, was hyperventilated, and was relatively hypocapnic. In this situation, relatively hypocapnic gas from the well-ventilated, low-airway resistance lung reached the CO₂ analyzer first (causing the first distinct low peak), and relatively hypercapnic gas from the poorly ventilated, high airway resistance lung reached the CO₂ analyzer last (causing the second distinct high peak). We are certain that spontaneous inhalation during exhalation of the manual intermittent positive pressure breaths (interposition of CO₂ free gas) did not cause the biphasic trace. In addition, the right stem bronchus granulomata were not responsible for the biphasic trace since the biphasic trace was present before and after removal of the granulomata. Although a very high compliance of the right lung could explain or contribute to a slow right lung emptying time, this possibility is very unlikely in view of the pulmonary pathophysiology of kyphoscoliosis. Finally, movement of air from one lung to the other (pendelluft) requires a pressure gradient between an open and closed hemithorax, which clearly was not the situation with our patient.

Investigations of pulmonary function abnormalities in patients with scoliosis have been based upon analyses that evaluate both lungs together, i.e., whole lung spirometry, lung volumes, and arterial blood gases. Findings have included reduced lung volumes, compliance, and ventilation/blood-flow maldistribution. The observation of a double-humped CO₂ excretion waveform described herein suggests that not only may whole lung function tests be abnormal, but that each lung will be differentially affected by the spinal curvature. Measurement of endobronchial flow rates and CO₂ concentrations and/or fluoroscopy would be necessary to prove this point and to clearly differentiate between the interpretation and mechanism possibilities mentioned above.

In summary, we observed a biphasic CO₂ excretion waveform in a patient who had severe kyphoscoliosis and very likely had two lungs with distinctly different mechanisms. The distinctly different lungs most probably had different airway resistances and CO₂ concentrations resulting in a biphasic CO₂ excretion waveform. There are potentially other unilateral causes of such a biphasic CO₂ excretion waveform (unilateral mass, endobronchial intubation, pneumothorax), and detection of a biphasic CO₂ excretion waveform may alert the observer to diagnose and treat a reversible unilateral pathophysiological condition.

REFERENCES