CLINICAL STUDIES OF GAS EXCHANGE DURING VENTILATORY SUPPORT—A METHOD USING THE SIEMENS–ELEMA CO₂ ANALYZER

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SUMMARY

We describe a new portable infra-red analyser for use with the Siemens–Elema Servo ventilator. The sensor head constitutes a Y-piece connecting the patient to the ventilator tubing, and gives instant carbon dioxide determination. It is based upon simple principles that can be realized with modern techniques, offering for instance freedom from interference by anaesthetic gases, and eliminating the need for calibration. A non-zero inspired carbon dioxide concentration interferes with the measurements. Integration of the carbon dioxide signal with the flow signal from the Servo ventilator yields data about carbon dioxide excretion, and additional calculation yields $V_{D/V_{T}}$ if $P_{aCO₂}$ is known. The accuracy of determination of end-tidal carbon dioxide and carbon dioxide elimination was found to be adequate for research purposes, and that of $V_{D/V_{T}}$ for clinical purposes. The device is considered to be of value in the operating theatre and intensive care unit, for monitoring, as a guide to ventilatory needs, and for the investigation of the magnitude and causes of increased deadspace.

When ventilatory support is required, control of gas exchange is at least as important as ventilation itself. The following equations show some factors that govern the maintenance of $P_{aCO₂}$:

$$P_{aCO₂} = \frac{\dot{V}CO₂}{\dot{V}A} \times k$$

(1)

$$\dot{V}A = \dot{V}T - \dot{V}D$$

(2)

It is assumed that equilibrium occurs between alveolar and arterial $PCO₂$. $\dot{V}CO₂$ is carbon dioxide production, $\dot{V}A$ is alveolar ventilation, $\dot{V}T$ is total ventilation and $\dot{V}D$ is ventilation of physiological deadspace. $k$ is a factor converting carbon dioxide fraction to $PCO₂$.

In the absence of lung disease, end-tidal $PCO₂$ ($P_{E'CO₂}$) closely reflects $P_{aCO₂}$ (Galdston, Benjamin and Hurewitz, 1951; Collier, 1955; Dahlgren and Symreng, 1974), and adequate $P_{aCO₂}$ is generally maintained with ordinary ventilation. When this is not the case the analysis of mechanisms involved is aided by knowledge of $\dot{V}CO₂$ and the various fractions of deadspace. Suitable systems for measurement of $P_{E'CO₂}$, $\dot{V}CO₂$ and $\dot{V}D$ have in the past been bulky, cumbersome and expensive. This paper presents an unobtrusive device for making these measurements in the intensive care unit and operating theatre. The basis of the measurements is the integration of signals for carbon dioxide concentration of expired gas, and expiratory flow. This yields much additional information, and the CO₂ Analyzer also offers advantages over previous devices in compactness, ease of handling, accuracy and freedom from errors caused by anaesthetic gases.

APPARATUS AND WORKING PRINCIPLES

The Servo ventilator 900 or 900 B (Ingelstedt et al., 1972) produces an expiratory flow signal and the carbon dioxide signal comes from the CO₂ Analyzer 930 described below (both from Siemens–Elema AB, Solna, Sweden). The CO₂ Analyzer is designed to operate with the ventilator, which provides a flow signal and power and timing pulses.

The carbon dioxide sensor (fig. 1) works on the principle of absorption of infra-red radiation from a broad spectrum IR emitter (fig. 2). The radiation passes via sapphire glass windows through a Y-piece connecting the patient to the ventilator tubing. The Y-piece offers a negligible resistance to flow (0.8 cm H₂O litre⁻¹ s⁻¹) at a flow rate of 0.5 litre s⁻¹ and 1.6 at 1 litre s⁻¹). Its deadspace is smaller than that of the ordinary Y-piece that it replaces. Part of the radiation is absorbed by the windows which are thereby heated, preventing condensation. Carbon dioxide molecules in the gas cause further absorption
of IR radiation of specific wavelengths. The radiation is then mechanically chopped at a frequency of 180 Hz. An interference filter transmits only light with a wavelength of 4.2 μm at which carbon dioxide has a main absorption peak. The band-width is 0.07 μm. The chopped and filtered radiation is received by a photoelectric Ge-As-sensor, the signal of which is amplified. The signal oscillates between one value when the chopper is closed and another when it is open. Thus the chopper generates a carrier frequency that is modulated by the transmitted radiation. In this way problems inherent in detection of small signals superimposed upon large drifting ones are solved.

The amplitude of the oscillations generated by the chopper reflects transmitted pulsed light, which is a function of carbon dioxide absorption within the gas. Irrelevant factors such as the amount of emitted radiation, its absorption within the windows and the temperature of the IR detector also affect the signal. This problem is eliminated by the signal processor to which the signal is transmitted after amplification.

The signal processor (fig. 2) demodulates the signal by an amplifier that is phase-locked to the chopper signal. After demodulation a signal U corresponds to the amount of light received. At the end of inspiration there is no carbon dioxide in the sensor head. The signal at this moment (U₁) is sampled and held to be used as a reference for the following expiration. An analog divider gives the quotient U/U₁. In the absence of carbon dioxide, when U = U₁, the output signal is standardized to 1 arithmetic unit. The division by U₁ corrects for changes in the amount of emitted light, absorption in the windows, the sensitivity of the IR detector and primary amplification of the signal. If for example dirt, or a droplet of sputum, lands on one of the windows, this will only influence the current expiration. For the following expiration a new U₁ will restore correct amplification.

![Fig. 1. Carbon dioxide sensor and cuvette.](image)

![Fig. 2. The carbon dioxide transducer and initial part of circuitry within the CO₂ Analyzer 930. A beam of infra-red radiation passes through the expired gas via sapphire windows in a detachable Y-piece connecting the patient to the ventilator tubing. The beam is mechanically chopped, filtered and sensed by a photoelectric sensor. The signal is amplified and transmitted to the Analyzer. The original signal is processed to yield a signal, Uₐ that is proportional to carbon dioxide irrespective of drift of the carbon dioxide transducer (see text).](image)
The signal $U/U_1$ will only be influenced by carbon dioxide molecules in the pathway of radiation within the sensor head. The length of this pathway is the only critical factor, and this can be well controlled at manufacture. After the divider the signal level is high and the electronics operate under optimal conditions at which drift of amplification or base-line is negligible. The features described explain why the equipment does not need any zero adjustment or recalibration: there are no exterior controls for such procedures. The signal $U/U_1$ is a strict, nearly logarithmic function of expired carbon dioxide concentration. After further processing, mainly linearization, a signal proportional to carbon dioxide concentration is obtained ($1 \text{ V} = 1\% \text{ carbon dioxide}$). Apart from the chopping there is no delay in the analysis. One hundred per cent response to a change of carbon dioxide is obtained within 6 ms.

Interference with other gases such as water vapour and nitrous oxide is avoided by the use of a very narrow band-width of infra-red radiation, carefully selected for optimum separation. A contributory factor is that the CO$_2$ Analyzer measures differences between expired and inspired gases. However, even during induction of nitrous oxide anaesthesia when there are great differences between inspired and expired nitrous oxide (measured with a mass spectrometer), the carbon dioxide signal remains unaffected. When carbon dioxide is added to the inspired gas the Analyzer measures the increase of carbon dioxide over that concentration. Added carbon dioxide should be delivered in a way that ensures that the inspired carbon dioxide concentration, serving as a new baseline, is stable. If this is achieved, then the values for carbon dioxide production are still valid, and the stated end-tidal carbon dioxide becomes the excess.

![Diagram](https://example.com/diagram.png)

FIG. 3. A: Diagrammatic explanation of four of the indices which are presented on the CO$_2$ Analyzer. B: Front view of CO$_2$ Analyzer.
over the inspired value. If the inspired carbon dioxide concentration varies, the Analyzer can give misleading results.

**Pressure dependence.** With a given gas in the sensor head an increase of pressure will cause an increasing carbon dioxide signal for two reasons. First, the number of carbon dioxide molecules increases in proportion to pressure—a 1% increase causes a 1% increase of the number of radiation-absorbing carbon dioxide molecules. Second, intermolecular forces that increase with pressure will enhance absorption by carbon dioxide. This factor will cause an additional increase of the carbon dioxide signal by 0.8%. In all, a 1% increase of pressure in the sensor head will increase the signal by 1.8%. If the CO₂ Analyzer is calibrated at a barometric pressure of 100 kPa (750 mm Hg) and tested with 4% carbon dioxide at 101 kPa (758 mm Hg) a reading of 4 × 1.018 = 4.07 will be obtained. As the concentration is 4% an error of 0.07% will appear if the reading is regarded as concentration. In conjunction with estimates of arterial blood-gas tensions, it is preferable to regard the reading as P<sub>CO₂</sub> (kPa) and not per cent carbon dioxide as stated on the Analyzer. In this case the true value at a barometric pressure of 101 kPa (758 mm Hg) is 4.04 kPa (40 mm Hg), and the error of the reading is only 0.03 kPa (0.2 mm Hg). In studies in which precision is needed, correction for variations in barometric pressure may be useful. A similar correction should then also be made when very great expiratory airway pressures are applied. In routine clinical use corrections appear to be unnecessary.

**Presentation of data.** The carbon dioxide signal is processed with the expiratory flow signal to provide further digital and analog information. Figure 3b shows the front panel of the instrument from which six values can be read, four of which are explained in figure 3a.

**End-tidal carbon dioxide concentration.** The initial carbon dioxide-free part of the expired tidal volume represents gas compressed in the ventilator tubing and humidifier, and gas from conducting airways (ineffective tidal volume); the carbon dioxide-containing part is the effective tidal volume. As soon as the carbon dioxide concentration exceeds 5% of the previous end-tidal carbon dioxide, the effective part of the tidal volume is recognized. (Ineffective tidal volume is therefore less than the anatomical dead-space.) Averaging of this volume provides a measure of effective minute ventilation. Integration of the product carbon dioxide concentration × instantaneous expiratory flow yields the carbon dioxide tidal production which is also averaged to carbon dioxide minute production. A more appropriate label on the carbon dioxide minute production.

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**Fig. 4.** Mingograf tracing obtained from CO₂ Analyzer. The continuous tracings are of the four signals named on the left, and the calibrations are given by the labelled dots. The values named on the right can be obtained from the penultimate (labelled) dot in the calibration complex which also serves as a scale for these values. For instance, on the uppermost tracing the dots give the calibrations for both the continuous tracing (airway flow) and for ineffective tidal volume. Inspiratory flow is 0.7 litre s<sup>−1</sup> and ineffective volume 0.06 litre.
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The single breath test for carbon dioxide and determination of $V_D/V_T$

Although the above method of obtaining carbon dioxide tracings is convenient for clinical use, more information can be obtained from the single breath test for carbon dioxide (SBT-\(\text{CO}_2\)) in which the x-axis represents volume instead of time. Analog signals available from the Analyzer make it possible to present SBT-\(\text{CO}_2\) on an \(XY\) oscilloscope or recorder, directly or via a computer, in one of two ways. In the standard presentation (Comroe, 1962), carbon dioxide concentration is recorded against expired volume (fig. 3A). In the presentation suggested by Langley and others (1975), expired carbon dioxide volume is recorded against expired volume. (A separate cable, in which the signals are not interrupted by calibration dots as in figure 4, is used for this purpose.)

With the latter presentation, mixed expired carbon dioxide fraction or partial pressure ($P_{ECO_2}$) can be calculated by dividing the volume of carbon dioxide per breath by the tidal volume. $V_D/V_T$ can therefore be calculated if $P_{a_{CO_2}}$ is measured simultaneously, by substituting in the Bohr equation (Bohr, 1891):

\[
V_D/V_T = 1 - \frac{P_{ECO_2}}{P_{a_{CO_2}}}
\]

$P_{ECO_2}$ can also be calculated from the digital displays during controlled ventilation, by dividing "carbon dioxide tidal production" by the tidal volume—ineffective plus effective tidal volume. This method is unreliable during spontaneous breathing since tidal volume and carbon dioxide tidal production are obtained at different positions of the control knob on the Analyzer and therefore cannot be obtained for the same breath.

CLINICAL TESTS

The linearity of the \(\text{CO}_2\) Analyzer was checked repeatedly with gases analysed with the Scholander apparatus (Scholander, 1947). Figure 5 shows a typical result.

End-tidal carbon dioxide concentration (%) from the infrared Analyzer (IR) and a Perkin Elmer mass spectrometer MGA 1300 A (MS) were compared in anaesthetized patients. The mass numbers used were 12 and 44 for nitrous oxide—oxygen and oxygen—air mixtures respectively. With oxygen—air mixtures (78 observations on 18 individuals) we found: end-tidal carbon dioxide (%) (IR) = 0.218 + 0.927 x end-tidal carbon dioxide (MS) \((r = 0.987, SD = 0.22)\) (residual SD about the regression), SEM of intercept = 0.119, SEM of slope = 0.028).

In oxygen—nitrous oxide mixtures (91 observations on 22 individuals): end-tidal carbon dioxide (%) (IR) = 0.156 + 0.9783 x end-tidal carbon dioxide (MS) \((r = 0.987, SD = 0.15, SEM\ of\ intercept = 0.068, SEM\ of\ slope = 0.017)\).

A \(t\) test showed that the differences in intercept and slope between oxygen—air and oxygen—nitrous oxide mixtures were not significant \((P>0.05)\).

Carbon dioxide production \((\text{FCO}_2)\) (ml min\(^{-1}\)) obtained digitally from the \(\text{CO}_2\) Analyzer was compared with values obtained from mass spectrometry by multiplying mixed expired carbon dioxide concentration with expired gas volume as measured by the Servo ventilator. Mixed expired gas was obtained by leading the expired gases to a mixing chamber before admission to the mass spectrometer.
For oxygen–air mixtures (73 observations on 18 individuals): $V_{CO_2} (IR) = -0.649 + 1.047 \times V_{CO_2} (MS)$ ($r = 0.991$, $SD = 14.0$, SEM of intercept = 2.84, SEM of slope = 0.0147).

For oxygen–nitrous oxide mixtures (91 observations on 22 individuals) (fig. 6): $V_{CO_2} (IR) = 10.56 + 1.006 \times V_{CO_2} (MS)$ ($r = 0.993$, $SD = 10.1$, SEM of intercept = 2.728, SEM of slope = 0.0174).

A t test showed that the difference in slope between oxygen–air and oxygen–nitrous oxide mixtures was not significant ($P > 0.05$). The difference in the intercepts was significant (0.01 > $P > 0.005$).

The physiological deadspace: tidal volume ratio was measured during spontaneous breathing by the single breath method. At steady state, mixed expired gas was collected for analysis (Scholander, 1947), arterial blood was sampled and the single breath profile was recorded. The mixed expired carbon dioxide fraction was obtained from a single tidal breath. In 10 patients with lung disease the following regression was obtained: $V_d/V_t (SBT-CO_2) = 0.028 + 0.8599 \times V_d/V_t$ (Scholander) ($r = 0.949$, $SD = 0.024$, SEM of intercept = 0.041, SEM of slope = 0.106).

**DISCUSSION**

The operating theatre or intensive care unit make special demands on technical equipment with respect to size, maintenance and safety. The CO$_2$ Analyzer is compact and silent and has only one cable running with the ventilator tubing. The analysis of carbon dioxide within the airway is instant and makes a gas withdrawal system unnecessary. This makes the device simple to use, and safety is not compromised by the potential for creating a subatmospheric pressure in the airway.

The features that eliminate the need for daily calibration were described in some detail to illustrate how simple principles can be realized by modern electronics. The price of achieving this simplicity is limited usefulness in systems with carbon dioxide in the inspired gas, and that the Analyzer can only be used in conjunction with the Servo 900 ventilator.

The results show that the measurement of $V_{CO_2}$ and end-tidal carbon dioxide is sufficiently accurate for research purposes.

The carbon dioxide measurement was not affected by nitrous oxide. The signal representing $V_{CO_2}$ showed similar results in adults with and without nitrous oxide. The significant difference in intercept should not be regarded as implying that the CO$_2$ Analyzer yields a positive carbon dioxide reading at zero $V_{CO_2}$ values. Thus the relationship between the two $V_{CO_2}$ estimates is non-linear and is not adequately described by the regression equation. It is, however, difficult to see why non-linearity should be confined to the nitrous oxide–oxygen mixture. In the presence of nitrous oxide, the mass spectrometer was used in the anaesthetic mode, which made the accuracy of carbon dioxide determination less, but did not introduce a systematic error. The difference in the intercepts should not be overemphasized, for in view of the complexity of both methods the extent of the agreement was reassuring.

Estimation of $V_d/V_t$ during spontaneous breathing is acceptable for clinical use.

Greater accuracy for $V_d/V_t$ would be expected during controlled ventilation, because of the smaller breath-to-breath variation in tidal volume and carbon dioxide content. Apart from $P_{aCO_2}$ all the data needed for calculation of $V_d/V_t$ can be obtained from the carbon dioxide unit itself. For example, mixed expired carbon dioxide concentration can be obtained from either $V_{CO_2}/V_e$ or from carbon dioxide tidal production/(ineffective+effective tidal volume).

The most common application of the analysis of expired carbon dioxide is control of ventilation to maintain suitable end-tidal and arterial $P_{aCO_2}$ values (Collier, 1955; Dahlgren and Symreng, 1974; Prakash et al., 1978). However, although useful under most circumstances, the use of end-tidal carbon dioxide has limitations in the presence of lung disease.
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(Fletcher and Jonson, 1977). The present CO$_2$ Analyzer yields information that can reveal subclinical lung disease (see below), and we are studying how this information can be used to improve the usefulness, and to avoid the pitfalls, of end-tidal measurements in the control of ventilation.

A rough guide to ventilatory needs may be obtained from a nomogram (Radford, 1955; Engström and Herzog, 1959; Engström et al., 1962). However, our experience with the CO$_2$ Analyzer suggests that large variations in $V_{CO_2}$ and, to a lesser extent, $V_D/V_T$, are commonplace during surgery.

When a standard ventilator setting does not give an acceptable $P_{aCO_2}$, the information from the CO$_2$ Analyzer should be used in a logical search for the reason. The carbon dioxide production may be chosen as the starting point. If, at steady state, this is greater than expected, the need for ventilation is correspondingly increased. Further search should be directed towards non-pulmonary factors, such as fever, pain, anxiety and shivering.

In other cases the alveolar ventilation is low. In the presence of normal or high total ventilation this implies increased deadspace. Total "physiological" deadspace ventilation can be calculated and the physiological deadspace (ml) by division with the frequency. Increased $V_D$ can result from a high ineffective ventilation (absolute deadspace) (Bartels et al., 1954). Increased compressed volumes in the tubings or humidifier may be caused by increased airway pressures or inadequate levels of water in some humidifiers. This problem is of course of importance in children and especially in infants (Okmian, 1963). The lung mechanics calculator 940 (Jonson et al., 1975) (Siemens-Elema AB) gives additional information about compliance and resistance, possible causes of an increased airway pressure.

If the reason for dysfunction is still not obvious, increased intrapulmonary or alveolar deadspace must be present. This can be caused by several factors: ventilation-perfusion mismatching, pulmonary embolism and venous admixture may all contribute. The CO$_2$ Analyzer offers some possibilities for further analysis. Sequential emptying of lung compartments with different ventilation-perfusion relationships yields SBT-CO$_2$ with a poorly defined, steeply sloping alveolar plateau (fig. 7, left). This may be found in obstructive lung disease, even when other signs are missing.

Non-sequential phenomena, such as venous admixture or synchronous emptying of lung compartments with different carbon dioxide contents, yield another pattern (fig. 7, right). This pattern has been observed in conjunction with hypovolaemia and pulmonary embolism (non-perfusion of lung compartments) and congenital heart disease with variable right to left shunts (Prakash et al., 1978).

The usefulness and limitations of SBT-CO$_2$ as a diagnostic tool in lung disease remain to be explored.

Monitoring of the electrocardiogram (e.g.) and ventilation may continue undisturbed in spite of even circulatory arrest. As gas exchange is the immediate vital function of both ventilation and circulation, monitoring of carbon dioxide elimination or oxygen uptake offers a more fundamental guarantee against unobserved life-threatening malfunction of vital organs. Any sudden severe malfunction depresses the carbon dioxide elimination via the lungs (Smalhout and Kalenda, 1975). Such an observation should lead to a systematic search for the reason, starting with control of ventilation and the e.g. A common cause for circulatory depression during thoracic surgery in the presence of undisturbed e.g. and ventilation is temporary interference with venous return. It is important to be able to recognize such events before, for example, hypoxic arrhythmias occur. Continuous monitoring of aerobic metabolism probably offers the best prospects of early discovery of malignant hyperthermia.

Apart from ventilating the lungs in response to end-tidal $P_{CO_2}$, the control of other routine procedures...
may be based on information from gas analysis. Profound hypothermia during anaesthesia for cardiac surgery in infants may be performed with guidance from carbon dioxide analysis (Prakash et al., 1978). At extubation of the trachea it has been found useful to check the ability to maintain adequate gas exchange during a spontaneous ventilation test (Prakash et al., 1977). The efficiency of ventilation is, in some patients, dependent upon the breathing pattern produced by the ventilator; this aspect of the use of instant analysis of the gas exchange is largely unexplored.

Note added in proof: New evidence indicates that the balance of gases influences the reading of the CO₂ Analyzer (A. v. Bijnen, Department of Hospital Engineering, University Hospital, Leyden, The Netherlands, personal communication). Nitrous oxide should cause increased, and oxygen decreased readings. A 65% nitrous oxide:35% oxygen mixture should result in carbon dioxide values that are slightly too great. Although the comparison between different mixtures of gases presented in the article does not show significant differences in slopes, a trend towards higher readings in the presence of nitrous oxide is observed. The error is not related to absorption of infra-red radiation of nitrous oxide, but rather to intermolecular interaction between gases. Its nature and magnitude require further studies.

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REFERENCES


ETUDES CLINIQUES SUR L’ÉCHANGE DE GAZ PENDANT L’USAGE D’UN SYSTÈME VENTILATOIRE D’APPOINT—MÉTHODE BASEE SUR L’ANALYSEUR DE CO₂ SIEMENS-ELEMA (SIEMENS-ELEMA CO₂ ANALYZER)

RESUME

Nous décrivons dans cet article un nouvel analyseur portatif à infrarouges que l’on utilise avec le Servoventilateur Siemens-Elema. La tête du système sensible est en forme d’y; elle relie le patient au tuyau du ventilateur et permet de déterminer instantanément la quantité de gaz carbonique. Cet appareil est basé sur des principes simples qui peuvent être réalisés grâce aux techniques modernes. Il permet par exemple d’éviter toute interférence de la part des gaz anesthésiants et élimine la nécessité de procéder à des étalonnages. Toute concentration de gaz carbonique inspiré, d’une valeur autre que zéro, gêne les mesures. L’intégration du signal gaz carbonique dans le signal du débit émanant du Servoventilateur permet d’obtenir des données sur l’excès de gaz carbonique, et en faisant quelques calculs complémentaires on peut obtenir la Vd/Vt, lorsqu’on connaît la Pco₂. On a trouvé que la précision de la détermination du gaz carbonique en fin d’expiration ainsi que celle de l’élimination du gaz carbonique étaient adéquates pour les
besoins de la recherche, et qu'il en était de même pour la
\( Vd/Vt \) du point de vue clinique. Cet appareil est consi-
déré comme ayant son utilité dans les salles d'opérations
et les salles de soins intensifs, pour la surveillance générale,
pour la détermination des impératifs ventilatoires, et pour
faire des recherches sur l'importance et les causes de
l'augmentation de l'espace mort.

KLINISCHE STUDIEN DES GASAUSTAUSCHES
BEI KÜNSTLICHER BELÜFTUNG—EINE
METHODE MIT VERWENDUNG DES
SIEMENS-ELEMA \( \text{CO}_2 \) ANALYZER

ZUSAMMENFASSUNG
Wir beschreiben einen neuen, transportablen Infrarot-Ana-
lysator zur Benutzung mit dem Siemens-Elema-Servo-
ventilator. Der Sensorkopf stellt ein Y-förmiges Stück dar,
das den Patienten an den Ventilator anschließt, und sofort-
tige Kohlendioxydbestimmung ermöglicht. Es beruht auf
einfachen Prinzipien, die durch moderne Methoden rea-
listiert werden können, und bietet z.B. Freiheit von Störung
durch Anästhesiegase, und -eliminiert die Notwendigkeit
einer Kalibrierung. Ein Vorhandensein von angesaugten
Kohlendioxydkonzentrationen beeinträchtigt die Mess-
ungen. Integrierung des \( \text{CO}_2 \)-Signals mit dem Durchfluss-
signal vom Servoventilator ergibt Daten über \( \text{CO}_2 \)-Aus-
scheidung, und zusätzliche Berechnungen ergeben \( Vd/Vt \),
enken \( \text{Paco}_2 \), bekannt ist. Die Genauigkeit der Endaus-
atmung von Kohlendioxyd und von dessen Ausscheidung
hat sich als ausreichend für Forschungszwecke erwiesen,
und die Genauigkeit von \( Vd/Vt \) für klinische Zwecke.
Das Gerät ist wertvoll in Operationssaal und Intensiv-
station—für Überwachung, für eine Richtlinie der Belüft-
ungerfordernisse und für die Untersuchung von Grösse
und Ursachen vergrösserten Tutraums.

ESTUDIOS CLINICOS DEL INTERCAMBIO
DE GASES DURANTE APOYO
VENTILATORIO—UN METODO EN QUE SE
USA UN SIEMENS-ELEMA \( \text{CO}_2 \) ANALYZER

SUMARIO
Describemos un nuevo analizador infra-rojo portátil para
uso con el ventilador Siemens-Elema. La cabeza detectora
constituye una pieza en Y que conecta al paciente con la
tubería del ventilador y arroja una determinación instantánea
del dióxido de carbono. Se basa en principios sencillos que
se pueden poner en práctica con técnicas modernas que
ofrecen por ejemplo una independencia con respecto a los
gases anestésicos y eliminan la necesidad de calibración.
Una concentración de dióxido de carbono inspirado sin cero
interfiere con las mediciones. La integración de la señal de
dióxido de carbono con la señal del flujo del Servo-
ventilador arroja datos sobre la excreción de dióxido de
carbono y un cálculo adicional suministra el \( Vd/Vt \) si se
conoce el \( \text{Paco}_2 \). La exactitud de la determinación del
dióxido de carbono respiratorio-terminal y de la eliminación
del dióxido de carbono se consideró adecuada con respecto a
los fines de la investigación y la del \( Vd/Vt \) para fines clínicos.
Se considera que el aparato es valioso en la sala de operación
y en el servicio de cuidados intensivos, para el control así
como para guía respecto de las necesidades ventilatorias, al
igual que para la investigación de la magnitud y de las causas
del creciente espacio muerto.