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Original Contributions

THE USE OF END-TIDAL CAPNOGRAPHY TO MONITOR NON-INTUBATED PATIENTS PRESENTING WITH ACUTE EXACERBATION OF ASTHMA IN THE EMERGENCY DEPARTMENT

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☐ Abstract—Study Objective: To determine if the slope of Phase II and Phase III, and the alpha angle of the expiratory capnographic waveform, as measured via computer-recognizable algorithms, can reflect changes in bronchospasm in acute asthmatic non-intubated patients presenting to the emergency department (ED). Methods: In this prospective study carried out in a university hospital ED, 30 patients with acute asthma were monitored with clinical severity scoring and peak flow measurements, and then had a nasal cannula attached for sidestream sampling of expired carbon dioxide. The capnographic waveform was recorded onto a personal computer card for analysis. The patients were treated according to departmental protocols. After treatment, when they had improved enough for discharge, a second set of results was obtained for capnographic waveform recording. The pre-treatment and post-treatment results were then compared with paired-samples *t*-test analysis. Results: On the capnographic waveform pre- and post-treatment, there was a significant difference in the slope of Phase III ($p < 0.001$) and alpha angle ($p < 0.001$), but not in the Phase II slope ($p = 0.35$). There was significant change in peak flow meter reading, but it was poorly correlated with all the capnographic indices. Conclusion: The study provides some preliminary data showing that capnographic waveform indices can indicate improvement in airway diameter in acute asthmatics in the ED. Capnographic waveform analysis presents several advantages in that it is effort-independent, and provides continuous monitoring of normal tidal respiration. With further refined studies, it may serve as a new method of monitoring non-intubated asthmatics in the ED. © 2011 Elsevier Inc.

☐ Keywords—capnography; end tidal; acute asthma; emergency department

INTRODUCTION

Capnography comprises the continuous analysis and recording of carbon dioxide (CO_2) concentrations in respiratory gases. “Time capnography” (commonly referred to as just capnography) is the continuous plot of levels of expired carbon dioxide over time, producing a capnogram. This allows for visual inspection of changes in CO_2 concentrations by means of a waveform display, paper recording, or even digitized measurements. It is the analysis of such waveforms that forms the basis of this study. Capnometry, discrete measurements of carbon dioxide concentrations, was first developed during World War II as a means of monitoring the internal environment of submarines (1). In the 1950s, capnometers were used experimentally during anesthesia to measure expired CO_2. But it was only in the early 1980s that capnometry became widely used, mainly in the anesthetic practice (2). Today, capnography is considered essential in monitoring metabolic and respiratory functions during anesthesia. Its role has spread beyond the

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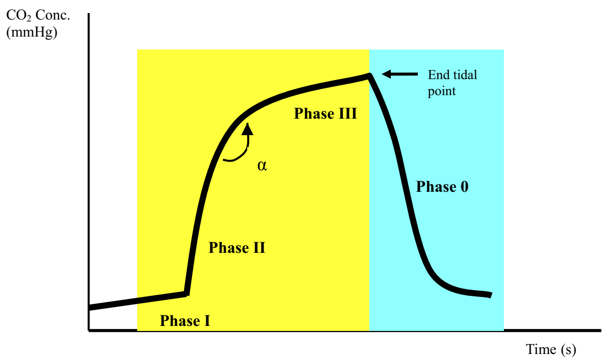

Figure 1. The single breath capnographic waveform.

realms of anesthesia, and capnography is now used in Emergency Medicine to confirm and verify endotracheal tube placement, monitor ventilatory status of respiratory-impaired patients, monitor ventilation of patients during sedation and analgesia, evaluate ventilator settings and circuit integrity, assess effectiveness of cardiopulmonary resuscitation, and for early detection of changes in airway resistance and circulatory collapse. Newer detection methods, for example, Microstream® (Novometrix, USA) technology, has allowed for more accurate recordings in smaller samples, thereby extending the use of capnographic monitoring not only to non-intubated patients but even to pediatric patients. Much in line with these advances, scientists and clinicians are looking into other uses of capnography; among them, the analysis of the capnographic waveform to provide information on airway obstruction in non-intubated asthmatic patients.

The normal capnogram has an almost square-wave pattern (Figure 1) marked by alternating inspiratory ($P_{insp}CO_2 = 0$) and expiratory phases ($P_{exp}CO_2$) (2–4). Expiration itself consists of three successive phases: 1) a latency phase (Phase I), corresponding to the expiration of the anatomical dead space ($P_{exp}CO_2 = 0$), which is indistinguishable from the preceding inspiration; 2) slope phase (Phase II) marked by a very rapid rise in $P_{exp}CO_2$, corresponding to expiration of mixed air; and 3) plateau phase (Phase III), reflecting the elimination of alveolar air (slightly increasing $P_{exp}CO_2$), resulting in a peak at the end of tidal expiration ($P_{et}CO_2$ close to alveolar carbon dioxide [P_ACO_2] tensions) (4,5). The end-tidal peak is occasionally referred to as the end-tidal point. This well-defined shape of the normal capnogram depends on a variety of factors. Normal aerobic metabolism will consume oxygen and result in the production of carbon dioxide. This will be carried by an adequately functioning circulatory system to the lungs where, in the normal lung, matched gas distribution and alveolar ventilation with pulmonary perfusion will ensure normal gas exchange. In the absence of bronchial obstruction, the verticality of Phase II indicates a regular separation front between the anatomical dead space air and alveolar air. The elimination of alveolar air is synchronous, and this is reflected by the sudden rise in Phase II and the subsequent elimination of alveolar air, which is indicated by the almost horizontal plateau of Phase III.

Asthma is a disease characterized by bronchial hyperreactivity, inflammatory exudates, and mucous plugging. The hallmark of asthma is the narrowing of the smaller airways causing obstruction to flow within the airways, especially during expiration. In asthma, airway obstruction causes regional decreases in airflow and, consequently, alveolar ventilation. This is responsible for the "parallel heterogeneity" of ventilation-perfusion ratios (V/Q ratios). Each bronchopulmonary territory is characterized by its own V/Q and determining its own partial pressure of P_ACO_2. Alveolar air is then evacuated at different times during expiration, resulting in desynchronization. This results in increased mixing of alveolar air from certain bronchopulmonary territories with dead space air from other territories. On the capnogram, this causes deformation of the normal curve, marked by the loss of verticality of Phase II, opening of the angle between Phase II and Phase III (alpha angle also known as angle Q), and the increased inclination of Phase III (Figure 2) (4). In severe cases, the capnogram takes on a "shark's fin" appearance. These changes in the capnogram are of particular interest as they indicate changes in airflow. This may provide the means for closer, continuous, and objective monitoring of airway diameter and airflow in patients with acute asthma. You et al. conducted one of the first studies on adult asthmatics and published a report in 1992. They initially studied the end-tidal slope, which was measured manually, and reported good correlations with forced expiratory volume at 1 s (FEV_1) as percentage of predicted. In this study, they were among the first to suggest the usefulness of computerization of capnogram analysis (6).

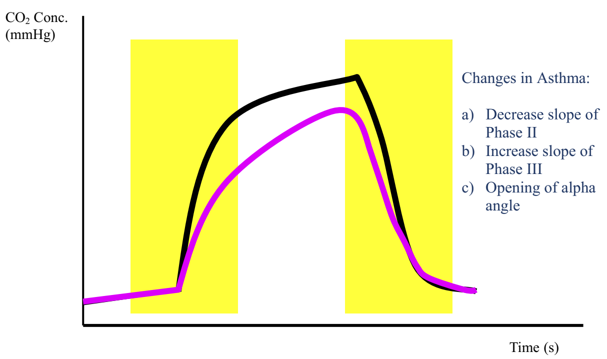

Figure 2. The capnographic waveform: changes in asthma.