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An educational programme for critical care nurses on the interpretation of ventilator graphics

By

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A dissertation submitted in fulfilment of the requirements for the degree of

MAGISTER CURATIONIS

In the
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Faculty of Health Sciences
University of Pretoria

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DECLARATION

Student number: 98259212

I, Sonja Windsor, hereby declare that:

AN EDUCATIONAL PROGRAMME FOR CRITICAL CARE NURSES ON THE INTERPRETATION OF VENTILATOR GRAPHICS

is my original work, and that it has not been submitted before for any degree or examination at any other institution. All the sources that have been used or quoted have been acknowledged by means of complete references in the text and bibliography.

____________________ ____________________

SONJA WINDSOR **DATE**

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Sonja Windsor

ABSTRACT

AN EDUCATIONAL PROGRAMME FOR CRITICAL CARE NURSES ON THE INTERPRETATION OF VENTILATOR GRAPHICS

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The aim of this study was to determine the knowledge of critical care nurses regarding ventilator waveforms in order to develop an educational programme on this topic. A quantitative, descriptive, contextual research design was used, and convenience sampling implemented. A survey, using a questionnaire as measuring instrument, was conducted among critical care nurses in selected private hospitals in Gauteng. The response rate was 69%. Cronbach's alpha indicated that the questionnaire was fairly reliable. The total average percentage achieved by the group of 111 respondents was 40,28%, which is 19.72% below the set competency indicator of 60%. Only 15 respondents achieved a percentage of or above the competency indicator. Results proved that the respondents required intensive training on the topic. A user-friendly education programme in the format of a PowerPoint presentation was developed to address knowledge deficiencies in critical care nurses' interpretation of ventilator graphics.

Key terms:
Ventilator waveforms; critical care nurses; educational programme; measuring instrument; Cronbach's alpha; competency indicator; knowledge deficiencies; PowerPoint presentation

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LIST OF ABBREVIATIONS

ABBREVIATIONS USED IN TEXT

ARDS	Adult respiratory distress syndrome
auto-PEEP	Auto-positive-end-expiratory-pressure
BiPAP	Bilevel positive airway pressure
COPD	Chronic obstructive pulmonary disease
CPAP	Continuous positive airway pressure
CPD	Continuous practice development

i.e.	*id est* (that is)
I:E ratio	Inspiration-expiration ratio
IMV	Intermittent mandatory ventilation
kg.m.min	Kilogram per metre per minute
L/min	Litres per minute
Ø	Flow waveform
P	Pressure waveform
P_{AO_2}	Partial pressure of alveolar oxygen
P_{CO_2}	Partial pressure of carbon dioxide
PEEP	Positive end-expiratory pressure
PIP	Peak inflation pressure/peak inspiratory pressure
PPP	PowerPoint presentation
PRVC	Pressure-regulated volume control
SANC	South African Nursing Council
Sec	Second
SIMV	Synchronised intermittent mandatory ventilation
UP	University of Pretoria
V	Volume waveform
VIMV	Volume intermittent mandatory ventilation

ABBREVIATIONS USED IN FIGURES

cmH_2O	Centimetres of water
Lpm	Litres per minute
$P_{ALVEOLAR}$	Alveolar pressure
P_{AW}	Airway pressure
PCV	Pressure controlled ventilation
PRES HIGH	High pressure
PRES LOW	Low pressure
TCT	Total cycle time
T_E	Expiratory time

T_I	Inspiratory time
V	Flow
V_T	Tidal volume
ΔP	Increase in pressure
ΔV	Increase in volume

LIST OF ANNEXURES

ANNEXURE A	PARTICIPANT INFORMATION LEAFLET AND QUESTIONNAIRE
ANNEXURE B	APPROVAL FROM FACULTY OF HEALTH SCIENCES' RESEARCH ETHICS COMMITTEE TO CONDUCT STUDY

CHAPTER 1

ORIENTATION TO THE STUDY

1.1 INTRODUCTION

Against the backdrop of a shortage of nursing personnel in South Africa, few hands are expected to perform an enormous task, namely to effectively and efficiently care for critically ill patients. Because of the continuing personnel shortage in the critical care environment, novice nurses are exposed to patients with complex health problems (Reischman & Yarandi 2002:25). This is a worldwide phenomenon. Since the recognition of complex health problems and appropriate interventions may lead to improved patient outcomes, serious consideration should be given to the education and training of non-critical care nurses.

Not only does the shortage in staff numbers escalate but the financial cost regarding health care escalates as well, especially in healthcare settings where advanced nursing actions are required. Reischman and Yarandi (2002:25) stated: “Failure to match nursing expertise to the type and complexity of patient problems can result in costly human and financial outcomes.”

These authors suggest that the utilisation of both nursing expertise and support systems can positively impact on patient and financial outcomes. Subsequently, the issue of diagnostic expertise in the critical care setting comes to the fore, because effective and efficient interventions are based upon it. The ability to interpret ventilator graphics is an example of diagnostic expertise.

1.2 BACKGROUND AND RATIONALE

Despite an extensive literature search, the researcher could find no evidence of research that had been conducted about nurses' knowledge of ventilator graphics. A reason could be that the availability of graphics on most of the new types of ventilator is a relatively new phenomenon. In critical care units in foreign countries, respiratory technicians are responsible for ventilator settings and manipulation, so the same level of expertise regarding ventilator graphics is not expected of the nursing staff.

The explosive growth in healthcare knowledge and technology does put pressure on nurses to develop efficient mental and technological models for managing progressively more complex and larger amounts of information in diagnosing patient problems (Reischman & Yarandi 2002:25). Bion (1997:129) describes this as "tension between technical ability and its appropriate application".

The ventilator is not the only diagnostic equipment next to the bed of a critically ill patient, but it contributes to this 'tension'. Bion (1997:129) refers to the practice of critical care as a compilation of interventions for either obtaining data or providing organ system support. In the current critical care setting, best practice means obtaining and interpreting data and providing appropriate organ support. Reischman and Yarandi (2002:25) are quoting Baker when they state that, by improving understanding of the nature of nursing, diagnostic expertise will enhance the quality of emerging problem-based learning methodologies in nursing.

Buchnall and Thomas (1997:229-37), who investigated nurses' perceptions of problems associated with decision-making in critical care settings, reported the concerns of nurses about keeping up with the demands posed by new knowledge and technology. These authors identified causes of nurse dissatisfaction, among others, the demands of new critical-care technology upon nurses' knowledge base. Excerpts from the study included data that indicated that nurses experienced their knowledge as inadequate. According to these nurses, because of their lack of knowledge, more time was spent on decision-making. The following quotes from this qualitative research study are relevant:

> "I find I never have enough knowledge. I'd like new memory banks every 12 months!!"
>
> "The exposure to different cases/equipment, etc., is sporadic. The inconsistency results in a feeling of not being familiar enough with a wide range of cases, therefore clinical decisions are made with more thought – taking more time. More consistent experience leads to decisions that are easy to make. Decisions need a good knowledge base…"
> (Buchnall & Thomas 1997:235.)

Continuous practice development (CPD) is not yet compulsory for registered nurses in South Africa. However, CPD requirements are in the pipeline and could be compulsory by 2007 (Geyer 2005). When CPD programmes are developed, it would be meaningful to include educational contents that would address the current knowledge deficits of critical care nurses, as well as non-critical care nursing personnel working in critical care units. Knowledge deficits should also decide the level and complexity of future CPD programme contents.

According to Reischman and Yarandi (2002:25), very little has been reported on objective measures of clinical nursing expertise in the practical setting. Although they regard diagnostic skill as only one dimension of nursing expertise, they also see it as a vital initial component of nursing practice because effective intervention is based upon it. In contrast, Bion (1997:129) quotes Bertrand Russel who says: "As skill increases, wisdom fades".

Learning to read clinical situations in rapidly changing healthcare environments is critical to providing quality nursing care (Diekelmann 2003:483). Fewer nursing staff are available to deliver high quality nursing services. Enabling them to arrive at expert conclusions or improving decision-making will enhance the efficiency and appropriateness of nursing care. Reading and interpreting ventilator graphics would enhance the diagnostic ability of critical care nurses. However, the problem is that the knowledge level of critical care nurses regarding ventilator graphics is unknown.

1.3 RESEARCH QUESTION

In order to attain an answer to this problem, the following research question is formulated:

What is the knowledge level of critical care nurses working in private hospitals in Gauteng regarding ventilator graphics?

1.4 AIM AND OBJECTIVES

1.4.1 RESEARCH AIM

The research aim is to determine the knowledge of critical care nurses regarding ventilator waveforms, in order to provide an educational programme on this topic.

1.4.2 OBJECTIVES OF THE STUDY

The objectives of the research study are to:

- To orientate the researcher regarding literature on the topic, in order to highlight important aspects and assist the researcher in the development of a questionnaire;
- Determine the knowledge of critical care nurses regarding ventilator graphics, using a measurement instrument in the form of a questionnaire; and

- Design an educational programme regarding the use of ventilator waveforms, based on findings of the empirical phase, so that optimal nursing care could be provided to ventilated patients.

1.5 DEFINITIONS OF KEY CONCEPTS

For the purposes of this study, the following short definitions apply:

Ventilator:	A positive- or negative-pressure breathing device that supports ventilation and oxygenation
Ventilator graphics:	Graphics that display graphic and numerical data about ventilation
Critical care nurses:	Nurses working in critical care settings and registered with the South African Nursing Council (SANC) as critical care nurses. Working in critical care units does not require the acquisition of an additional diploma in critical care and surgical nursing. (The terms 'critical care' and 'intensive care' is interchangeable.)
Competency indicator:	The level of knowledge that represents competence in an area of knowledge, in this case ventilator graphics. The competency indicator is determined by a group of specialists on the topic.

1.6 OVERVIEW OF THE RESEARCH DESIGN AND METHODOLOGY

According to Polit, Beck and Hungler (2001:167), the research design refers to the researcher's "…overall plan for answering the research questions…". For this quantitative study, it would set the strategy for ensuring the accuracy and interpretability of the information provided.

As this study is aimed at describing the knowledge of critical care nurses regarding a specific phenomenon, namely ventilator graphics, it will progress according to a descriptive and contextual design, using a quantitative methodology.

A questionnaire will be used as measuring instrument.

Survey research, according to Polit *et al.* (2001:472), refers to the direct questioning of respondents representing the research population, in order to obtain data about specific phenomena. According to Babbie and Mouton (1998:258), self-administrative questionnaires are only appropriate when the research population is adequately literate. All critical care nurses have received tertiary education; therefore, the researcher can accept that all potential respondents will be able to complete a self-administrative questionnaire.

This type of questionnaire is more appropriate when sensitive issues, such as knowledge acquisition or knowledge deficiencies, are explored. Researching the knowledge of any particular person could be interpreted as a threatening experience, leading to unwillingness to participate or rendering of inaccurate data. In using a self-administrative questionnaire, the threat of being exposed is eliminated.

Measurements to ensure reliability and validity will be fully explained in Chapter 3.

1.6.1 SETTING, POPULATION AND SAMPLE

The setting for this study is critical care units in Gauteng that are equipped with ventilator graphics.

All critical care nurses working in critical care units in Gauteng will form the population of this study. One criterion for participation in the study would be that these nurses should have been exposed to graphic display monitors for a period of at least three months. Valid research results will not be obtained if the knowledge of nurses with less than three months exposure to ventilator graphics were tested. Convenience sampling will be used. The researcher will distribute questionnaires among critical care nurses who had the necessary exposure to ventilator graphics in critical care units in Gauteng, until the desired sample size has been reached.

1.7 LIMITATIONS OF THE STUDY

Due to the fact that the research will be conducted in only Gauteng Province, findings will be contextualised. Generalisation of findings will not be feasible. Conclusions drawn will be relevant to the specific context of the study.

1.8 DATA ANALYSIS

Polit *et al.* (2001:460) describe data analysis as "…the systematic organization and synthesis of research data…". Descriptive and inferential statistics will be used to describe and synthesise the data and to draw conclusions regarding critical care nurses' knowledge of ventilator graphics. Data will be visually displayed by means of graphs and tables. STATOMET, the statistical support service at the University of Pretoria (UP), will be consulted in order to assist with the data analysis.

1.9 ETHICAL CONSIDERATIONS

Written approval to conduct the study was obtained from the UP Faculty of Health Sciences' Ethics Committee. (See Annexure B.) Written consent was also obtained from the participatory private hospitals.

The anonymity of the participatory hospitals and participant nurses will be preserved throughout the study. Confidentiality will be assured. The voluntary completion of the questionnaire will imply that informed consent has been given by the respondent. An information leaflet will be attached to the questionnaire, explaining the principle of informed consent by means of voluntary participation.

1.10 OUTLINE OF THE STUDY

Chapter 1: Orientation to the study:

This chapter introduces the topic of the study, namely the knowledge and competence of critical care nurses regarding ventilator graphics. The research question and the aims and objectives of the study are described. The research design and ethical considerations are discussed briefly.

Chapter 2: Mechanical ventilation:

This chapter orientates the reader toward ventilator graphics.

Chapter 3: Research design and methodology:

The research design and method, population and sampling, the pilot study and the data collection process, the validity and reliability of the research, and ethical considerations are addressed in this chapter.

Chapter 4: Data analysis:

The data are analysed in detail and the results are visually presented by means of figures and tables.

Chapter 5: Conclusions, limitations, recommendations and reflection of the study:

This chapter includes the conclusions drawn from the data analysis, the limitations of the study, as well as recommendations for further research and critical care practice. The researcher will also reflect on the aim of the study and the course of events during the research.

Chapter 6: Education programme on ventilator graphics:

This chapter includes the framework for the educational programme on ventilator graphics. A copy of this programme, developed in Microsoft PowerPoint presentation (PPP) format, is attached to Chapter 6.

1.11 CONCLUSION

Based on the experience of the researcher and available literature on the topic, a possible lack of knowledge regarding ventilator graphics among critical care nurses working with critically ill patients could be a reason for concern. The acquisition of more knowledge about ventilator graphics will take nurses a step closer to achieving a high level of nursing expertise in the practical setting. To establish the knowledge base (and thus knowledge deficiencies) of critical care nurses regarding ventilator waveforms, research has to be conducted.

By means of this study, the researcher wishes to describe the specific knowledge base of critical care nurses regarding ventilator graphics, so that an educational programme can be designed to meet their knowledge needs.

CHAPTER 2

MECHANICAL VENTILATION

2.1 INTRODUCTION

Mechanical ventilation dates back to 1929 when the so-called iron lung or negative-pressure ventilation was invented. Negative-pressure ventilation picked up momentum and was frequently used during the polio epidemics of the 1950s (Ibsen 1954:52). Only during World War II did positive pressure ventilation gained support and acceptance; however, it was mainly used for anaesthesia administration (Wright, Doyle & Yoshihara 1996:262). By the early 1950s the Swedish had come up with the idea of using positive pressure ventilation for critically ill patients. The idea took root, and by the mid 1950s positive pressure ventilation had come into use in critical care units in Sweden and elsewhere (Ibsen 1954:52).

Mechanical ventilation creates a flow of gas into and out of the lungs by manipulating airway pressures. It achieves effective ventilation by altering the relationship between intrathoracic and extrathoracic pressures (Dolan 1991:622).

For many years, clinical measurement of flow, pressure and volume was restricted to readings on the ventilator control panel, digital monitors and mechanical gauges. However, new developments such as real-time graphical displays of curves and loops are emerging rapidly (Ouellet 1997:7). According to Macintyre (1998:1-1), clinical professionals should become familiar with ventilator waveforms in order to be able to analyse them. In the critical care setting, the critical care nurse is at the patient’s bedside 24 hours a day, which requires, among other things, analytical knowledge of ventilator graphics.

2.2 INDICATIONS FOR MECHANICAL VENTILATION

Identifying the reason for mechanically ventilating a patient ensures better understanding of and insight into ventilator graphics. Indications for mechanical ventilation are broadly classified under the following headings:

Respiratory abnormalities: These are the result of central nervous system depression with apnoea due to:

- Drugs.
- Cerebrovascular incident.
- Increased intracranial pressure.

Injury:

- Chest wall trauma (Flail chest).

Chronic diseases, including:

- Obstructive lung disease.
- Asthma.
- Chronic bronchitis.
- Emphysema.

Neuromuscular diseases, including:

- Myasthenia gravis.
- Guillain-Barré syndrome.
- Poliomyelitis.

Acute respiratory failure, including:

- Pneumonia.
- Tuberculosis.
- Pneumocystis.

Insufficient gas exchange resulting from:

- Pulmonary oedema.
- Atelectasis.
- Pulmonary fibrosis.
- Adult respiratory distress syndrome (ARDS).

Others:

- General anaesthesia.
- Cardiac arrest.

In short, the motivation for mechanical ventilation is the inability to adequately ventilate due to different reasons. Mechanical ventilation, therefore, aids in establishing and maintaining ventilation and oxygenation.

2.3 APPROACHES TO VENTILATION

Traditionally mechanical ventilation included two approaches: volume-cycled ventilation and pressure-cycled ventilation (Marino 1998:421). A brief explanation of both approaches will be given, as they remain the basis of most ventilator strategies that are currently in use. Both approaches to ventilation will be graphically illustrated, and specific examples of each approach will be discussed in detail in this chapter.

2.3.1 VOLUME-CYCLED VENTILATION

Volume-cycled ventilation refers to the delivery of a set tidal volume at a set breathing rate. The variable for volume-cycled ventilation is thus pressure. As airway compliance decreases, pressure increases to accommodate the same tidal volume. Volume-cycled ventilation can be delivered in the following modes: volume controlled ventilation, assist-control ventilation, intermittent mandatory ventilation (IMV) or synchronised intermittent mandatory ventilation (SIMV). A short description of each mode of volume-cycled ventilation will be given in Subsections 2.3.1.1 to 2.3.1.4.

2.3.1.1 Volume controlled mode

The volume controlled mode or setting of a mechanical ventilator completely controls the ventilation cycle for the patient. Thus, the patient's own breathing efforts are not allowed. (Refer to Figure 2.1.) The volume delivered and the frequency (breathing rate) are predetermined by the clinician for the patient. Spontaneous breathing efforts (Figure 2.2) are not recognised by the ventilator because should the ventilator register a spontaneous breath, asynchrony between the ventilator and the patient would develop. The control mode can therefore override a high respiratory rate. In newer ventilator models, the control mode is combined with the assist mode (Wright *et al.* 1996:266). Figures 2.1 and 2.2 display controlled ventilation and spontaneous breathing respectively.

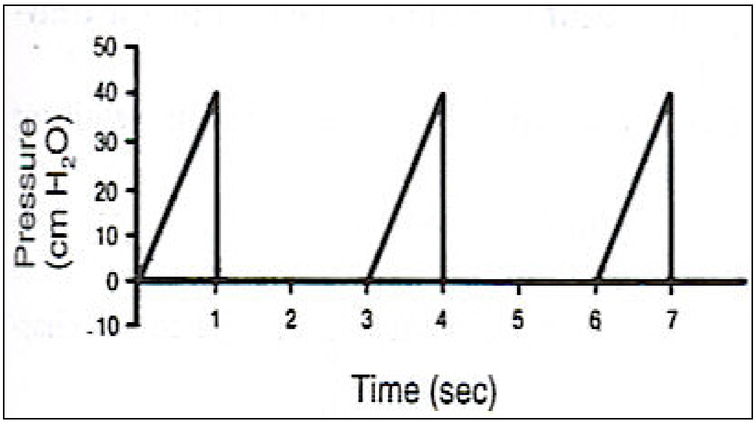

Figure 2.1: Controlled ventilation
Acknowledgement: Valenti, Rozinsky and Tamblyn

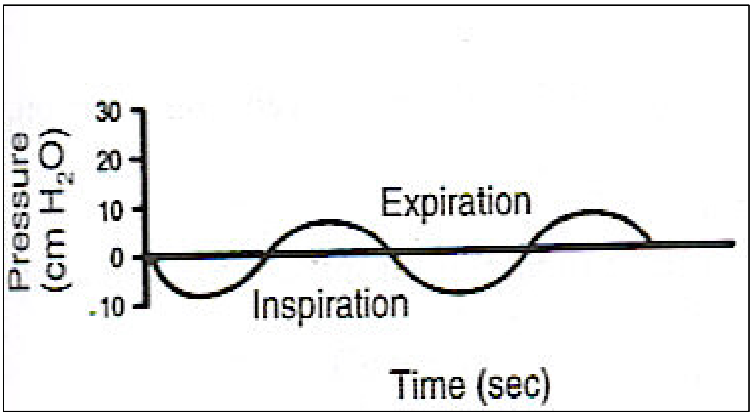

Figure 2.2: Spontaneous ventilation
Acknowledgement: Valenti et al.

2.3.1.2 *Assist-control mode*

The assist-control mode facilitates the patient's spontaneous breath by delivering a preset tidal volume when the patient initiates the breath (Wright *et al.* 1996:266). In this case, the ventilator is sensitive to the patient's effort at breathing and reacts to it.

2.3.1.3 *Control/assist mode*

When the ventilator is set on the control/assist mode, it means the tidal volume and rate are preset in the control or assist mode. When the patient triggers the breath, the ventilator responds by delivering the set tidal volume. (Refer to Figure 2.3.) However, if the patient fails to trigger, the control mode will automatically trigger, and deliver the preset tidal volume. This ensures that a minimum minute volume is maintained. This mode is indicated for patients who require a reduction in the work of breathing. However, the delivery of a preset tidal volume might result in respiratory alkalosis because the amount of tidal volume might facilitate a decrease in carbon dioxide in the blood. Inadequate settings on the ventilator, like a high pressure sensitivity or inadequate pressure support, may also increase the work of breathing for the patient (Wright *et al.* 1996:266).

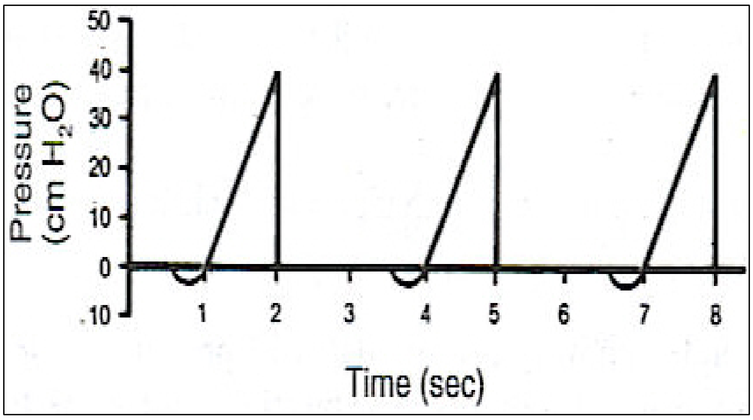

Figure 2.3: Control/assist mode
Acknowledgement: Valenti et al.

2.3.1.4 Volume intermittent mandatory ventilation (VIMV) and synchronised intermittent mandatory ventilation (SIMV)

In the case of VIMV, the ventilator delivers a preset tidal volume at a preset rate but allows the patient to take additional breaths at *unspecified* tidal volumes. The patient's effort will determine the amount of the tidal volume. The mandatory breath, however, might impose on the patient's spontaneous inspiration, causing 'stacking' (Wright *et al.* 1996:267). 'Stacking' is accumulation of air in the airways when, for example, not enough expiratory time is allowed.

SIMV was developed to prevent 'stacking'. It allows spontaneous triggered breaths as well as mandatory breaths if patient inspiratory efforts are absent. In addition, it also supports the spontaneous breath if it occurs near the time of the next scheduled mandatory breath. Thus, mandatory breaths and the patient's efforts at breathing are synchronised (Wright *et al.* 1996:267). Ventilator breaths and self-initiated breaths do not compete as is possible in the case of IMV (Dolan 1991:627). Figure 2.4 illustrates SIMV.

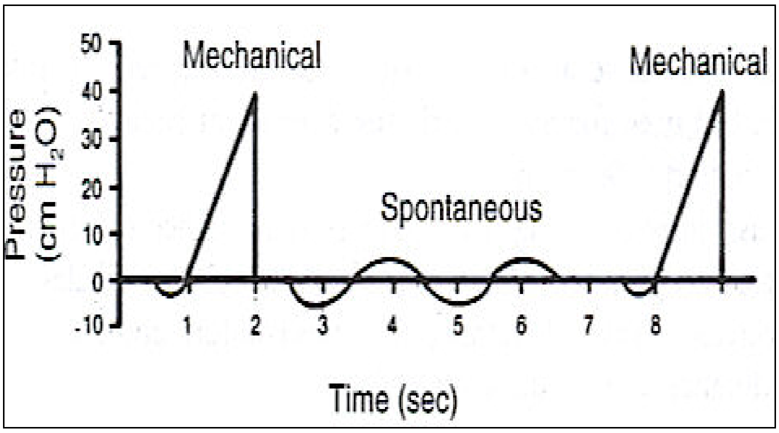

Figure 2.4: Synchronised intermittent mandatory ventilation
Acknowledgement: Valenti et al.

2.3.1.5 Pressure-regulated volume control (PRVC)

PRVC combines the benefits of pressure and volume ventilation. The ventilator calculates a compliance value based on a 'test' breath and then monitors the lung mechanics, adjusting the pressure level when necessary to maintain a set tidal volume (Wright *et al.* 1996:270).

2.3.2 PRESSURE-CYCLED VENTILATION

Pressure-cycled ventilation is described as an inspiratory cycle that is terminated when a specific airway pressure has been reached (Dolan 1991:626).

2.3.2.1 Pressure controlled ventilation

Pressure controlled ventilation involves the delivery of a preset pressure for a predetermined inspiratory time or inspiration-expiration time ratio (I:E ratio) (Wright *et al.* 1996:268). The variable for pressure-cycled ventilation is tidal volume.

An advantage of pressure ventilation (over volume ventilation) is the method by which airflow is delivered. Although airflow patterns will be discussed at a later stage, it is valuable to note that the decelerating flow pattern used in pressure ventilation enables the ventilator to deliver approximately the same volume as in volume ventilation, but with a lower positive inspiratory pressure (Wright *et al.* 1996:268). To compare the normal pressure waveforms during a volume controlled and a pressure controlled mode of ventilation, refer to Figure 2.5.

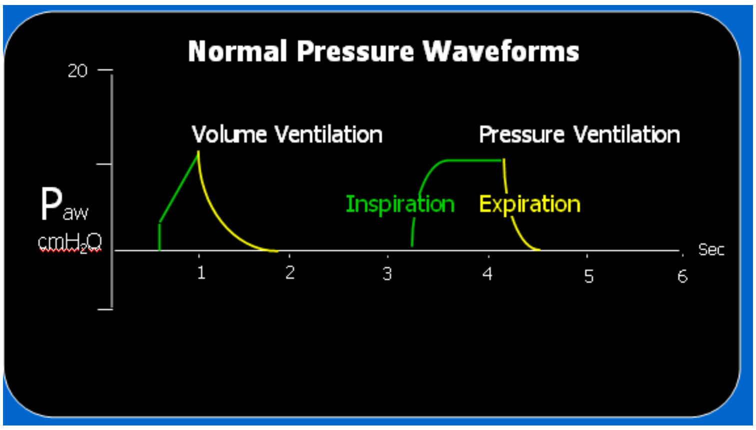

Figure 2.5: Normal pressure waveforms
Acknowledgement: Newport (In: Visser)

Normal pressure waveforms are illustrated in Figure 2.5. The inspiration phase is traced in green, and expiration in yellow.

- The first wave represents a pressure wave during a volume controlled mode of ventilation.
- The second wave represents a pressure wave during a pressure controlled mode of ventilation.

2.3.2.2 Bilevel positive airway pressure (BiPAP) ventilation, also called BiLevel or BiPhasic ventilation

According to Fenstermacher and Hong (2004:270), two pressure settings are selected for a bilevel positive airway pressure (BiPAP) mode of ventilation. Refer to Figure 2.6.

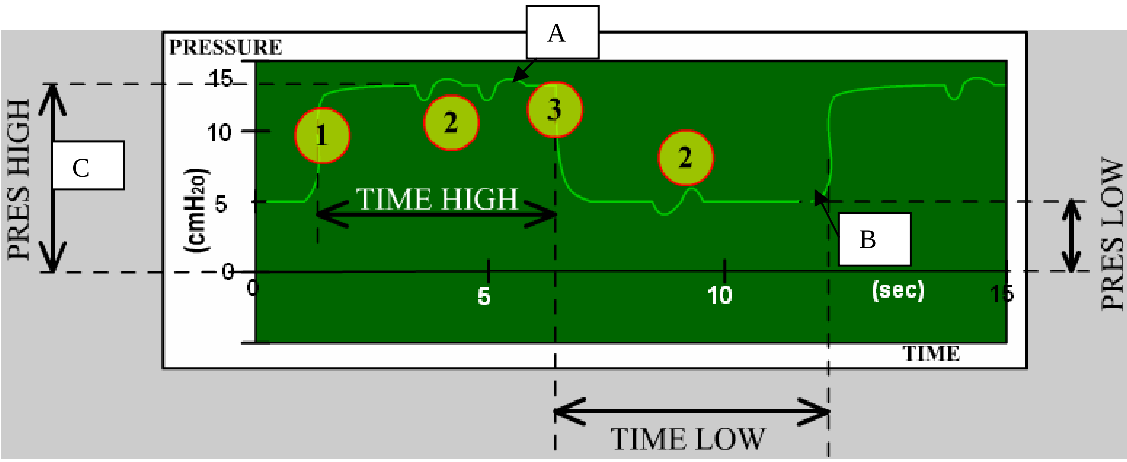

Figure 2.6: Biphasic waveforms
Acknowledgement: Vyasis (Adapted)

Figure 2.6, representing a BiPAP mode of ventilation, can be explained as follows:

- The first or higher pressure setting for inspiration, indicated by A, facilitates the tidal volume, represented by C. The high pressure is also called PRES HIGH.
- The second or lower pressure setting for expiration prevents alveolar collapse and is known as positive end-expiratory pressure (PEEP), represented by B. It is also called PRES LOW.

- In this ventilator mode, the patient can breathe spontaneously (indicated by the number [2]) at both pressure levels.
- The time spent at each level is called TIME HIGH and TIME LOW respectively. Once the time set for PRES LOW by the operator has elapsed, passage from PRES LOW to PRES HIGH occurs.

2.3.2.3 Volume target pressure control

New ventilators offer novel modes of ventilation. Volume as well as pressure are selected and used to deliver the most effective breath for the patient.

Volume target pressure control combines the benefits of pressure and volume ventilation. According to Visser (2004b), in this mode, both the pressure controlled breath and the desired volume are guaranteed. Thus, protected lung strategy with predicted minute ventilation is ensured.

2.4 PRINCIPLES FOR UNDERSTANDING WAVEFORMS

The physiology of normal breathing provides the basis for understanding waveform analysis. A short review of the physiology of spontaneous breathing is therefore given as introduction to a discussion on the analysis of graphic patterns.

2.4.1 SPONTANEOUS VERSUS MECHANICAL VENTILATION

According to Sherwood (2001:437), air moves down a pressure gradient, from a region of high pressure to a region of lower pressure.

2.4.1.1 Normal inspiration

During the no-flow situation at the end of expiration and before the onset of inspiration, the pressure in the atmosphere and the thorax is identical. Due to an increase in partial pressure of carbon dioxide (P_{CO_2}) in the brain, the diaphragmatic and external intercostal muscles are stimulated to contract.

These contractions increase the vertical, lateral (side-to-side) and anteroposterior (front-to-back) dimensions of the thoracic cavity, causing a sudden increase in thoracic space and volume. As the thoracic cavity expands, the lungs are forced to expand to fill the thoracic space. This causes a decrease in intra-alveolar pressure (Sherwood 2001:442). Due to the subsequent negative pressure gradient generated between the atmosphere and the thorax, gas moves from the atmosphere to the alveoli and inspiration occurs. Inspiration will continue until alveolar pressure equals atmospheric pressure (Viasys [S.a.]a). The expansion of the thoracic cavity during normal inspiration is illustrated in Figure 2.7.

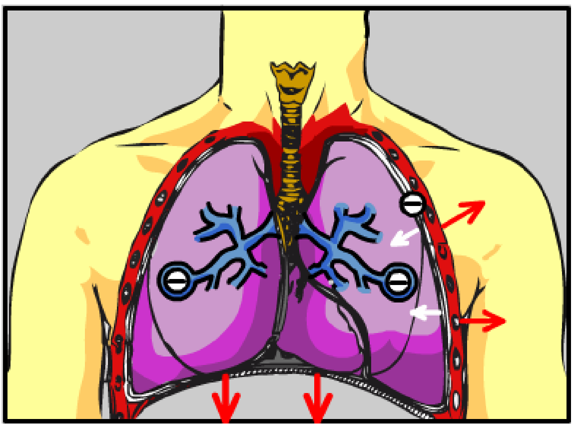

Figure 2.7: Expansion of the thoracic cavity during normal inspiration
Acknowledgement: Viasys

2.4.1.2 Inspiration during mechanical ventilation

In mechanically ventilated patients, the ventilator generates positive transrespiratory pressure. By letting air flow or, to an extent, by forcing air into the lungs, the thorax is expanded (Viasys [S.a.]a).

2.4.1.3 Normal passive expiration and expiration during mechanical ventilation

Expiration is a passive process irrespective of the initial method of inspiration. Expiration occurs due to the elastic recoil force of the lungs. During the end of the normal inspiration phase, the inspiratory muscles cease contracting, causing first the thoracic cavity and then the lungs to try to recover their normal size. Thoracic capacity and lung volume decrease, resulting in alveolar pressure exceeding airway pressure. Therefore, air moves down the pressure gradient generated between the alveoli and the atmosphere, and air flows out of the lungs (Viasys [S.a.]a).

Normal expiration is illustrated in Figure 2.8.

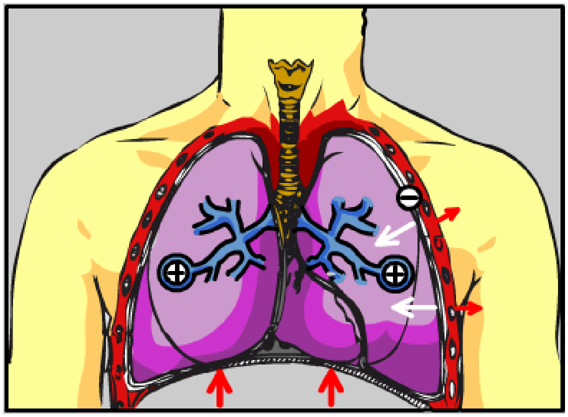

Figure 2.8 Normal expiration
Acknowledgement: Viasys

A breath cycle consists of both inspiration and expiration. Understanding the physiology of normal breathing will facilitate differentiating between ventilator waveforms.

2.4.2 DIFFERENTIATING BETWEEN GRAPHICAL PATTERNS

Burns describes positive pressure as an upward or positive baseline deflection (Burns 2003:134). Negative pressure will then be indicated as a downward or negative baseline deflection.

Refer to Figure 2.9 on page 21.

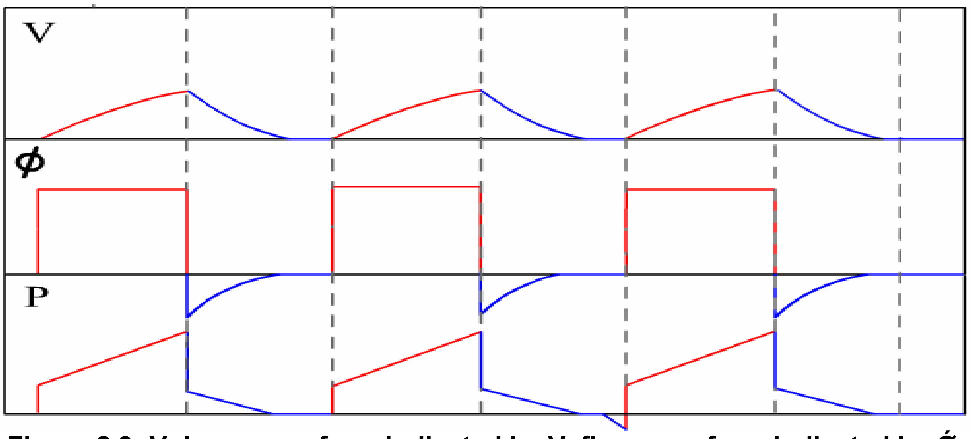

Figure 2.9: Volume waveform indicated by V, flow waveform indicated by Ǿ, and pressure waveform indicated by P *Acknowledgement: Viasys*

Figure 2.9 can be explained as follows:

- The first waveform, indicated with V, represents a volume waveform.
- The second waveform, indicated with Ø, represents a flow waveform.
- The third waveform, indicated with P, represents a pressure waveform.

Pressure, volume and flow are plotted on the vertical axis, and time on the horizontal axis (Burns 2003:134,137).

2.4.3 TRIGGER MECHANISMS

Ventilator breaths must be initiated or triggered. The trigger refers to the starting point - a particular stage in a process when the inspiratory valve opens and gas flow is initiated (Fenstermacher & Hong 2004:260). According to Fenstermacher and Hong (2004:261), the trigger can be time or patient activated. The kind of trigger can be observed in the pressure curve (Viasys [S.a.]a). (Refer to Figure 2.9.) The different trigger mechanisms will be discussed briefly.

2.4.3.1 Time trigger versus patient trigger

During ventilator-initiated or controlled breaths, time is set so that it triggers inspiration. Inspiration is initiated after a preset period of time in which the patient failed to initiate a breath (Viasys [S.a.]a). Refer to Figure 2.10 on page 22.

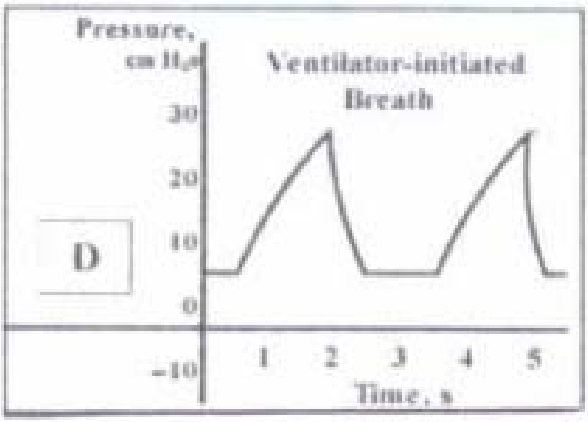

Figure 2.10: Pressure-time waveform indicating a time trigger
Acknowledgement: Fenstermacher and Hong

Figure 2.10, displaying a pressure-time waveform of two ventilator initiated breaths, can be explained as follows:

- The figure represents a time-triggered breath. The breath starts at a pressure setting of possibly 5 cmH_2O on the vertical axis without a negative deflection before the inspiratory limb rises in pressure. Compare Figure 2.10 to Figure 2.11.

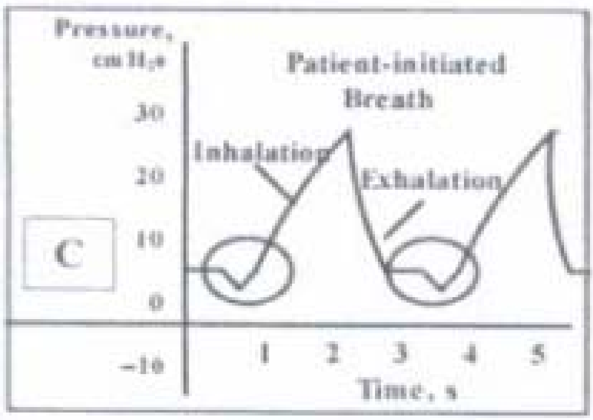

Figure 2.11: Pressure-time waveform indicating a spontaneous trigger
Acknowledgement: Fenstermacher and Hong

Figure 2.11, representing a pressure-time waveform with patient-initiated breaths, can be explained as follows:

- This figure represents a spontaneous patient-triggered breath, *i.e.* the patient initiates the breath. Inspiration is indicated by a negative drop in the baseline (circled on the waveform) before the upward rise of the inspiratory limb.

For patient-initiated breaths, different ventilators offer a choice between pressure, flow or volume trigger methods. These will be discussed briefly.

2.4.3.2 Pressure trigger method

Spontaneous breaths are initiated by the respiratory muscles creating a negative pressure. This pressure drop is recognised by the ventilator as 'sensitivity'. Sensitivity settings are set below PEEP. According to Fenstermacher and Hong (2004:261), the expiratory valve in the ventilator circuit must be closed before the patient generates the preset negative pressure that is needed to open the flow controller valve. An alternative to this process is the flow trigger method.

2.4.3.3 Flow trigger method

Ventilator inspiration is triggered when a change in measured flow rate (flow sensitivity) is detected from within the ventilator circuit. The inspiratory valve is constantly open, allowing an amount of air to flow through the circuit at all times (Fenstermacher & Hong 2004:261). Flow sensors detect the flow of gas from the circuit to the patient and trigger the ventilator to either allow an unassisted breath or assist a breath (Wright *et al.* 1996:265).

According to Fenstermacher and Hong (2004:261), the flow trigger method is used more frequently today. During this method of ventilation, the next breath can be sensed by the ventilator as described above, even if the expiratory valve were still open. As stated above, during pressure triggering, the expiratory valve must be closed before the patient generates the negative pressure sensitivity needed to open the inspiratory valve. This causes a short delay between patient demand and ventilator delivery, thus increasing the work of breathing for the patient. This aspect will be discussed in more detail under loops and trigger mechanisms (See Subsection 2.8.3.5).

2.4.3.4 Volume trigger method

This is similar to the flow trigger method. The difference is that the set inspired volume is detected, instead of a change in constant flow (Wright *et al.* 1996:266).

2.4.4 CYCLING MECHANISMS

Fenstermacher and Hong (2004:263) describe 'cycling' as the end of inspiration or flow of gas into the lungs and the opening of the expiratory valve. Cycling is related to a cycle variable (volume, pressure, flow or time) and ventilators are classified according to their method of cycling. The term 'cycling' is used to indicate a terminating event as opposed to an initiating event of breathing (Wright *et al.* 1996:264).

Refer to Figure 2.12.

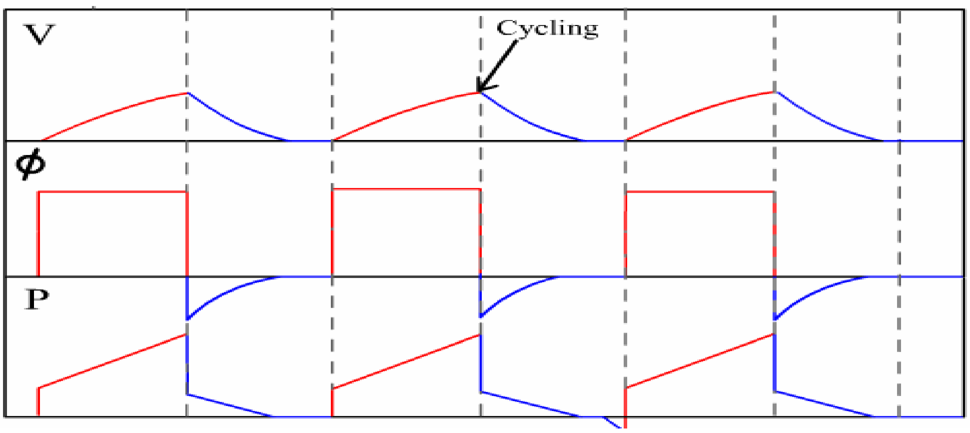

Figure 2.12: Indicating cycling
Acknowledgement: Viasys

Ventilators generate volume-, pressure-, flow- or time-cycled breaths according to the method of cycling. Each type of ventilator breath will be described briefly.

2.4.4.1 Volume-cycled breaths

A volume-cycled ventilator breath is terminated when a preset volume of air has left the ventilator. This type of ventilator breath is characterised by a more consistent delivery of volumes (Dolan 1991:625).

2.4.4.2 Pressure-cycled breaths

In a pressure-cycled breath the inspiratory flow will end when the preset pressure is reached (Fenstermacher & Hong 2004:263). The breaths delivered are not always consistent in volume. Changes in airway resistance, lung compliance, and inspiratory demand may result in the delivery of inappropriate or inconsistent volumes.

For a patient to initiate a breath, the sensitivity threshold needs to be exceeded, and only then will the ventilator deliver a tidal volume. However, if the same sensitivity threshold is exceeded because of a leak in the endotracheal tube, the ventilator will interpret it as though the patient wants to inspire, and will trigger continuously. This phenomenon is called ‘auto cycling’, and is solved either by flow triggering or by varying the pressure sensitivity value (Viasys [S.a.]a). Auto cycling is illustrated in Figure 2.13.

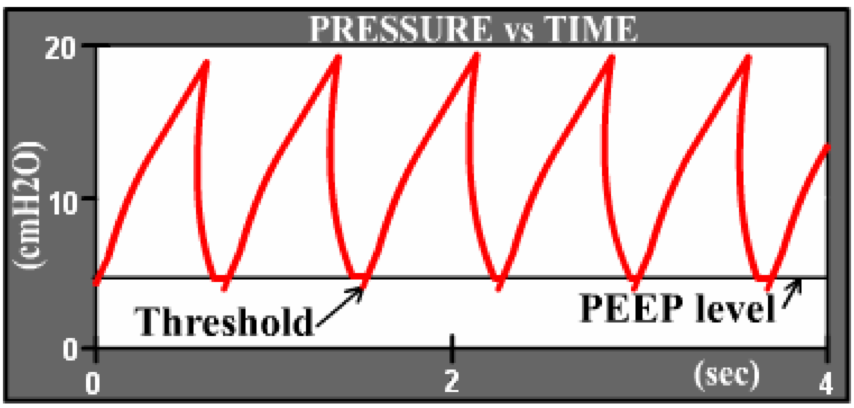

Figure 2.13: Auto cycling
Acknowledgement: Viasys

Figure 2.13 displays a pressure-time waveform that indicates a leak in the ventilator circuit. It can be explained as follows:

- The waveform reflects the continuous triggering of a pressure-cycled breath. PEEP is set at 5 cmH_2O, which is also the sensitivity threshold.

2.4.4.3 Flow-cycled breaths

A flow-cycled ventilator breath is terminated when a preset inspiratory flow rate is achieved. According to Fenstermacher and Hong (2004:263), the ventilator will end the inspiratory flow once it senses a drop of between 5-25% in the peak flow rate. This is also called the breath-ending criterion (Visser 2004a).

2.4.4.4 Time-cycled breaths

A time-cycled breath terminates when a preset inspiratory time has elapsed. Pressure controlled ventilation is a time-cycled, pressure-limited form of ventilation that is commonly used. Improved gas distribution is suggested when it is combined with a decelerating flow pattern (Wright *et al.* 1996:264).

2.4.5 INSPIRATORY AND EXPIRATORY TIME

The time it takes to inspire plus the time it takes to expire represents the timespan of a single breath. The timespan demonstrates the relationship between inspired and expired time. Inspiratory time is usually half the expiratory time (Viasys [S.a.]a). Thus, the I:E ratio = 1:2.

This ratio is however not reflected in Figure 2.14 on page 27.

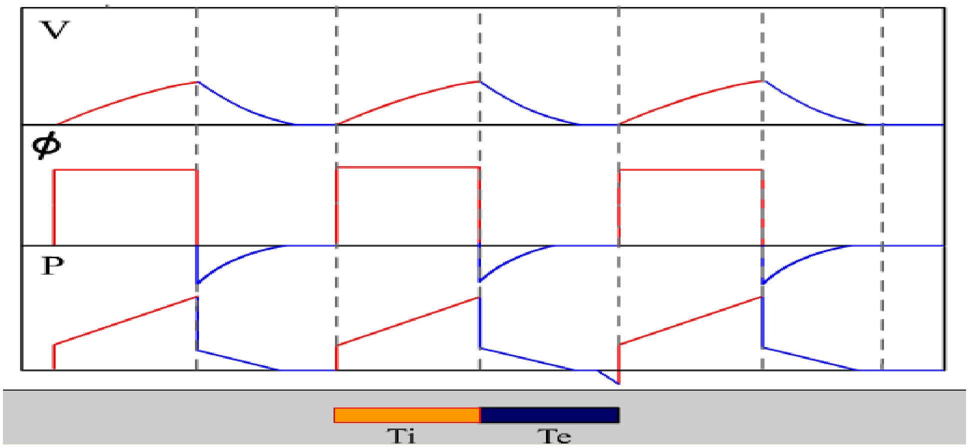

Figure 2.14: Indicating inspiratory time (Ti) and expiratory time (Te)
Acknowledgement: Viasys

Figure 2.14 displays a combination of volume, flow, and pressure waveforms. The red indicates the inspiratory phase, and the blue the expiratory phase.

- The inspiratory time is the time between the beginning (trigger) of inspiration and the end of the inspiratory phase (cycling).
- The expiratory time begins at the cycling and ends at the trigger or the start of a new inspiratory phase (Viasys [S.a.]a).
- The I:E ratio in Figure 2.14 is 1:1 and not 1:2.

2.4.6 POSITIVE END-EXPIRATORY PRESSURE (PEEP)

PEEP is positive pressure applied at the end of expiration to increase alveolar pressure and alveolar volume. This increase in the volume of air in the lung at the end of expiration may improve lung compliance, reduce work of breathing, and improve ventilation-to-perfusion matching (Dolan 1991:627). According to Valenti *et al.* (1998:248), PEEP prevents or decreases collapse of the alveoli at end-expiration, and helps to re-inflate collapsed alveoli. Although serious complications might occur as a result of PEEP (such as overexpansion of the lung resulting in alveolar trauma), its most significant benefit is adequately maintaining partial pressure of alveolar oxygen (PAO_2) at a lower oxygen concentration, thereby reducing the risk of oxygen toxicity (Wright *et al.* 1996:266).

2.4.7 CONTINUOUS POSITIVE AIRWAY PRESSURE (CPAP)

Continuous positive airway pressure (CPAP) in a patient who is breathing spontaneously is considered the equivalent of PEEP. Benefit is derived from the positive pressure maintained within the airways and alveoli at the end of expiration (Dolan 1991:627).

2.5 UNDERSTANDING FLOW GRAPHICS

Airflow is measured in the ventilator circuit in either the inspiratory or the expiratory limb of the ventilator or both. The flow graphic has two distinct parts, namely: the inspiratory flow part and the expiratory flow part (Macintyre 1998:2-1). The respiratory flow is the speed with which gas moves into and out of the lungs. The flow values are indicated in litres/second or litres/minute and are plotted on the vertical axis, whereas the time values in seconds are placed on the horizontal axis (Viasys [S.a.]a). The two distinct parts of respiration, namely inspiration and expiration, are illustrated in Figure 2.15.

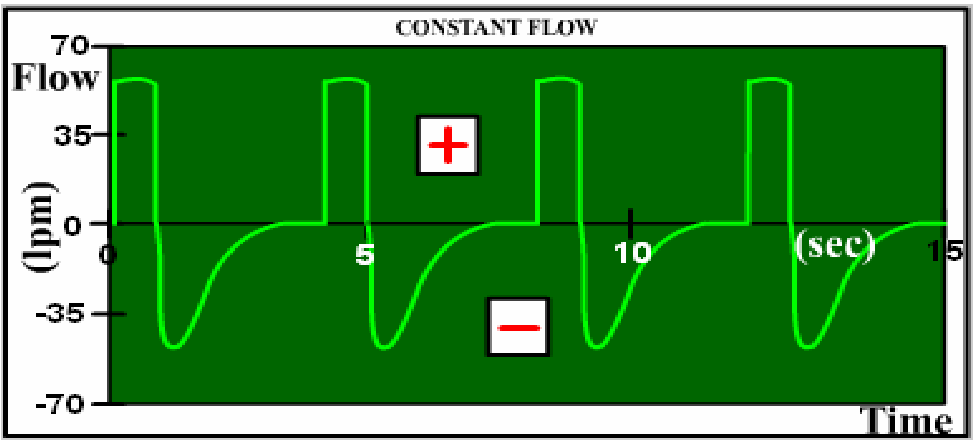

Figure 2.15: Indicating inspiration as a positive and expiration as a negative flow
Acknowledgement: Viasys

Figure 2.15 displays a flow-time waveform for a ventilated patient, and can be explained as follows:

- During the inspiratory phase, air flows from the ventilator toward the patient. This is graphically illustrated as a positive flow [+].

- Expiration follows and air flows from the patient toward the ventilator. This is graphically indicated as a negative flow [-]. (Viasys [S.a.]a.)

2.5.1 FLOW GRAPHICS: IMPORTANT ASPECTS

2.5.1.1 Inspiratory phase

The flow delivery pattern in the case of a spontaneous breath is determined by the characteristics of patient demand. Aspects of the inspiratory flow pattern, such as magnitude (peak flow), duration (time), trigger (starting point) and cycling (end of inspiration), are therefore determined by the patient. Figure 2.16 (Macintyre 1998:2-1) illustrates the flow delivery pattern of a spontaneous breath.

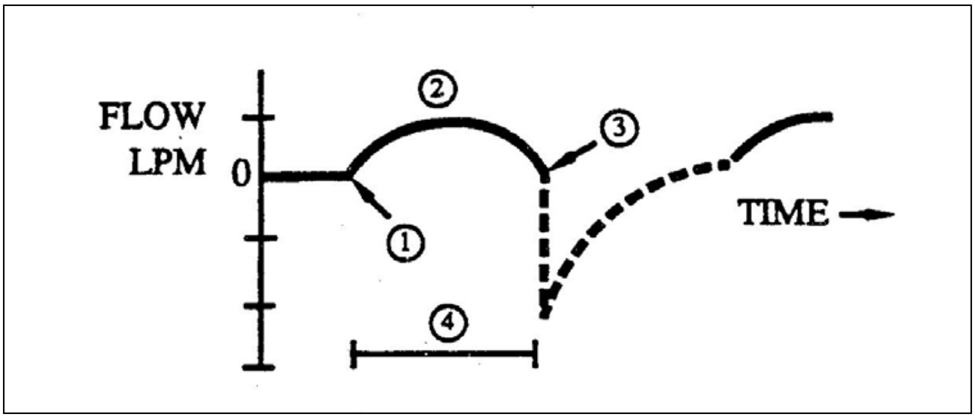

Figure 2.16: Indicating the flow delivery pattern of a spontaneous breath
Acknowledgement: Macintyre

Figure 2.16, illustrating the inspiratory flow pattern of a spontaneous breath, is explained as follows:

- The start of inspiration (trigger) is represented by [1].
- The magnitude of inspiratory flow, *i.e.* peak flow, is represented by [2].
- The end of inspiration (cycling) is represented by [3].
- The duration of inspiratory flow, *i.e.* inspiratory time, is represented by [4]. (Macintyre 1998:2-4.)

In the case of a mechanical breath, the inspiratory flow is reflected as a mechanical breath flow pattern, also called a 'square wave' flow pattern (Macintyre 1998:2-1). Figure 2.17 depicts a mechanical breath or 'square wave' flow pattern.

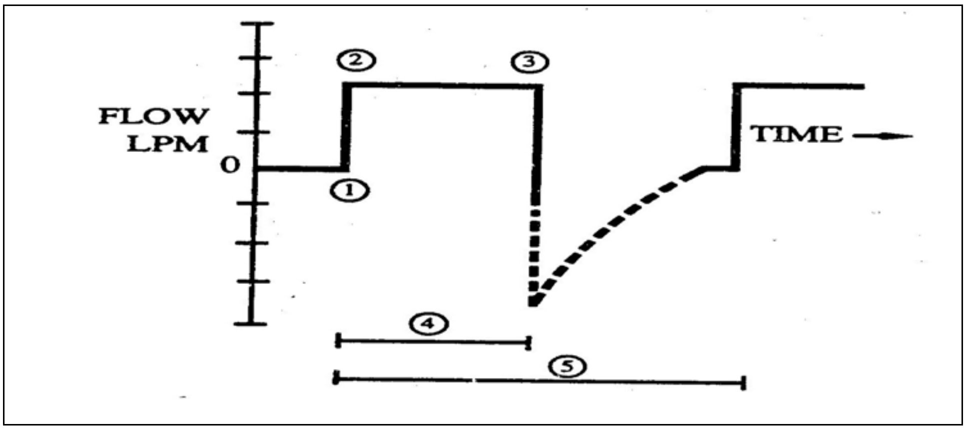

Figure 2.17: Indicating the flow delivery pattern of a mechanical breath
Acknowledgement: Macintyre

Figure 2.17, representing a mechanical breath or 'square wave' flow pattern, is explained as follows:

- The initiation of flow from the ventilator is represented by [1].
- The magnitude of inspiratory flow, or 'peak flow', is represented by [2].
- The end of inspiration (and the end of flow delivery) is represented by [3].
- The duration of inspiratory flow, *i.e.* inspiratory time, is represented by [4].
- The total cycle time determined by the preset ventilator rate is represented by [5]. (Macintyre 1998:2-1.)

The 'square wave' flow pattern is described as being characteristically a constant flow from the start of inspiration to the end of expiration (Macintyre 1998:2-2). However, the so-called 'true' square wave is affected by response time phenomena. Macintyre (1998:2-2) states: "The 'true' square waveform is not achievable in reality due to an inherent response time, i.e. the time it takes to accelerate from zero flow to the peak flow setting. Similarly, there is also a time associated with returning to zero flow at the end of inspiration." The influence of response time phenomena is illustrated in Figure 2.18 by superimposing slightly sloped lines on the sides of the true square wave (shown in dotted lines). In reality the sloped lines might not even be as straight as they are depicted in Figure 2.18.

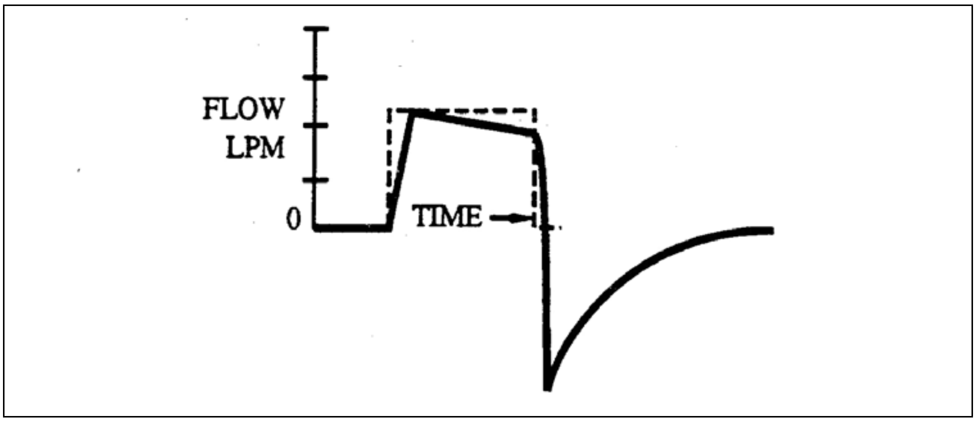

Figure 2.18: Indicating influence of response time phenomena on 'true' square wave shown in dotted lines *Acknowledgement: Macintyre*

This observation is noteworthy because, in order for nurses to understand ventilator graphics, they should realise that perfect flow graphics, such as those depicted in Figures 2.12 and 2.15 do not exist.

2.5.1.2 Inspiratory pause

The inspiratory pause is conventionally considered part of the inspiratory phase (Viasys [S.a.]a). Refer to Figure 2.19 below.

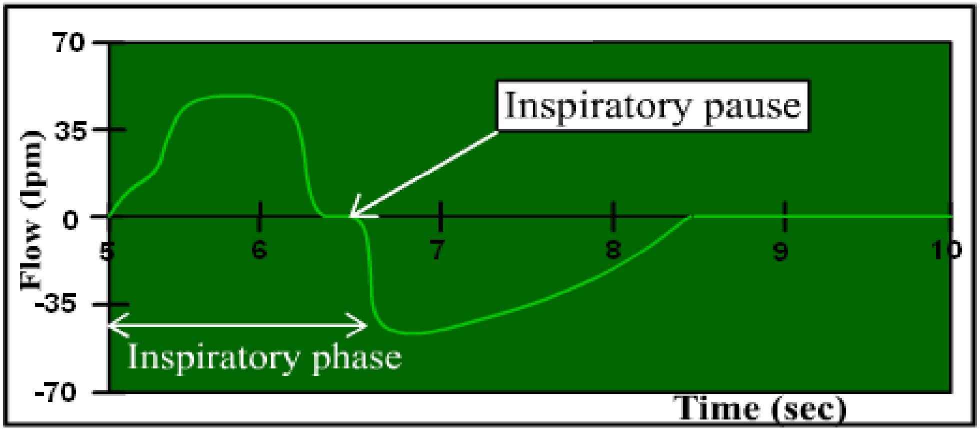

Figure 2.19: Inspiratory pause
Acknowledgement: Viasys

The inspiratory pause refers to the few milliseconds when no air is flowing and gas exchange is taking place. It also indicates the start of the expiratory phase.

2.5.1.3 Expiratory phase

Expiration can be active exhalation, but is generally a passive manoeuvre. The characteristics of expiration, namely magnitude, duration, pattern and flow, are influenced by airway and ventilator circuit compliance and resistance. Figure 2.20 depicts a normal (passive) expiratory flow pattern (Macintyre 1998:2-4).

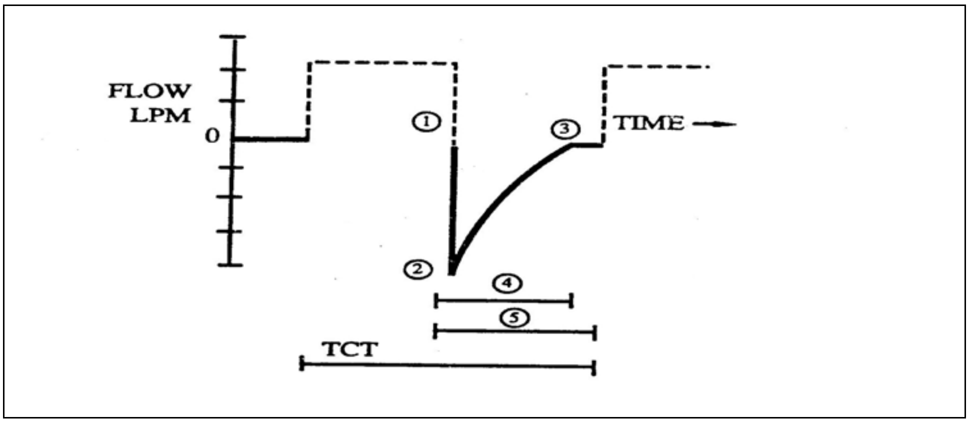

Figure 2.20: Expiratory flow graphic
Acknowledgement : Macintyre

Figure 2.20 represents a normal expiratory flow graphic. It can be explained as follows:

- The start of expiration is represented by [1].
- The peak expiratory flow is represented by [2]. Because a mechanically delivered tidal volume is generally larger than a spontaneous tidal volume, the peak expiratory flow of a positive pressure breath will generally be higher than that of a spontaneous breath.
- The end of the expiratory flow is represented by [3]. End-expiration, combined with the start of the next mechanical inspiration, is important in assessing the I:E ratio and the potential for air-trapping.
- The duration of the expiratory flow is represented by [4].

* The total available expiratory time, *i.e.* the total cycle time minus the actual inspiratory time, is represented by [5]. (Macintyre 1998:2-5.)

According to Sherwood (2001:443), 'active expiration' means emptying the lungs more completely and more rapidly than what is being accomplished during quiet breathing with the elastic recoiling of the lungs. During active expiration, contraction of the abdominal muscles results in pushing the diaphragm further into the thoracic cavity, thereby increasing intrathoracic pressure and allowing more airflow down the pressure gradient.

A comparison between normal expiration and active expiration is displayed in Figure 2.21.

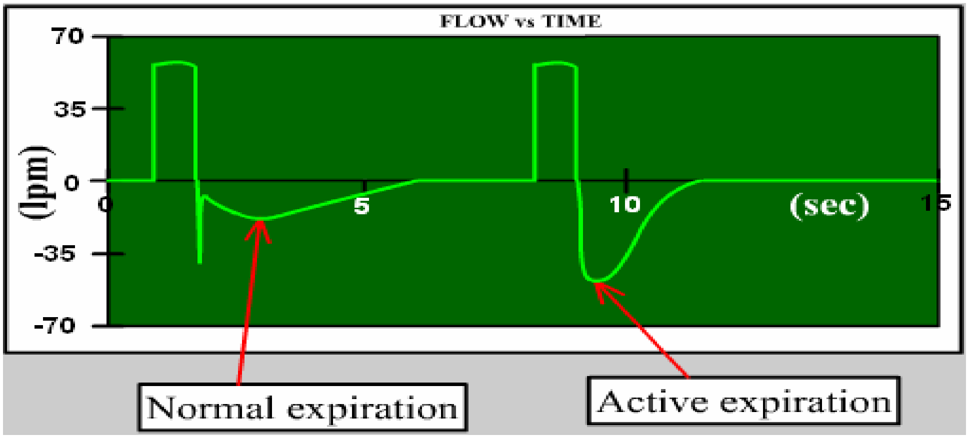

Figure 2.21: Comparison between normal expiration and active expiration
Acknowledgement: Viasys

Figure 2.21, displaying passive and active expiration, can be explained as follows:

* During active exhalation the peak expiratory pressure increases, and this results in a shorter expiratory time.

When an active exhalation effort is superimposed on a normal exhalation effort, changes in peak expiratory pressure and expiratory time are even more evident. Refer to Figure 2.22 on page 34 (Macintyre 1998:2-6).

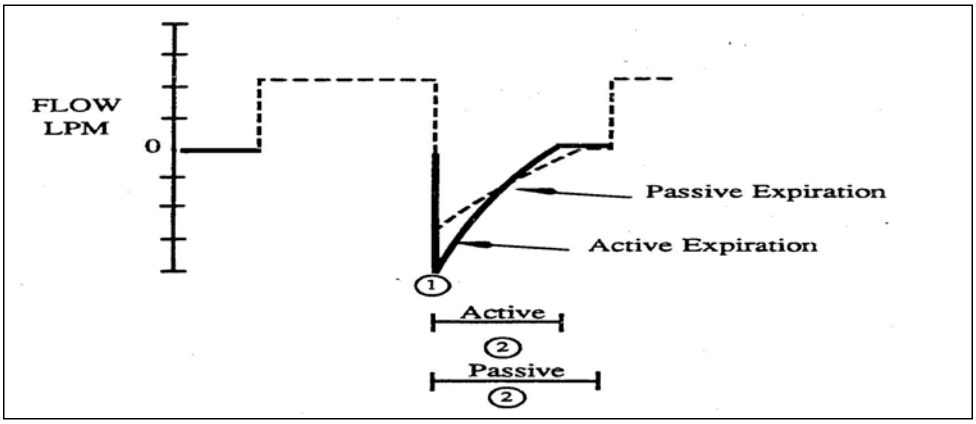

Figure 2.22: Expiratory flow graphic indicating passive and active expiration
Acknowledgement: Macintyre

Figure 2.22, representing a flow-time waveform, can be explained as follows:

- An active exhalation effort is superimposed upon a normal exhalation effort (illustrated in dotted lines), with the increase in peak pressure indicated by [1].
- Active expiration results in a reduction in expiration time. This is indicated as Active [2]. The normal expiration time for passive expiration is indicated as Passive [2].

In a mechanically ventilated patient, various factors can adversely affect flow patterns. Factors influencing the patient's airway are considered less constant than factors affecting the ventilator circuit. Airway resistance in a patient is caused by factors such as the use of muscles during exhalation, neurological disorders, and respiratory insufficiency (Viasys [S.a.]a). Bronchospasm and airway obstruction can also affect flow patterns.

Flow patterns are also influenced by ventilator circuit factors. These include the size and length of the endotracheal tube, the internal diameter and length of the ventilator circuit, as well as the exhalation valve and/or the volume monitoring system resisting airflow (Macintyre 1998:2-4). When a set tidal volume is delivered at a set flow, thinner and longer tubes will produce larger resistance to airflow than thicker, shorter tubes (Ouellet 1997:30). Figure 2.23 graphically illustrates the effects of increased expiratory resistance.

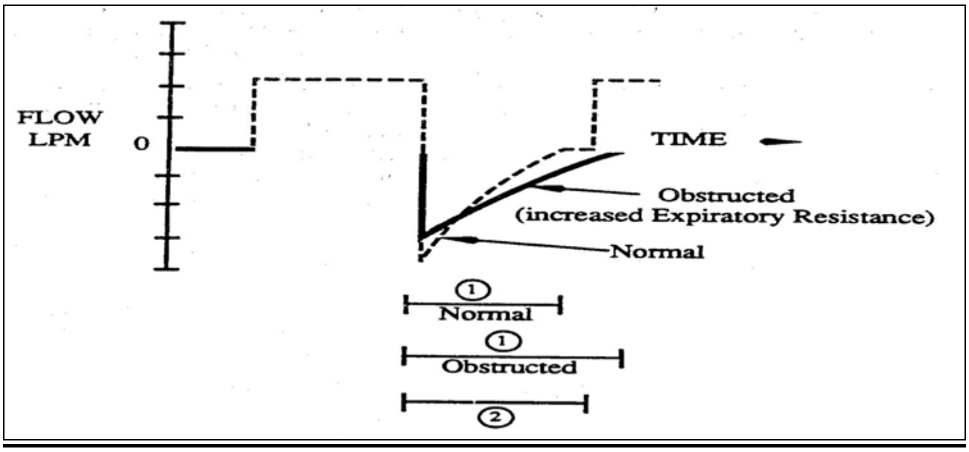

Figure 2.23: Flow graphic indicating effects of obstruction on expiratory time and flow
Acknowledgement: Macintyre

Figure 2.23, representing a flow-time waveform, is explained as follows:

- Note the duration of obstructed expiratory flow (represented by [1]) exceeds the time that is available for expiration (represented by [2]).
- If airway obstruction has occurred, air-trapping or 'stacking' will occur due to incomplete expiration (Macintyre 1998:2-6).

2.5.2 FLOW PATTERNS

For delivering tidal volume, different flow pattern selections are available. The most frequently used patterns are the constant flow pattern (square wave), the decelerating ramp and the sinusoidal flow patterns. By manipulating flow patterns, peak pressures, mean airway pressures and inspiratory time, tidal volume can be influenced. By modifying the flow pattern in order to achieve the same peak flow, the inspiratory time in a volume-cycled breath can be increased (Viasys [S.a.]a). The constant flow waveform, the decelerating flow waveform and a sinusoidal flow pattern will be discussed briefly.

2.5.2.1 Constant flow waveform

The constant flow waveform delivers tidal volume at a stable flow. (Refer to Figure 2.24 on page 36.) Burns (2003:137) explains this as follows: "This means that the speed that the gas is moving at, is essentially the same at the beginning of the breath compared to the end of the breath."

The inspiratory waveform appears square. When the flow-time relationship of the different inspiratory waveforms is compared, it becomes evident that the square wave delivers tidal volume in the shortest inspiratory time. Enough time is allowed for expiration, which may be advantageous for patients who are at risk of developing auto-positive-end-expiratory-pressure (auto-PEEP) (Fenstermacher & Hong 2004:276). The square wave also generates the highest peak inspiratory pressure - PIP (Viasys [S.a.]a).

Figure 2.24 displays a constant flow waveform.

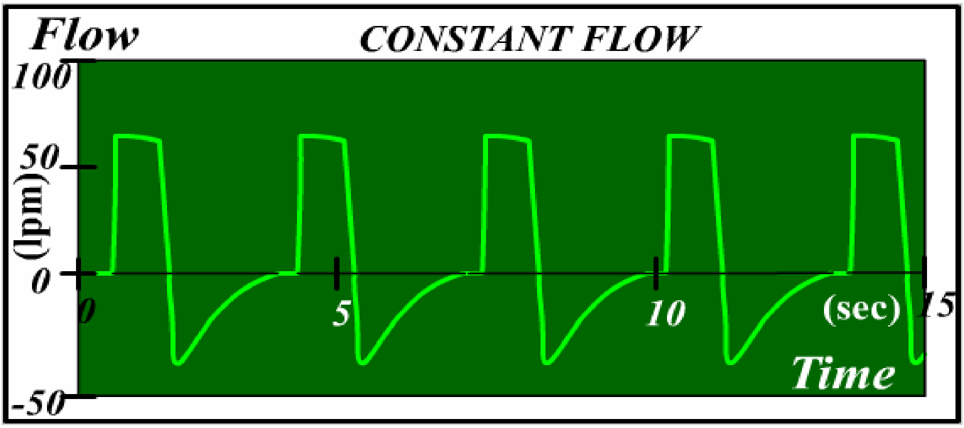

Figure 2.24: Flow-time waveform indicating constant flow
Acknowledgement: Viasys

2.5.2.2 Decelerating flow waveform

A decelerating waveform is the result of a rapid increase in airway pressure at the beginning of inspiration. The inspiratory phase will be prolonged, leaving less time for expiration. This may affect patients with an obstructive airway disease (Viasys [S.a.]a). The decelerating flow pattern delivers tidal volume in the longest inspiratory time, and this has the result of a more even distribution of gases in the lungs. According to Fenstermacher and Hong (2004:276), a decelerating waveform is therefore recommended for patients with primary obstructive airway diseases such as ARDS. These authors state that prolonged decelerating flows produce the highest mean airway pressures, which in turn improve oxygenation. Figure 2.25 displays a decelerating flow pattern.

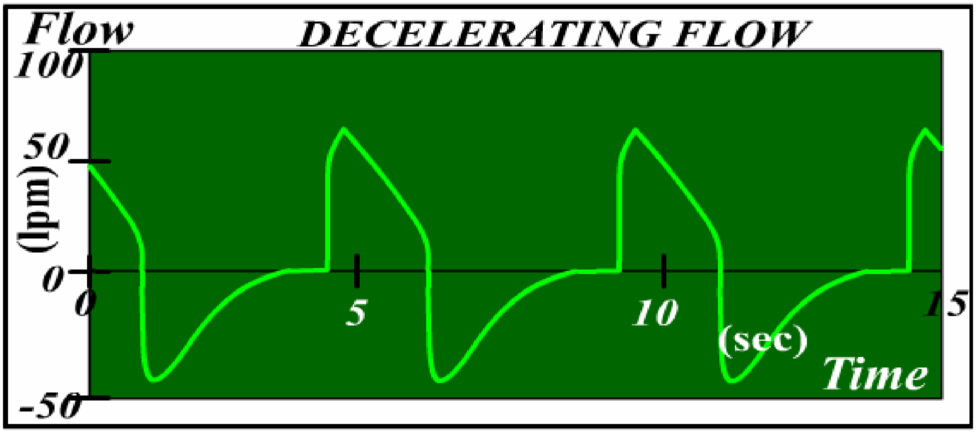

Figure 2.25: Flow-time waveform indicating a decelerating flow pattern
Acknowledgement: Viasys

2.5.2.3 Sinusoidal flow pattern

Sinusoidal flow patterns are seen with spontaneous breathing. (Refer to Figure 2.26.) They are described by Fenstermacher and Hong (2004:276) as "building to a crescendo then tapering off". The inspiratory time is longer than in the decelerating waveform, but it has the same advantage of volume distribution (Viasys [S.a.]a).

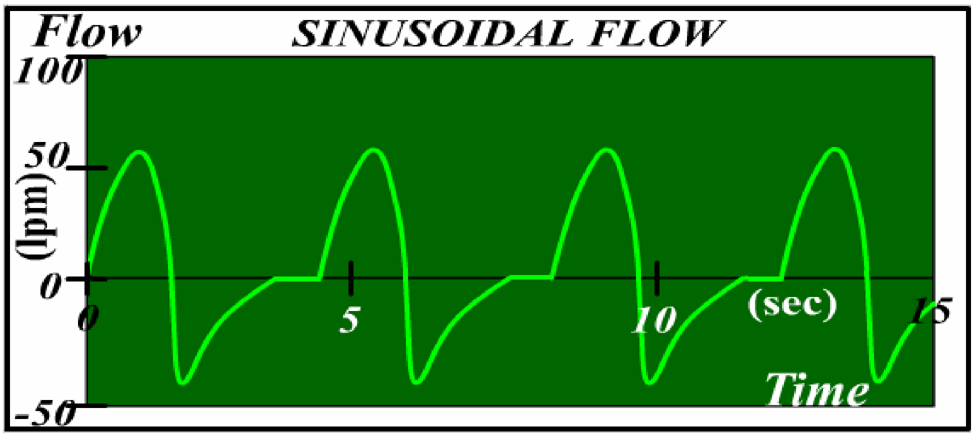

Figure 2.26: Flow-time waveform indicating a sinusoidal flow pattern
Acknowledgement: Viasys

2.5.2.4 Comparison between flow patterns

Changes in the inspiratory time as reflected in the different flow patterns are depicted in Figure 2.27.

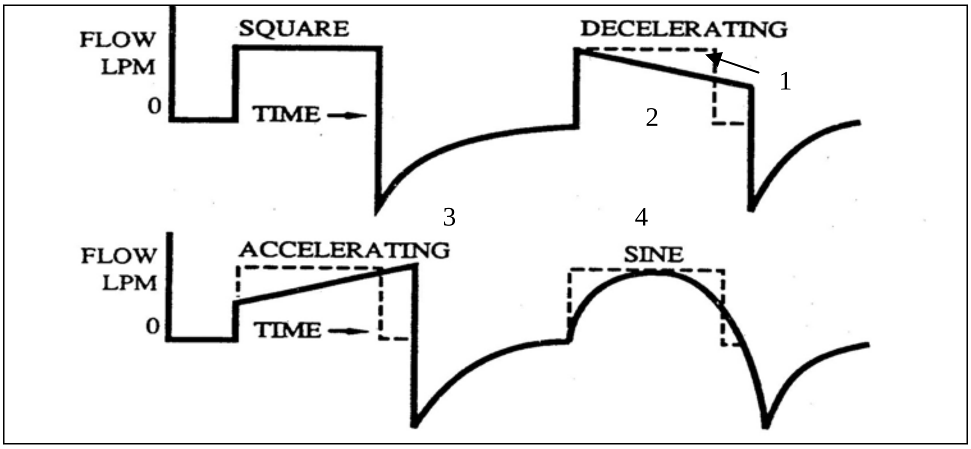

Figure 2.27: Flow graphics indicating changes in the inspiratory time as compared to the square wave *Acknowledgement: Macintyre (Adapted)*

Figure 2.27 represents four flow-time waveforms that can be explained as follows:

- The first flow-time waveform is the square wave. The square wave is superimposed on the decelerating, accelerating and the sinusoidal waveform respectively.
- When the square waveform [1] (in dotted lines) is compared to the decelerating waveform [2], it is evident that the inspiratory time for the decelerating flow delivery breath is longer than for the square wave delivery breath.
- The accelerating flow pattern [3] also requires a longer inspiratory time and reaches PIP just before cycling occurs.
- The sinusoidal [4] waveform also requires a longer inspiratory time to deliver the same tidal volume.

2.5.3 APPLICATION OF VENTILATOR GRAPHICS: CHANGES IN MECHANICAL PROPERTIES

According to Burns (2003:137), the flow-time waveform is useful for assessing auto-PEEP and the patient's response to therapy, such as bronchodilator use for asthma. A discussion on the mechanical properties of ventilator graphics follows.

2.5.3.1 Normal constant flow

As stated in Subsection 2.5.2.1, the normal constant waveform delivers tidal volume in the shortest inspiratory time, leaving ample time for expiration, which may be beneficial to patients who are at risk of developing auto-PEEP (Fenstermacher & Hong 2004:276). For a detailed description, the reader is referred back to Subsection 2.5.2.1 that also includes a graphic of a normal constant flow-time waveform (Figure 2.24). To emphasise the flow pattern and facilitate further comparison, a second example of a normal constant flow-time waveform is included as Figure 2.28 below (Viasys [S.a.]a).

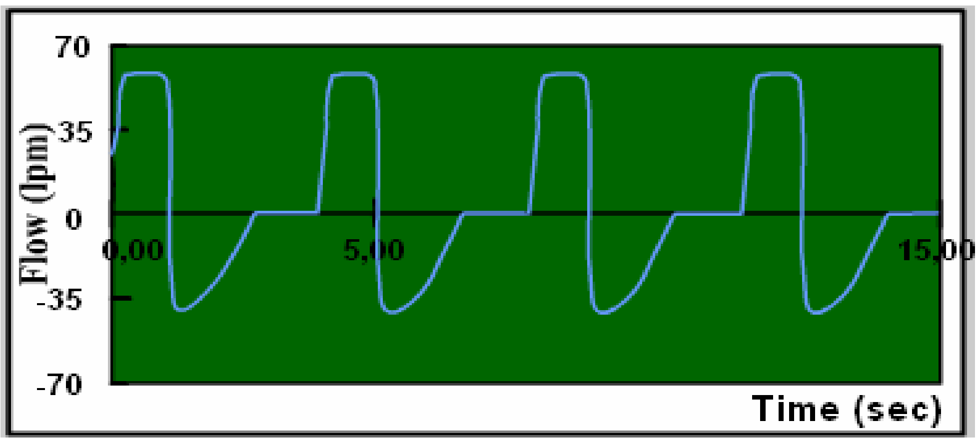

Figure 2.28: Normal constant flow waveform
Acknowledgement: Viasys

2.5.3.2 Decrease in lung compliance

Fenstermacher and Hong (2004:280) describe compliance as "... the lung's ability to distend and its elastic quality to recoil after being stretched". Lung compliance can decrease without effecting resistance to airflow. This will result in an increase in pressure at the end of inspiration because the alveoli would be less accommodating than the airways (the unaffected trachea, bronchi and bronchioli). In Figure 2.29, the normal constant flow pattern is indicated in blue, while the green expiratory flow graph illustrates a decrease in lung compliance.

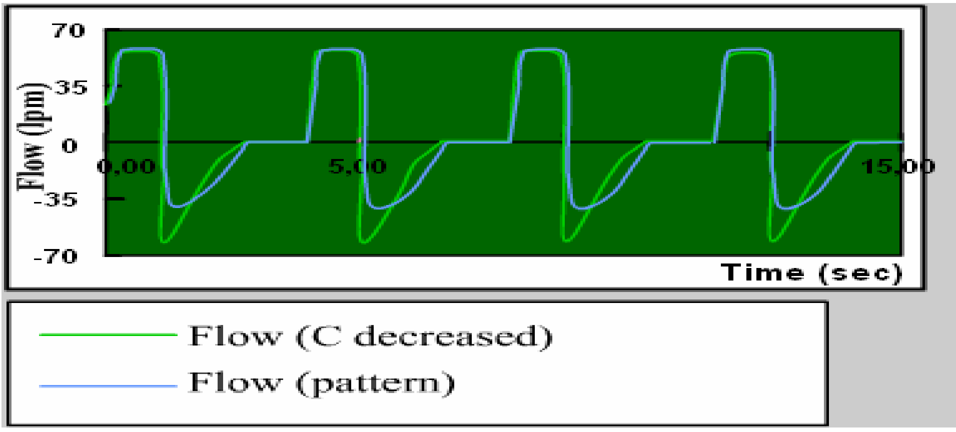

Figure 2.29: Indicating a decrease in lung compliance
Acknowledgement: Viasys

To reiterate, a decrease in lung compliance should not be confused with an increase in airway resistance to airflow. Viasys ([S.a.]a) points out that the effects on the pressure curve (peak airway pressure and plateau pressure) should be observed in this case.

2.5.3.3 Increase in airway resistance

Burns (2001:161) describes airway resistance as “a measure of how easy it is to move gases down the airways” or, in other words, the resistance of the airways to the flow of gas. According to Rittner and Döring ([S.a.]), an increase in airway resistance can be the result of disease, accumulation of secretions, or fluid in the lungs. Burns (2003:138) suggests bronchospasm as a cause of increased airway resistance. The effects of this disease on expiratory flow are illustrated in Figure 2.30 on page 41.

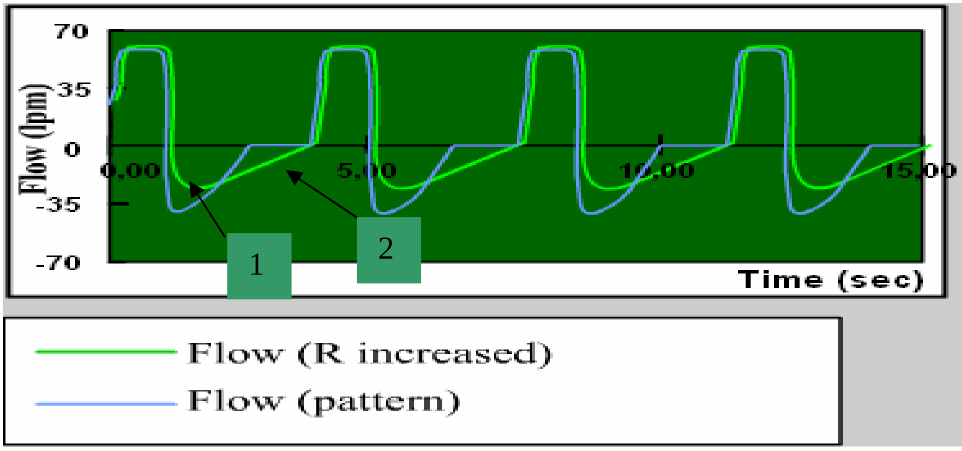

Figure 2.30: Indicating effects of increased airway resistance on expiratory flow
Acknowledgement: Viasys

Figure 2.30, representing a flow-time waveform, can be explained as follows:

- The blue wave indicates a normal constant flow pattern, while the green wave indicates the effects of airway resistance on expiratory flow.
- Note the decrease in expiratory peak flow, indicated by [1], and a marked change in the slope of the expiratory waveform (indicated by [2]), resulting in insufficient time to eliminate the air volume existing in the lungs (Viasys [S.a.]a).
- The effects of bronchodilator therapy would be seen when the green wave becomes more similar to the blue wave, and the blue flow pattern returns.

2.5.3.4 Auto-PEEP

Auto-PEEP is the term used to refer to the air trapped in the airways when insufficient expiratory time is allowed. According to Fenstermacher and Hong (2004:264), patients at high risk of developing auto-PEEP include patients with a history of chronic obstructive pulmonary disease (COPD), status asthmaticus and occasional bronchospasms.

Auto-PEEP can develop in the following cases:

- The patient is manually Ambu-bagged, and insufficient time allowed for exhalation; or
- The patient is mechanically ventilated with either a fast respiratory rate or an increased inspiratory time.

Auto-PEEP can be detected in a flow-time waveform that does not return to zero at the end of exhalation (Viasys [S.a.]a) as depicted in the second (bottom) graph in Figure 2.31 below. It is however not identifiable on the pressure-time waveform (top graph) due to the fact that the volumes retained in the alveoli are not significant enough to be easily detected on the pressure waveform. Thus, Figure 2.31, displaying a flow-time (bottom) and a pressure-time (top) waveform, shows how auto-PEEP can be detected on a flow-time waveform.

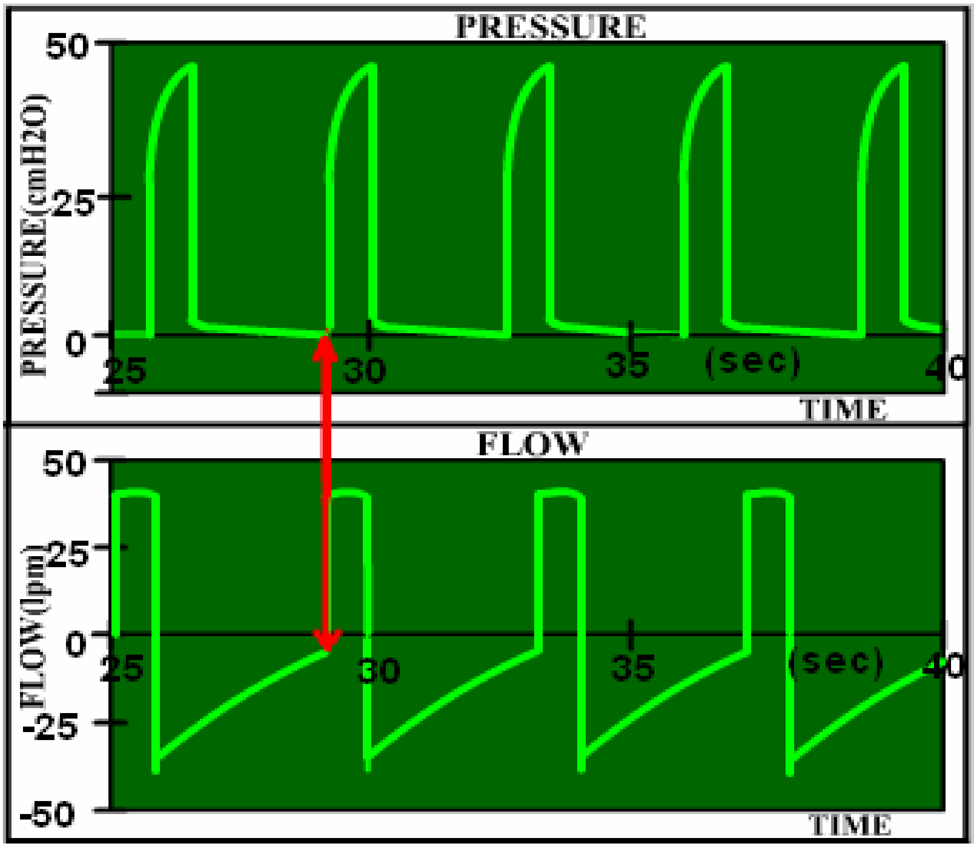

Figure 2.31: Flow-time waveform indicating the presence of auto-PEEP
Acknowledgement: Viasys

2.6 UNDERSTANDING VOLUME GRAPHICS

In volume graphics the volume is plotted on the vertical axis and time on the horizontal axis. The tidal volume, *i.e.* the volume inspired and exhaled by the patient with each breath, is represented by these kinds of graph (Viasys [S.a.]a). Refer to Figure 2.32.

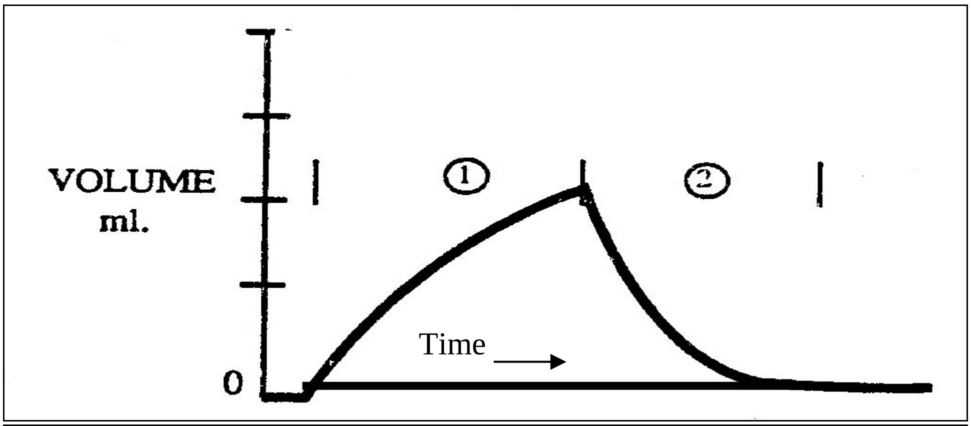

Figure 2.32: Volume-time waveform
Acknowledgement: Macintyre (Adapted)

Figure 2.32 represents a volume-time waveform that can be explained as follows:

- The initial rise in volume is represented by [1]. In volume modes, this is the preset tidal volume. In a pressure mode, volume is dependent upon the pressure, time, and lung compliance. Also see Figure 3.33 below.
- The total expiratory volume is represented by [2].
  (Macintyre 1998:2-14.)

During a breath cycle the volume of gas inhaled should equal the gas exhaled. However, in case of leaks or disconnection in the patient circuit or the development of air-trapping or auto-PEEP, the expired tidal volume would be less. The effects of air-trapping are illustrated in Figure 2.33 on page 44.

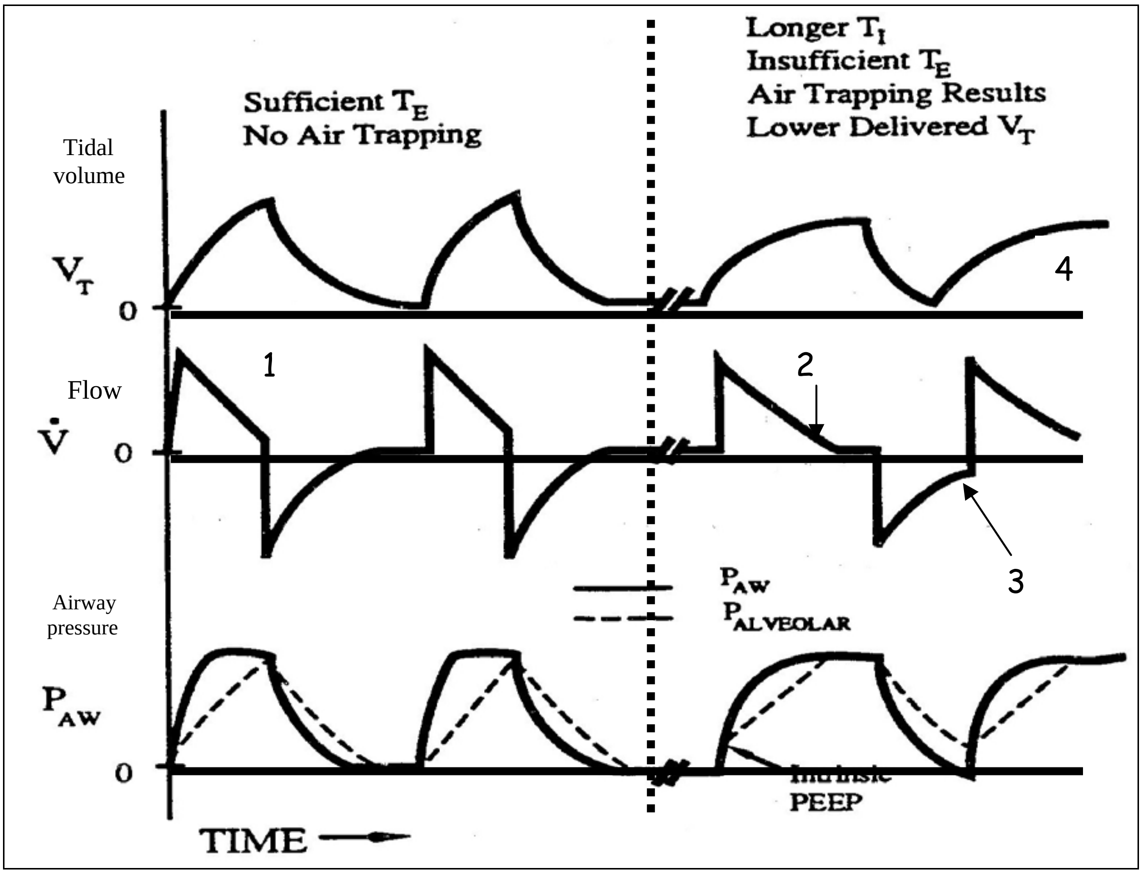

Figure 2.33: Indicating the effects of air-trapping
Acknowledgement: Macintyre (Adapted)

Figure 2.33, illustrating the effects of air-trapping, can be explained as follows:

- The first two breaths (indicated by [1]) represent normal tidal volumes and normal flow waveforms.
- The third breath has a longer inspiratory time (indicated by [2]), which results in insufficient expiratory time, indicated by [3]. The next flow wave, therefore, starts below the baseline, and delivers a lower tidal volume, indicated by [4]. With respect to the pressure-time waveform, examine the changes in airway and alveolar pressure.

2.7 UNDERSTANDING PRESSURE GRAPHICS

2.7.1 PRESSURE WAVEFORM

A spontaneous breath can be distinguished from a mechanical breath by virtue of the appearance of their pressure waveforms during real-time graphical displays or on paper copy.

Figure 2.34 depicts a normal spontaneous breath (Macintyre 1998:2-7).

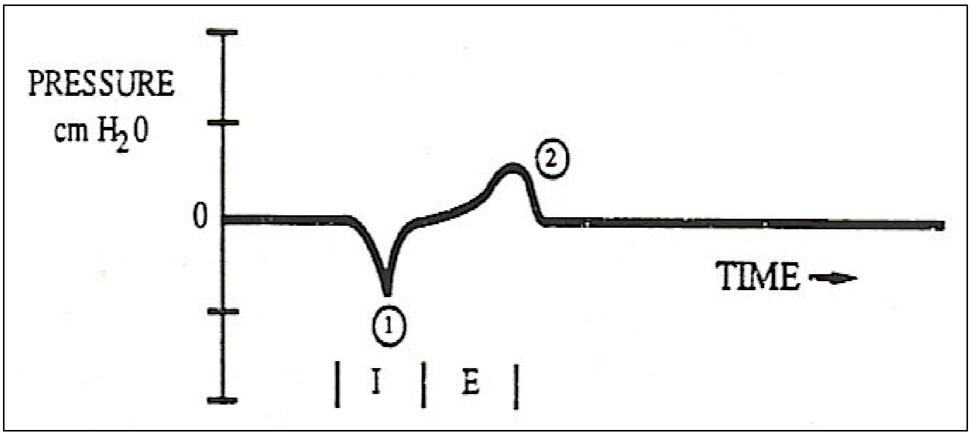

Figure 2.34: Indicating the pressure waveform of a spontaneous breath
Acknowledgement: Macintyre

Figure 2.34, representing a normal spontaneous breath, is explained as follows:

- The negative pressure that acts just before the start of inspiration is presented by [1].
- The rise in pressure during inspiration and the start of the expiratory phase is represented by [2]. Because the peak expiratory flow rate increases when the respiratory muscles are active during the expiratory phase, the pressure may rise more dramatically if the patient were exhaling actively or forcibly (Macintyre 1998:2-7).

Volume controlled and pressure controlled ventilation results in pressure-time waveforms that differ in appearance. Figure 2.35 represents a ventilator delivered breath during a volume controlled mode of ventilation. According to

Visser (2004a), the pressure-time waveform of a volume controlled breath has a 'shark-fin' appearance.

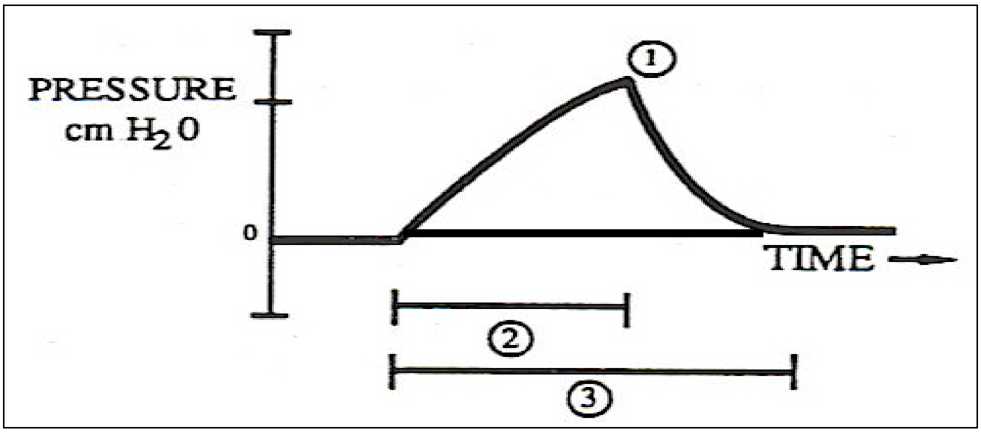

Figure 2.35: Indicating the pressure waveform of a mechanical breath during a volume controlled mode of ventilation *Acknowledgement: Macintyre*

Figure 2.35, representing a mechanical breath during a volume controlled mode of ventilation, is explained as follows:

- Peak inflation pressure or PIP is indicated by [1]. Peak pressure is determined by the patient's lung and circuit compliance and resistance as well as the delivered tidal volume and set flow rate. There is no negative deflection at the onset of inspiration.
- The inspiratory time is indicated by [2].
- The duration of positive pressure is represented by [3].
  (Macintyre 1998:2-8.)

For a pressure-time waveform during a pressure controlled mode of ventilation refer to Figure 2.36 on page 47.

The pressure-time waveform of a pressure controlled breath appears square in comparison with the fin-shaped pressure-time waveform of the volume controlled breath (Figure 2.35 above).

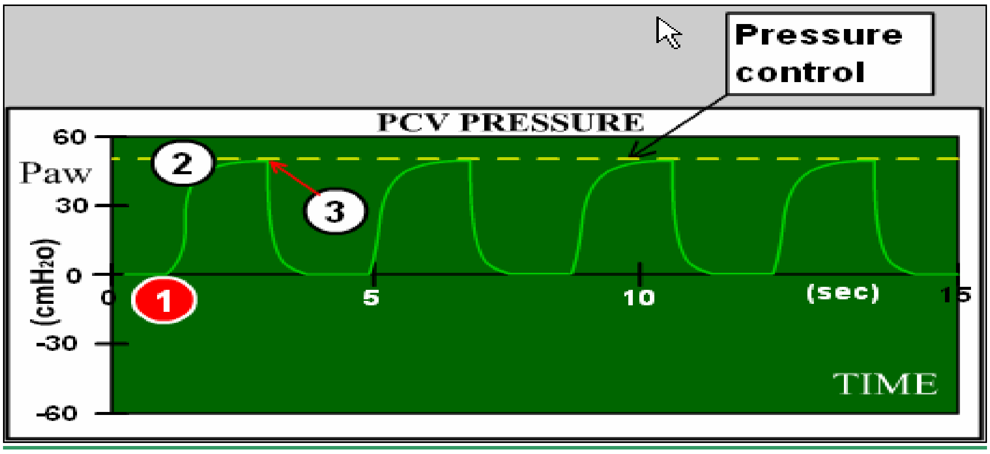

Figure 2.36: Indicating a pressure-time waveform during a pressure controlled mode of ventilation *Acknowledgement: Viasys*

Figure 2.36 illustrates a pressure-time waveform of a pressure controlled breath. It can be explained as follows:

- The trigger point is represented by [1]. If the breath is patient-triggered (assisted), a negative deflection is present, meaning the trigger point is below the set baseline pressure level. When a deflection is absent, the breath is ventilator-triggered (controlled).
- PIP (represented by [2]) is fixed, and is to be exerted throughout the inspiratory phase. Ideally, the pressure would remain constant throughout inspiration.
- Breaths are time-cycled: Inspiratory time or the I:E ratio can be set, in which case the ventilator will calculate the corresponding expiratory time. When the set inspiratory time is reached, cycling (indicated by [3]) is produced, and expiration allowed. (Viasys [S.a.]a.)

Figure 2.37 on page 48 illustrates a pressure-time waveform in colour codes. Each of the four colour-coded respiratory aspects, namely the trigger [1], inspiratory curve (including PIP) [2], inspiratory pause [3] and expiratory phase [4] will be discussed separately. The expiratory pressure and the mean pressure will also be discussed shortly.

2.7.1.1 Trigger

With reference to the discussion on trigger mechanisms (Subsection 2.4.3), the negative deflection (marked as the yellow trigger in Figure 2.37) indicates that the patient has initiated this breath, hence a patient-triggered breath. According to Burns (2003:134), the starting point or the trigger would reflect either zero or the PEEP value.

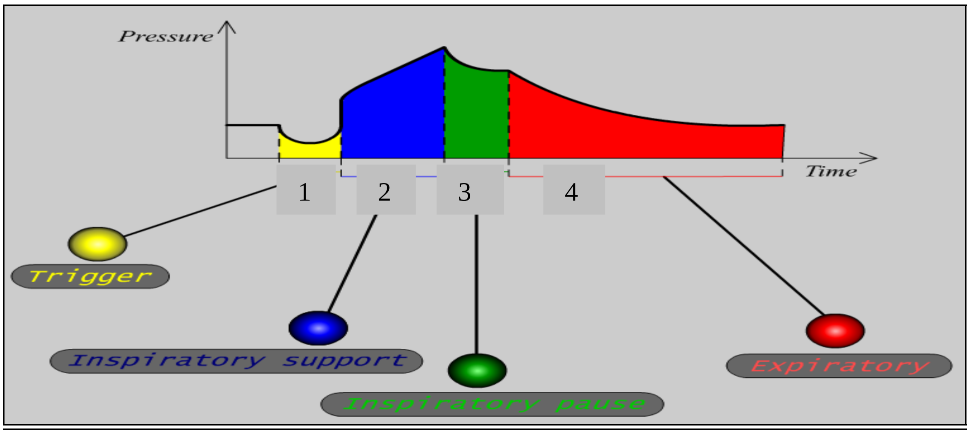

Figure 2.37: Colour-coded pressure-time waveform
Acknowledgement: Viasys (Adapted)

According to Figure 2.37, the patient had reached the preset assist sensitivity threshold and consequently the ventilator assisted the breath.

Quite the reverse is true in Figure 2.38 below.

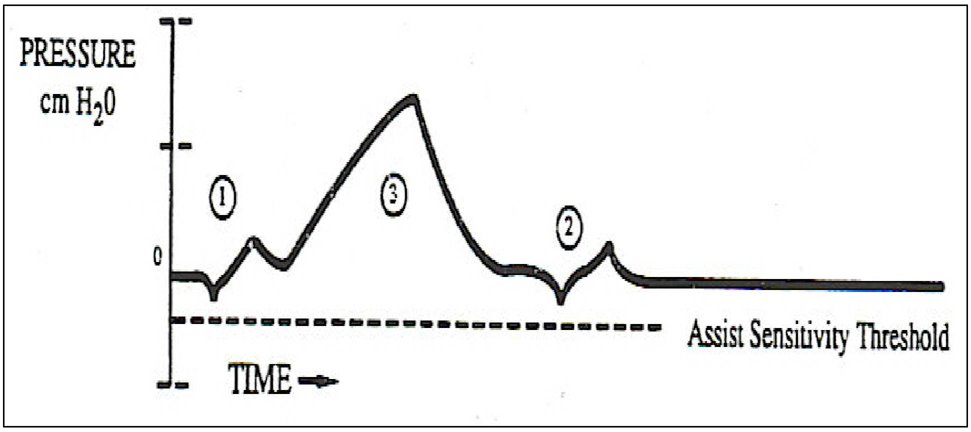

Figure 2.38: Patient effort insufficient to cycle mechanical breath
Acknowledgement: Macintyre

Figure 2.38 represents a pressure-time waveform with the dotted line indicating the assist sensitivity threshold. The graph can be explained as follows:

- Numbers [1] and [2] would represent shallow patient breaths that did not meet the assist sensitivity threshold and, therefore, the ventilator did not assist the breaths (Macintyre 1998:2-12).
- Number [3] indicates a ventilator controlled breath following the lapse of the time trigger.

2.7.1.2 Inspiratory curve or slope rise

The pressure wave's inspiratory limb has characteristically a linear or even-bowed upward rise in pressure following the trigger. This rise would reflect the ventilator's response to the patient's effort at initiating the breath (Fenstermacher & Hong 2004:277). See Figure 2.39.

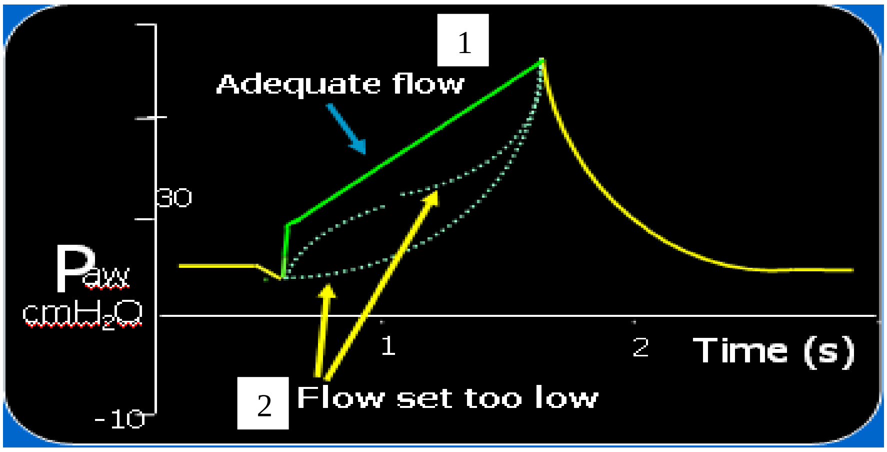

Figure 2.39: Pressure-time waveform indicating normal flow rise
Acknowledgement: Newport (In: Visser)

Figure 2.39 represents a pressure-time waveform with a linear inspiratory limb. The graph can be explained as follows:

- The green inspiratory limb reflects an adequate airflow setting with the resulting linear rise in pressure toward PIP, indicated by [1].
- The dotted lines (curving inwards) reflect insufficient airflow; thus, a slow rise in pressure. The concave shape of the inspiratory limb of the pressure wave (marked [2]) is an indication that an increase in flow is required (Visser 2004a).

According to Fenstermacher and Hong (2004:277), patients suffering from COPD or restrictive lung diseases would benefit from a faster delivery of peak flow. To achieve this, a shorter rise time is selected. The opposite proves to be true for patients with noncompliant lungs. Lengthening the rise time would delay reaching the pressure limit. The effects of different airflow settings are illustrated in Figure 2.40.

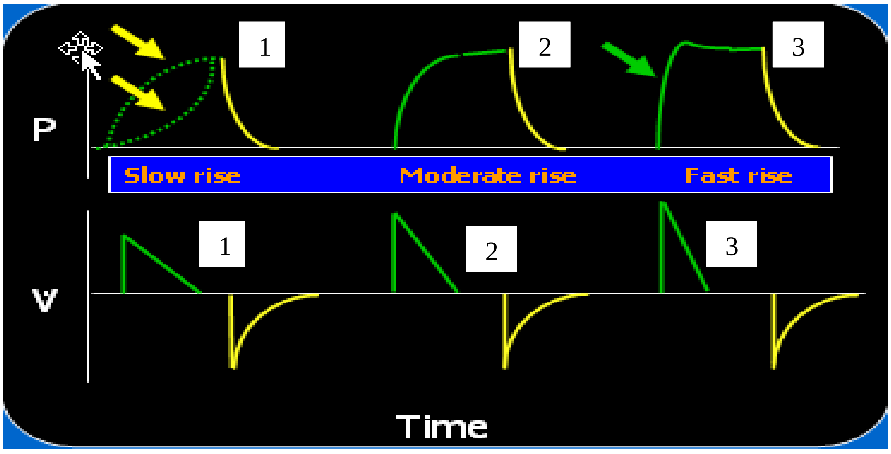

Figure 2.40: Pressure-time and flow-time waveforms during different flow settings *Acknowledgement: Newport (In: Visser) (Adapted)*

Figure 2.40 represents pressure-time and flow-time waveforms during different airflow settings. These waveforms can be explained as follows:

- Inspiration is coloured green, and expiration yellow. The slope rise/inspiratory rise, according to Visser (2004a), should be a quick upswing, indicated by [2]. On the flow-time waveform, a normal I:E ratio is illustrated.
- When inspiratory flow is set too low, a slow rise will occur as indicated by the concave shape of the inspiratory limb [1] on the pressure-time waveform. A longer inspiratory time is required as indicated by [1] on the flow-time waveform. Peak pressures are correspondingly lower in breath number [1] than in breath number [2].
- When a high inspiratory flow is selected, as indicated by [3] on the pressure-time waveform, tidal volume will be delivered quickly. Inspiratory time will decrease, as indicated by [3] on the flow-time waveform. PIP will be higher than in breath number [2].

2.7.1.3 Peak inspiratory pressure (PIP)

Fenstermacher and Hong (2004:280) describe PIP as "… the driving pressure that is needed to instill the prescribed volume from the ventilator down an artificial airway into the lungs." Peak pressure is dependent on several factors, including lung and chest wall compliance, airway resistance, tidal volume, and flow pattern. Other factors that cause a change in peak flow are an increase or a decrease in inspiratory flow and the presence of auto-PEEP. Refer to Figures 2.41 and 2.42.

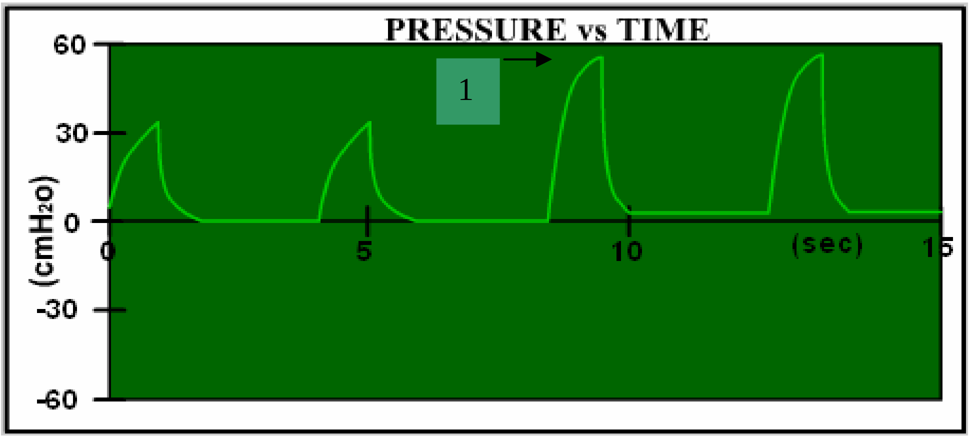

Figure 2.41: Increase in peak pressure due to an increase in inspiratory flow
Acknowledgement: Viasys (Adapted)

The pressure-time waveform in Figure 2.41 can be explained as follows:

- An increase in inspiratory flow generates an increase in PIP, as indicated by [1].

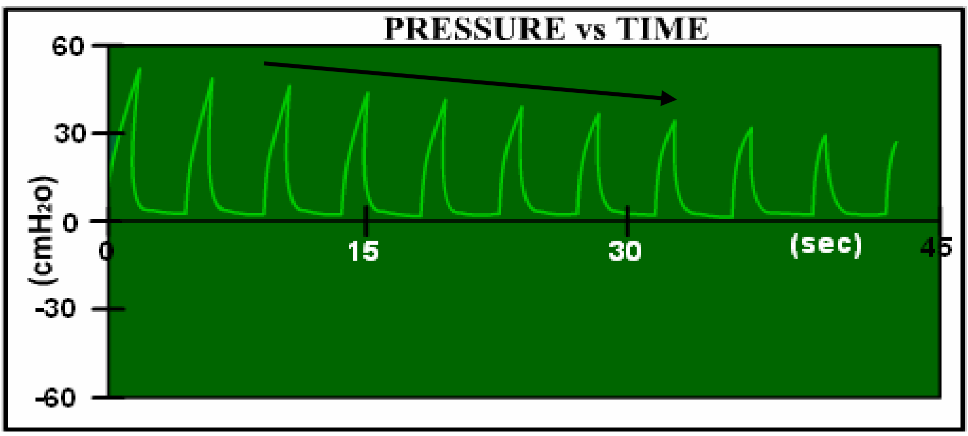

Figure 2.42: Decrease in peak pressure due to a decrease in inspiratory flow
Acknowledgement: Viasys (Adapted)

Figure 2.42, depicting a pressure-time waveform with descending peak pressures, can be explained as follows:

- PIP is visibly decreasing. This is generated by lowering flow by 10 L/min every two respiratory cycles (Viasys [S.a.]a). Compare this to Figure 2.41 on page 51.

2.7.1.4 *Inspiratory pause*

According to Fenstermacher and Hong (2004:280), inspiratory pause reflects lung and chest wall compliance. It remains part of the inspiratory value of the I:E ratio. Refer to Figure 2.43.

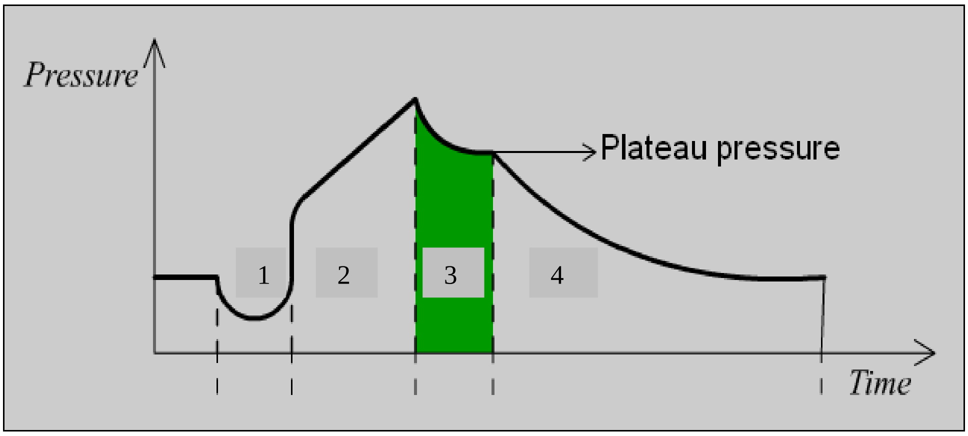

Figure 2.43: Inspiratory pause indicated by 3
Acknowledgement: Viasys (Adapted)

Figure 2.43, highlighting an inspiratory pause as part of a pressure-time waveform, can be explained as follows:

- The inspiratory pause does not always appear – only if inspiratory time is set with a distinct pause time as indicated by [3]. (Also refer to Figure 2.37.) Inspiratory flow ceases during the inspiratory pause. Alveolar pressure, resistance and static compliance values are measured during this no-flow state.

According to Viasys ([S.a.]a), plateau pressure (indicated on the graph) represents alveolar pressure, *i.e.* "…the pressure required distending the alveoli in zero flow condition...". Also refer to Figure 2.44 on page 53.

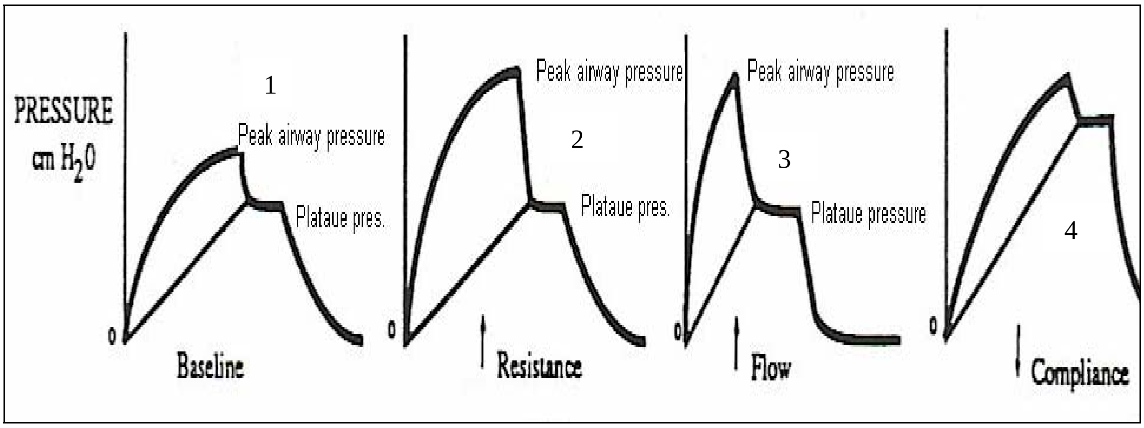

Figure 2.44: Effect of resistance, flow and compliance on PIP and plateau pressure for a given tidal volume *Acknowledgement: Macintyre (Adapted)*

Figure 2.44, representing four pressure-time waveforms, can be explained as follows:

- A normal baseline pressure-time graphic is represented by number [1]. The peak airway pressure (or PIP) is indicated, and the plateau pressure as well.
- An increase in resistance, resulting in an increase in PIP, is represented by the second pressure-time waveform. The plateau pressure/alveolar pressure has remained unchanged (Macintyre 1998:2-9). Viasys ([S.a.]a) states that the difference between PIP and plateau pressure/alveolar pressure reflects the magnitude of the resistance.
- An increase in inspiratory flow, indicated by [3], correspondingly results in an increase in PIP. Once again plateau pressure has not been affected by the change.
- However, a decrease in compliance, as represented by [4], leads to an increase in both PIP and plateau pressure. Fenstermacher and Hong (2004:280) describe a noncompliant lung as a lung "…commonly referred to as being stiff, as it takes more pressure to deliver a targeted tidal volume."

2.7.1.5 Expiratory phase

Expiration is normally a totally passive phenomenon. During expiration, pressure is primarily determined by lung compliance, expiratory resistance of the respiratory system and ventilator circuit, and the length and diameter of the ventilator circuit. In both Figures 2.37 and 2.45, the expiratory phase is shaded red and numbered [4].

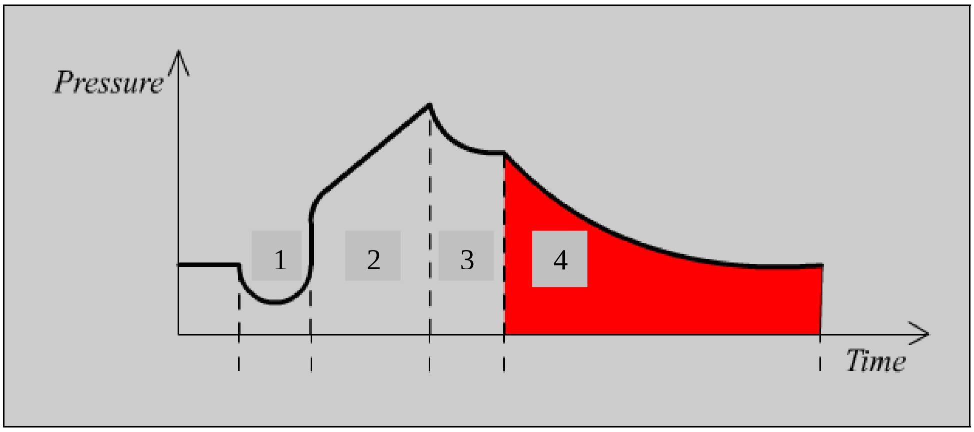

Figure 2.45: Expiratory phase indicated by number 4
Acknowledgement: Viasys (Adapted)

2.7.1.6 Expiratory pressure

Expiratory pressure refers to the pressure in the circuit during the expiration phase (Viasys [S.a.]a). In both the spontaneous breath and the mandatory breath, the cycle ends and starts at zero level; therefore, expiratory pressure should be measuring at zero at the end of expiration. However, if PEEP (mandatory breaths) or CPAP (spontaneous breaths) is used, the cycle will begin and end at the PEEP or CPAP level selected for the patient (Viasys [S.a.]a). With reference to the pressure-time waveform displayed in Figure 2.48, the PEEP/CPAP is set at 10 cmH_2O.

Compare Figures 2.46, 2.47 and 2.48 on page 55.

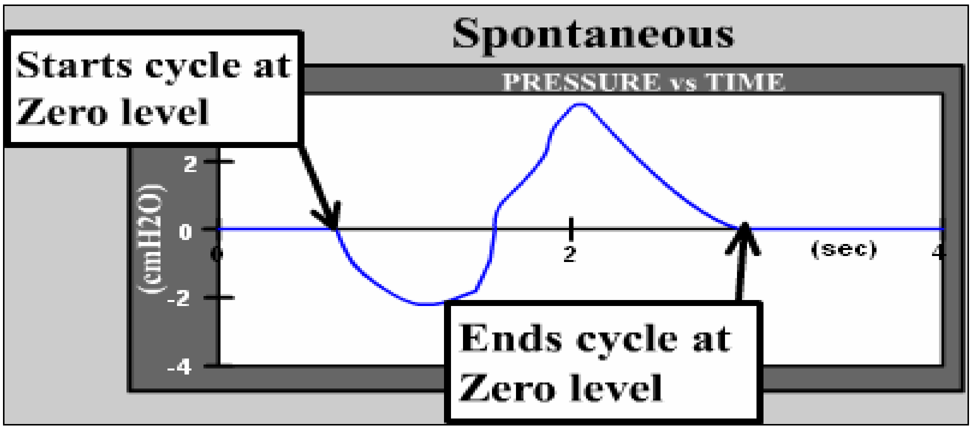

Figure 2.46: Indicating expiratory pressure during spontaneous ventilation
Acknowledgement: Viasys

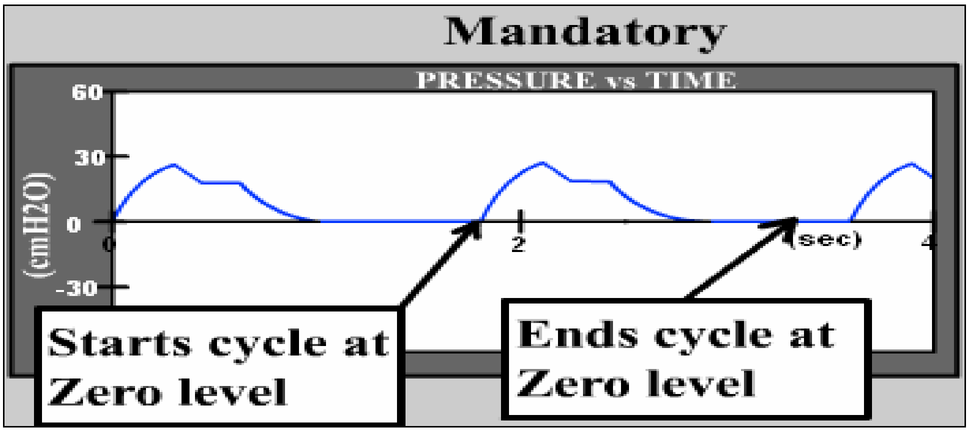

Figure 2.47: Indicating expiratory pressure during mechanical ventilation
Acknowledgement: Viasys

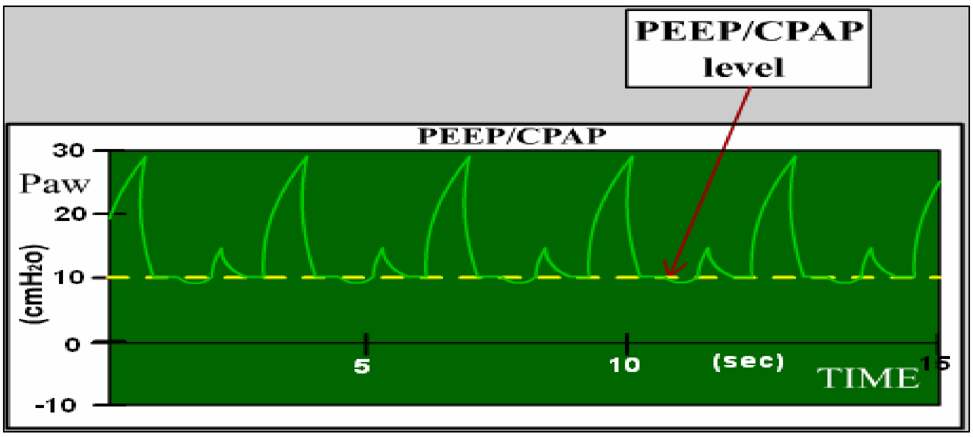

Figure 2.48: Indicating expiratory pressure when PEEP/CPAP is set at 10 cmH_2O
Acknowledgement: Viasys

2.7.1.7 Mean pressure

Mean pressure is the average pressure of a respiratory cycle and cannot be seen as a specific point on the pressure graphic. Some ventilators calculate the mean pressure and then indicate it conceptually and/or visually on the waveform (Viasys [S.a.]a). Refer to Figure 2.49.

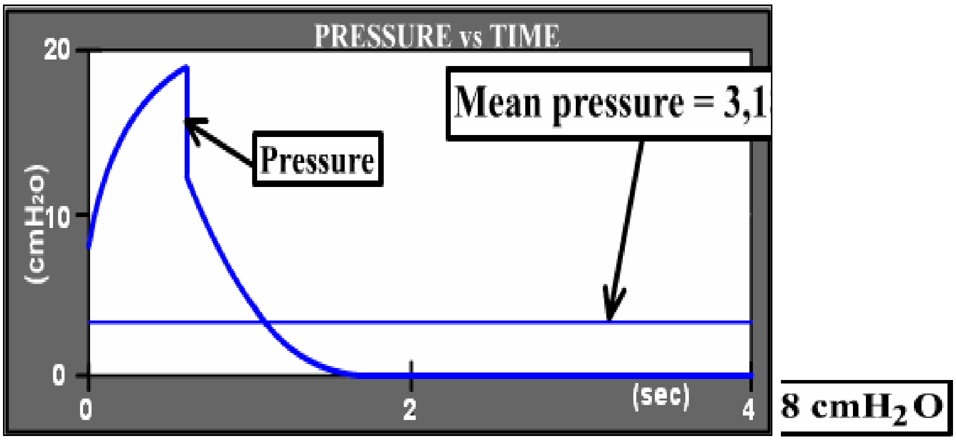

Figure 2.49: Indicating mean pressure visually and conceptually on a graph
Acknowledgement: Viasys

Mean pressure is affected by an increase in any of the following: PEEP, peak pressures (as discussed previously) or inspiratory time (Viasys [S.a.]a).

Under certain circumstances, in order to improve gas exchange, an increase in mean pressure is indicated. However, increasing mean pressure can have side effects such as decreasing venous return. Although gas exchange might be improved somewhat, a decrease in venous return could prove to be a greater contra-indication. The objective is increasing mean pressure while maintaining gas exchange at a desirable value (Viasys [S.a.]b).

2.8 UNDERSTANDING LOOP GRAPHICS

2.8.1 PRESSURE-VOLUME LOOPS

In flow, pressure or volume graphics the parameters are singularly compared to time. However, when these parameters are plotted against each other, because of the fact that the beginning of inspiration coincides with the end of expiration and the tracing is a closed curve, the graphic is called a loop (Macintyre 1998:2-18). The advantage of a loop graphic is that the interaction of two variables can be appreciated within the same graphic (Viasys [S.a.]b). For the purposes of this study, pressure-volume and flow-volume loops will be discussed.

Rittner and Döring ([S.a.]:19) describe the creation of a pressure-volume loop as plotting the actual pressure, milliseconds after a small increase in volume is delivered. Refer to Figure 2.50.

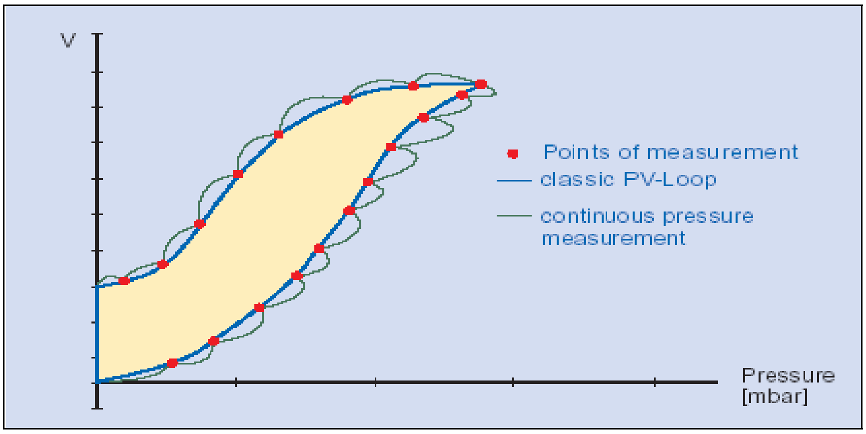

Figure 2.50: Pressure-volume loop measurement
Acknowledgement: Dräger (In: Rittner and Döring)

Figure 2.50, illustrating pressure-volume measuring, can be explained as follows:

- The dots represent the relationship between the increase in volume and the corresponding increase in pressure.
- The link between the dots represents continuous pressure measurement and is reflected as the pressure-volume loop (Rittner & Döring [S.a.]:21).

Loops may circle either *clockwise* or *anticlockwise*, depending on the mode of ventilation (Viasys [S.a.]b). Spontaneous, volume controlled, pressure controlled, and pressure support ventilation loops are discussed.

2.8.2 MODES OF VENTILATION PRESENTED AS PRESSURE-VOLUME LOOPS

2.8.2.1 Spontaneous ventilation

A pressure-volume loop representing a spontaneous breath starts at zero pressure and circulates *clockwise*. The patient's inspiratory effort creates a negative pressure. The inspiratory phase of the loop therefore tends to be on the side of negative pressure, and the expiratory phase on the positive side. If a CPAP value is set, the inspiratory phase will be below this value and the expiratory phase will be above this value, as illustrated in Figure 2.51.

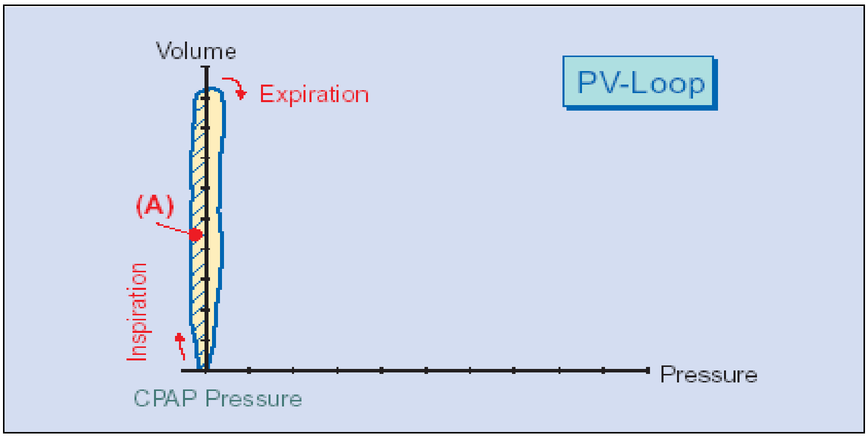

Figure 2.51: Pressure-volume loop representing a spontaneous breath with a set CPAP value
Acknowledgement: Dräger (In: Rittner and Döring)

2.8.2.2 Pressure support ventilation

In this mode of mechanical ventilation, spontaneous breaths are patient-triggered, pressure-limited and flow-cycled. The patient initiates the breath by creating a negative pressure, and this is followed by the ventilator creating flow as a positive pressure (Rittner & Döring [S.a.]:30).

Refer to Figure 2.52 on page 59.

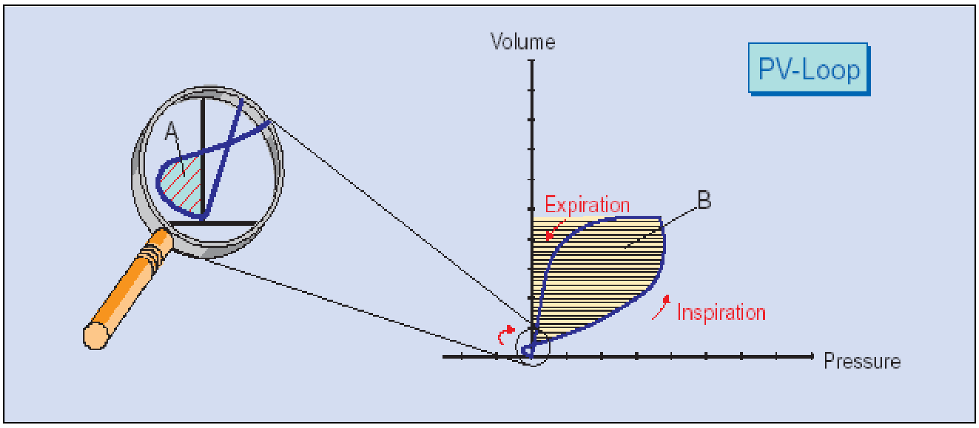

Figure 2.52: Pressure-volume loop representing pressure support ventilation
Acknowledgement: Dräger (In: Rittner and Döring)

Figure 2.52, a pressure-volume loop graphic representing the pressure support mode of ventilation, can be explained as follows:

- The area to the left of the vertical axis indicates the patient's effort to initiate the breath. On the graph, this area is magnified and indicated as A. The loop to the left of the vertical axis circulates *clockwise*.
- The area to the right of the vertical axis represents the work performed by the ventilator to support the patient's breathing efforts. It is indicated as B, and the loop to the right of the vertical axis circulates *anti-clockwise* (Rittner & Döring [S.a.]:30).

2.8.2.3 Volume controlled ventilation

The pressure-volume loop representing a volume controlled mode of ventilation circulates *anti-clockwise*. During volume controlled ventilation, a constant flow of air is delivered to the patient, resulting in a gradual increase in pressure. At the end of inspiration, the pressure in both the lungs and the ventilator circuit is equal. At the beginning of expiration the ventilator opens the exhalation valve at the preset PEEP setting, resulting in a pressure difference between the lungs and the ventilator. This difference allows air to flow out of the lungs (Rittner & Döring [S.a.]:26). Refer to Figure 2.53 on page 60.

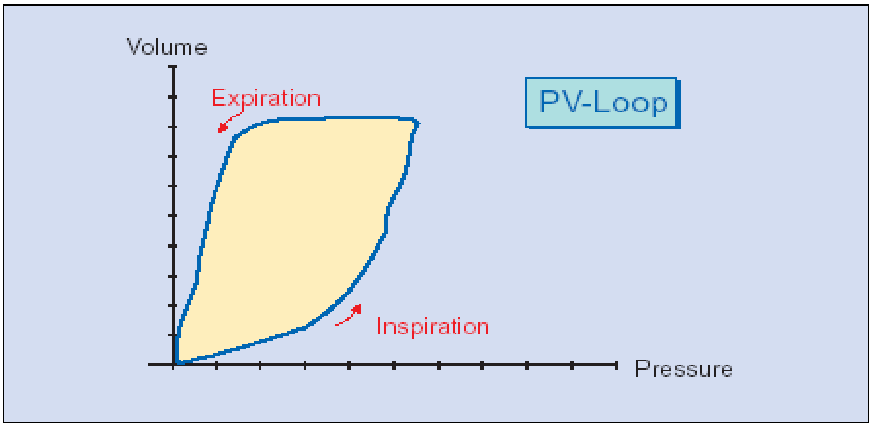

Figure 2.53: Pressure-volume loop representing volume controlled ventilation
Acknowledgement: Dräger (In: Rittner and Döring)

2.8.2.4 Pressure controlled ventilation

The pressure-volume loop representing pressure controlled ventilation also circles *anti-clockwise*. In a decelerating flow delivery, the lungs are not filled with an even flow of air as in a volume controlled mode of ventilation (as stated earlier). In a decelerating air delivery mode, the ventilator generates a greater pressure in the ventilator circuit than in the lungs. The ventilator also maintains this pressure during inspiration. Due to the difference in pressure of the ventilator circuit and the lungs, air flows from the ventilator circuit into the lungs. The volume in the lungs gradually increases, resulting in a corresponding increase in pressure. Rittner and Döring ([S.a.]:28) describe the shape of the pressure-volume loop as more or less 'box-like'. Refer to Figure 2.54.

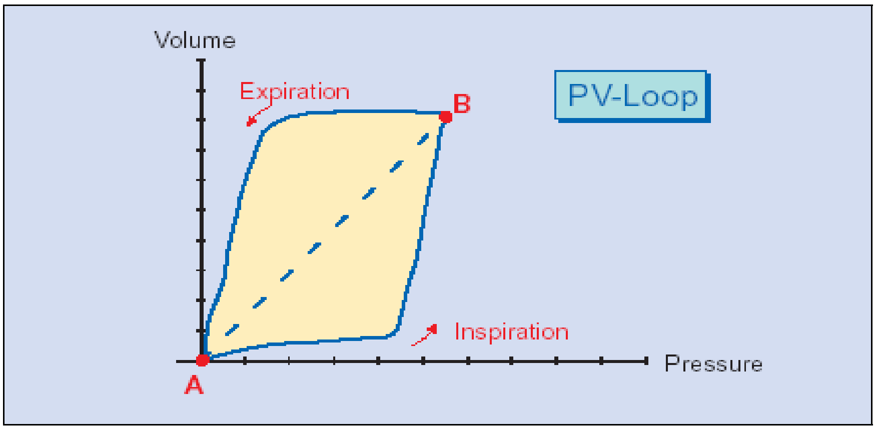

Figure 2.54: Pressure-volume loop representing pressure controlled ventilation
Acknowledgement: Dräger (In: Rittner and Döring)

By way of summary, compare the different pressure-volume loops during different modes of ventilation as presented in Figure 2.55 below.

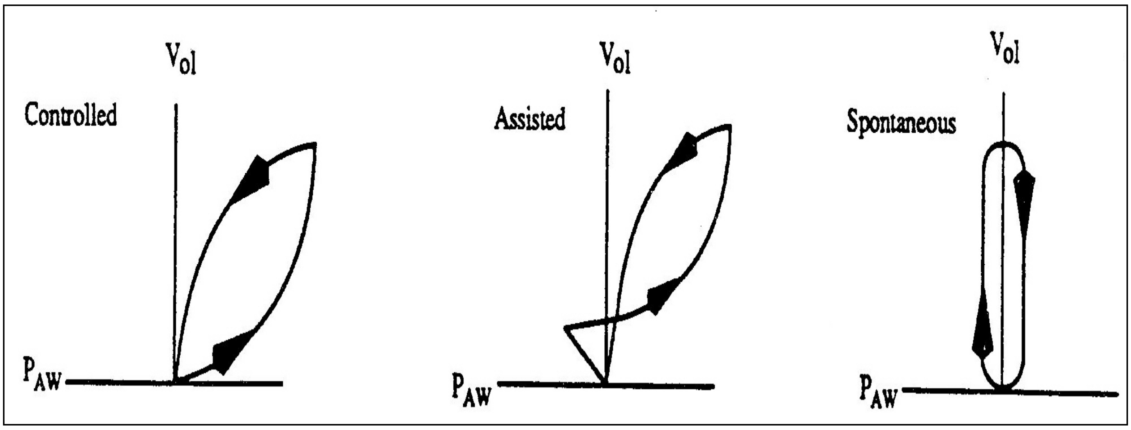

Figure 2.55 Pressure-volume loops representing a controlled, assisted and spontaneous breath respectively *Acknowledgement: Macintyre*

2.8.3 WORK OF BREATHING

The work performed by the respiratory muscles to increase the size of the thoracic cavity and decrease the intrathoracic pressure in order to inhale is called work of breathing. However, work of breathing also includes efforts to exhale forcefully. When lung diseases are present, work of breathing is increased.

Although the aim of mechanical ventilation would be to only limit it, work of breathing is often eliminated for extended periods, causing muscular atrophy.

Figure 2.56 on page 62 illustrates the relationship between work of breathing and muscular energy demand. While muscular disuse would result in wasting and atrophy, muscular exertion could lead to fatigue.

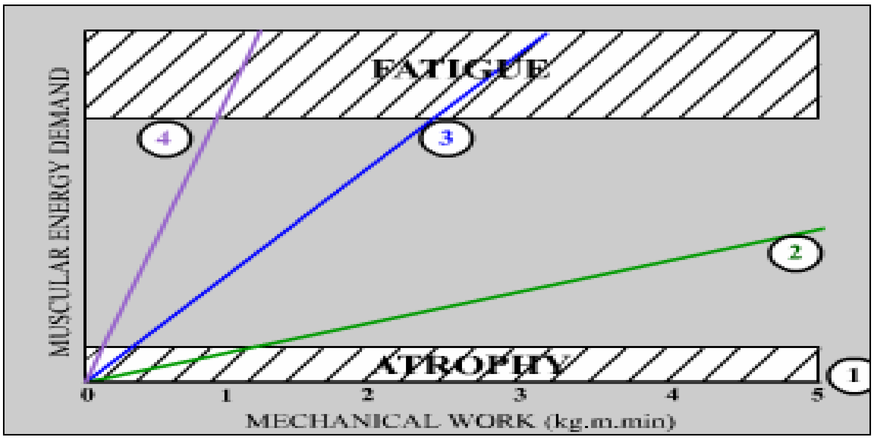

Figure 2.56: Characteristics of work of breathing versus muscular energy demand
Acknowledgement: Viasys

Figure 2.56, illustrating work of breathing versus muscular energy demand, is explained as follows:

- When the respiratory workload or energy expenditure (expressed in kg.m.min) is too low, as indicated by [1], the muscular energy demand will be as low, resulting in a high probability of the patient developing muscular atrophy (Viasys [S.a.]a).
- Normal energy demand is represented by [2]. Depending on the patient's condition, to perform the same amount of work, greater energy would be required.
- Greater energy expenditure is represented by [3]. This could signify health deterioration and the development of muscular fatigue.
- High energy expenditure is represented by [4]. Performing a task might lead to muscular fatigue in a short period of time (Viasys [S.a.]a).

Pressure versus volume is the most important loop, for its analysis allows of drawing conclusions about work of breathing.

2.8.3.1 Inspiratory work during spontaneous breaths

Rittner and Döring ([S.a.]:34) describe *inspiratory work of breathing for a ventilated patient* as the work that needs to be done to "… combat the ventilator's inspiratory resistance". Refer to Figure 2.57 on page 63.

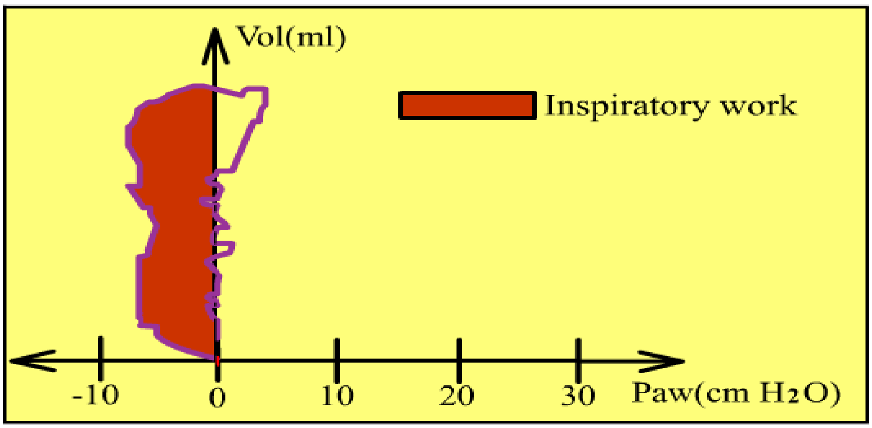

Figure 2.57: Inspiratory work during a spontaneous breath
Acknowledgement: Viasys

The area shaded red in the pressure-volume loop in Figure 2.57 represents inspiratory work during a spontaneous breath. Rittner and Döring ([S.a.]:34) state that the narrower the area to the left of the vertical axis, *i.e.* the area shaded on the graph, the less additional work of breathing is required of the patient.

2.8.3.2 Expiratory work during spontaneous breaths

Expiration is mostly classified as a passive phase. Data about expiratory work of breathing are therefore not considered important interpretive information (Viasys [S.a.]b). Compare the expiratory work of breathing during a spontaneous breath (shaded in blue in Figure 2.58) to the inspiratory work of breathing required for the same breath (shaded red in Figure 2.57 above).

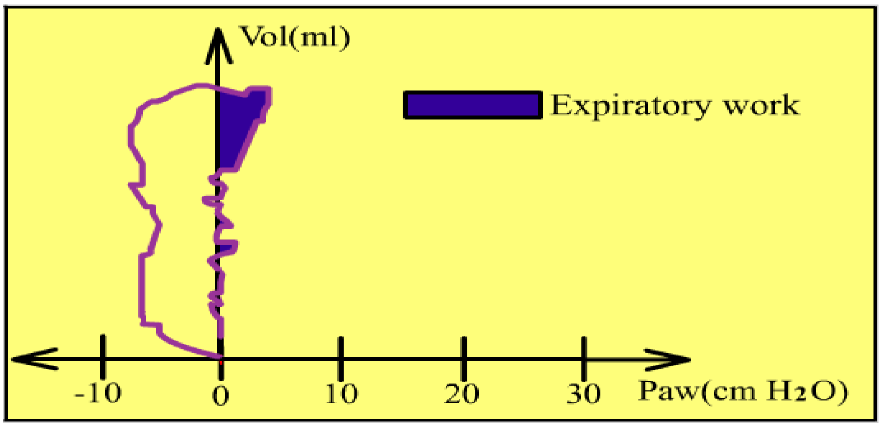

Figure 2.58: Expiratory work during a spontaneous breath
Acknowledgement: Viasys

2.8.3.3 Inspiratory work during controlled breaths

Controlled breaths are mechanically produced and therefore create no direct work of breathing for the patient (Viasys [S.a.]a). The area shaded in grey in Figure 2.59 represents inspiratory work during a controlled mode of breathing. The entire gray shaded area lies to the right of the vertical axis, implying no work of breathing for the patient.

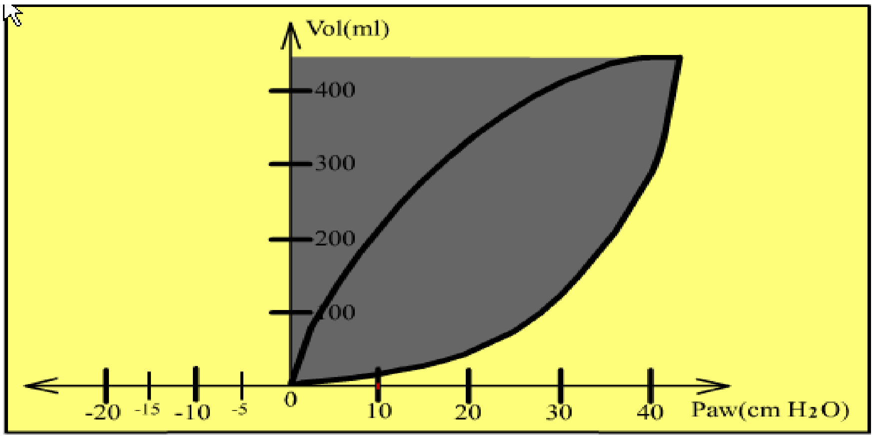

Figure 2.59: Inspiratory work during a controlled breath
Acknowledgement: Viasys

2.8.3.4 Expiratory work during controlled breaths

In Figure 2.60, the expiratory work phase of a controlled breath is shaded red.

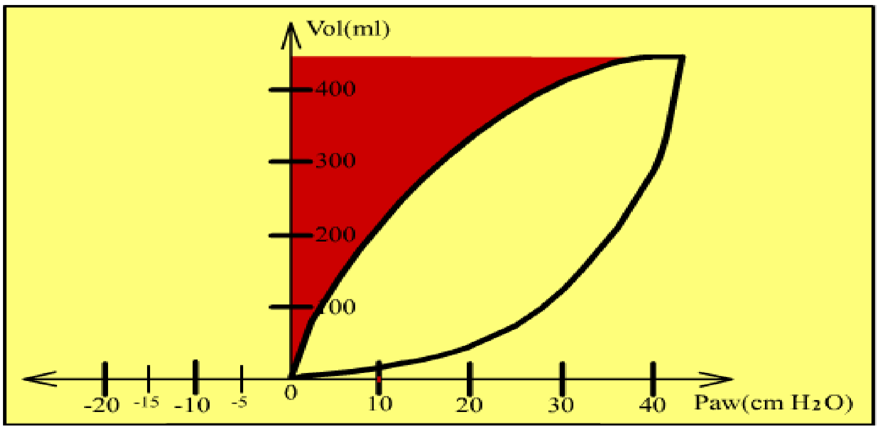

Figure 2.60: Expiratory work during a controlled breath
Acknowledgement: Viasys

The red area lies to the right of the vertical axis, indicating no expiratory work of breathing for the patient. As is the case for inspiratory work, the expiratory work phase of a controlled mode of ventilation is usually not regarded as being part of serious work of breathing. (Viasys [S.a.]a.)

However, evaluating the work of breathing for a patient on a PEEP or CPAP setting involves considering the PEEP/CPAP value. When external PEEP is applied, the loop moves to the right as seen in Figure 2.61 (Ouellet 1997:67). Evaluating the work of breathing on a pressure-volume loop if a PEEP or CPAP setting is used will require using a movable axis, *i.e.* it will require moving the axis up to the PEEP or CPAP setting. The area to the left of the axis will indicate the work of breathing (Viasys [S.a.]a).

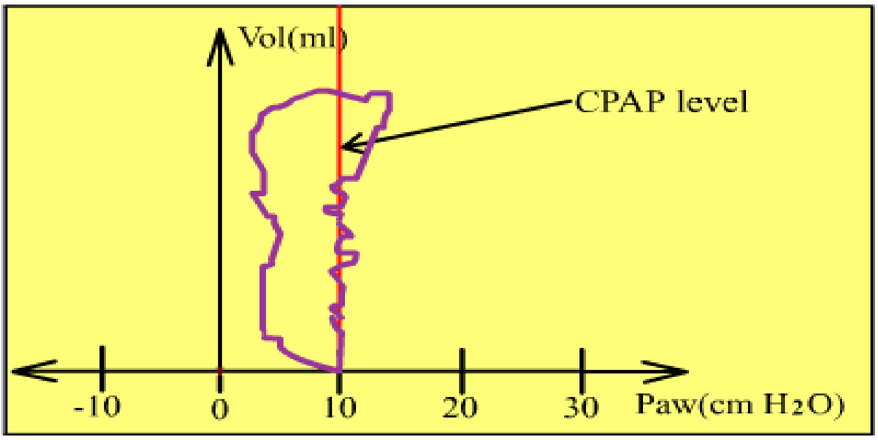

Figure 2.61: Indicating work of breathing when a CPAP or PEEP setting is used
Acknowledgement: Viasys

According to Fenstermacher and Hong (2004:260), the following factors may influence work of breathing: posture changes due to obesity or pregnancy, massive ascites, clogging of heat and moisture filters, and condensation in ventilator tubing. Viasys ([S.a.]a) lists additional factors such as the trigger mechanism and pressure overflow that may affect work of breathing. Rittner and Döring ([S.a.]:36) suggest that a smaller endotracheal tube size results in greater work of breathing. The following discussion will illustrate the effects of the trigger mechanism and the endotracheal tube size on work of breathing.

2.8.3.5 Triggering mechanism

A comparison between flow triggering and pressure triggering will prove that the flow trigger set for a patient will decrease work of breathing (Viasys [S.a.]a). Figure 2.62 represents a spontaneous breath.

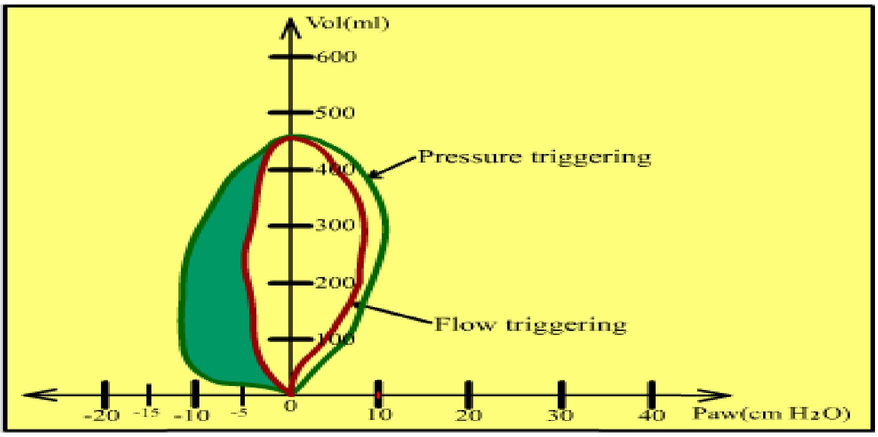

Figure 2.62: Indicating flow triggering versus pressure triggering
Acknowledgement: Viasys

Figure 2.62 which compares flow triggering to pressure triggering can be explained as follows:

- The green loop indicates pressure triggering. The patient initiates a breath by exceeding the pressure sensitivity threshold. However, there is a delay between the patient's effort at inspiration and the ventilator's response, *i.e.* the actual moment the ventilator opens the inspiratory valve to allow spontaneous flow toward the lungs. This delay results in an increase in work of breathing for the patient.
- The red loop, representing flow triggering, indicates a considerably decreased level of work of breathing for the patient due to the synchrony between the patient and the ventilator. Although it seems that the threshold setting for the flow trigger were slightly more sensitive than the pressure sensitivity threshold, the fact remains that the flow trigger is causing less work of breathing (Fenstermacher & Hong 2004:262).
- The difference in the work of breathing created by the two trigger options is indicated by the area shaded in green (Viasys [S.a.]a).

2.8.3.6 Size of the endotracheal tube

According to Rittner and Döring ([S.a.]:36), the smaller the tube diameter, the more the patient has to work to combat tube resistance. Refer to Figure 2.63.

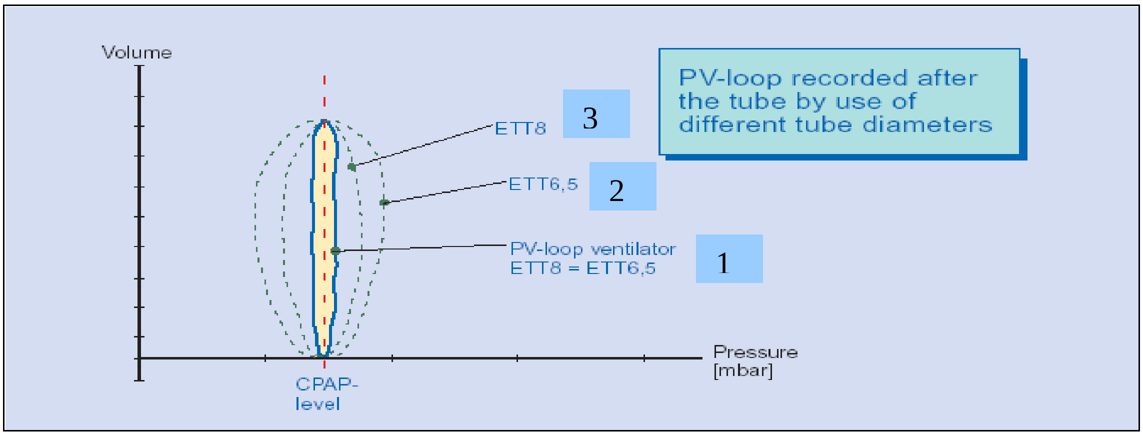

Figure 2.63: Indicating the effect of tube diameter on the pressure-volume loop
Acknowledgement: Viasys (Adapted)

Figure 2.63 illustrates the effect of the tube diameter on a pressure-volume loop. The graph can be explained as follows:

- The pressure-volume loop marked [1] was drawn according to *measurements taken on the ventilator circuit* connecting to the endotracheal tube. For both endotracheal tubes, sizes 8 and 6.5, the pressure-volume loop appears to be identical.
- The pressure-volume loop marked [2] was drawn according to *measurements taken inside the trachea and just below a size 6.5 endotracheal tube*.
- The pressure-volume loop marked [3] was drawn according to *measurements taken in the trachea below a size 8 endotracheal tube*.
- A comparison between loops [2] and [3] shows that the smaller-sized tube caused more work of breathing for the patient as indicated by the size of the area positioned to the left of the vertical axis.

2.8.4 CHANGES IN RESPIRATORY MECHANICS REFLECTED IN THE PRESSURE-VOLUME LOOP

Changes in either resistance or compliance can be identified on the pressure-volume loop by interpreting changes in the slope. The slope must firstly be identified. Refer to Figure 2.64.

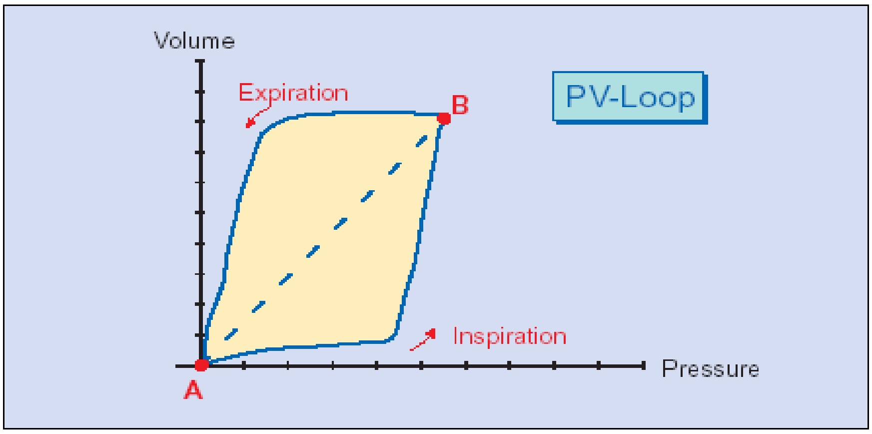

Figure 2.64: Pressure-volume loop with slope marked A,B
Acknowledgement: Dräger (In: Rittner and Döring)

The pressure-volume loop in Figure 2.64 represents a fairly normal controlled breath. The dotted line joining the end-inspiratory pause or pressure plateau [B] to the end-expiratory point [A] indicates the slope. Changes in the position of the slope will indicate either improvement in compliance or development of resistance.

2.8.4.1 Compliance increase

In the case of an improvement in lung injury, and thus in lung compliance, the loop will move toward the left. The same volume of air will be distributed more easily and, therefore, will produce a reduced pressure setting, as seen in Figure 2.65 (Viasys [S.a.]a) on page 69.

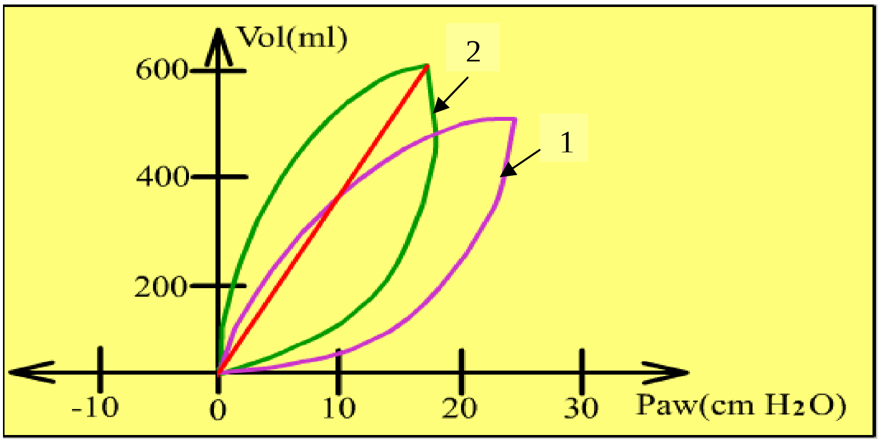

Figure 2.65: Change in slope indicating increased lung compliance
Acknowledgement: Viasys (Adapted)

Figure 2.65 represents two pressure-volume loops.

- The purple pressure-volume loop (marked [1]) indicates the original pressure loop, which required a high airway pressure to accommodate the volume.
- The green pressure-volume loop (marked [2]) indicates a movement to the left due to improvement in lung compliance.

2.8.4.2 Compliance decrease

When compliance decreases, a higher pressure is required to accommodate the same volume. Refer to Figure 2.66.

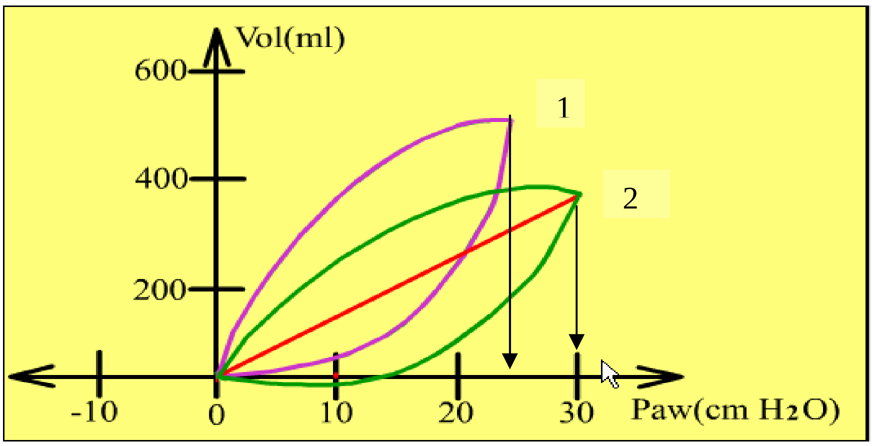

Figure 2.66: Indicating change in slope and higher pressure requirement due to a decrease in compliance *Acknowledgement: Viasys (Adapted)*

Figure 2.66 represents two pressure-volume loops.

- The purple pressure-volume loop indicated by [1] is the original pressure loop.
- The green pressure-volume loop indicated by [2] reflects a decrease in compliance, resulting in the slope moving toward the right [1].
- Rittner and Döring ([S.a.]:31) describe the steepness of the inspiratory branch of the pressure-volume loop as being proportional to the change in lung compliance.
- Rittner and Döring ([S.a.]:25) also state that, only if the inspiratory flow is constant, can compliance be evaluated.

2.8.4.3 Resistance increase

Resistance is indicated by the area lying between the slope and the inspiratory limb of the pressure-volume loop. An increase in this area will therefore indicate an increase in resistance. Figure 2.67 illustrates increased resistance due to an increase in bronchial secretions.

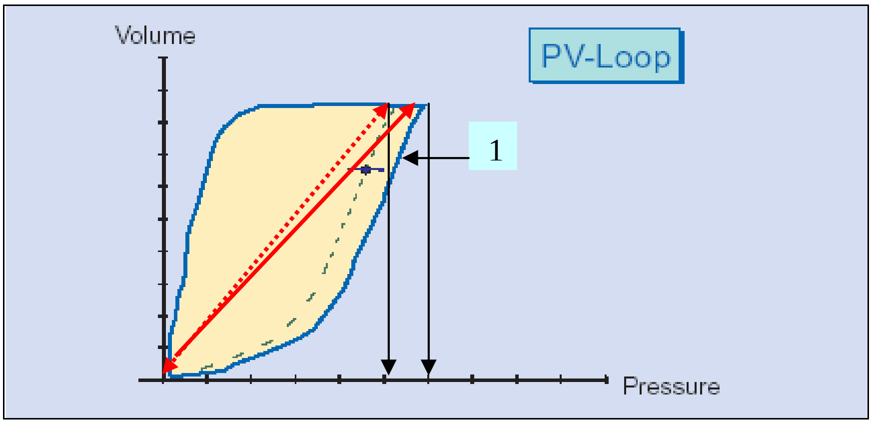

Figure 2.67: Indicating increased resistance and higher pressure requirement due to bronchial secretions
Acknowledgement: Dräger (In: Rittner and Döring) Adapted

The pressure-volume loop in Figure 2.67 indicates a controlled mode of ventilation. Changes in the inspiratory limb and, therefore, in the slope are marked with a solid red and blue line respectively.

Figure 2.67 is explained as follows:

- When resistance changes, the position of the inspiratory limb of the loop changes. With an increase in resistance it moves to the right or toward the solid blue line (marked [1]), reaching a higher PIP.
- When resistance decreases, the inspiratory limb moves toward the left, indicating that the same volume delivery resulted in a lower PIP (Burns 2003:141).

2.8.4.4 Overdistension

The phenomenon of lung overdistension is evident when the pressure continues increasing, with a small or almost non-existing volume increase, as seen in Figure 2.68 (Viasys [S.a.]a).

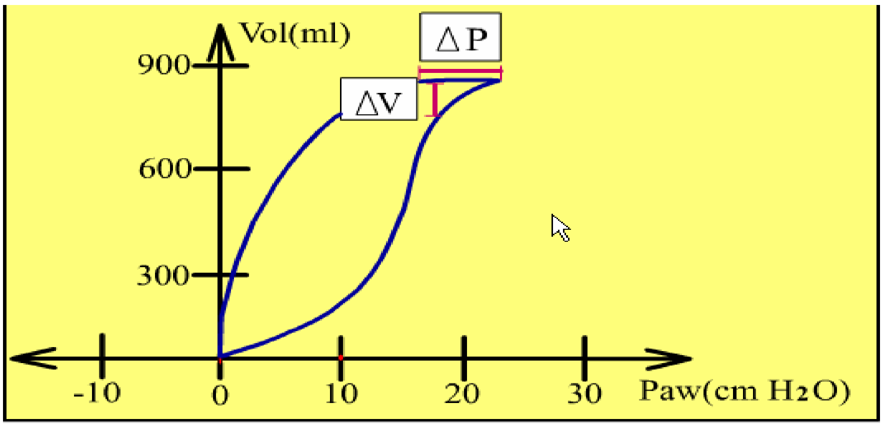

Figure 2.68: Indicating pulmonary overdistension
Acknowledgement: Viasys

The pressure-volume loop in Figure 2.68 indicates overdistension of certain areas in the lung. This occurs if the increase in pressure (ΔP) is greater than the increase in volume (ΔV) and is identified by the levelling out of the inspiratory branch of the loop.

2.9 FLOW-VOLUME LOOPS

The second loop of interest is the flow-volume loop. The flow-volume loop plots volume on the horizontal axis and flow on the vertical axis (Burns 2003:141).

Depending on the manufacturer, the flow-volume loops circulate in either a clockwise or anti-clockwise direction. Refer to Figure 2.69.

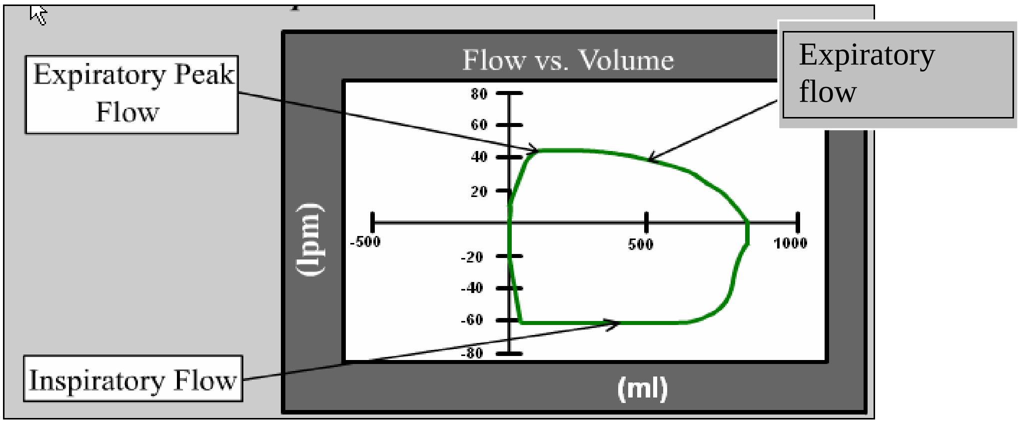

Figure 2.69: Flow-volume loop
Acknowledgement: Viasys (Adapted)

Figure 2.69 represents a flow-volume loop circulating anti-clockwise (Viasys [S.a.]a). Inspiration is plotted on the lower portion of the loop and expiration on the upper portion.

However, contrary to Figure 2.69, ventilator models by two other manufacturers indicate inspired flow as a positive and expired flow as a negative flow (Macintyre 1998; Ouellet 1997). Refer to Figure 2.70.

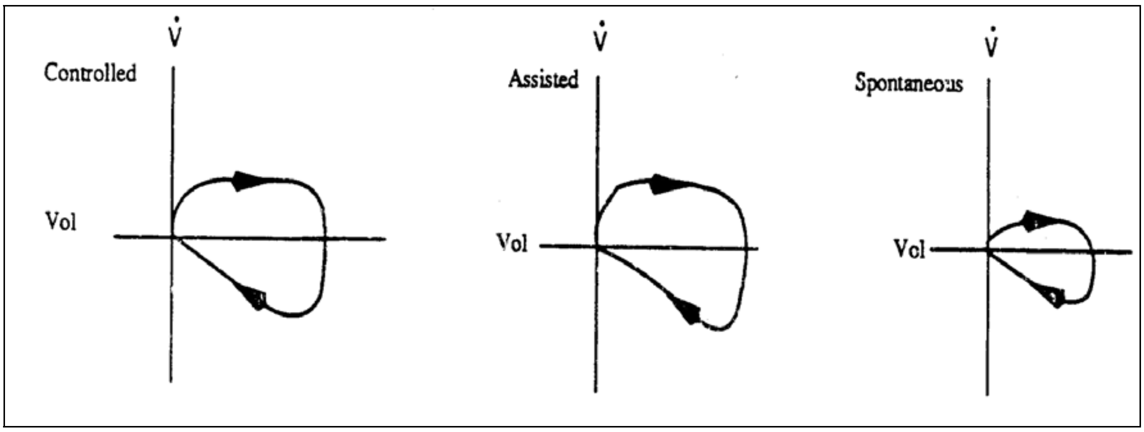

Figure 2.70: Flow-volume loop for a controlled, assisted and spontaneous breath
Acknowledgement: Macintyre

2.9.1 FLOW-VOLUME LOOPS AND MODES OF VENTILATION

Depending on the mode of ventilation, the appearance of flow-volume loops changes.

2.9.1.1 Constant flow mode of ventilation

A constant flow setting ensures a steady maintenance of flow. Refer to Figure 2.71.

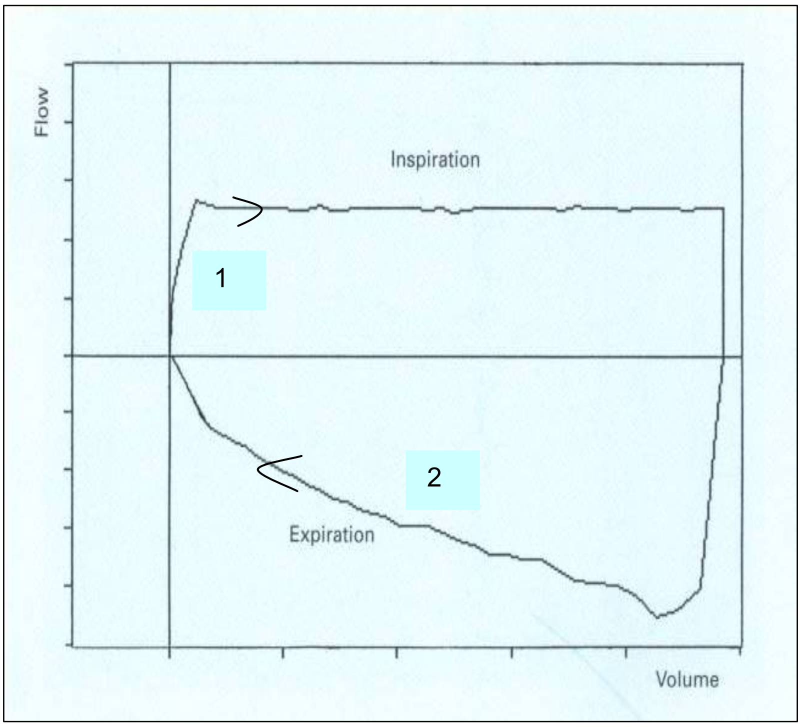

Figure 2.71: Flow-volume loop from a constant flow mode of ventilation
Acknowledgement: Ouellet (Adapted)

Figure 2.71, representing a flow-volume loop during a constant flow mode of ventilation, can be explained as follows:

- When a constant flow mode is selected the initial rise to inspiratory flow and decay will be rapid, as indicated by [1].
- The expiratory phase is started by a rapid decay to peak expiratory flow, followed by a progressive return to baseline, indicated by [2]. Also refer to Figure 2.9.
  (Ouellet 1997:70.)

2.9.1.2 Constant pressure mode of ventilation

Due to the nature of the information that is acquired for analysis, the flow-volume loop is considered to be of lesser value than the pressure-volume loop. Although both a constant flow setting and a constant pressure mode ensure a rapid rise to peak inspiratory flow, a constant pressure mode does not allow a steady maintenance of flow. To the contrary, airflow progressively returns to baseline. Compare Figure 2.72 below to Figure 2.71.

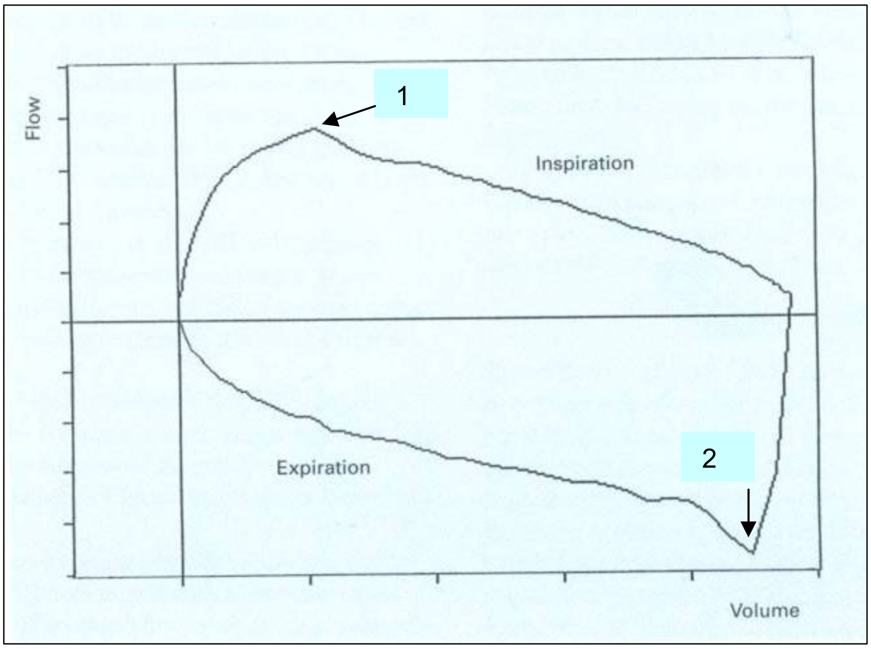

Figure 2.72: Flow-volume loop from a constant pressure mode of ventilation
Acknowledgement: Ouellet (Adapted)

Figure 2.72 represents a flow-volume loop during a constant pressure mode of ventilation.

- A constant pressure loop begins with a rapid rise to peak inspiratory flow [1], then decays to baseline.
- The expiratory phase is a repeat of the inspiratory flow with a rapid decay to peak expiratory flow [2], followed by a progressive return to baseline. Also refer to Figure 2.75.
- Airflow limitation appears to be the same as in a constant flow loop (Ouellet 1997:71).

2.9.2 THE VALUE OF FLOW-VOLUME LOOPS

2.9.2.1 Detection of air leaks

Leaks in the system (circuit or patient) can be seen when the expiratory volume is less than the inspired volume (Viasys [S.a.]a). Refer to Figure 2.73.

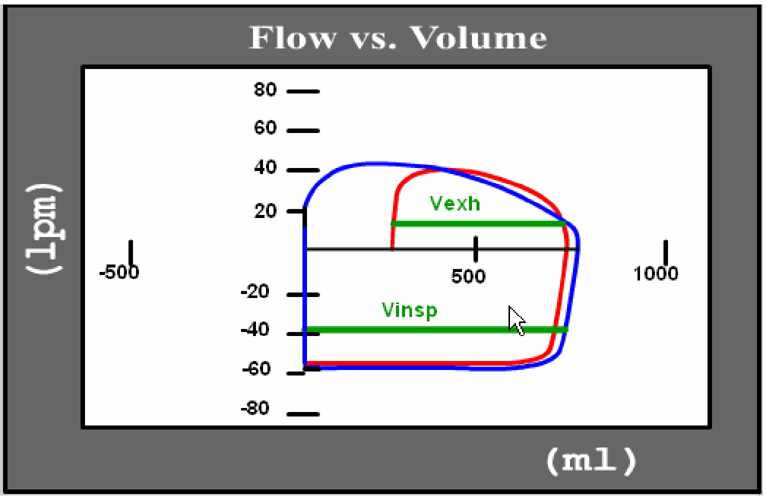

Figure 2.73: Indicating difference between volume inspired and volume exhaled
Acknowledgement: Viasys

Figure 2.73 represents a flow-volume loop that circulates anti-clockwise.

- The loop in blue is a normal flow-volume loop. The red flow-volume loop appears incomplete because it does not end where inspiration has started, indicating a leak in the circuit.

2.9.2.2 Bronchodilator effect on loops

Airflow limitation due to constriction of the airways is associated with a concave shape to the volume axis during the second phase of the expiratory profile of the loop (Ouellet 1997:70). Refer to Figure 2.74 on page 76.

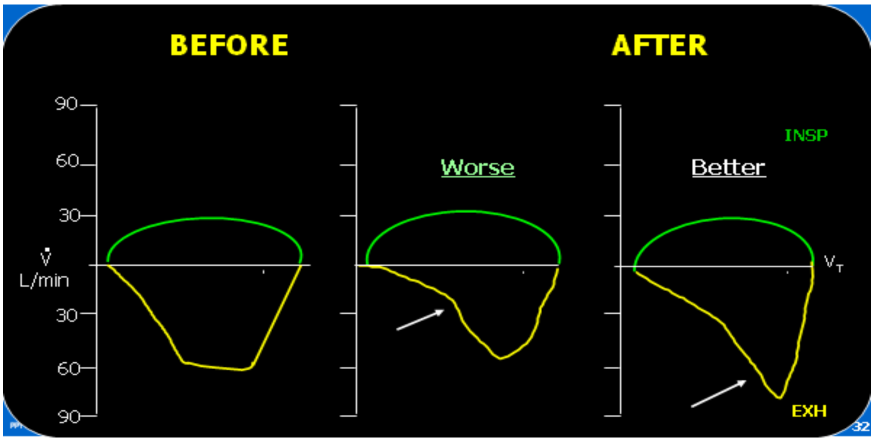

Figure 2.74: Flow-volume loops indicating normal flow, airflow limitation and effect of bronchodilator therapy on airflow limitation
Acknowledgement: Newport (In: Visser)

Figure 2.74 represents three consecutive flow-volume loops that are circling clockwise. The green indicates inspiratory flow, and the yellow the expiratory phase.

- Loop 1 (with the header 'before') indicates a normal inspiration and expiration loop.
- The expiratory branch of loop 2 returning to the volume axis has a concave shape, indicating airflow limitation due to constriction of the airways.
- Loop 3 indicates the effect on the loop following bronchodilator therapy. The peak expiratory flow increases and the expiratory branch becomes less concave to the volume axis.

A fixed obstruction is associated with both decreased peak inspiratory flow and decreased peak expiratory flow. The effect of a bronchodilator is present when the peak expiratory flow increases and the expiratory profile becomes less concave to the volume axis (Ouellet 1997:70).

2.9.2.3 Increase in resistance

A decreased peak expiratory flow and a descent in the flow drop indicate an increase in resistance. Refer to Figure 2.75 on page 77.

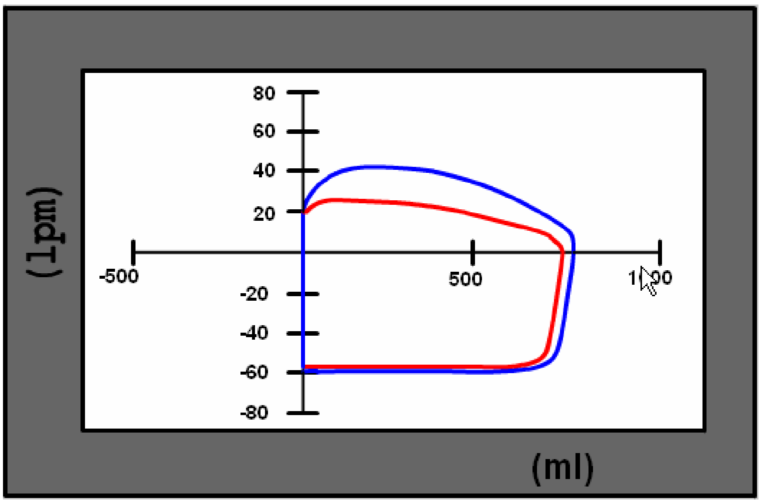

Figure 2.75: Indicating an increase in airway resistance
Acknowledgement: Viasys

Figure 2.75 represents a flow-volume loop in an anti-clockwise direction.

- The loop in blue is a normal flow-volume loop.
- The flow-volume loop in red reflects an increase in resistance. A decreased peak expiratory flow and a descent in the flow drop indicate increased resistance.

2.10 CONCLUSION

Schaar (2003:487) states: "The future is not some place we are going, but one we are creating. The paths to it are not found but made, and the activity of making them changes both the maker and the destination." Visser (2004a) emphasises the value of waves and loops in managing ventilated patients. Changes in patient condition and effects of treatment can be monitored closely. The acquisition of skills and the development of competence regarding ventilator graphics in the present will merely form the foundation of clinical nursing expertise in the future.

Although technology certainly can contribute to the delivery of care, nursing the patient and not the equipment remains the golden rule. Ouellet (1997) states: "We must never forget that the patient needs all our attention and compassion.

Time spent at the bedside manipulating technology should never compromise the caring devotion for the most important person, the patient in need of critical care."

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

3.1 INTRODUCTION

A thorough review of ventilator graphics was conducted by the researcher and presented in Chapter 2. The aim of this study was to determine the level of knowledge of critical care nurses regarding ventilator graphics. Armed with data on this topic, the researcher would be in a position to compile an in-service training programme that would enable nurses to recognise normal and abnormal waveforms and evaluate a patient's response to treatment. In order to obtain information on this topic, a survey was conducted among critical care nurses in private hospitals in Gauteng. A quantitative research design was adopted to facilitate the gathering of information and the analysis of data. A questionnaire was used as research instrument.

3.2 RESEARCH DESIGN

Burns and Grove (2001:795) describe a research design as a "blueprint for conducting a study that maximizes control over factors that could interfere with the validity of the findings". Polit *et al.* (2001:167) describe a research design as the researcher's overall plan for answering the research question. A quantitative, descriptive, contextual design was adopted for this study.

Quantitative research is any research that uses procedures that gather data in numerical form. A quantitative design begins with preconceived ideas about how the key research concepts are interrelated, and uses structured procedures and formal instruments to collect information (Brink 2001:13). For the purposes of this study, a questionnaire was designed and used as formal research instrument. The compilation of the questionnaire was based on a literature study conducted by the researcher.

Descriptive research, according to Burns and Grove (2001:52), "…is the exploration and description of phenomena in real-life situations". The descriptive research approach is used to generate new knowledge about concepts or topics about which limited or no research has been conducted. This study aims to describe critical care nurses' knowledge of ventilator graphics, as a literature review failed to expose any previous findings relating to the South African context in this regard. The expectation is that the study will generate new knowledge and, for this reason, the study can be considered descriptive research.

A naturalistic setting, according to Polit *et al.* (2001:169), is a real-world setting where data collection is performed. This study was conducted in a naturalistic setting, *i.e.* among critical care nurses who were working in selected critical care units in Gauteng.

A contextual study is conducted within a specific context. This context is described by De Vos (2001:281) as a 'small-scale world' of, amongst others, gangs, clinics, hospital wards, or critical care units. In order to answer this study's research question, research was conducted among nurses who were working in critical care settings in selective private hospitals in Gauteng. However, in the context of this study, these units have to use *ventilators that are equipped with ventilator graphics*. Nurses who were working in critical care units that use older types of ventilators that are not equipped with ventilator graphics were excluded from the study. The researcher assumed that, as these nurses were probably unfamiliar with most of the concepts, they should not be included in a study of this nature.

3.3 RESEARCH METHOD

A survey was conducted in order to determine the knowledge of participant critical care nurses about ventilator graphics. A questionnaire was used as measuring instrument. According to Polit *et al.* (2001:472), a survey is a non-experimental research method that focuses on obtaining information regarding the activities, beliefs, preferences, attitudes and other aspects of people via direct questioning of a sample of respondents. This research is considered non-experimental in nature, as no interventions that can have an impact on variables are implemented.

Measuring the knowledge of professionals in any field of practice might be perceived as a sensitive matter by some. Due to the sensitive nature of this study, an anonymous survey would offer the most valuable information in the least threatening manner.

3.4 POPULATION AND SAMPLE

A study population is a set of individuals who have certain characteristics in common (Polit *et al.* 2001:467). The population of this study consisted of all nurses who were exposed to ventilator graphics in selected critical care units in Gauteng. Permission to conduct the research was obtained from five hospitals in this area.

According to Burns and Grove (2001:39), sampling refers to the process of selecting a portion of the study population to represent the entire population. Critical care nurses who operated a graphic display ventilator in any of the critical care units of five hospitals in Gauteng for a period of at least three months were requested to participate in the survey.

This action constituted convenience sampling. Convenience sampling, according to Brink (2001:140), involves selecting readily available people or objects for a study. In this study, it meant selecting persons who were 'on the right place at the right time'. Convenience sampling was suitable because this study dealt with relatively new technology.

3.5 DATA COLLECTION

3.5.1 DATA COLLECTION PROCESS

In order to gather data, a questionnaire was used as research instrument. The researcher prepared 160 questionnaires for distribution among critical care respondents in five hospitals. By offering an incentive (a small gift was attached to each questionnaire), the researcher wanted to motivate the respondents to participate in the study. A sealed box was provided to each hospital to facilitate the collection of completed questionnaires. The questionnaires were handed out by the clinical facilitator/unit manager of each participatory hospital and on completion placed in the sealed boxes. Each respondent completed only one questionnaire.

3.5.2 THE QUESTIONNAIRE

Brink (2001:154) considers direct questioning the easiest and most effective way to determine what people believe, think or know. According to Burns and Grove (2001:426), a questionnaire can be used to determine facts about a subject or situations known by subjects. For this reason, the researcher selected a questionnaire as data collection instrument.

3.5.2.1 Advantages and disadvantages

In selecting a questionnaire as data collection instrument, the researcher considers its advantages and disadvantages (Brink 2001:153).

Questionnaires have the following advantages:

- They promote anonymity, and, due to the sensitive nature of the survey, this was considered beneficial by the researcher.
- Questionnaires are economical since they demand less time and energy to administer.
- Its standard format allows data collection from numerous respondents.

- Since questionnaires promote consistent and accurate measurement, validity and reliability are easier established.

However, questionnaires have the following disadvantages:

- Respondents may fail to answer some of the questions.
- Respondents may not understand a question, and for this reason fail to answer it accurately.
- The response rate may be low.
- The compilation of the questions or the format of the questionnaire may influence the respondent.

3.5.2.2 Layout of the questionnaire

The questionnaire consisted of a covering letter and three sections. The first section would elicit biographical data from the respondents, while sections 2 and 3 measure the knowledge of respondents on ventilator graphics. The layout and contents of the questionnaire are discussed and presented in table format. (Refer to Table 3.1 on pages 84 and 85.) A copy of the information leaflet and questionnaire is attached as Annexure A.

Covering letter

The covering letter introduced the respondent to the researcher, the institution supporting this research, the purpose of the survey, as well as the principles of voluntary participation and informed consent. The respondent is assured that participation would be anonymous.

Section 1

Section 1 of the questionnaire elicited general biographical information about the respondents. These data were used to obtain and present a general image of the study's sample and population. Furthermore, the relationship between the biographical data and the respondents' level of knowledge (represented by data obtained from Sections 2 and 3) could also be investigated.

Section 2

Section 2 of the questionnaire tested the respondents' general knowledge about ventilator graphics, specifically waveforms.

Section 3

Section 3 of the questionnaire tested the critical thinking ability of respondents by requesting them to match preset modes of ventilation with corresponding waveform formats.

(For the purpose of data analysis, sections 2 and 3 of the questionnaire were further subdivided into five themes. The knowledge questions were then reorganised and a further two themes identified. The first five themes are also indicated in Table 3.1.)

Table 3.1: Layout of questionnaire

SECTIONS: INCLUDING THEMES	**QUESTIONS: DESCRIPTION AND MOTIVATION**
SECTION 1: BIOGRAPHICAL DATA	Questions 1, 2 & 3: Information was requested about the respondents' level of qualification, years of experience in the critical care environment as well as equipment used. *The data obtained were used to describe the population and sample and to establish relationships between the biographical data and the respondents' level of knowledge.*
SECTION 2: GENERAL KNOWLEDGE **Theme 1: Waveform identification**	Questions 4, 5 & 6: Respondents were requested to identify three basic waveforms. *Recognition of the basic waveforms is important because this forms the foundation of ventilator graphic interpretation.*

Theme 2: Modes of ventilation	Questions 7, 8, 9 & 10: Respondents had to identify different modes of ventilation. *Recognition of the mode of ventilation is important because data have to be interpreted according to the selected mode of ventilation.*
Theme 3: Ventilation phenomena	Questions 11, 12, 13, 14 & 15: Respondents were requested to identify different phenomena. *Recognition of these phenomena is valuable to shorten ventilation days and improve patient outcomes.*
Theme 4: Flow-time waveforms	Questions 16.1-16.4, 17.1-17.4 & 18.1-18.3: Respondents were requested to identify different aspects of flow-time waveforms. *Recognition is important, as each aspect would relay important information about the whole ventilation cycle. The correct interpretation of each aspect may lead to ventilator adjustments and improved ventilator-patient synchrony*.
SECTION 3: MATCHING WAVEFORMS **Theme 5: Waveform differentiation**	Question 19 – 21: Respondents were requested to match corresponding waveform formats. *This is important, as critical thinking is required to interpret the entire ventilator graphic profile.*

3.5.2.3 Refinement of the questionnaire

Professionals in the field of critical care nursing were requested to check the accuracy and applicability of the questions and to make suggestions about the way they were structured. These professionals included a lecturer in critical care nursing at UP, a trained critical care nurse, and a paediatric nurse. Because of the recommendations of these experts, refinements were made. These professionals did not partake in the actual survey.

The revised questionnaire was presented to the UP Faculty of Health Sciences' Research Ethics Committee for approval. Critical care nurses working in critical care units that are equipped with graphic display ventilators were requested to participate in a pilot study. A pilot study is described as a trial run of the major study (Polit *et al.* 2001:267). The revised questionnaire was thoroughly tested and further refinements were made. Nurses who participated in the pilot study were excluded from the survey.

3.5.2.4 Competency indicator

The questionnaire was presented to experts in the field of study to obtain their opinions about the minimum mark that should be achieved by respondents. This mark would indicate that nurses were knowledgeable in ventilator graphics. These experts included a critical care educator and trained critical care nurses. Consensus was reached that the competency indicator would be 60%.

The involvement of professional nurses and other experts in the setting of standards enhanced the validity and reliability of the questionnaire as measuring instrument.

3.6 VALIDITY OF THE MEASURING INSTRUMENT

3.6.1 INTRODUCTION

According to De Vos (2001:166), the definition of validity is twofold: it is the degree to which the instrument actually measures the concept in question, and the extent to which the concept is measured accurately. On the one hand, the instrument should measure a specific construct and, on the other hand, the construct should be measured consistently and accurately.

3.6.1.1 Content validity

Content validity, according to Polit *et al.* (2001:309), is concerned with "…adequacy of coverage of the content area being measured". Content validity is determined by asking the following questions (De Vos 2001:167):

- Is the instrument measuring the concept one assumes it is?
- Does the instrument provide an adequate sample of items that represent that concept?

In this study, all questions included in the questionnaire were based upon a thorough literature review and a multiple-choice questionnaire by the ventilator company, Vyasis Healthcare. This step assured the validity of the content of the research instrument. According to De Vos (2001:167), content validation is a judgmental process whereby the content validity of an instrument is assessed. The researcher requested representatives of ventilator distributors as well as a nursing educator to judge the validity of the questionnaire.

3.6.1.2 Face validity

Brink (2001:168) describes face validity as the extent to which a measuring instrument appears to be measuring what it is supposed to measure. That an instrument can be taken at face value is a desirable characteristic (De Vos 2001:167). To ensure face validity, professionals within the field of critical care nursing and experts on ventilator graphics were requested to review the questionnaire.

3.6.1.3 Criterion validity

Criterion validation involves multiple measurements. It is established by comparing scores on an instrument with an external criterion, which is another instrument that is believed to measure the concept (De Vos 2001:167). Establishing criterion validity during this study could not be done, as another measure on the same theme could not be found. However, criterion validity could be applicable to similar research in future, were this study to be used as the external criterion against which scores on a subsequent instrument could be compared.

3.6.1.4 Construct validity

Construct validity is the degree to which an instrument successfully measures a theoretical construct. According to De Vos (2001:167), a construct cannot be seen, felt or heard, nor can it be measured directly. Construct validity was not applicable to this study, as knowledge about a well-defined area (ventilator graphics) was measured. Knowledge about ventilator waveforms could not be confused with any other construct. The construct of the study was clarified when content and face validity was ensured.

3.6.2 VALIDITY OF THE DATA COLLECTION PROCESS

The way data was collected enhanced the validity of the data collection process. A non-threatening environment was created. This was done by providing each respondent with a pencil and an envelope. The questionnaire was completed in pencil, sealed in an envelope and then placed in a box. These actions established anonymity for both the institution and the individual respondent. The particular circumstances under which the respondents participated in the survey were very similar.

3.7 RELIABILITY OF THE MEASURING INSTRUMENT

The reliability of the data collection instrument is a major criterion for evaluating the quality of the research (Polit *et al.* 2001:305). According to Brink (2001:171), the degree to which the instrument can be depended upon to yield consistent results if used repeatedly over time, or if used by two different investigators, determines the reliability of a research instrument. Brink's criteria for the reliability of an instrument can be summarised as stability, internal consistency and equivalence.

3.7.1 STABILITY

Polit *et al.* (2001:305) suggest assessing the stability of a research instrument by applying a test-retest procedure. However, as convenience sampling was used and the names of the participants were not known, test-retest reliability of the instrument used in this study could not be estimated. In addition, when knowledge is tested (and not feelings or attitudes), two administrations of the test may produce unreliable results. After completing the test for the first time, respondents could be motivated to gain knowledge on the subject. The results of a retest will then show an increase in knowledge.

3.7.2 INTERNAL CONSISTENCY

Internal consistency reliability refers to the ability of the entire instrument to measure the same characteristic (Polit *et al.* 2001:307). One way to estimate internal consistency reliability is to divide the test items into two groups and to compare the scores of the two groups.

Internal consistency reliability is often estimated by the Cronbach alpha approach. Cronbach's alpha assesses the extent to which the items on a test correlate with one another (Knapp 1998:130). In order to measure the degree to which the items on the questionnaire used in this study were consistent with each other, Cronbach's alpha was estimated with the aid of a UP statistician, Ms L Bodenstein. Cronbach's alpha was estimated at a level of 0,6. Although a level of 0.8-0.9 is considered good by Burns and Grove (2001:398), Sommerville (2005) states that, for any new instrument in the UP Department of Statistics, a level of above 0.6 is regarded as acceptable. According to Knapp (1998:130), in quantitative nursing research, Cronbach's alpha is used more than all the other types of reliability coefficient combined.

3.7.3 EQUIVALENCE

The equivalence approach can also be used to estimate the reliability of an instrument. Polit *et al*. (2001:307) state that this approach is mainly used to determine the reliability of structured observational instruments. Applying the internal consistency reliability approach to this study's measuring instrument, as described in Subsection 3.7.2, is sufficient for a study of this kind.

3.8 DATA ANALYSIS

According to Burns and Grove (2001:794), a data analysis involves the reduction, organisation and interpretation of data. A wide variety of methods or techniques is used "…to convert and condense a collection of data into an organized, visual representation of data" (Brink 2001:179). In preparing the research data for analysis, the researcher consulted a statistician for assistance in developing an analysis plan for this specific study.

3.9 ETHICAL CONSIDERATIONS

To protect the ethical rights of the respondents, the research protocol was reviewed by the UP Faculty of Health Sciences' Research Ethics Committee. Permission was granted to conduct the research. The researcher also obtained written consent from the Nursing Services Manager of each hospital involved in the study. An agreement was reached that the results of the study would be made available to each participatory hospital and, prior to releasing information for publication, the hospitals would be informed. The names of the participatory institutions will not be released, and be kept confidential at all times.

Obtaining informed consent from human subjects is essential for conducting ethical research (Burns & Grove 2001:206). The respondents were informed about the purpose of the research and the extent of their participation in the study. The principles of voluntary participation and informed consent were explained to the respondents. After being informed of its aim and objectives, participants had a choice whether or not to participate. By completing the questionnaire, the respondents had given their informed consent.

The anonymity of the respondents was ensured. Anonymity means that the respondents' participation in a study is protected in such a manner that not even the researcher could link a respondent to the information offered (Polit *et al.* 2001:457). In this study, anonymity was ensured by handing each respondent a questionnaire inside an envelope as well as a pencil. Once the questionnaire was completed in pencil, it was placed back into the unmarked envelope. The completed questionnaires were kept in a sealed box until they were collected by the researcher.

In this study, confidentiality means keeping the names of the participant nurses as well as the names of the participatory institutions secret at all times. It would not be possible to link any person or institution to the information in the study, as their names will not be disclosed (Polit *et al*. 2001:459).

All the ventilator companies referred to in this study gladly gave permission for the reproduction of graphs.

3.10 SCOPE AND LIMITATIONS OF THE STUDY

Because the research took place in a restricted setting (*i.e.* five hospitals equipped with graphic display ventilators), the study is considered contextual. For this reason, it would not be possible to generalise the study findings to other settings. Furthermore, generalisability of findings is restricted since the sample may not be representative of the population. The sample's relatively small size and the sampling technique used might have affected the representativeness of the sample.

3.11 CONCLUSION

In this chapter, the research design and methodology, which could be described as quantitative, descriptive and contextual, was reviewed. The population, sampling, the data collection process and the research instrument were discussed in detail. The researcher, with the aid of a statistician, conducted the data analysis and the results will be presented in Chapter 4.

The aim of this study was to determine how knowledgeable critical care nurses are about ventilator graphics. As graphic display ventilators represent new technology in the critical care unit, the objective of the study is to develop an in-service training session to enrich the knowledge of critical care nurses in this regard.

CHAPTER 4

DATA ANALYSIS

4.1 INTRODUCTION

In this chapter, the research findings are discussed.

This study made use of descriptive, as well as inferential statistics. The UP statistical support service, STATOMET, was consulted in order to assist with the data analysis.

A total of 160 questionnaires were distributed between the five hospitals and 113 were returned. The response rate is therefore 70.6%. Burns and Grove (2001:430) regard response rates of above 50% as satisfactory. Of the 113 questionnaires, only 111 could be used, because two were incomplete to the extent that it was not useful to include them in the study. The questionnaire was designed with a few questions that do not test knowledge and 26 questions that do. Only 25 of these questions were used during the analysis as the researcher discovered an incorrect selection option in question 17.1 and excluded it from the final analysis.

Note:

- All percentage values are rounded off to the nearest two decimal places. This may influence the total, as it may sometimes be 101%.
- The assumption was made that unanswered questions indicated that the respondent could not decide on the correct answer. Therefore, the researcher considered any unanswered questions as incorrect.
- n = 111 throughout the data analysis unless indicated differently.

4.2 SECTION 1: BIOGRAPHICAL DATA

In this section, biographical information gathered is presented and analysed.

4.2.1 QUESTION 1: LEVEL OF QUALIFICATION

Question 1 determined the level of qualification of the respondents. Figure 4.1 reflects the results.

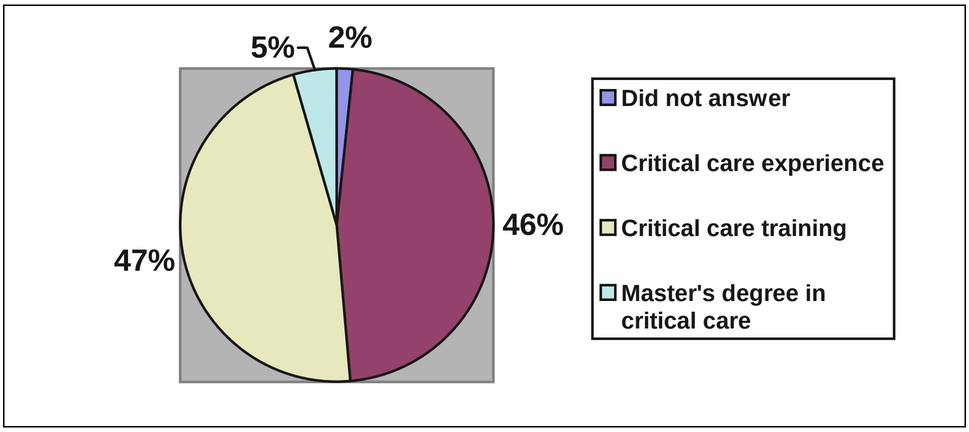

Figure 4.1: Pie diagram illustrating the level of qualification of respondents

Of the 111 respondents, 46% indicated that they had critical care experience while 47% indicated that they were trained in critical care. A further 5% had obtained a master's degree in critical care nursing and 2% of the respondents did not answer the question.

4.2.2 QUESTION 2: YEARS OF EXPERIENCE IN NURSING VENTILATED PATIENTS

In question 2, the respondents were asked to indicate how many years of experience they had in nursing ventilated patients. Essentially, this would signify the time spent in a critical care unit, because the majority of ventilated patients are nursed in such a unit. Figure 4.2 on page 95 reflects the results.

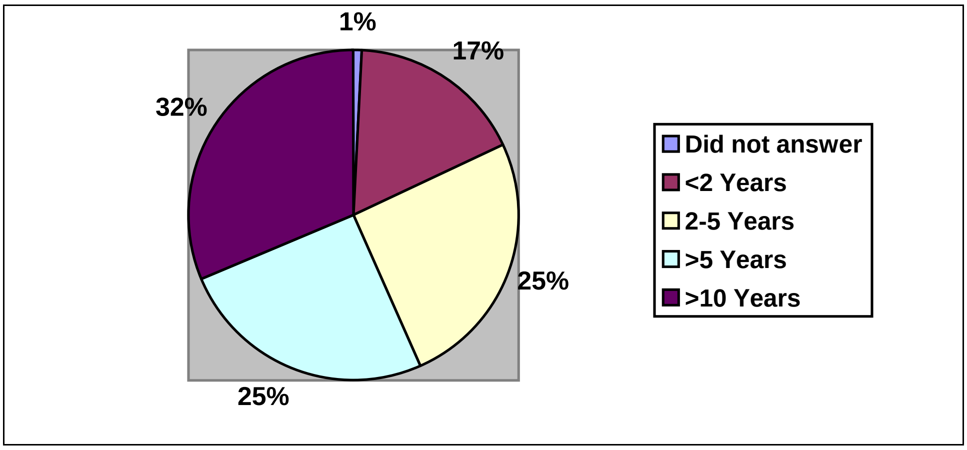

Figure 4.2: Pie diagram illustrating the years of experience of respondents working with ventilated patients

Thirty-five of the respondents (32%) had more than ten years of experience, whilst 28 of the respondents (25%) had more than five years of experience. A further 28 respondents (25%) had between two to five years of experience and 19 of the respondents (17%) had less than two years of experience. One respondent did not answer this question.

4.2.3 QUESTION 3: TRAINING RECEIVED ON VENTILATOR GRAPHICS AS WELL AS THE TYPES OF TRAINING ON THE TOPIC

The majority of the respondents did not receive any training in ventilator graphics. Refer to Figure 4.3.

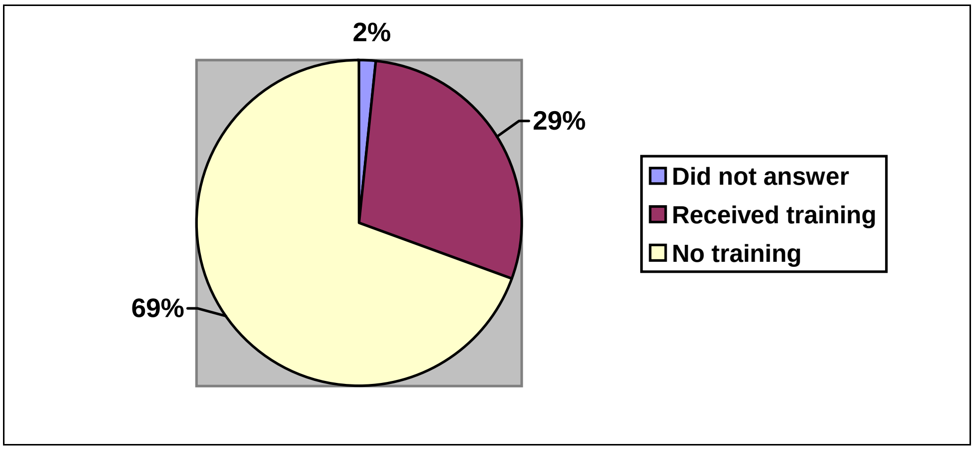

Figure 4.3: Ventilator graphics training received by respondents

The extent of the respondents' training on ventilator graphics was reflected in the two questions included under question 3. Only those who answered the first question under question 3 positively, had to complete the second question. Figure 4.3 on page 95 reflects the results.

Seventy-seven of the respondents (69%) had received no training on ventilator graphics, whilst 32 (29%) had received training in this regard.

The 32 respondents (29%) who indicated that they had some form of ventilator graphic training were further asked to indicate the type of training they had received. As some of these respondents received more than one form of training, the results are reflected as numbers in table form and not as percentages, as the total number of responses does not equal the actual number of respondents that answered.

Table 4.1: Types of ventilator graphic training attended by respondents (n=32)

TYPES OF TRAINING	FREQUENCY
Training offered by hospital	9
Training offered by ventilator company	6
Ventilator workshop	8
Other	4
More than one of the options mentioned above	3
Did not specify the type of training received	2

4.3 SECTIONS 2 AND 3: KNOWLEDGE BASE

4.3.1 INTRODUCTION

Sections 2 and 3 of the questionnaire assessed the actual knowledge, concerning ventilator graphics, of the respondents. The respondents' scores were measured against a competency indicator of 60%. Firstly, the results of the whole group on each individual question are presented. Secondly, the results of some of the questions, which were grouped together in order to assess the scores of the group on different themes within the broader topic of ventilator graphics, are presented. This was done in order to determine if some of the themes need less attention in an educational programme. The identified themes are set out below.

4.3.1.1 Theme 1: Waveform identification

Questions 4, 5 and 6 tested identification of three basic waveforms. *Recognition of the basic waveforms is important because this forms the foundation of ventilator graphic interpretation.*

4.3.1.2 Theme 2: Modes of ventilation

Questions 7, 8, 9 and 10 tested the identification of different modes of ventilation. *Recognition of the mode of ventilation is important because the resulting data, as well as the planned interventions, would differ based on the selected mode of ventilation.*

4.3.1.3 Theme 3: Phenomena that can affect patient outcomes during ventilation

Questions 11, 12, 13, 14 and 15 tested the identification of different phenomena that can affect patient outcomes. *Recognition of these phenomena is valuable to improve patient outcomes and shorten ventilation days.*

4.3.1.4 Theme 4: Different aspects of flow-time waveforms

Questions 16.1 to 18.3 tested the identification of different aspects of the waveforms. *Recognition is important, as each aspect would relay important data of the whole ventilation cycle. Correct interpretation of each aspect may lead to ventilator adjustments and improved ventilator-patient synchrony*.

4.3.1.5 Theme 5: Waveform differentiation

Question 19 to 21 tested the respondents' ability to match corresponding waveform formats. *This is important, as critical thinking is required to interpret the entire ventilator graphic profile and not only single aspects in isolation.*

4.3.1.6 Theme 6: Identification of volume-time waveforms

Questions 5, 11, 16, 17, 18, and 19 were regrouped under the theme volume-time waveforms, as these questions also tested the respondents' knowledge about volume-time graphics. *It is important to assess if the concept of volume-time graphics is sufficiently understood.*

4.3.1.7 Theme 7: Pressure-time graphics

Questions 6 to 10, 13, 20 and 21 were also regrouped under the theme pressure-time graphics. *It is important to assess if the concept of pressure-time graphics is sufficiently understood.*

4.3.2 QUESTION 4: IDENTIFICATION OF A VOLUME-TIME WAVEFORM

This question determined whether the respondents could recognise a volume-time waveform. Table 4.2 reflects the results.

Table 4.2: Recognising a volume-time waveform

RESPONSE	FREQUENCY (n)	PER CENT
Correct	77	69.37
Incorrect	34	30.63

Knowledge regarding the recognition of a volume-time waveform was fair, as 77 respondents (69.37%) could answer the question correctly.

4.3.3 QUESTION 5: IDENTIFICATION OF A FLOW-TIME WAVEFORM

This question determined whether the respondents could recognise a flow-time waveform. Table 4.3 reflects the results.

Table 4.3: Recognising a flow-time waveform

RESPONSE	FREQUENCY (n)	PER CENT
Correct	79	71.17
Incorrect	32	28.83

Knowledge regarding the recognition of a flow-time waveform was fair, as 79 respondents (71.17%) could answer the question correctly.

4.3.4 QUESTION 6: IDENTIFICATION OF A PRESSURE-TIME WAVEFORM

This question determined whether the respondents could recognise a pressure-time waveform. Table 4.4 reflects the results.

Table 4.4: Recognising a pressure-time waveform

RESPONSE	FREQUENCY (n)	PER CENT
Correct	88	79.28
Incorrect	23	20.72

Knowledge regarding the recognition of a pressure-time waveform was good, as 88 respondents (79.28%) could answer the question correctly.

4.3.5 QUESTION 7: IDENTIFICATION OF THE VOLUME MODE OF VENTILATION ON A PRESSURE-TIME GRAPH

This question determined whether the respondents could recognise a volume mode of ventilation. Table 4.5 on page 100 reflects the results.

Table 4.5: Recognition of a volume mode of ventilation

RESPONSE	FREQUENCY (n)	PER CENT
Correct	76	68.47
Incorrect	35	31.53

Knowledge regarding the recognition of a volume mode of ventilation was fair, as 76 respondents (68.47%) could answer the question correctly.

4.3.6 QUESTION 8: IDENTIFICATION OF A PRESSURE MODE OF VENTILATION ON A PRESSURE-TIME GRAPH

This question determined whether the respondents could recognise a pressure mode of ventilation. Table 4.6 reflects the results.

Table 4.6: Recognition of a pressure mode of ventilation

RESPONSE	FREQUENCY (n)	PER CENT
Correct	69	62.16
Incorrect	42	37.84

Knowledge regarding the recognition of a pressure mode of ventilation could be considered as adequate as 69 respondents (62.16%) could answer the question correctly.

4.3.7 QUESTION 9: IDENTIFICATION OF THE TRIGGER OF VENTILATION IN A CONTROLLED MODE OF VENTILATION

This question determined whether the respondents could recognise a mechanically controlled breath on a pressure-time graph. Table 4.7 reflects the results.

Table 4.7: Recognition of a controlled mode of ventilation

RESPONSE	FREQUENCY (n)	PER CENT
Correct	32	28.83
Incorrect	79	71.17

Knowledge regarding the recognition of a controlled mode of ventilation was poor as only 32 respondents (28.83%) could answer the question correctly.

4.3.8 QUESTION 10: IDENTIFICATION OF THE ASSIST MODE OF VENTILATION

This question determined whether the respondents could recognise an assisted breath on a pressure-time graph. Table 4.8 reflects the results.

Table 4.8: Recognition of the assist mode of ventilation

RESPONSE	FREQUENCY (n)	PER CENT
Correct	47	42.34
Incorrect	64	57.66

Knowledge regarding the recognition of the assist mode of ventilation was poor, as 64 respondents (57.66%) could not answer the question correctly.

4.3.9 QUESTION 11: IDENTIFICATION OF AUTO-PEEP ON A FLOW-TIME GRAPH

This question determined whether the respondents could recognise the development of auto-PEEP on a flow-time graph. Table 4.9 reflects the results.

Table 4.9: Recognising auto-PEEP on a flow-time graph

RESPONSE	FREQUENCY (n)	PER CENT
Correct	52	46.85
Incorrect	59	53.15

In terms of the knowledge regarding the recognition of auto-PEEP, 52 of the respondents (46.85%) answered correctly while 59 (53.15%) answered incorrectly.

4.3.10 QUESTION 12: IDENTIFICATION OF OVERDISTENSION OF THE LUNGS IN A VOLUME-PRESSURE LOOP

This question determined whether the respondents could recognise overdistension of the lungs on a volume-pressure loop. Table 4.10 reflects the results.

Table 4.10: Recognition of overdistension on a volume-pressure loop

RESPONSE	FREQUENCY (n)	PER CENT
Correct	76	68.47
Incorrect	35	31.53

In terms of the knowledge regarding the recognition of overdistension in a volume-pressure loop, 76 of the respondents (68.47%) answered correctly while 35 of the respondents (31.53%) answered incorrectly.

4.3.11 QUESTION 13: IDENTIFICATION OF AN INCREASE IN PEAK AIRWAY PRESSURE OR PIP ON A PRESSURE-TIME GRAPH

This question determined whether the respondents could recognise an increase in peak airway pressure on a pressure-time graph. Table 4.11 reflects the results.

Table 4.11: Recognising an increase in PIP on a pressure-time graph

RESPONSE	FREQUENCY (n)	PER CENT
Correct	54	48.65
Incorrect	57	51.35

In terms of the knowledge regarding the recognition of PIP, 54 of the respondents (48.65%) answered correctly while 57 of the respondents (51.35%) answered incorrectly.

4.3.12 QUESTION 14: IDENTIFICATION OF AN AIR LEAK IN THE VENTILATOR CIRCUIT

This question determined whether the respondents could recognise an air leak from the ventilator circuit. Table 4.12 reflects the results.

Table 4.12: Recognition of an air leak from the ventilator circuit

RESPONSE	FREQUENCY (n)	PER CENT
Correct	96	86.49
Incorrect	15	13.51

Knowledge regarding the recognition of an air leak in the ventilator circuit was good as 96 respondents (86.49%) could answer the question correctly.

4.3.13 QUESTION 15: IDENTIFICATION OF A DECREASE IN RESISTANCE ON A VOLUME-PRESSURE LOOP

This question determined whether the respondents could use a volume-pressure loop to recognise a decrease in resistance. Table 4.13 reflects the results.

Table 4.13: Recognition of a decrease in resistance in a volume-pressure loop

RESPONSE	FREQUENCY (n)	PER CENT
Correct	89	80.18
Incorrect	22	19.82

Knowledge regarding the recognition of a decrease in resistance was good, as 89 respondents (80.18%) could answer the question correctly.

4.3.14 QUESTION 16.1: IDENTIFICATION OF THE START OF INSPIRATION ON A FLOW-TIME GRAPH

This question determined whether the respondents could recognise the start of inspiration on a flow-time graph. Table 4.14 (page 104) reflects the results.

Table 4.14: Recognition of the start of inspiration on a flow-time graph

RESPONSE	FREQUENCY (n)	PER CENT
Correct	36	32.43
Incorrect	75	67.57

Knowledge regarding the recognition of the start of inspiration was poor, as only 36 respondents (32.43%) could answer the question correctly.

4.3.15 QUESTION 16.2: IDENTIFICATION OF THE END OF INSPIRATION ON A FLOW-TIME GRAPH

This question determined whether the respondents could recognise the end of inspiration on a flow-time graph. Table 4.15 reflects the results.

Table 4.15: Recognition of the end of inspiration on a flow-time graph

RESPONSE	FREQUENCY (n)	PER CENT
Correct	72	64.86
Incorrect	39	35.14

Knowledge regarding the recognition of the end of inspiration could be considered as adequate, as 72 respondents (64.86%) could answer the question correctly.

4.3.16 QUESTION 16.3: IDENTIFICATION OF THE INSPIRATORY TIME ON A FLOW-TIME GRAPH

This question determined whether the respondents could recognise the inspiratory time on a flow-time graph. Table 4.16 reflects the results.

Table 4.16: Recognition of the inspiratory time on a flow-time graph

RESPONSE	FREQUENCY (n)	PER CENT
Correct	72	64.86
Incorrect	39	35.14

Knowledge regarding the recognition of the inspiratory time could be considered as adequate, as 72 respondents (64.86%) could answer the question correctly.

4.3.17 QUESTION 16.4: RECOGNITION OF THE TOTAL CYCLE TIME ON A FLOW-TIME GRAPH

This question determined whether the respondents could recognise the total cycle time on a flow-time graph. Table 4.17 reflects the results.

Table 4.17: Recognition of the total cycle time on a flow-time graph

RESPONSE	FREQUENCY (n)	PER CENT
Correct	62	55.86
Incorrect	49	44.14

In terms of the knowledge regarding the recognition of the total cycle time, 62 of the respondents (55.86%) answered correctly while 49 of the respondents (44.14%) answered incorrectly.

NOTE: QUESTION 17.1 WAS EXCLUDED FROM THE FINAL ANALYSIS.

4.3.18 QUESTION 17.2: RECOGNITION OF THE PEAK EXPIRATORY FLOW ON A FLOW-TIME GRAPH

This question determined whether the respondents could recognise the peak expiratory flow on a flow-time graph. Table 4.18 reflects the results.

Table 4.18: Recognition of the peak expiratory flow on a flow-time graph

RESPONSE	FREQUENCY (n)	PER CENT
Correct	76	68.47
Incorrect	35	31.53

Knowledge regarding the recognition of the peak expiratory flow was fair, as 76 respondents (68.47%) could answer the question correctly.

4.3.19 QUESTION 17.3: RECOGNITION OF THE END-EXPIRATORY FLOW ON A FLOW-TIME GRAPH

This question determined whether the respondents could recognise the end-expiratory flow on a flow-time graph. Table 4.19 reflects the results.

Table 4.19: Recognition of the end-expiratory flow on a flow-time graph

RESPONSE	FREQUENCY (n)	PER CENT
Correct	74	66.67
Incorrect	37	33.33

Knowledge regarding the recognition of the end-expiratory flow could be considered as adequate, as 74 respondents (66.67%) could answer the question correctly.

4.3.20 QUESTION 17.4: RECOGNITION OF THE DURATION OF EXPIRATORY FLOW ON A FLOW-TIME GRAPH

This question determined whether the respondents could recognise the duration of expiratory flow on a flow-time graph. Table 4.20 reflects the results.

Table 4.20: Recognition of the duration of expiratory flow on a flow-time graph

RESPONSE	FREQUENCY (n)	PER CENT
Correct	76	68.47
Incorrect	35	31.53

Knowledge regarding the recognition of the duration of expiratory flow was fair, as 76 respondents (68.47%) could answer the question correctly.

4.3.21 QUESTION 18.1: RECOGNITION OF THE START OF INSPIRATION ON A FLOW-TIME GRAPH

This question determined whether the respondents could recognise the start of inspiration on a flow-time graph. Table 4.21 (page 107) reflects the results.

Table 4.21: Recognition of the start of inspiration on a flow-time graph

RESPONSE	FREQUENCY (n)	PER CENT
Correct	40	36.04
Incorrect	71	63.96

Knowledge regarding the recognition of the inspiratory point was poor as only 40 respondents (36.04%) could answer the question correctly.

4.3.22 QUESTION 18.2: RECOGNITION OF THE PEAK FLOW DURING INSPIRATION ON A FLOW-TIME GRAPH

This question determined whether the respondents could recognise the peak flow during inspiration on a flow-time graph. Table 4.22 reflects the results.

Table 4.22: Recognising the peak flow during inspiration on a flow-time graph

RESPONSE	FREQUENCY (n)	PER CENT
Correct	58	52.25
Incorrect	53	47.75

In terms of the knowledge regarding the recognition of the peak flow, 58 of the respondents (52.25%) answered correctly while 53 of the respondents (47.75%) answered incorrectly.

4.3.23 QUESTION 18.3: RECOGNITION OF THE END OF INSPIRATION ON A FLOW-TIME GRAPH

This question determined whether the respondents could recognise the end of inspiration on a flow-time graph. Table 4.23 reflects the results.

Table 4.23: Recognition of the end of inspiration on a flow-time graph

RESPONSE	FREQUENCY (n)	PER CENT
Correct	35	31.53
Incorrect	76	68.47

Knowledge regarding the recognition of the end of inspiratory flow was poor, as only 35 respondents (31.53%) could answer the question correctly.

4.3.24 QUESTION 19: IDENTIFICATION OF THE FLOW GRAPH THAT MATCHES A SIMV MODE OF VENTILATION

This question determined whether the respondents could recognise the flow graph that matches the given volume-time and pressure-time graphs in the case of a SIMV mode of ventilation. Table 4.24 reflects the results.

Table 4.24: Recognition of the matching flow-time graph for a SIMV ventilated patient

RESPONSE	FREQUENCY (n)	PER CENT
Correct	67	60.36
Incorrect	44	39.64

Knowledge of how a flow-time waveform matches volume-time and pressure-time waveforms with respect to a SIMV ventilated patient could be considered as adequate, as 67 respondents (60.36%) could answer the question correctly.

4.3.25 QUESTION 20: IDENTIFICATION OF THE PRESSURE-TIME GRAPH THAT MATCHES A VOLUME CONTROLLED MODE OF VENTILATION

This question determined whether the respondents could recognise the pressure-time graph that matches the given volume-time and flow-time graphs in the case of a volume controlled mode of ventilation. Table 4.25 reflects the results.

Table 4.25: Recognition of the matching pressure-time graph for a volume controlled mode of ventilation

RESPONSE	FREQUENCY (n)	PER CENT
Correct	79	71.17
Incorrect	32	28.83

Knowledge of how a pressure graph had to be matched to volume-time and flow-time graphs was fair, as 79 respondents (71.17%) could answer the question correctly.

4.3.26 QUESTION 21: IDENTIFICATION OF THE PRESSURE-TIME GRAPH THAT MATCHES A PRESSURE CONTROLLED MODE OF VENTILATION

This question determined whether the respondents could recognise the pressure-time graph that matches the given volume-time and flow-time graphs in the case of a pressure controlled mode of ventilation. Table 4.26 reflects the results.

Table 4.26: Recognition of the matching pressure-time graph for a pressure controlled mode of ventilation

RESPONSE	FREQUENCY (n)	PER CENT
Correct	75	67.57
Incorrect	36	32.43

Knowledge of how a pressure graph had to be matched to volume-time and flow-time graphs could be considered as adequate as 75 respondents (67.57%) could answer the question correctly.

4.3.27 QUESTION 22: IDENTIFICATION OF THE NEED FOR TRAINING

This question determined whether the respondents wanted training. Forty-six respondents (42.82%) did not answer the question. Table 4.27 reflects the results.

Table 4.27: Identifying the need for in-service training on ventilator graphics

RESPONSE	FREQUENCY (n)	PER CENT
Did not answer	46	41.82
Wanted training	62	56.36
Did not want training	2	1.82

The results of this question were surprising, as 46 respondents (41.82%) did not answer the question and 62 (56.36%) indicated that they required training. Only two respondents (1.82%) indicated that they did not want training. It is not clear why the question was not answered by 41.82% of the respondents.

4.4 THE RESULTS OF THE ENTIRE GROUP

4.4.1 RESULTS OF THE ENTIRE GROUP FOR THE KNOWLEDGE SECTION AS A WHOLE

The results of the entire group of 111 respondents for the knowledge sections of the questionnaire are presented in Table 4.28.

Table 4.28: Results of the entire group of respondents

RESPONDENTS	TOTAL NUMBER OF QUESTIONS	MEAN		STD DEVIATION IN PERCENTAGE	MINIMUM		MAXIMUM	
		RS	%		RS	%	RS	%
111	25	10.1	40.3	18.1	0	0	20	80
RS = Raw scores								

The questionnaire had a total of 25 knowledge questions. A mean score of 40.3% (10.1 out of 25) was obtained with a standard deviation in the percentage of 18.1.

As explained in Subsection 4.3.1, the entire knowledge section of the questionnaire was subdivided into groups of questions, each considering a specific theme of ventilator graphics. The respondents' knowledge level regarding each of the seven themes was evaluated and the results are presented in Subsections 4.4.2 to 4.4.8.

4.4.2 THEME 1: WAVEFORM IDENTIFICATION

Theme 1 was covered by questions 4, 5 and 6. Refer to Table 4.29 for the results.

Table 4.29: Results of questions on waveform identification (Theme 1)

RESPONDENTS	TOTAL NUMBER OF QUESTIONS	MEAN		STD DEVIATION IN PERCENTAGE	MINIMUM		MAXIMUM	
		RS	%		RS	%	RS	%
111	3	0.8	26.7	25.4	0	0	3	100
RS = Raw scores								

The mean percentage achieved by the group for this theme was 26.7%.

4.4.3 THEME 2: MODES OF VENTILATION

Theme 2 was covered by questions 7 to 10 and assessed the identification of different modes of ventilation. Refer to Table 4.30.

Table 4.30: Results of questions on modes of ventilation (Theme 2)

RESPONDENTS	TOTAL NUMBER OF QUESTIONS	MEAN		STD DEVIATION IN PERCENTAGE	MINIMUM		MAXIMUM	
		RS	%		RS	%	RS	%
111	4	1.98	49.5	29.6	0	0	4	100
RS = Raw scores								

The mean percentage achieved by the group for this theme was 49.5%.

4.4.4 THEME 3: PHENOMENA THAT CAN AFFECT PATIENT OUTCOMES DURING VENTILATION

Theme 3 was covered by questions 11 to 15. Refer to Table 4.31 on page 112 for the results.

Table 4.31: Results of questions on phenomena affecting patient outcomes (Theme 3)

RESPONDENTS	TOTAL NUMBER OF QUESTIONS	MEAN		STD DEVIATION IN PERCENTAGE	MINIMUM		MAXIMUM	
		RS	%		RS	%	RS	%
111	5	1.7	33.9	22.7	0	0	5	100
RS = Raw scores								

The mean percentage achieved by the group for this theme was 33.9%.

4.4.5 THEME 4: DIFFERENT ASPECTS OF FLOW-TIME WAVEFORMS

Theme 4 was covered by questions 16.1 to 18.3 and assessed the identification of different aspects of flow-time waveforms. Refer to Table 4.32.

Table 4.32: Results of questions on different aspects of flow-time waveforms (Theme 4)

RESPONDENTS	TOTAL NUMBER OF QUESTIONS	MEAN		STD DEVIATION IN PERCENTAGE	MINIMUM		MAXIMUM	
		RS	%		RS	%	RS	%
111	10	4.6	45.9	26.1	0	0	10	100
RS = Raw scores								

The mean percentage achieved by the group for this theme was 45.9%.

4.4.6 THEME 5: WAVEFORM DIFFERENTIATION

Theme 5 was covered by questions 19 to 21. Refer to Table 4.33.

Table 4.33: Results of questions regarding waveform differentiation (Theme 5)

RESPONDENTS	TOTAL NUMBER OF QUESTIONS	MEAN		STD DEVIATION IN PERCENTAGE	MINIMUM		MAXIMUM	
		RS	%		RS	%	RS	%
111	3	1	33.6	32.9	0	0	13	100
RS = Raw scores								

The mean percentage achieved by the group for this theme was 33.6%.

4.4.7 THEME 6: ASSESSMENT OF FLOW-TIME GRAPHICS

Theme 6 was covered by questions 5, 11, 16.1 to 18.3, and question 19, and described flow-time graphics. Refer to Table 4.34.

Table 4.34: Results of questions regarding assessment of flow-time graphics (Theme 6)

RESPONDENTS	TOTAL NUMBER OF QUESTIONS	MEAN		STD DEVIATION IN PERCENTAGE	MINIMUM		MAXIMUM	
		RS	%		RS	%	RS	%
111	13	5.8	44.6	24.1	0	0	13	100
RS = Raw scores								

The mean percentage achieved by the group for this theme was 44.6%.

4.4.8 THEME 7: ASSESSMENT OF PRESSURE-TIME GRAPHICS

Theme 7 was covered by questions 6 to 10, 13, 20 and 21. Refer to Table 4.35.

Table 4.35: Results of questions regarding assessment of pressure-time graphics (Theme 7)

RESPONDENTS	TOTAL NUMBER OF QUESTIONS	MEAN		STD DEVIATION OF PERCENTAGE	MINIMUM		MAXIMUM	
		RS	%		RS	%	RS	%
111	8	2.7	39.1	22.9	0	0	7	100
RS = Raw scores								

The mean percentage achieved by the group for this theme was 39.1%.

4.5 THE RESULTS OF THE QUESTIONNAIRE: ACHIEVEMENTS ACCORDING TO ASPECTS OF THE BIOGRAPHICAL DATA

In order to determine if some of the groups within the study population require more or less training than others, the results for those groups are also presented.

4.5.1 SCORES ACHIEVED ACCORDING TO QUALIFICATION

In Table 4.36, the scores of groups of respondents with different qualifications are presented for the questionnaire as a whole, as well as for each of the seven themes identified. Refer to Table 4.36.

Table 4.36: Scores achieved by respondents grouped together according to qualification

Qualification	Total number of respondents (n)	MEAN PERCENTAGE FOR WHOLE QUESTIONNAIRE AND THEMES								MINIMUM SCORE								MAXIMUM SCORE							
			THEMES								THEMES								THEMES						
		Total	1	2	3	4	5	6	7	Total	1	2	3	4	5	6	7	Total	1	2	3	4	5	6	7
Experience	52	39.3	25	45.7	32.3	47.9	28.2	45.6	34.3	0	0	0	0	0	0	0	0	80	100	100	80	100	100	100	100
Training	52	42.5	28.2	52.9	36.5	46	41.7	46	44.8	0	0	0	0	0	0	0	0	76	100	100	100	100	100	100	85.7
Master's degree	5	36	26.7	65	32	34	20	32.3	40	20	0	50	20	0	0	0	28.6	60	33.3	100	40	90	66.7	76.9	71.4

(Two respondents did not answer the question on qualification.)

With reference to the whole questionnaire, the highest mean percentage (42.5%) was achieved by respondents with critical care training, while respondents with a master's degree in critical care nursing achieved the lowest mean percentage, namely 36%. With reference to the individual themes, the lowest range of mean percentages (25%; 26.7%; 28.2%) was achieved for theme 1 (waveform identification). However, on a level of 0.001 there was no significant differences between the p-values of all the groups of respondents' scores.

4.5.2 SCORES ACHIEVED BY EXPERIENCE

In Table 4.37, the scores of the respondents with different numbers of years of experience are presented for the questionnaire as a whole as well as for each theme. Refer to Table 4.37.

Table 4.37: Scores achieved by respondents grouped together according to years of experience

EXPERIENCE	Total number of respondents (n)	MEAN PERCENTAGE FOR WHOLE QUESTIONNAIRE AND THEMES								MINIMUM SCORE								MAXIMUM SCORE							
			THEMES								THEMES								THEMES						
		Total	1	2	3	4	5	6	7	Total	1	2	3	4	5	6	7	Total	1	2	3	4	5	6	7
< 2 YEARS	19	38.1	15.8	47.4	31.6	45.3	35.1	42.1	34.6	0	0	0	0	0	0	0	0	72	66.7	100	80	80	100	76.9	100
2- 5 YEARS	28	42.6	29.8	50.9	35	48.9	45.7	48.9	38.8	0	0	0	0	0	0	0	0	76	100	100	80	90	100	84.6	85.7
> 5 YEARS	28	45.6	27.4	54.5	40.7	53.2	34.5	50	43.9	4	0	0	0	0	0	7.7	0	76	100	100	100	100	100	100	85.7
> 10 YEARS	35	36.6	30.5	47.1	29.7	39.1	31.4	39.6	40	0	0	0	0	0	0	0	0	80	66.7	100	60	100	100	100	85.7

(One respondent did not answer the question on experience.)

When respondents are grouped together according to years of experience, the highest mean percentage for the whole questionnaire (45.6%) was achieved by respondents who had 5 to 10 years of critical care experience. Respondents who had more than ten years of experience achieved the lowest mean percentage, namely 36.6%. The highest range of mean percentages (47.1%; 54.5%; 50.9%; 47.4%) was achieved for theme 2 (modes of ventilation). However, on a level of 0.001 there was no significant differences between the p-values of all the groups of respondents' scores.

4.5.3 SCORES ACHIEVED BY RESPONDENTS WHO RECEIVED TRAINING IN VENTILATOR GRAPHICS

Refer to Table 4.38.

Table 4.38: Scores achieved by respondents grouped together according to type of training received

TYPE OF TRAINING	NUMBER OF RESPONDENTS	AVERAGE SCORE IN %
Hospital	9	41.33
Company	6	40.67
Workshop	8	46.50
Other	4	56.0
> One type	3	33.33
Did not identify type of training	2	30.76
TOTAL	32	39.01

4.6 COMPETENCY INDICATOR

4.6.1 THE WHOLE QUESTIONNAIRE FOR THE ENTIRE GROUP

The total average percentage achieved by the group of 111 respondents was 40.28%, which is 19.72% below the set competency indicator of 60%. It can thus be concluded that the knowledge of the respondents regarding ventilator graphics was far below standard. The lowest total average score obtained by a respondent was 0% and the highest was 80%. Only 15 respondents achieved a percentage on or above the competency indicator. Ninety-six (96) respondents could not achieve a percentage on or above 60% – the level of knowledge deemed necessary and acceptable in the critical care setting and a performance standard, which should be attainable by every critical care nurse.

In order to gain perspective on their competency, the group of 111 respondents was again broken down according to the biographical data. Each of these groups will be discussed separately.

4.6.2 COMPETENCY BY QUALIFICATION

4.6.2.1 Critical care experience

Fifty-two respondents had experience, rather than training, in critical care. Forty-seven of these respondents (90.38%) achieved below the competency indicator while five (9.62%) were found to be competent.

4.6.2.2 Critical care training

Fifty-two respondents were trained critical care nurses. Forty-three respondents (82.7%) achieved below the competency indicator while nine (17.31%) were found to be competent.

4.6.2.3 Master's degree in critical care

Five respondents reported that they have a master's degree in critical care. Four (80%) achieved below the competency indicator while one (20%) was found to be competent.

4.6.3 COMPETENCY BY EXPERIENCE

4.6.3.1 <2 years

Nineteen respondents reported that they had less than two years of experience. Seventeen (89.47%) achieved below the competency indicator while two (10.53%) were found to be competent.

4.6.3.2 2- 5 years

Twenty-eight respondents reported that they had between two and five years of experience. Twenty-four (85.71%) achieved below the competency indicator while four (14.29%) were found to be competent.

4.6.3.3 > 5 years

Twenty-eight respondents reported that they had more than five years of experience. Twenty-three (82.14%) achieved below the competency indicator while five (17.86%) were found to be competent.

4.6.3.4 > 10 years

Thirty-five respondents reported that they had more than ten years of experience. Thirty-one (88.57%) achieved below the competency indicator while four (11.43%) were found to be competent.

4.6.4 COMPETENCY BY TRAINING IN VENTILATOR GRAPHICS

4.6.4.1 Hospital training in ventilator graphics

Nine respondents reported that they received hospital training in ventilator graphics. Eight (88.9%) of these respondents achieved below the set competency indicator while one (11.1%) was found to be competent. Refer to Table 4.39.

Table 4.39: Mean score of respondents who received hospital training in ventilator graphics

NUMBER OF RESPONDENTS	MEAN %
9	41.33

4.6.4.2 Company training

Six respondents reported that they received training offered by the ventilator companies. Six (100%) achieved below the competency indicator. Refer to Table 4.40.

Table 4.40: Mean score of respondents who received company training in ventilator graphics

NUMBER OF RESPONDENTS	MEAN %
6	40.67

4.6.4.3 Workshops attended

Eight respondents reported that they attended ventilator workshops. Seven (87.5%) achieved below the competency indicator while one (12.5%) was found to be competent. Refer to Table 4.41.

Table 4.41: Mean score of respondents who received workshop training in ventilator graphics

NUMBER OF RESPONDENTS	MEAN %
8	46.5

4.6.4.4 Other training

Four respondents reported that they received training from a source other than the ones mentioned above. Two (50%) achieved below the competency indicator and two (50%) were found to be competent. Refer to Table 4.42.

Table 4.42: Mean score of respondents who received training in ventilator graphics from other sources

NUMBER OF RESPONDENTS	MEAN %
4	56

4.6.4.5 More than one type of training

Three respondents reported that they received more than one type of training. All three (100%) achieved below the competency indicator. Refer to Table 4.43.

Table 4.43: Mean score of respondents who received more than one type of training in ventilator graphics

NUMBER OF RESPONDENTS	MEAN %
3	33.3

4.6.4.6 Did not identify the type of training

Two respondents did not identify the type of training they had received.

4.7 CONCLUSION

In Chapter 4, the research results were discussed. There were some surprises in the results, but overall the performance of the respondents was poor. Only 13.5% of the respondents achieved a percentage on or above the competency indicator. The majority of the respondents (86.5%) could not achieve a percentage of or above 60%. These results underline the necessity of an educational programme regarding ventilator graphics, a topic that will be addressed in Chapters 5 and 6 of this study. However, areas for improvements in the questionnaire were also identified and will be discussed in Chapter 5. Recommendations will be made for nursing practice and nursing education.

CHAPTER 5

CONCLUSIONS, LIMITATIONS, RECOMMENDATIONS AND REFLECTION OF THE STUDY

5.1 INTRODUCTION

In this chapter, conclusions and recommendations are made according to the objectives stated in the first chapter of this study. The objectives of this study were threefold:

- The first objective of this study was to familiarise the researcher with available literature on the topic. This was done in order to highlight important aspects and assist the researcher in the development of a questionnaire. Accordingly, a thorough literature research on the topic was conducted as set out in Chapter 2. The assumption is that a literature study usually forms part of any research, to provide a background to the study. However, in this case, the literature study is mentioned separately as it served in the generation of a measurement instrument in the form of a questionnaire.
- The second objective of this study was to determine critical care nurses' knowledge regarding ventilator graphics using a questionnaire. This objective was met during the data gathering and analysis portion of this study, as set out in Chapter 3.
- The third objective of this study was to design an educational programme based on the findings of the empirical phase. A Microsoft PPP about the use of ventilation waveforms in providing optimal nursing care to ventilated patients is designed. Refer to Chapter 6.

In attaining these objectives, the main aim of this study, that is, to determine the knowledge that critical care nurses, who work in private hospitals in Gauteng, have regarding ventilator graphics, is achieved.

In order to draw conclusions and make recommendations about critical care nurses' knowledge regarding ventilator graphics, the results of the data analysis are interpreted.

5.2 MAIN FINDINGS AND CONCLUSIONS

A questionnaire was used as a research instrument in the collection of data. The questionnaire was used to measure the knowledge that critical care nurses, who work in private hospitals in Gauteng, have regarding ventilator graphics.

One hundred and sixty (160) questionnaires were distributed to critical care nurses at five hospitals in the Gauteng province. While 113 of these questionnaires were returned, two could not be used. Therefore, 111 respondents participated in the survey, resulting in a response rate of 69.3%.

The data was processed with the assistance of a professional statistician. Descriptive statistics were used for the data analysis. In Chapter 4, the research findings were presented and described.

In this section, the results of the data analysis (refer to Chapter 4) are interpreted and discussed.

5.2.1 BIOGRAPHICAL DATA

In the study sample, the number of respondents who had critical care experience, namely 52 (representing 46.85% of the sample) was equal to the number of respondents who were registered in critical care nursing with the

SANC. This was surprising as it was expected that, in critical care units, nurses with only experience would outnumber those registered in critical care. As participation in this study was voluntary, it could be that trained critical care nurses had more confidence in themselves on a professional level and therefore volunteered in relatively larger numbers to participate in the study.

In the category dealing with years of experience, the group with the largest representation was the group of respondents (32%) who had more than ten years of experience in caring for ventilated patients in the critical care setting. The number of respondents (25%) who had between two and five years of experience in ventilating patients was equal to the number of respondents (25%) who had between five and ten years of experience. This was also unexpected, as the researcher believed that a larger part of the critical care nurses working in critical care units are younger and less experienced. However, this could be accounted for by the same reason, mentioned above.

A fairly high percentage (69%) of the respondents had never received training on ventilator graphics. Of the 29% that had received training, the larger number (35%) received training from the hospital itself, followed by those who received training from ventilator companies (27%). It was encouraging to observe that hospital administrations regard this topic as important and consequently allocate resources for training in this direction. In the past, this kind of training was only offered by ventilator companies.

5.2.2 WAVEFORM IDENTIFICATION

In terms of waveform identification, only 26% of the respondents answered all three waveform questions correctly. This was alarming as these three basic waves form the basis of ventilator graphics.

5.2.3 MODES OF VENTILATION

Three questions tested the respondents' recognition of the different modes of ventilation. A higher percentage (49.5%) of respondents answered the questions correctly. This indicated either that more of the respondents guessed correctly or that they are more familiar with the different modes of ventilation.

5.2.4 PHENOMENA THAT CAN AFFECT PATIENT OUTCOMES DURING VENTILATION

The next aspect that was considered was the phenomena that can affect patient outcomes during ventilation. Ventilation is a dynamic treatment modality. Patients' response to this treatment can easily be observed on waveforms. The basic illustrations used in questions 1 to 15 revealed that only 33.9% of the respondents could identify the important changes in patient-ventilator synchrony, despite the fact that the respondents' experience with ventilator patients was vast. It could be expected that they would be capable of recognising the most basic changes.

5.2.5 DIFFERENT ASPECTS OF FLOW-TIME WAVES

In the questions relating to flow-time waveforms, a flow-time wave was divided into different phases and the respondents were required to recognise each phase. The total percentage of respondents who were able to do this was 45.9%. This means that less than half of the respondents could recognise the phases of a normal flow-time waveform.

5.2.6 WAVEFORM DIFFERENTIATION

From the three potentially correct options available to the respondents, the correct option was indicated only 33.6% of the time. An understanding of the given waveforms would enable recognition of the matching waveform.

5.2.7 IDENTIFICATION OF FLOW-TIME WAVEFORM

The answers to a combination of questions illustrate the respondents' application knowledge of the theme of flow-time waveforms. Only 44.6% of the respondents could answer these questions correctly. This means that flow-time graphics have to be included and explained in detail during an educational programme dealing with ventilator graphics.

5.2.8 PRESSURE-TIME GRAPHICS

The answers to a combination of questions illustrate the respondents' application knowledge of the theme pressure-time waveforms. Only 39.1% of the respondents could answer these questions correctly. This means that pressure-time graphics have to be included and explained in detail during an educational programme dealing with ventilator graphics.

5.3 TOTAL AVERAGE PERCENTAGE ACHIEVED BY RESPONDENTS

The total average percentage achieved by the group of 111 respondents was 40.28%, a figure that is 19.72% below the set competency indicator of 60%. It can thus be concluded that the respondents' knowledge regarding ventilator graphics was below standard. The lowest total average score obtained by a respondent was zero (0%) and the highest was 80%. Only 15 respondents achieved a percentage of or above the competency indicator – the level of knowledge deemed necessary and acceptable in the critical care setting and a performance standard which should be attainable by every critical care nurse in ventilating patients.

If the average score of the study's seven themes are considered, the mean percentages of themes two (49.5%), four (45.9%) and six (44.68%) were slightly higher than the themes of which the averages were below 40%. This may be an indication that the respondents were more comfortable with some of the themes. However, it was clear that intensive training was needed in all these areas, as all the average percentages were below the competency indicator.

The questionnaire was statistically tested for reliability. Although the Cronbach alpha indicated that the questionnaire was fairly reliable, an item analysis indicated that questions 4, 5, 11 and 15 might need attention before the questionnaire's further use.

5.4 LIMITATIONS OF THE STUDY

The following limitations were identified:

- The study was contextual, as this research was conducted only in selected private hospitals in Gauteng. Therefore, the findings cannot be generalised to a larger population.
- A relatively small sample was used as only 160 questionnaires were distributed. This was due to the fact that not all critical care units had ventilator graphics available.
- As no previous studies on this topic were found, the validation of the research process could not be based on available studies and the reliability of the questionnaire had to be determined for the first time.

5.5 RECOMMENDATIONS

Recommendations, based on the findings of this study, are made for the clinical situation, nursing management, nursing education, as well as nursing research.

5.5.1 RECOMMENDATIONS FOR CRITICAL CARE NURSING PRACTICE

The critical care environment places a high demand on critical care nurses to employ critical thinking, and effectively and efficiently contribute to the total health of the patient. It is therefore important that critical care nurses are knowledgeable, competent and skilful. The following recommendations are made for the critical care nursing practice:

- An educational programme, addressing the most relevant aspects of ventilator graphics, should be implemented and used in the training of newly appointed, as well as other staff.
- Due to the high turnover of critical care nursing staff, the educational programme should be presented on a regular basis to ensure that nobody misses out on the opportunity of this training.
- Critical care nurses should on a continuous basis ask expert doctors to share their knowledge on ventilator graphics during ward rounds and the clinical application of ventilation.
- Critical care nurses that have knowledge on ventilator graphics should also share this knowledge and emphasise the importance of ventilator graphics.

5.5.2 RECOMMENDATIONS FOR NURSING MANAGEMENT

The following recommendations are made for nursing management and administration:

- It is important that nursing management and nursing administration make provision for the in-service training of critical care personnel.

Provision should also be made for workshops that are not offered in the hospital.

- Making provision for competency testing on critical outcomes will become part of the SANC's effort to promote the competency updating of South African nurses. Credits could be awarded in preparation of the competency-based point system proposed by the SANC.
- The critical care environment is a dynamic clinical set-up, and competent, knowledgeable, specially trained nurses should be responsible for the safe and quality care of patients. Thus, providing incentives for nursing staff to attend in-service training programmes, offered by ventilator companies, could be another avenue of training for hospital management to investigate.

5.5.3 RECOMMENDATIONS FOR NURSING EDUCATION

The following recommendations are made for nursing education:

- Ventilator graphics should be included in the subject matter of critical care training programmes presented in South Africa, whether the certificate, diploma or postgraduate courses.
- The practical component of ventilator graphics should be taught clinically, at the bedside during student accompaniment.
- Clinical facilitators and nurse educators should create and use learning opportunities in the critical care setting, with the purpose of enhancing the acquisition of this skill.
- As an outcomes-based education system is the main educational approach used in South Africa today, facilitating an improved patient outcome through the use of ventilator graphics is highly recommended.
- As the training offered prior to this study had no significant impact, in that there was no difference between the scores of the respondents who had attended training and those who did not, it is clear that clinically experienced staff should offer training. The current training methods are

not as effective as what was hoped. However, the researcher realises that this is only an assumption based on the content of the questionnaire.

- As the topic is still relatively new to critical care nurses, a self-study workbook could be developed for the purpose of upgrading critical care nurses' knowledge on ventilator graphics.

5.5.4 RECOMMENDATIONS FOR FURTHER RESEARCH

The following recommendations are made for nursing research:

- This study could be replicated in order to compare the knowledge and competence levels of critical care nurses employed in private and academic hospitals.
- This study could be replicated in order to test neonatal nurses' knowledge regarding ventilator graphics.
- This study could be extended by including more hospitals and by involving other provinces in the study.
- This study could be repeated after more hospitals have bought ventilators with graphic displays.
- A secondary study could be conducted in order to determine the knowledge of nursing staff that had received training following the development of the educational programme included in this study.
- The questionnaire could be further refined, in order to address the questions identified during the item analysis, as previously indicated.
- This study could be replicated in order to examine the skill in practice (competence) regarding ventilator graphics and correlate it with the outcomes in the questionnaire of the same group.

5.6 REFLECTION ON THE STUDY

Most of the training received by the respondents was offered by the hospital itself (35%). However, at a meeting of critical care facilitators, the response to a poorly attended critical care society meeting that hosted a talk on ventilator graphics was that the large amount of time spent on basic ventilator strategies during the two-year training of critical care nurses makes the interpretation of waveforms above any critical care nurse.

The researcher strongly disagrees with this sentiment. The clinical facilitation of students can have a phenomenal impact on the thinking of critical care nurses. While those involved in their training are negative regarding this topic, it can be expected that the staff and critical care students feel the same way. This could lead to a deficiency in the training of critical care nurses and the promotion of the skill and competence to improve patient-ventilator synchrony.

An additional study is currently underway at the University of Witwatersrand, which looks at the very basic knowledge of critical care nurses on ventilation. It would have been valuable to consider the basic knowledge, examined by this additional study, before an advanced level is tested. The experience and recommendations emulating from this study could also have been a useful guide.

Due to the dynamic nature of the critical care setting and its patients' conditions, the training or facilitation of critical care nurses should not be on a once-off basis and should likewise remain dynamic.

Being involved in this study brought the researcher in contact with other nurses who have a special interest in mechanical ventilation. It was worthwhile to realise that there were others who demonstrated interest and keen participation despite the limited knowledge on the subject. Their appreciation of the effect this study could have on the quality of care being rendered to patients, made it seem worthwhile.

5.7 CONCLUSION

In Chapter 5, a summary of the findings of the study is presented. The majority of the respondents (75%) have worked with ventilated patients for more than five years. The assumption is that this should have had some kind of impact on their responses. However, the statistics showed an overpowering incompetence. The statistics discussed in this chapter, prove that the respondents required intensive training regarding this topic. Therefore, an educational programme, focusing on these themes, has been designed. The outline of this education programme and a copy of the PPP are presented in Chapter 6.

CHAPTER 6

EDUCATION PROGRAMME ON VENTILATOR GRAPHICS

6.1 INTRODUCTION

In Chapter 5, the study findings were summarised. The study results, findings and conclusions confirmed the necessity of developing an educational programme on ventilator graphics.

6.2 STARTING POINT

As the contents of an education programme on ventilator graphics have to include both basic and advanced information, the researcher decided that it would be best to start with the most basic information. As the basic principles of ventilator waveforms are the fundamentals of ventilator graphic interpretation, they should be understood first. The researcher also argued that it would be best if an expert on ventilator waveform interpretation presents this programme.

Although the monitoring principles of most of the equipment in critical care units can be mastered through problem-based learning, ventilator graphic basics would be easier grasped if the learner were introduced to the topic by an expert. Therefore, although problem-based learning is more suited to the needs of adult learners, this topic needs to be presented as a lecture to those who are exposed to its contents for the first time. According to Mellish, Brink and Paton (1998:103), the lecture method has the advantages that the lecturer can explain and interpret facts, and point out different points of view. These actions can save learners a lot of time, as they do not need to find or figure out facts. The opportunity to present ventilator graphics with enthusiasm and in an inspirational manner is an additional advantage of the lecture method of teaching.

6.3 A VARIETY OF OPTIONS

The education programme on ventilator graphics is presented in the format of a PPP. However, this presentation only serves as a guideline and can be easily adapted to meet the needs of the audience.

The lecture method, which includes the PPP, allows interactive discussions between the presenter and the audience. Based on these interactive discussions, the contents of the PPP can be adapted to meet the specific needs of the learners. This feature enhances the learning experience.

The PPP can be adapted to suit the level of knowledge required by learners. Either a basic, applied or an advanced option can be chosen. The PPP thus caters for the needs of novice and advanced learners.

The PPP is also designed to address specific knowledge deficiencies. The presentation is divided into specific themes, namely ‘introduction to basic principles’, ‘flow graphics’, ‘volume graphics’, ‘pressure graphics’, ‘pressure-volume loops’ and ‘flow-volume loops’, and themes can be selected according to the needs of the audience. The basic, applied, or advanced option is applicable to each theme.

Al these options are packed into a user-friendly PPP. A number of slides are included under each theme. These slides are further divided according to the level of complexity, starting with basic knowledge, moving on to knowledge application, and closing with advanced information.

The presentation is designed as an open system - the lecturer can compile a programme according to the group’s requirements. For a particular lecture, the applicable slides would follow chronologically and unnecessary slides could be “hidden” during the presentation. The adaptability of the PPP is outlined in

Table 6.1. The different themes are set out in the first column, and the levels of complexity in columns two to four. The numbers of the applicable slides are indicated.

Table 6.1: Outline of the education programme on ventilator graphics

THEME	**LEVEL 1 BASIC KNOWLEDGE**	**LEVEL 2 KNOWLEDGE APPLICATION**	**LEVEL 3 ADVANCED INFORMATION**
INTRODUCTION	***Basics***	***Application***	***Advanced***
	Slides 1 - 14	*Review the basics if necessary*	*Review the basics if necessary*
FLOW GRAPHICS	***Basics***	***Application***	***Advanced***
	Slides 14 - 27	Slides 28 - 31 Slides 33 - 34	Slides 32, 35 - 39
VOLUME GRAPHICS	***Basics***	***Application***	***Advanced***
	Slides 40 - 43		
PRESSURE GRAPHICS	***Basics***	***Application***	***Advanced***
	Slides 44 - 48 Slides 51 - 52	Slide 53 Slides 59 - 69	Slides 49 - 50 Slides 54 - 58
PRESSURE-VOLUME LOOPS	***Basics***	***Application***	***Advanced***
	Slides 70 -72	Slides 74 - 77 Slide 93	Slides 78 - 92
FLOW-VOLUME LOOPS	***Basics***	***Application***	***Advanced***
	Slides 94 - 100	Slides 101 - 102	Slides 103 - 104
CONCLUSION		Slides 105 - 107	

6.4 CONCLUSION

Because of rapid advancements in new technology, the contents of the PPP would probably become basic knowledge within the next few years. Once learners have mastered ventilator basics, problem-based education can be used to enhance their diagnostic skills, including their critical thinking ability.

A copy of the PPP is attached to this chapter.

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ANNEXURE A

PARTICIPANT INFORMATION LEAFLET AND QUESTIONNAIRE

PARTICIPANT INFORMATION LEAFLET ATTACHED TO THE QUESTIONNAIRE

PO BOX 11171
ASTON MANOR
1630

Dear Respondent

RESEARCH: CRITICAL CARE NURSES KNOWLEDGE REGARDING VENTILATOR WAVEFORMS (GRAPHICS)

I am a critical care nurse and in the process of completing my MCur degree at the University of Pretoria.

The purpose of my study is to determine the knowledge of critical care nurses regarding ventilator waveforms (graphics). This will enable me to compile an in-service training programme regarding ventilator graphics from a critical care nursing perspective.

This letter requests your participation in this study. You will be asked to complete a questionnaire containing multiple-choice questions. Completion may take up to 30 minutes. Completed questionnaires have to be placed in the box provided by the researcher. In order to maintain your anonymity, you will not be asked to complete a consent form. **The implication of completing the questionnaire is that informed consent has been obtained from you. Your participation in this study is voluntary and you can refuse to participate, or withdraw at any time, without stating a reason.**

Please do not hesitate to ask the researcher any questions you may have.

Thank you for deciding to participate in the study. As a result of your cooperation, an in-service training programme will be developed. This programme will allow critical care nurses to gain knowledge regarding ventilator graphics.

Kind regards

____

Sonja Windsor

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INSTRUCTIONS

The following terminology appears in the questionnaire. The table below includes a short description of each term, as well as its abbreviated form, if applicable.

TERMINOLOGY	DESCRIPTION	ABBREVIATION
Ventilator	Machine used to provide the lungs with air.	
Ventilation	The process by which gases are moved into and out of the lungs.	
Ventilator graphics	Graphics that display graphic and numerical information about ventilation.	
Peak flow	Speed of airflow in litres per minute.	
Peak inspiratory pressure	The highest level of pressure observed on the manometer during a mechanically ventilated breath.	PIP
MINUTE VOLUME	The total ventilation per minute. The product of tidal volume and respiratory rate, as measured by expired gas collection for a period of 1-3 minutes. The normal rate is 5-10 litres per minute.	MV
Positive end-expiratory pressure	At the end of expiration a positive pressure is maintained in the lungs to facilitate gaseous exchange.	PEEP
Inspiratory-expiratory ratio	Inspiration time relative to expiration time. The normal ratio is 1:2.	I:E ratio

Synchronised intermittent mandatory ventilation	Patient has variable work of breathing. The mandatory ventilated breaths occur at a preset rate and tidal volume, but the patient may take spontaneous breaths between the machine delivered breaths.	SIMV
Assist-control ventilation	The patient has minimal work of breathing during the initial expansion of the chest, and then the ventilator will deliver the preset tidal volume.	ACV
Inspiratory time		Ti
Peak pressure	Pressure at the point between inspiration and expiration.	Ppeak
Plateau pressure	Pressure during the plateau phase.	Pplat
Continuous positive airway pressure		CPAP
Pressure controlled ventilation	Delivers gas until preset pressure is reached. Tidal volume varies because it depends on delivery pressure needed.	PCV
Volume controlled ventilation	Delivers gas until preset volume is reached. Pressure varies because it depends on delivery volume needed.	VCV
TIDAL VOLUME	The amount of air inhaled and exhaled during normal ventilation.	Vt

ANNEXURE B

APPROVAL FROM UP FACULTY OF HEALTH SCIENCES' RESEARCH ETHICS COMMITTEE TO CONDUCT STUDY

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Ventilator graphics

by

Sonja Windsor

Contents

- Introduction & background
- Mechanical ventilation
- Flow graphics
- Volume graphics
- Pressure graphics
- Loops

INTRODUCTION & BACKGROUND

- Physiology

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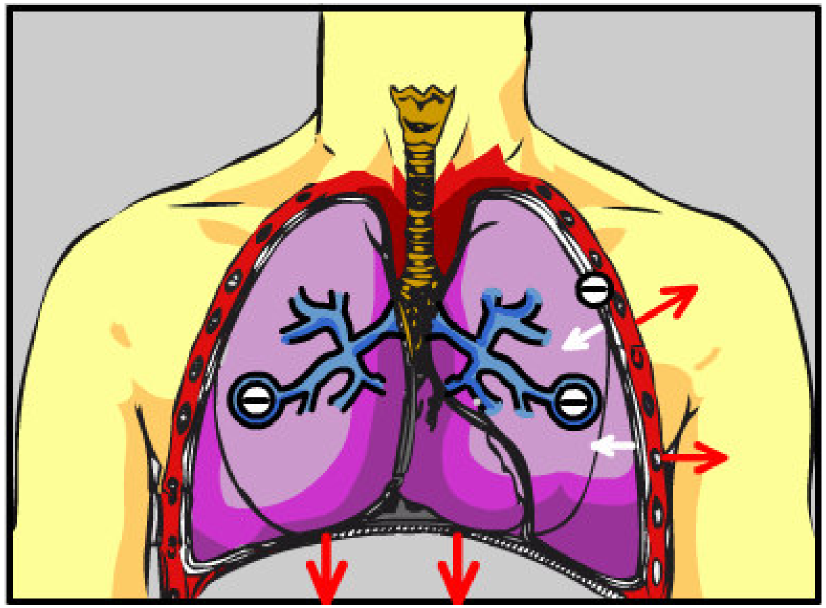
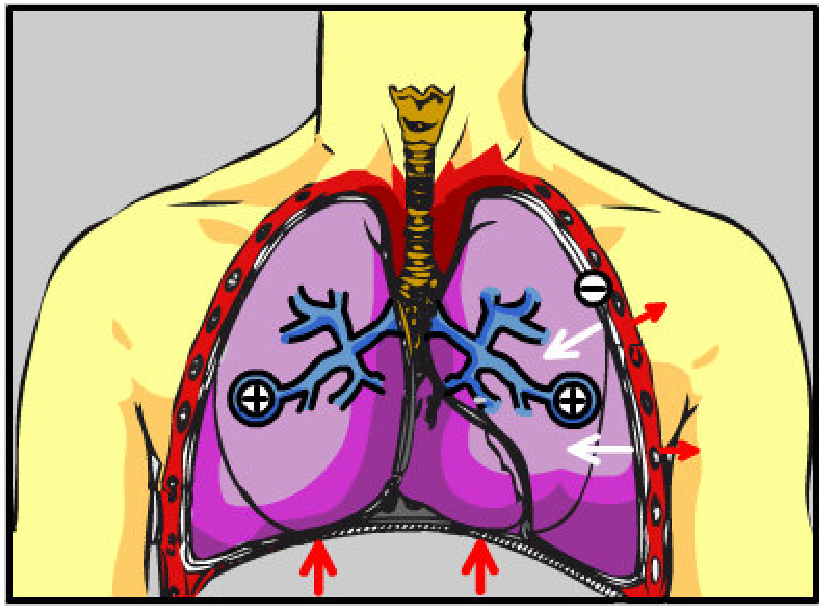
Review of ventilation





- Spontaneous breathing
- Pressure
- Volume

Mechanical ventilation

- Concept definition - process

Two approaches to mechanical ventilation

- Volume
  - Set volume
  - Variable - pressure
- Pressure
  - Set pressure
  - Variable - volume

Terminology

- IMV — Intermittent mandatory ventilation: Patient has a variable work of breathing: the mandatory ventilated breaths occur at a preset rate and tidal volume but the patient may take spontaneous breaths between the machine delivered breaths.
- CV — Controlled ventilation: Patient has no work during breathing: ventilator will rhythmically deliver tidal volume at preset rate
- ACV — Assist-control ventilation: Patient has minimal work of breathing during initial expansion of chest, and then ventilator will deliver preset tidal volume

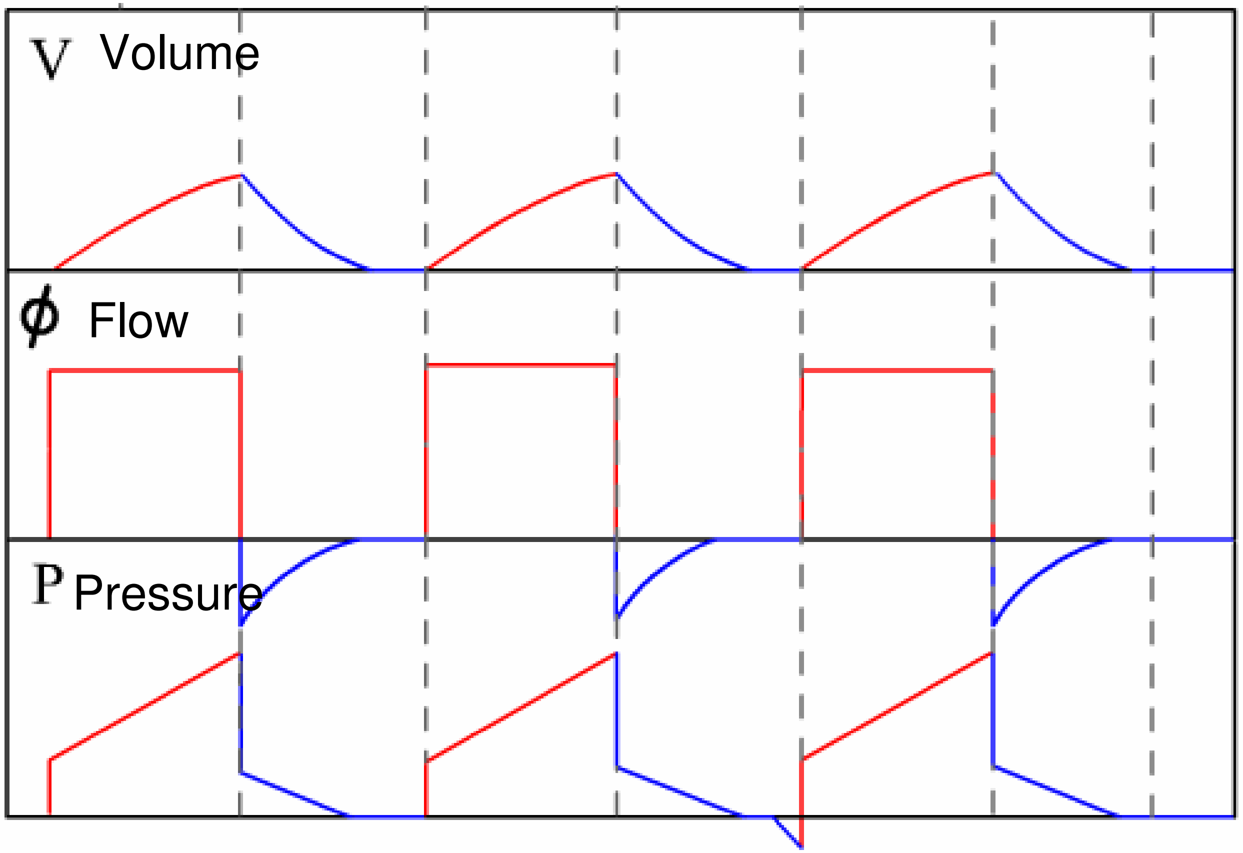
Terminology

- PRVC — Pressure-regulated volume control: Combines the benefits of pressure and volume ventilation
- Spontaneous — Patient initiates and completes a ventilation cycle
- Air-trapping — Expiration time is not enough to allow complete exhalation before the next inspiratory flow starts
- Alveolar pressure — Pressure existing in the alveolar space
- Pleural pressure — Pressure existing inside the pleural space.
- Trigger — Refers to the starting point of an inspiration

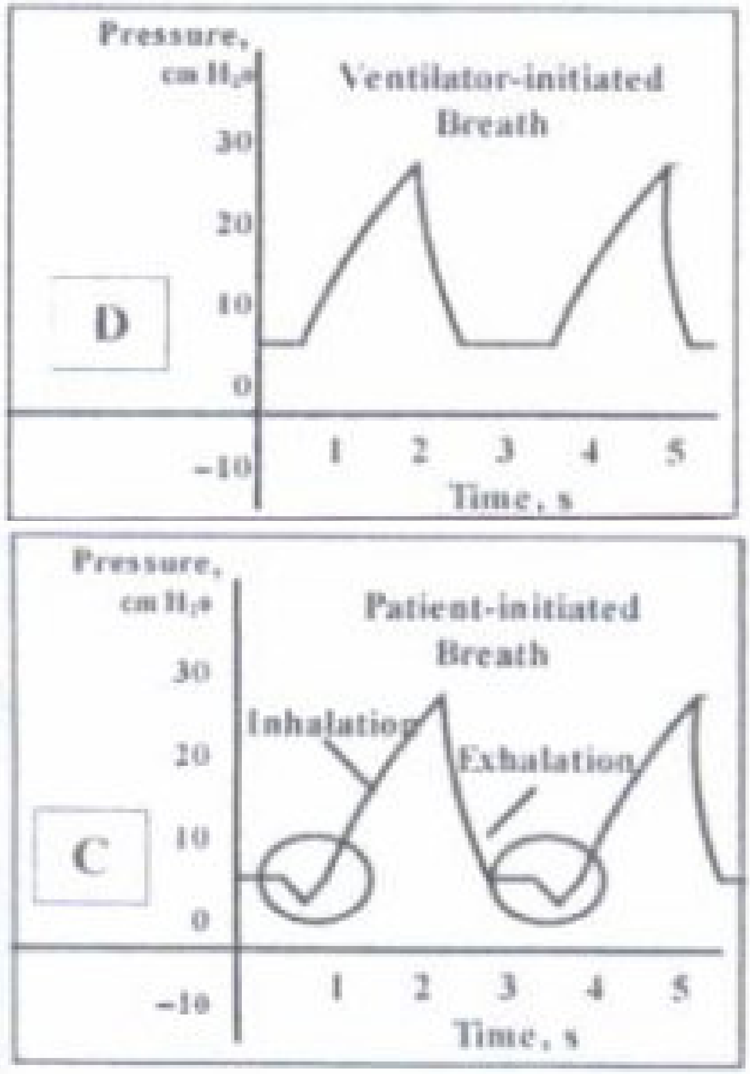
Terminology

PIP	The highest level of pressure observed on the manometer during a mechanical ventilation breath is called the **peak inspiratory pressure (PIP)**
PEEP	Positive end-expiratory pressure - Baseline pressure level is termed PEEP
TIDAL VOLUME	Volume of air delivered with each breath
MINUTE VOLUME	Volume of air per minute
Peak flow	Speed of air flow in litres per minute
Sensitivity	The amount of effort from the patient needed to initiate a breath
I:E ratio	Inspiration to expiration time: 1:2 is normal

Different graphics



Trigger mechanism



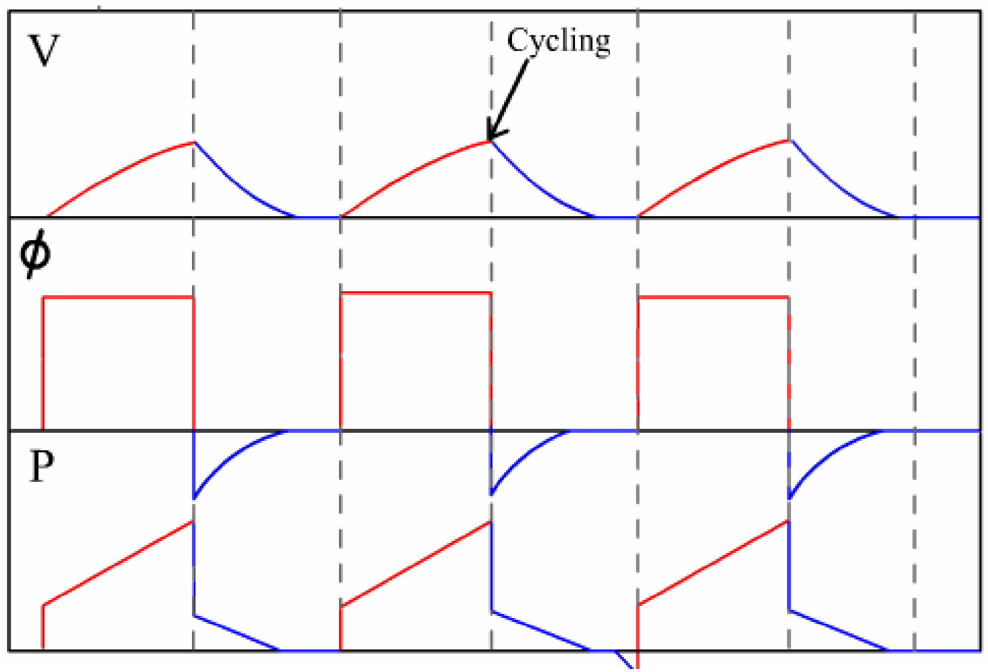
- Breaths must be initiated or triggered. The trigger refers to the starting point of the inspiratory phase.
- The trigger can be generated by the ventilator/patient.
- The kind of trigger can be observed in the pressure curve.

Trigger mechanism on ventilator

- Pressure trigger - Sensitivity settings are set below PEEP. Auto-triggering might occur due to premature triggering as in leaks and hiccups (Viasys).

- Flow trigger - Ventilator inspiration is triggered when a measured flow rate (flow sensitivity) is inspired from the ventilator circuit. Flow sensors detect the flow of gas and trigger the ventilator (Wright *et al.* 1996:265).

Cycling



- ***Cycling*** is the point where the inspiratory phase ends and the expiratory phase begins.
- It is related to a cycle variable (volume, pressure, flow or time).
- Ventilators is classified according to their mechanism of cycling. The term ‘cycle’ will be used here to indicate a terminating event as opposed to an initiating event (Wright *et al*. 996:264).

Cycling mechanisms' criteria

- **Volume-cycled breath: A** ventilator breath that is terminated when a preset volume has left the ventilator. This is characterised by a more consistent delivery of volumes (Dolan 1991:625).

- **Pressure-cycled breath:** A ventilator breath that is terminated when a preset pressure is reached (1- 3 cm H_2O depending on the ventilator).

- **Time-cycled breath:** Is terminated when a preset inspiratory time has elapsed. Pressure controlled ventilation is a time-cycled, pressure-limited form of ventilation commonly used. *In combination with a decelerating flow pattern it suggests improved gas distribution* (Wright *et al*. 1996:264).

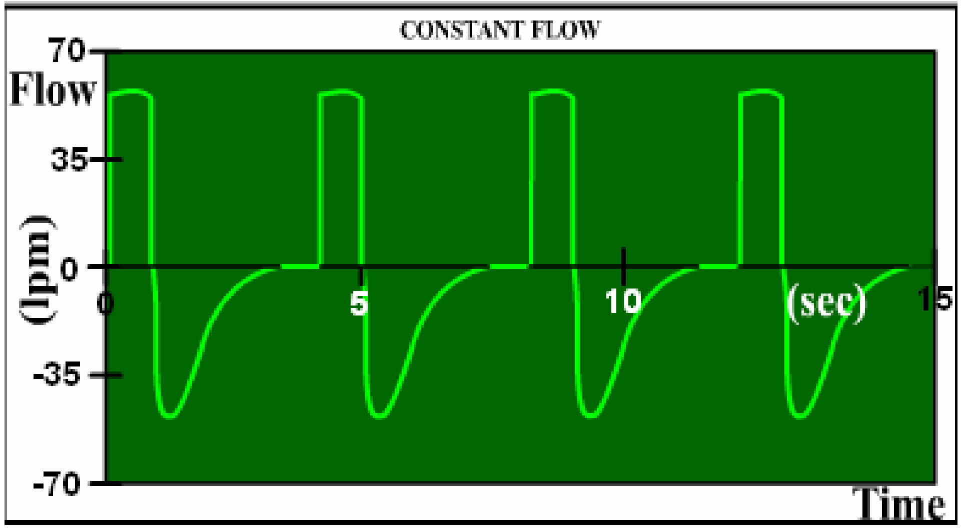
- **Flow-cycled breath:** If the flow is lower than a set flow value (set by the manufacturer) or a given percentage of peak flow (generally 25%), cycling is produced.

<u>There is only one flow-cycling criterion for the equipment</u>

PART 1

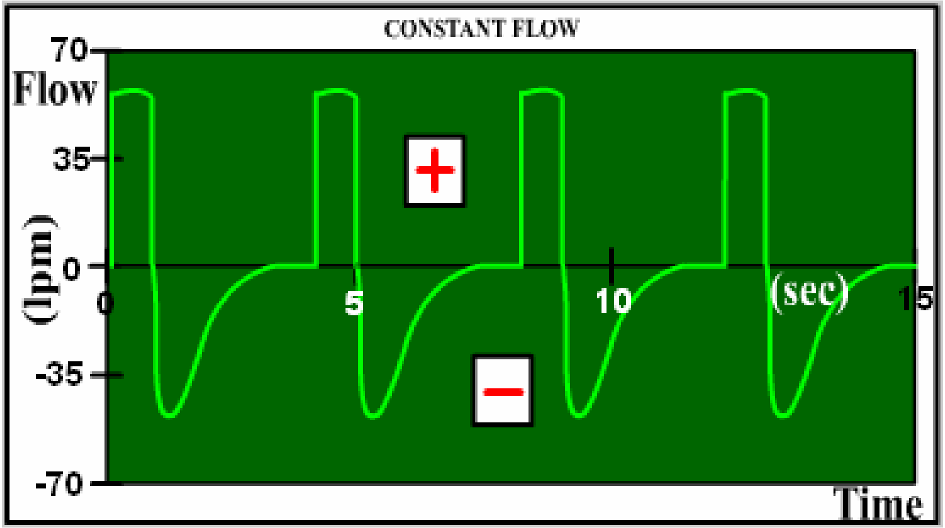
FLOW GRAPHICS

Flow graphics



- The respiratory flow is the speed with which gas enters and leaves the lungs
- Flow values in litres/second or litres/minute are generally indicated on the vertical axis
- Time values in seconds are on the horizontal axis

Airflow

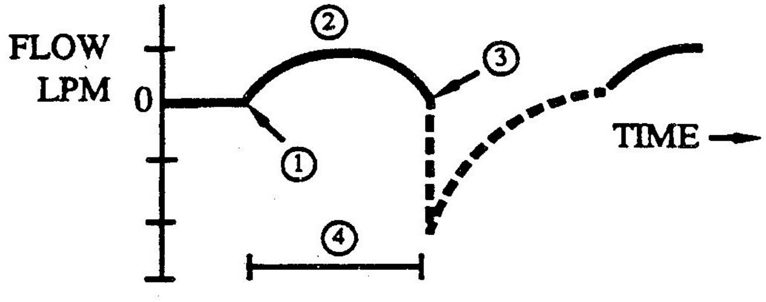


- **During the inspiratory phase, air moves from the ventilator (or equipment) toward the patient (positive flow) and, in the expiratory phase, from the patient to the ventilator (negative flow) (Viasys).**

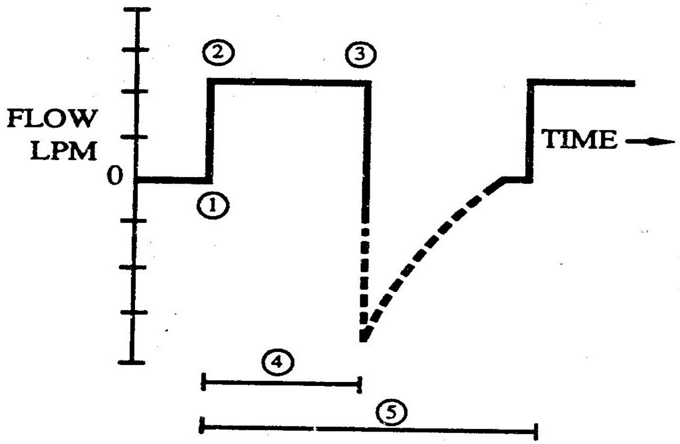
Flow graphic – Inspiration

Spontaneous versus mechanical ventilation

Spontaneous breath

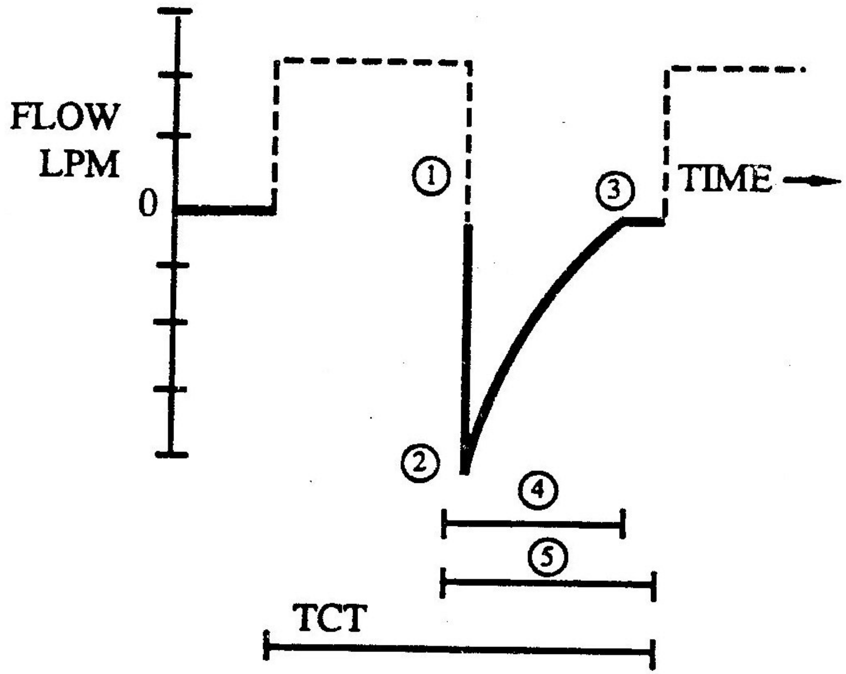


Mechanically ventilated – 'square wave'



1. Represents the start of inspiration
2. Represents the magnitude of inspiratory flow, *i.e.* peak flow
3. Represents the end of inspiration
4. Represents the duration of inspiratory flow, *i.e.* inspiratory time (Macintyre 1998:2-1).

Flow graphic - Expiration

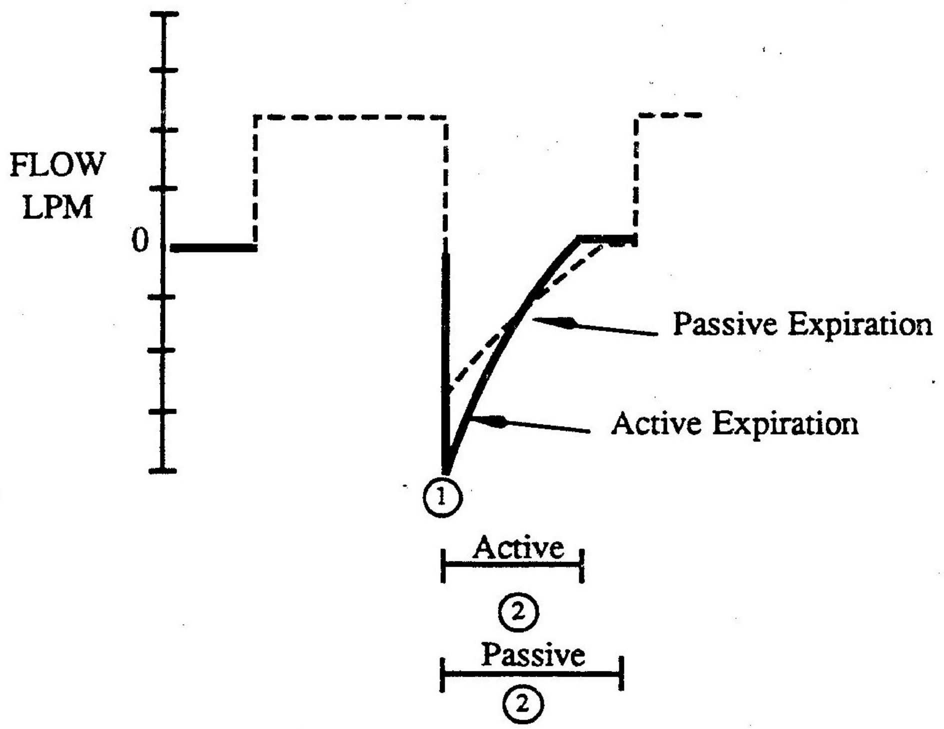


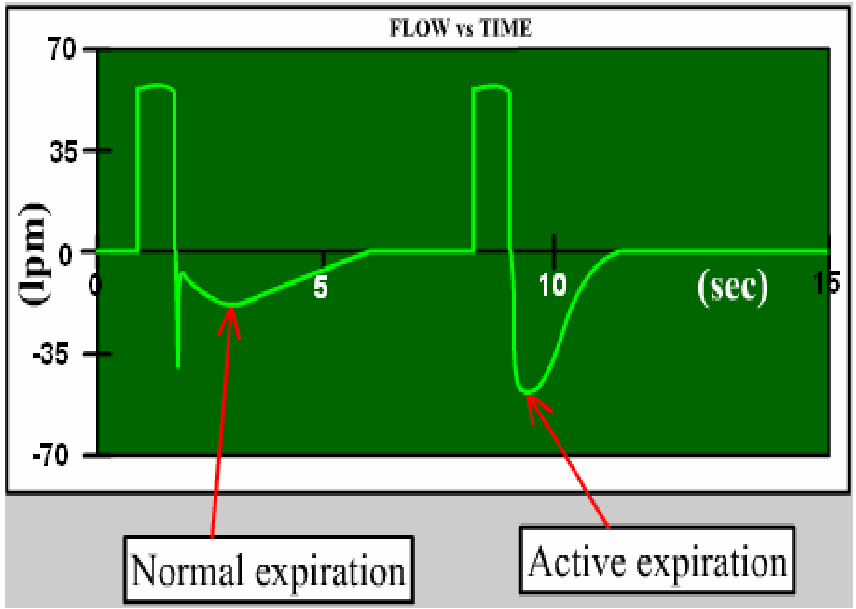
1. Represents the start of expiration
2. Represents the peak expiratory flow
3. Represents the end of expiration
4. Represents the duration of expiration
5. Represents the total available expiratory time, *i.e.* the total cycle time minus the actual inspiratory time

(Macintyre 1998:2-5)

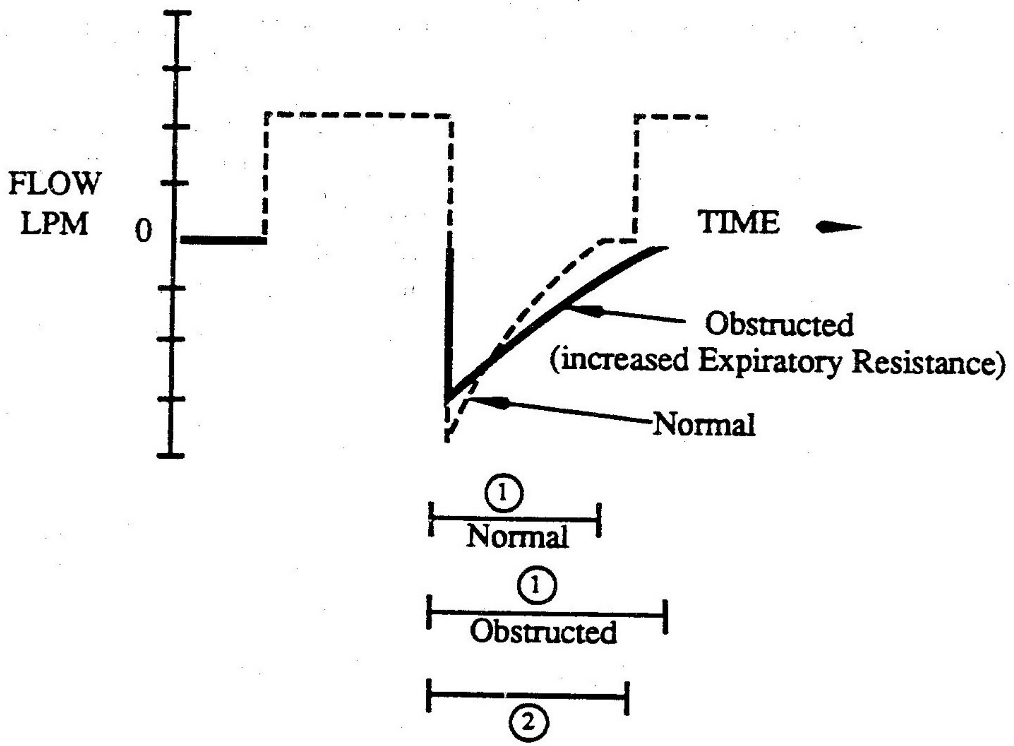
Flow graphic – Expiration

Difference between active and passive expiration





Flow graphic – Expiration
Problems due to airway obstruction



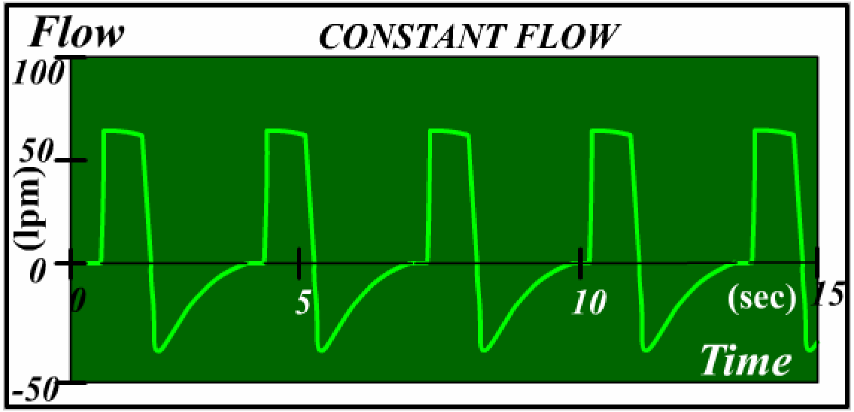
Note the duration of obstructed expiratory flow (1) exceeds the available expiratory time (2).

Air-trapping occurs because of incomplete expiration, the result of airway obstruction (Macintyre 1998:2-6).

Flow graphics - flow patterns

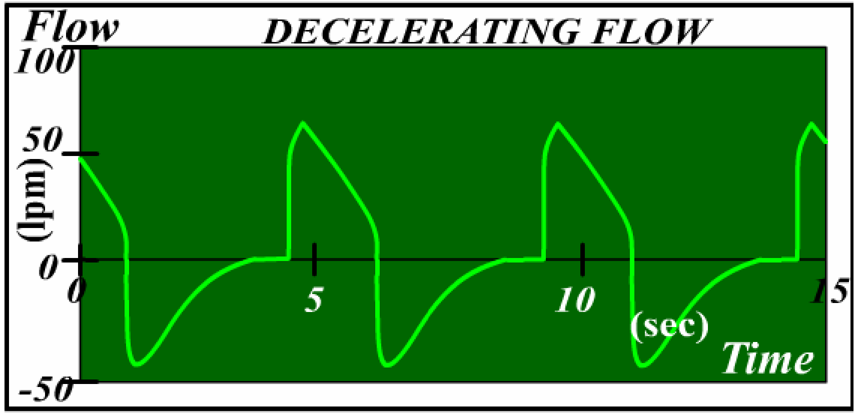
- Tidal volume can be delivered in different flow patterns.
- The most common patterns are:
  - Constant
  - Decelerating ramp
  - Sinusoidal.
- By modifying the flow pattern for the same peak flow, the inspiratory time in a volume-cycled breath can be increased (Viasys).

Flow pattern - Constant



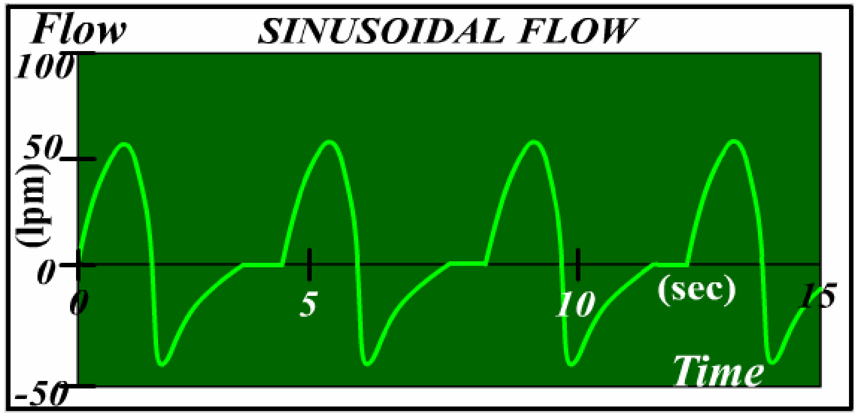
- First advantage: It delivers the set tidal volume in the least inspiratory time.
- Second advantage: It generates greater pressure in the airways than any other flow waveform (Viasys).

Flow pattern – Decelerating ramp



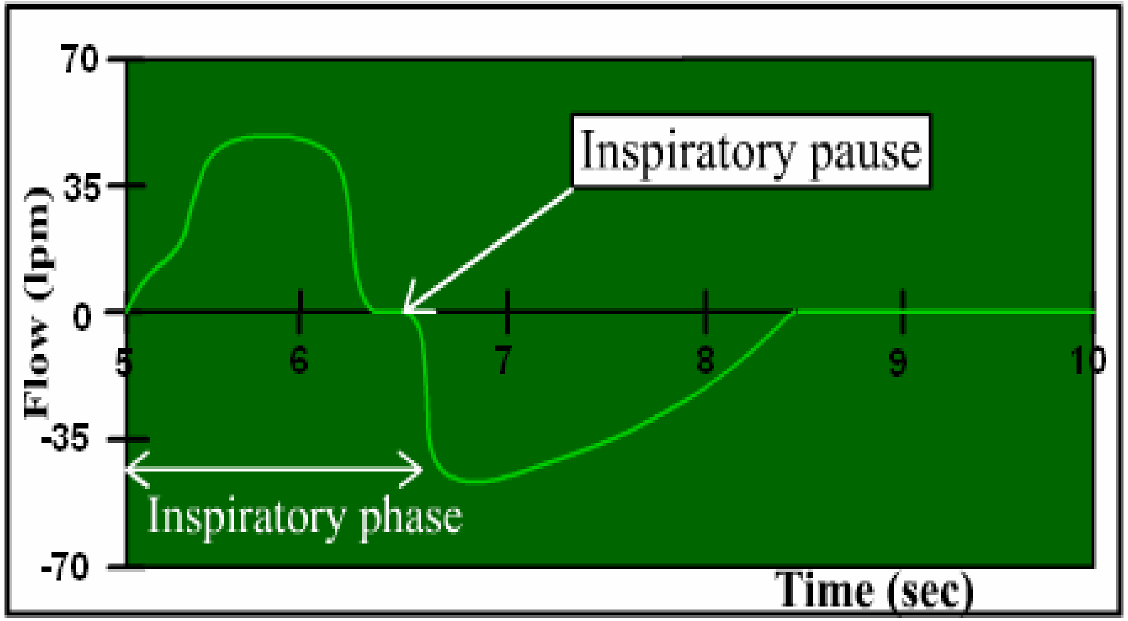
- This waveform generates a rapid increase in airway pressure at the start of inspiration.
- The inspiratory phase is prolonged, leaving less time for expiration.
- Prolonged inspiration is recommended for patients with obstructive airway diseases (Viasys).

Flow pattern - Sinusoidal



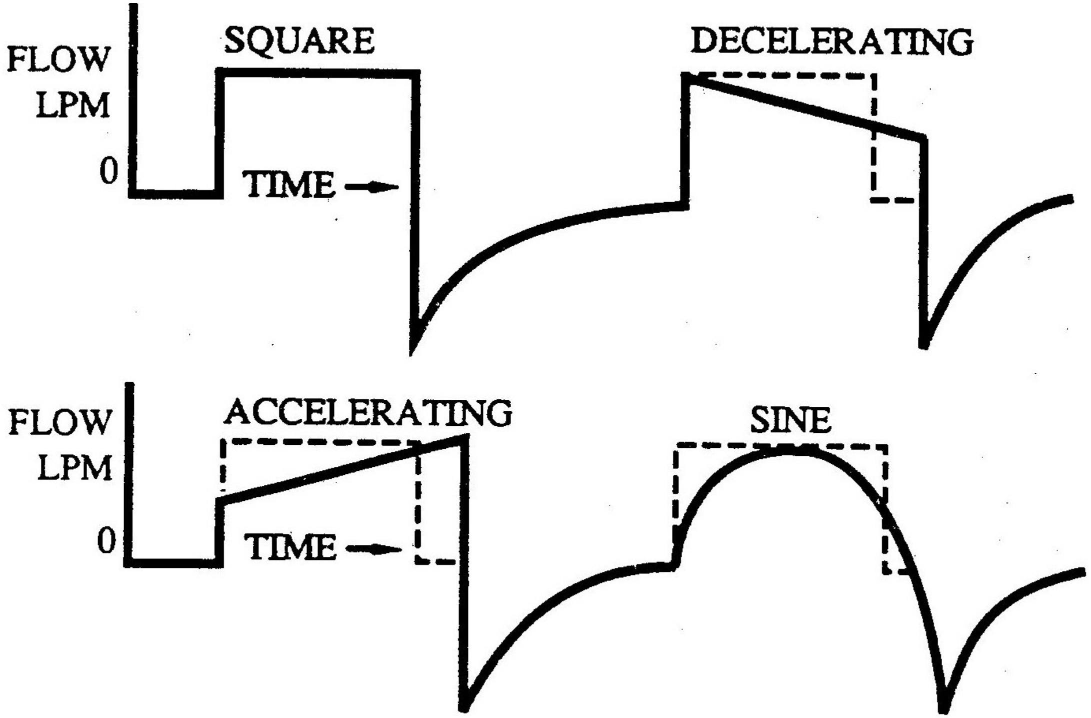
- The inspiratory time is even longer than in the decelerating waveform.
- It has the same advantage of volume distribution (Viasys).

Flow graphic – Inspiratory pause



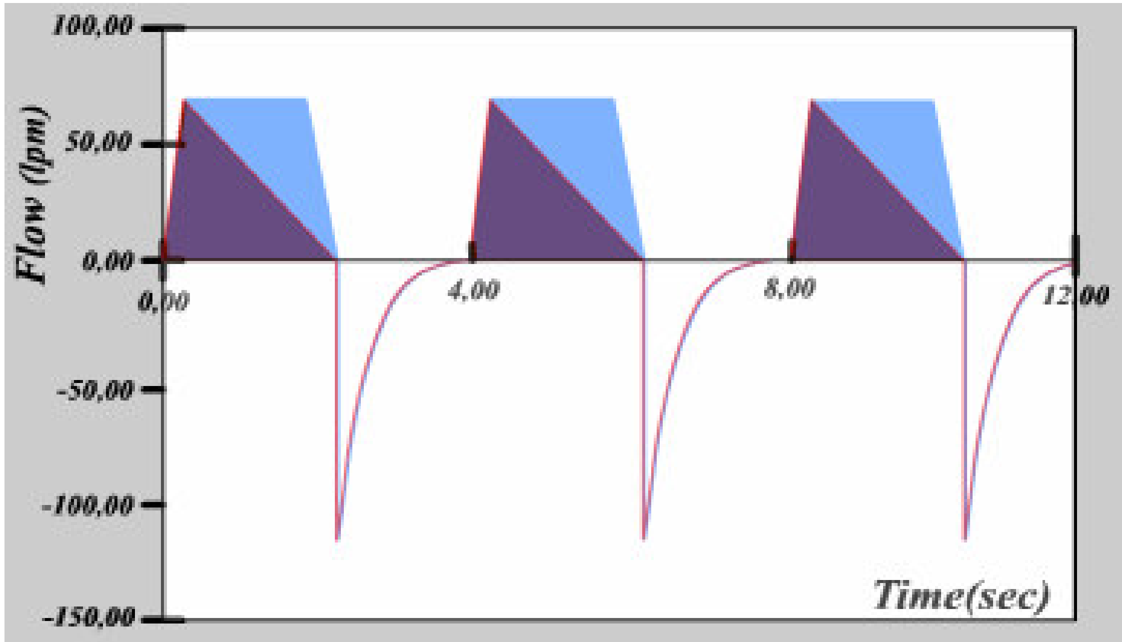
- A zero flow or pause.
- Conventionally considered part of the inspiratory phase (Viasys).

Flow graphic – I & E time



- Note the changes in inspiratory time when the square wave (in dotted line) is superimposed on other waveforms.

Flow graphic – I & E time

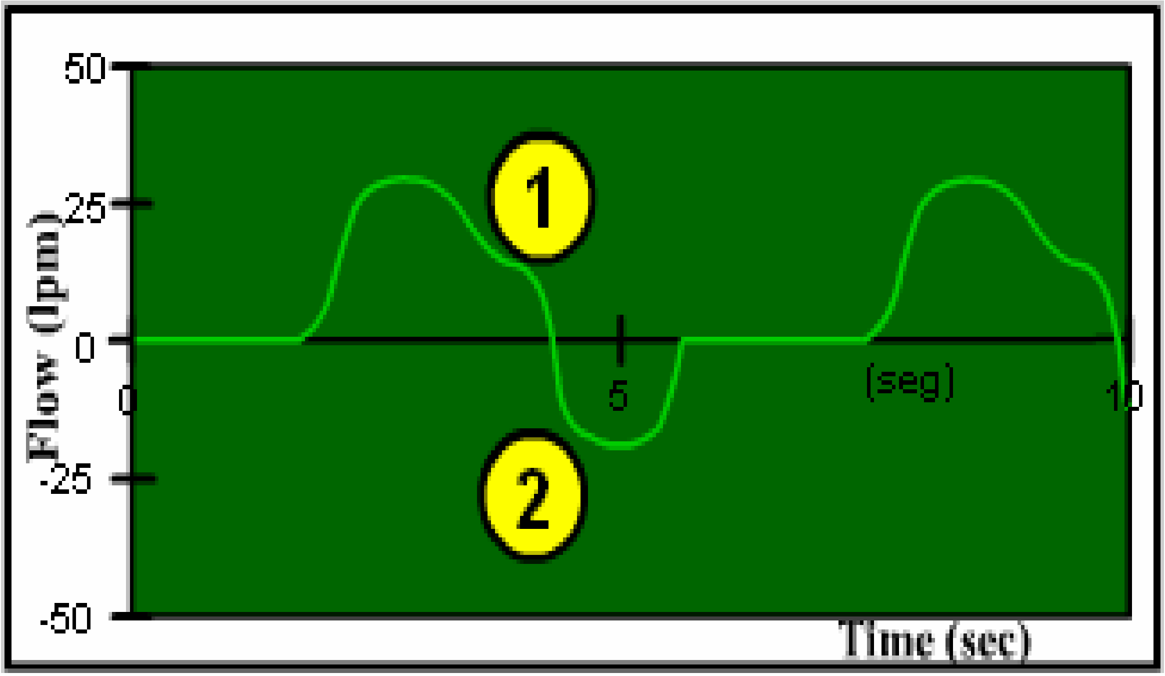


- Area below the decelerating flow will be smaller; therefore, the tidal volume will be less than in square waveform

Flow graphics during different modes of ventilation

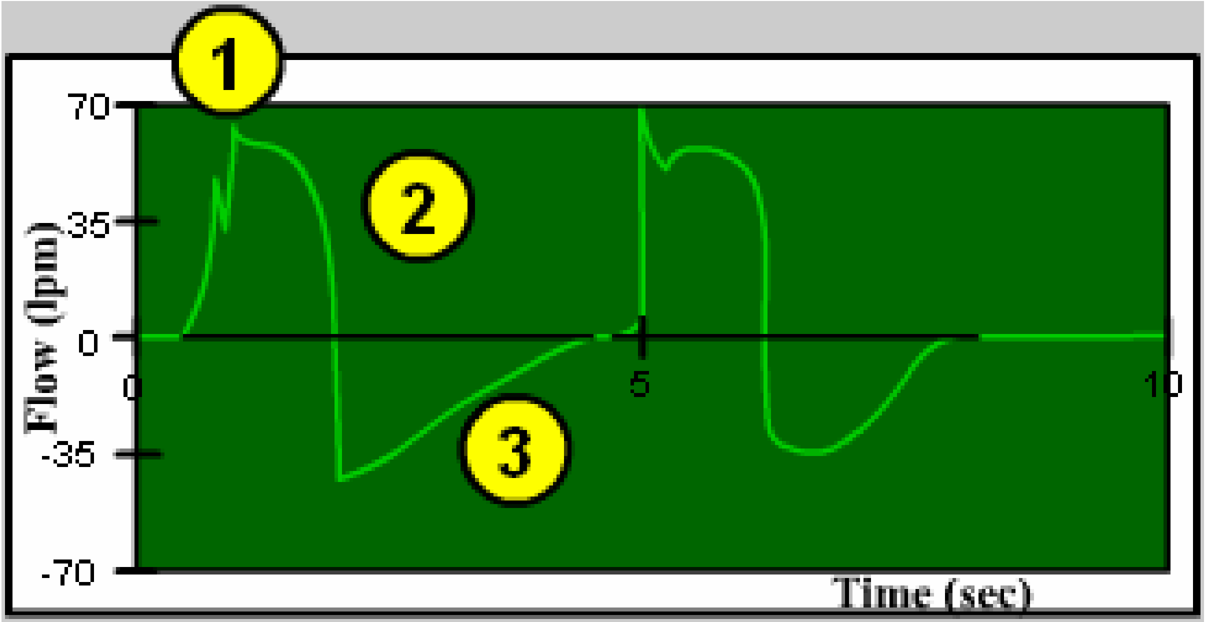
- Spontaneous
- Pressure support
- Pressure controlled ventilation

Flow during spontaneous breathing



- Inspiration
- Expiration

Flow during pressure support ventilation



1. Inspiratory pressure
2. Cycling
3. Expiration

Pressure support ventilation

- Interpreting cycling criteria:

If the inspiratory time is greater than a set time value (set by the manufacturer), cycling occurs.

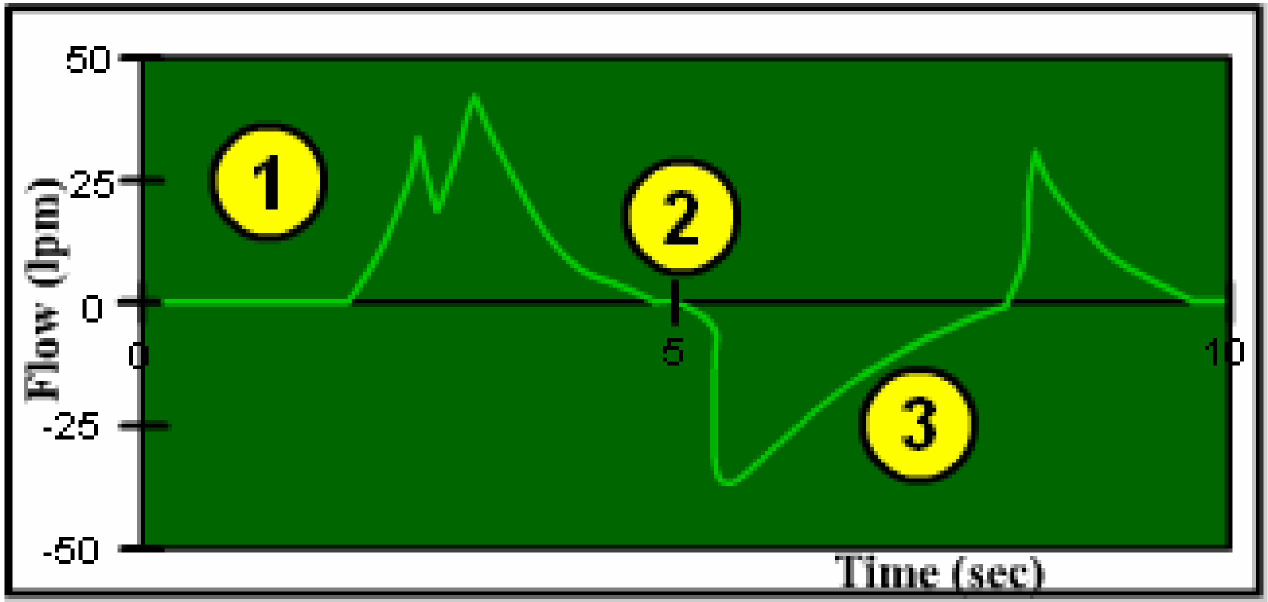
How is it observed?

If the inspiratory flow is very high when cycling occurs, the **pressure** criterion is being used.

If the inspiratory flow has a value close to threshold, the **flow** criterion is being used.

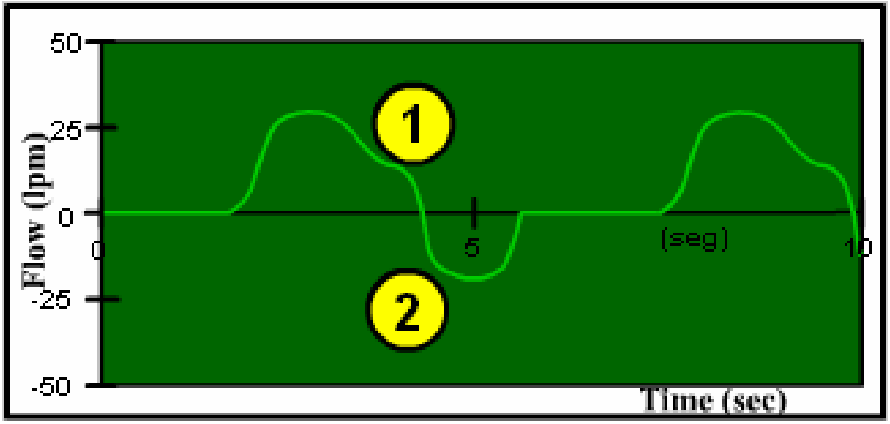
If the inspiratory flow is high during the whole inspiratory phase and stops at a set time, the **time** criterion is being used. When this criterion is used, the Ti will stay the same. This type of cycling is common when there are leaks in the circuit.

Flow during pressure controlled ventilation

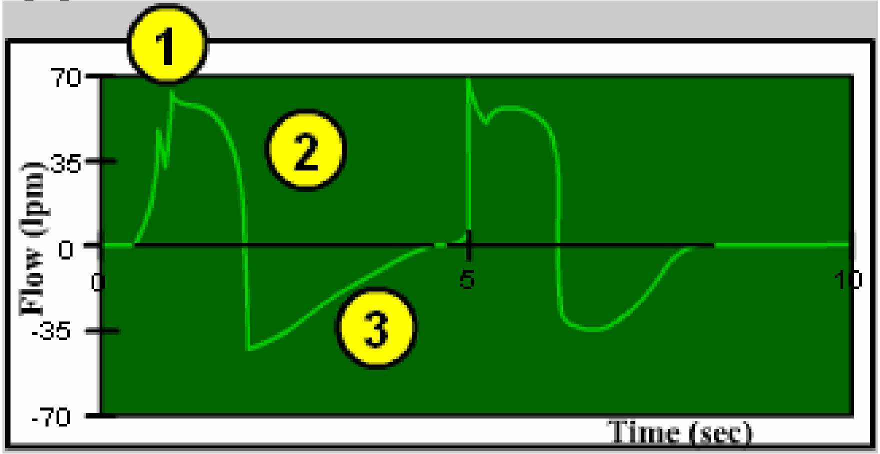


1. Inspiratory flow
2. No inspiratory pause
3. Expiration

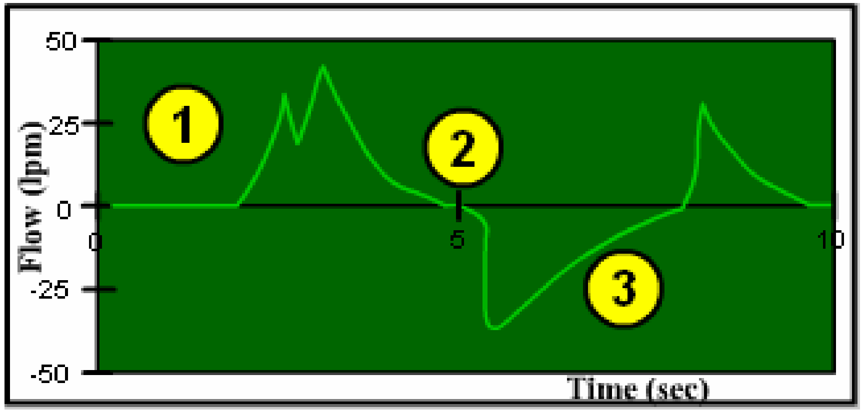
Flow graphics during different modes of ventilation



Flow during spontaneous breathing

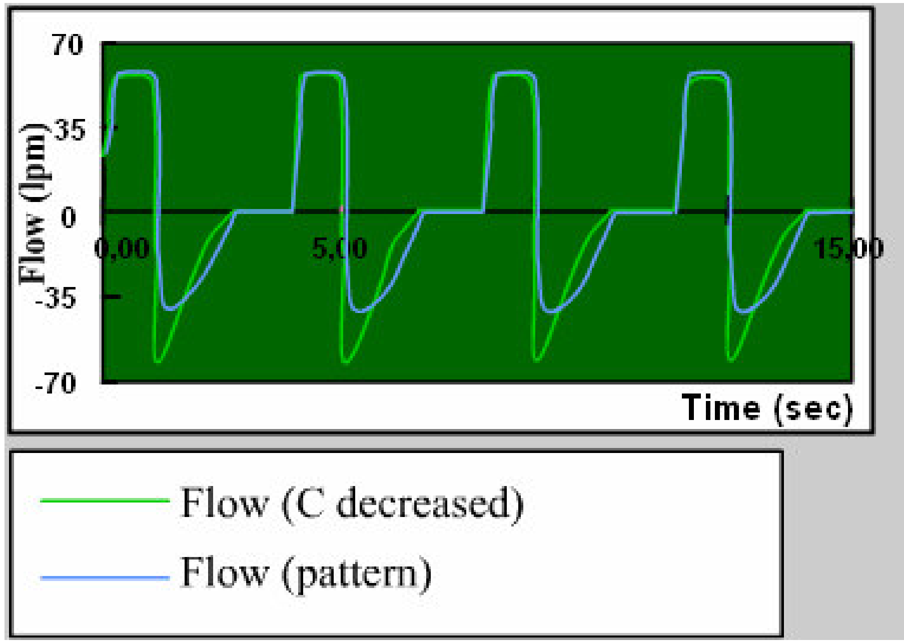


Flow during pressure support ventilation



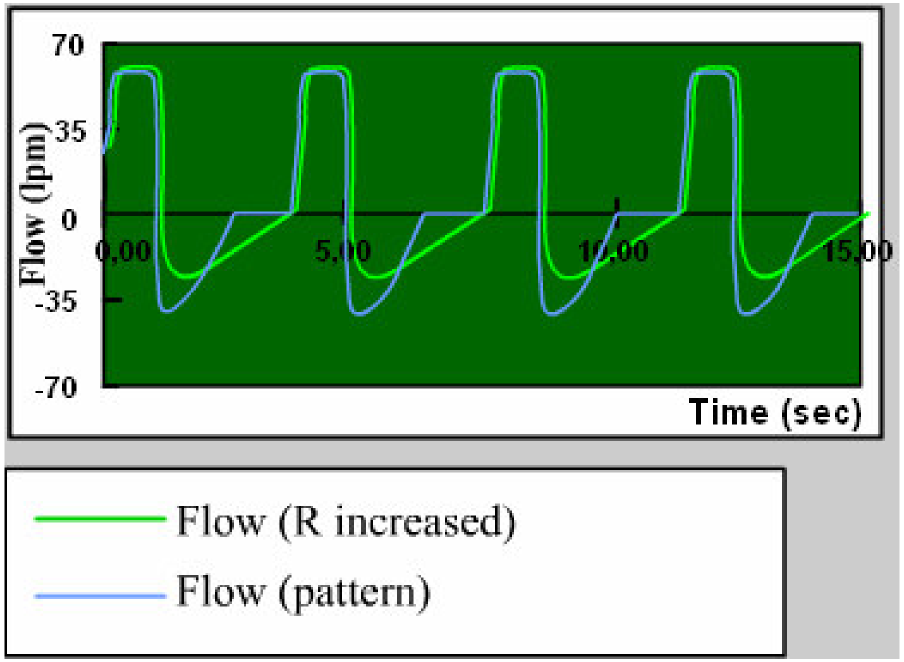
Flow during PCV

Flow graphics – Compliance & Resistance



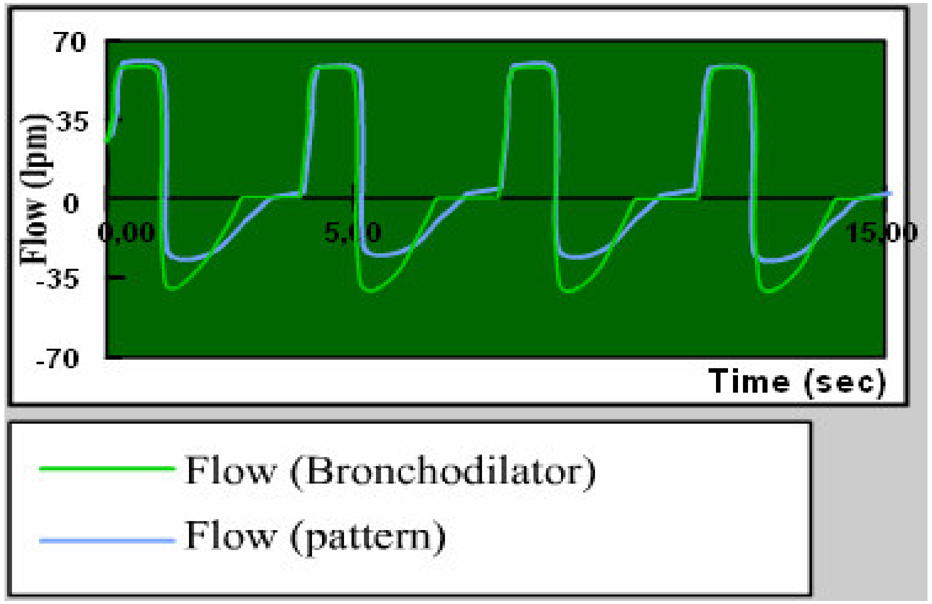
- When compliance decreases without effecting resistance,
  - peak expiratory flow will be greater because of an increase in alveolar pressure at the end of inspiration. *So as not to confuse this with resistance increase, the effects on the pressure curve (peak Paw and plateau) should be observed (Viasys).*

Flow graphics – Compliance & Resistance



- When resistance increase, note the decrease in expiratory peak flow and a less marked slope that indicates the increase in resistance (Viasys).

Flow graphics – Compliance & Resistance

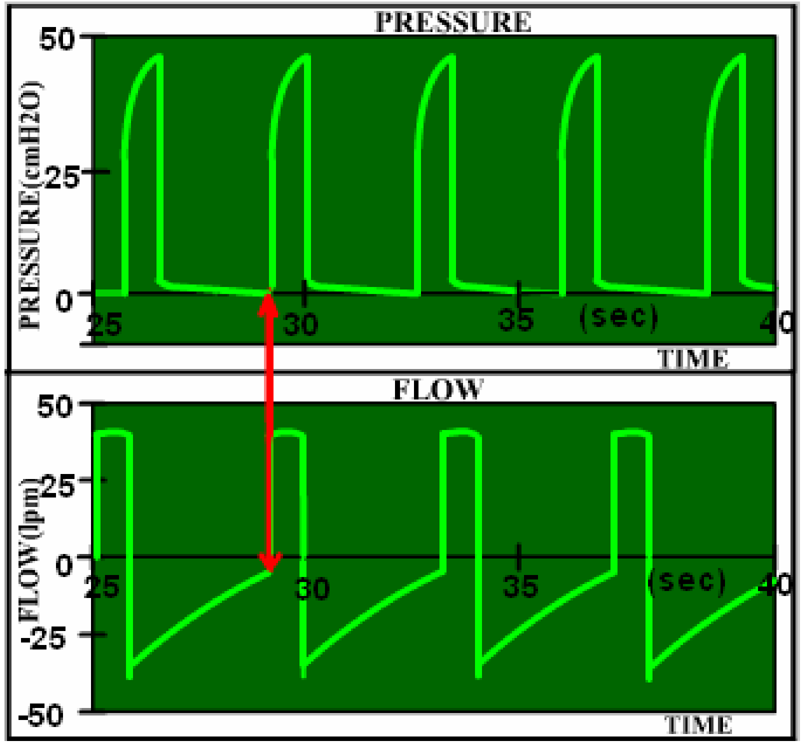


- Resistance can be decreased by administering a bronchodilator

Flow graphics – auto-PEEP

- Auto-PEEP represents the air trapped in the airways when for example insufficient expiratory time is allowed.
- It can be caused by mechanical obstruction of the patient's airways, asynchrony between the ventilator and the patient or application of less than optimal ventilator settings for a given patient (Viasys).

Flow graphics – auto-PEEP

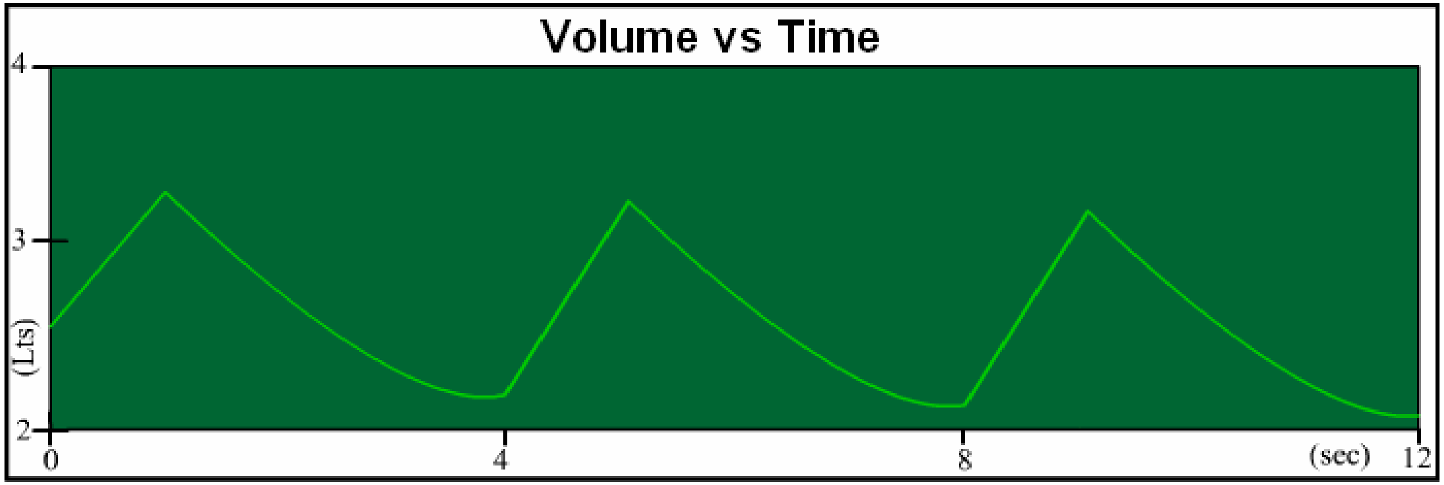


- Auto-PEEP is not represented on the pressure waveform.
- It can however be detected in a flow waveform that does not return to zero at the end of exhalation.
- One advantage of understanding flow graphics.

PART 2

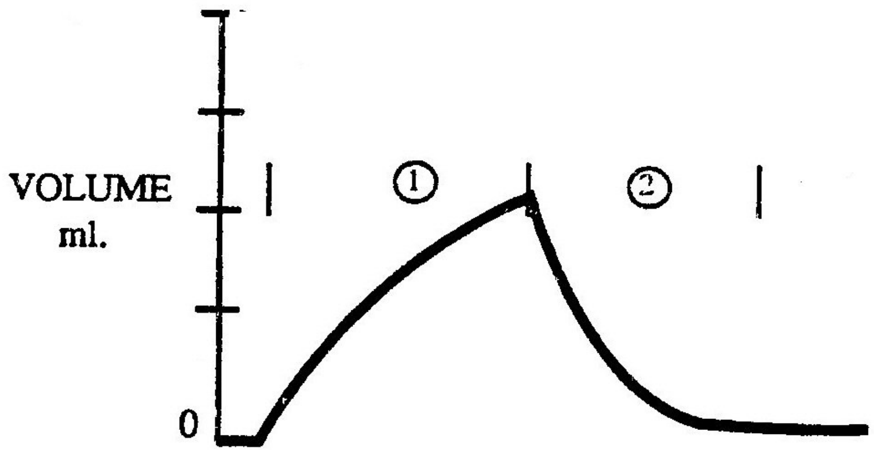
VOLUME GRAPHICS

Volume graphics



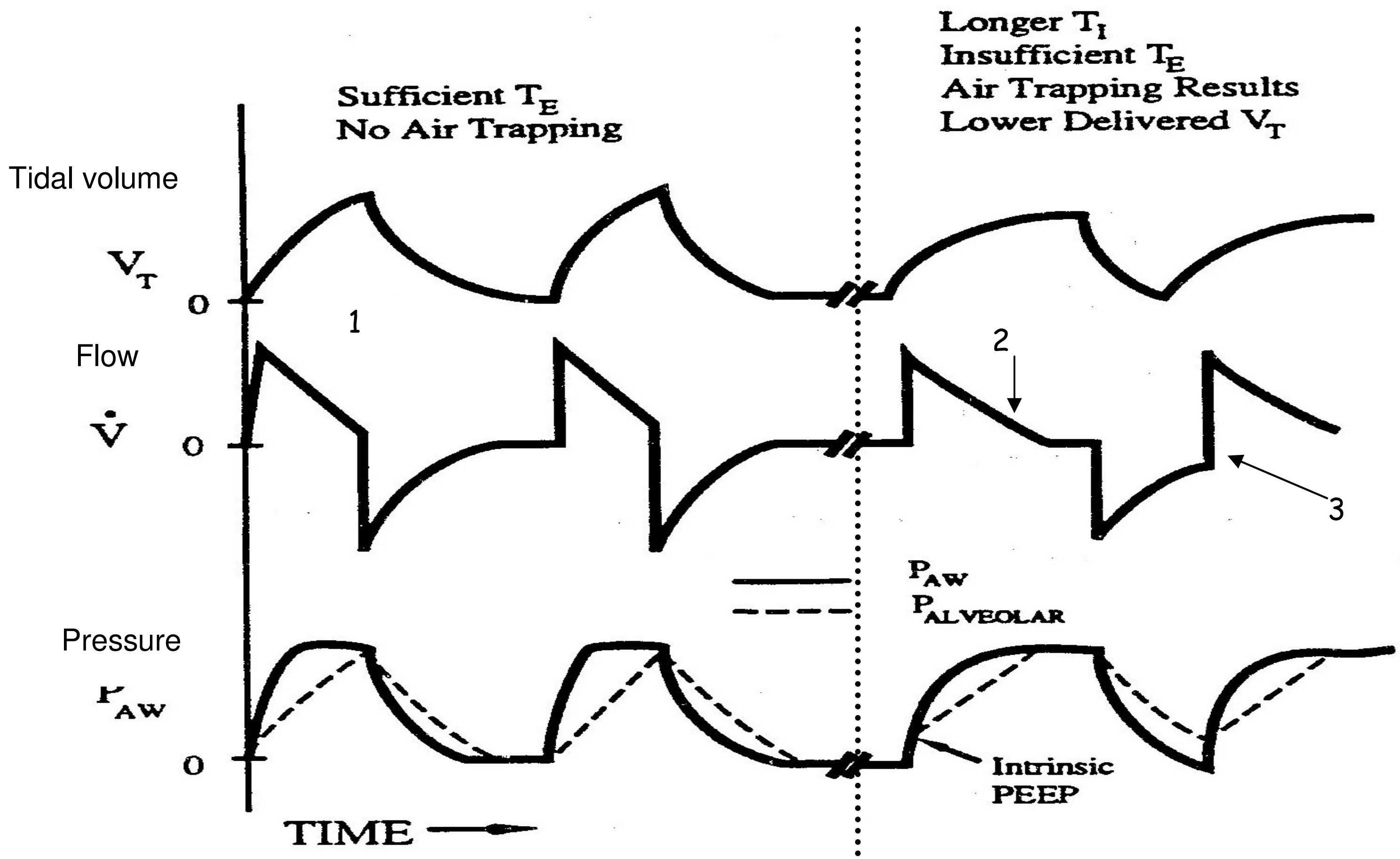
- The volume inspired and exhaled by the patient during each breath is represented.
- The word volume in this case refers to the amount of gas in L or mL.
- It is obtained as the integral of the flow signal over time (Viasys).

Volume graphics



- The up sweep of the graphic represents the volume delivered to the patient circuit.
- The down sweep of the graphic represents the total expiratory volume.

Volume graphics: Interpretation



1.Normal breath 2.Longer inspiratory time 3. Expiratory graph does not return to baseline

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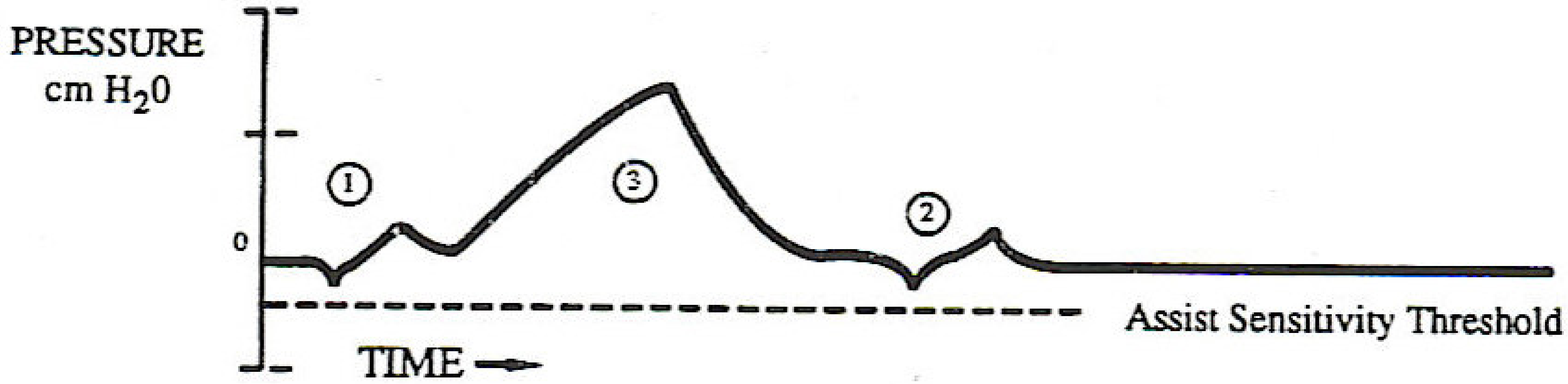
PART 3

PRESSURE GRAPHICS

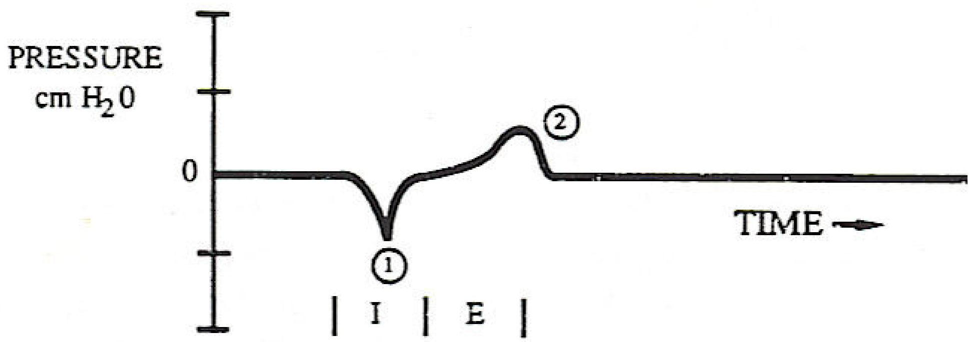
Pressure waveform – Spontaneous breathing during mechanical ventilation



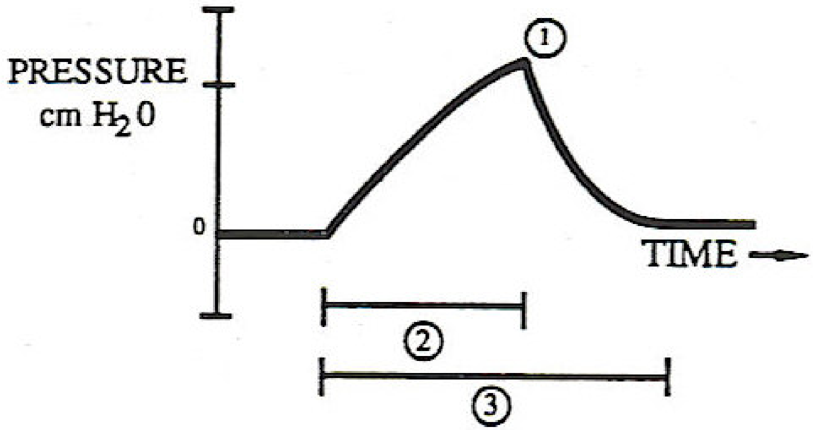
1. Spontaneous breath not reaching threshold
2. Mechanical breath
3. Spontaneous breath not reaching threshold

Pressure-time waveforms - Spontaneous versus Mechanical

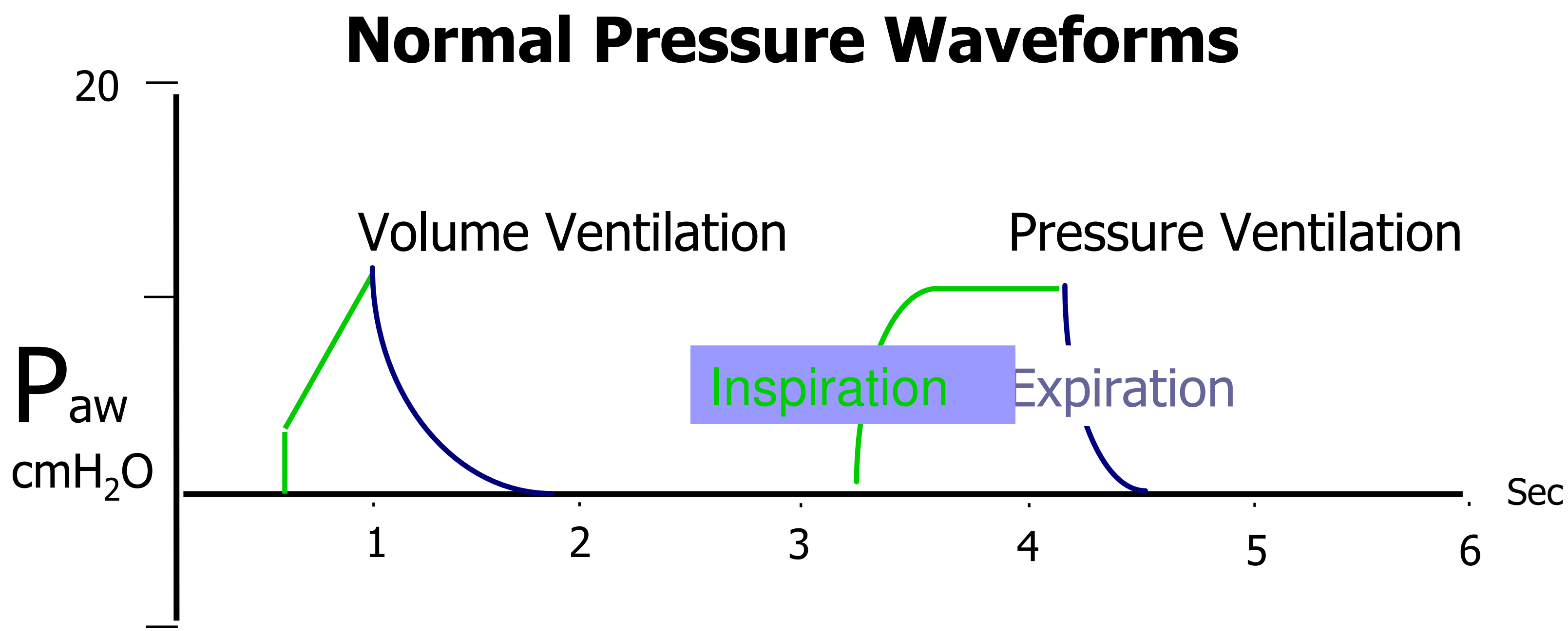
Spontaneous



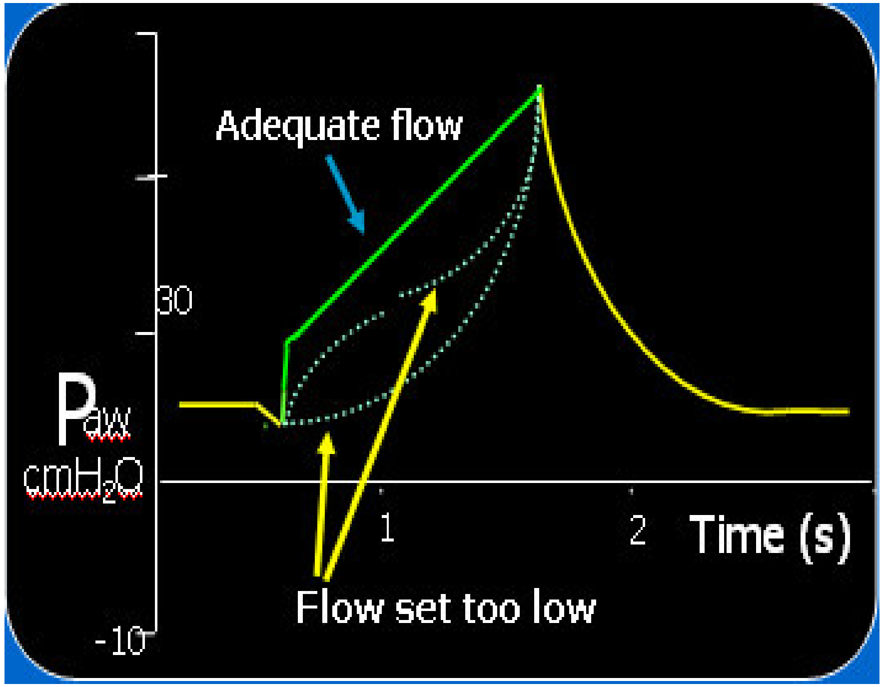
Mechanical



Pressure-time waveforms -
Mechanical: Volume versus Pressure

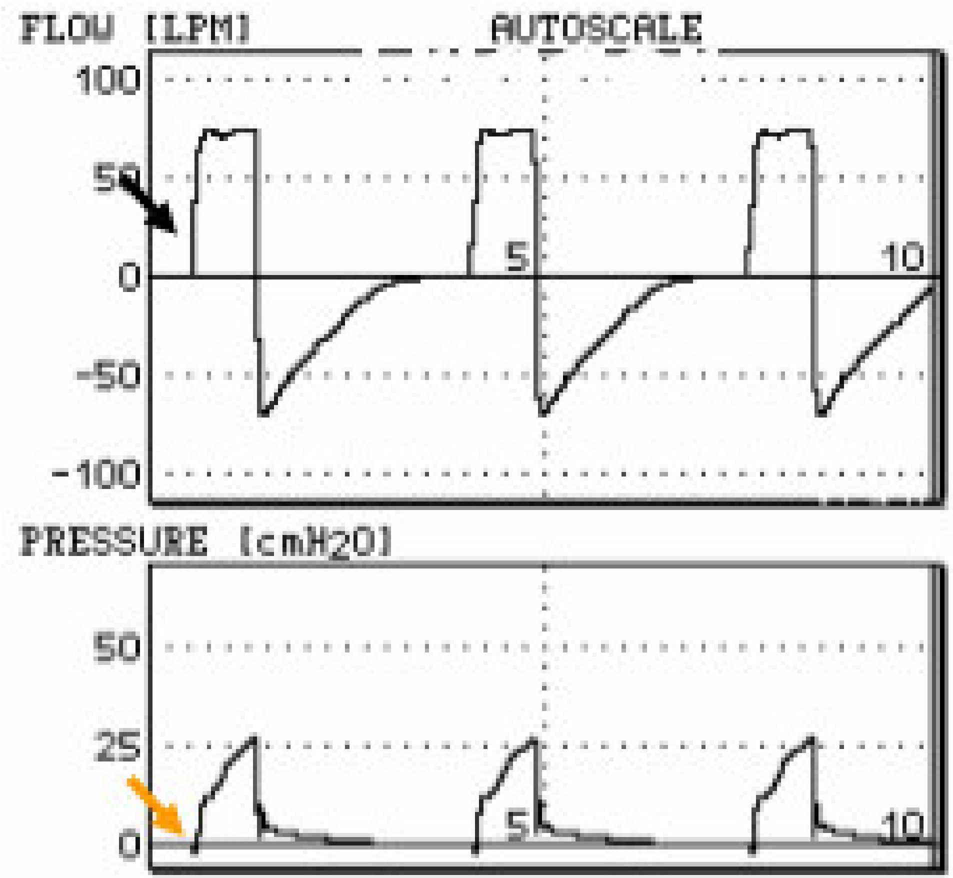


Pressure waveform



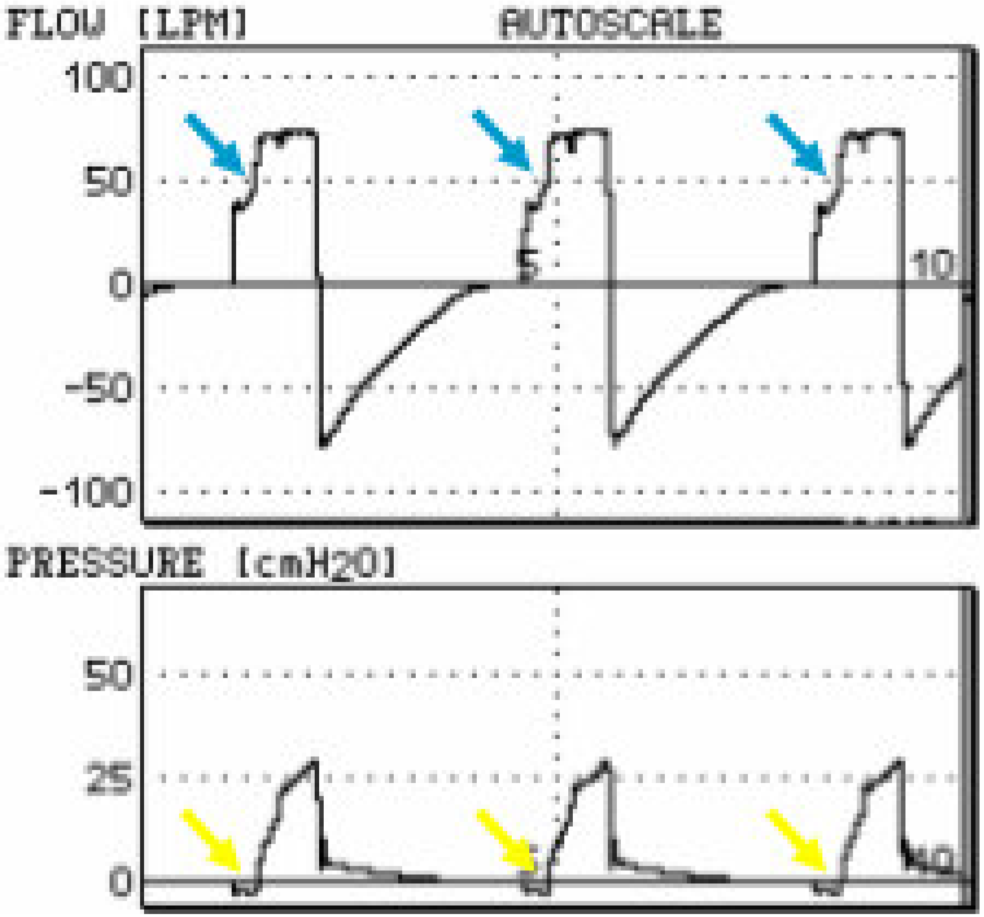
- The pressure wave characteristically has a linear or even-bowed upward rise in pressure after the trigger.
- A slow rise in pressure or a concave shape to the volume axis of the pressure wave requires an increase in flow (Visser).

Pressure waveform – Slope rise



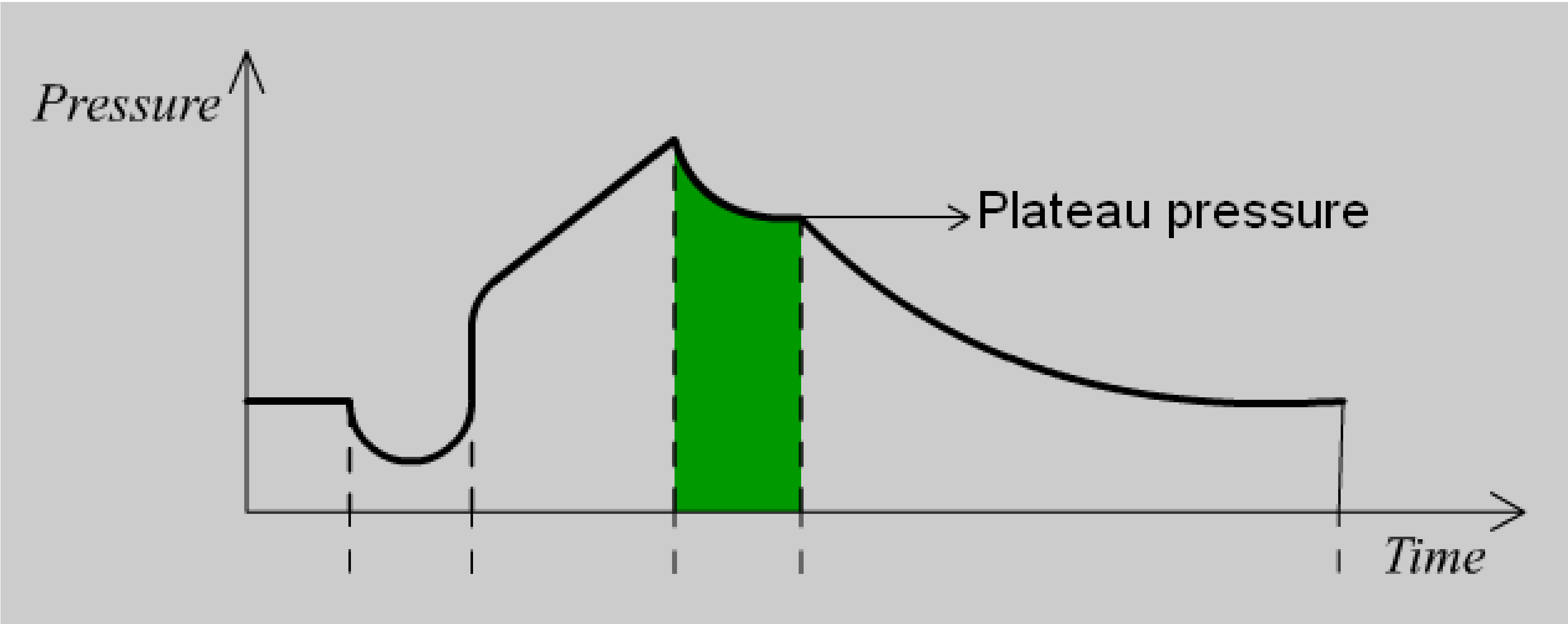
- A quick upswing of the flow waveform should be seen (black arrow).
- Another sign of a good/adequate trigger is a minimum pressure drop at the onset of patient effort, indicated on the pressure wave by an orange arrow.

Pressure waveform - Trigger



- Poor triggering is visible by the scooping on the upswing of the flow waveform and the significant drop at the onset of patient effort on the pressure waveform (Visser).

Pressure waveform



- The inspiratory pause or plateau pressure occurs when inspiratory flow ceases.
- The inspiratory pause is commonly used to establish alveolar pressure, resistance and static compliance values (Viasys). It remains part of the inspiratory value of the I:E ratio.

Pressure waveform

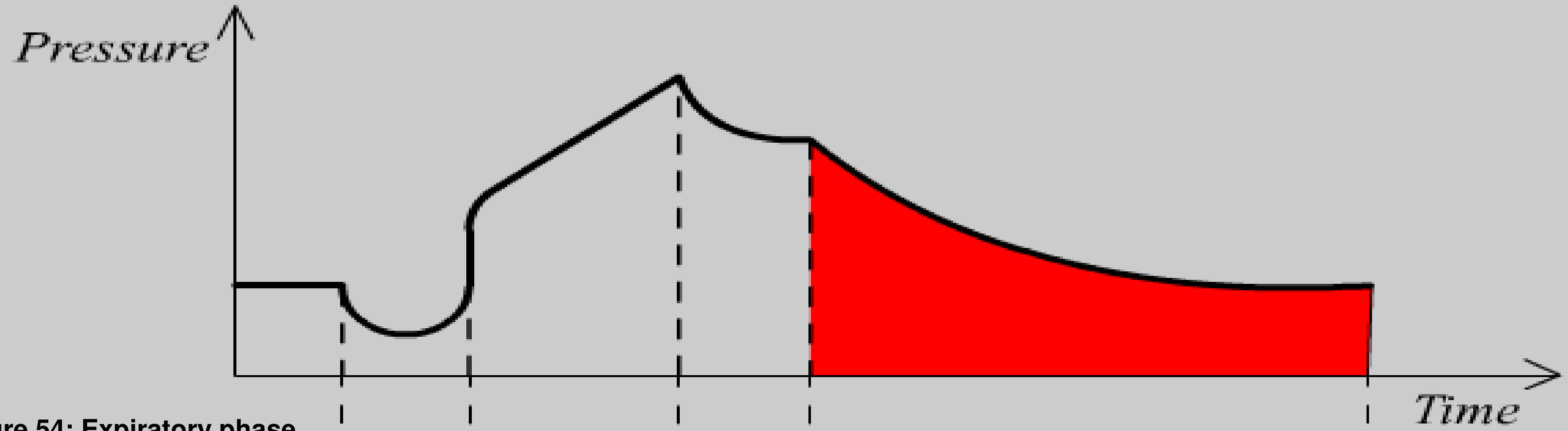
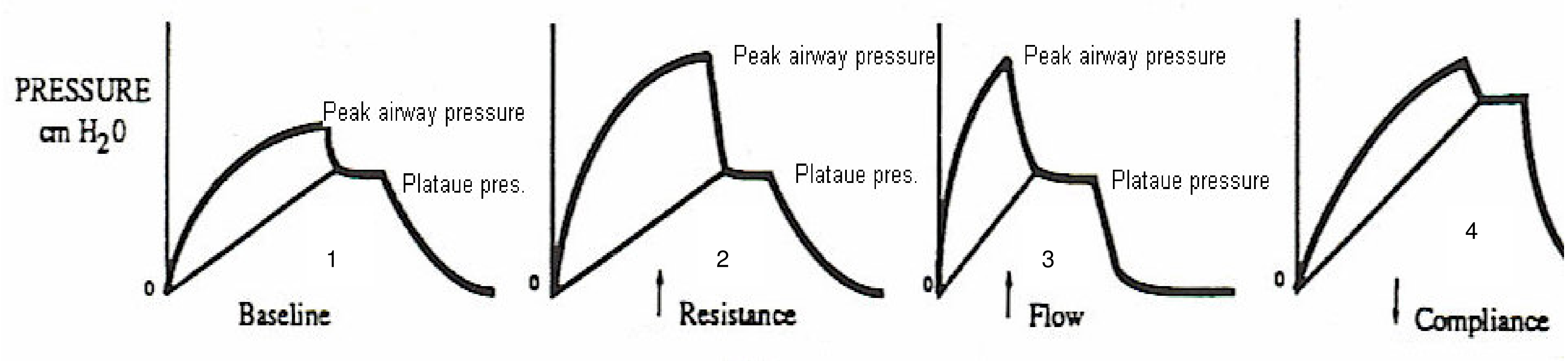


Figure 54: Expiratory phase
Acknowledgement: Viasys

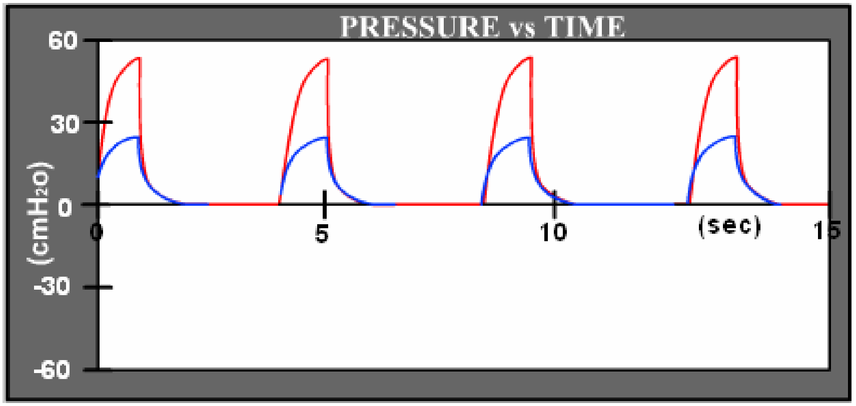
- Expiration is normally a passive phenomenon. During expiration, pressure is mainly determined by the expiratory resistance of the circuit. The compliance and expiratory resistance of the respiratory system are also determining factors.

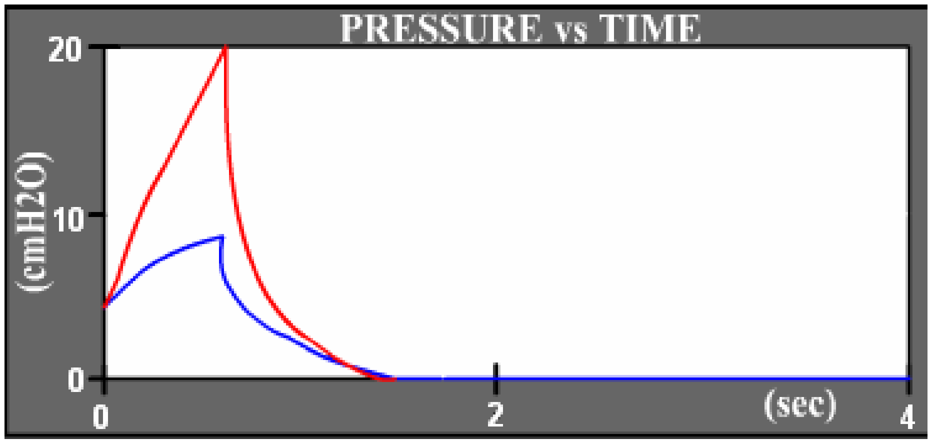
Pressure waveform



- Pressure graphics can change depending on flow rate, flow pattern, airway resistance, and lung compliance.
- Note changes in PIP and plateau airway pressure: When airway resistance is increased (2), when flow rate is increased (3), or when lung compliance is decreased (4) (Macintyre 1998:2-9).

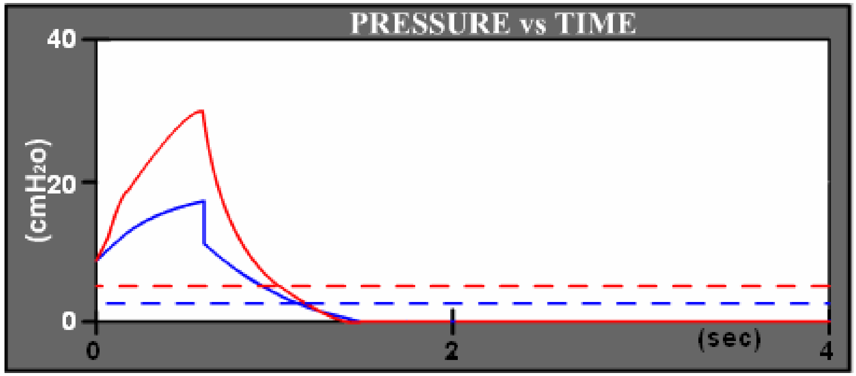
Peak pressures - Resistance

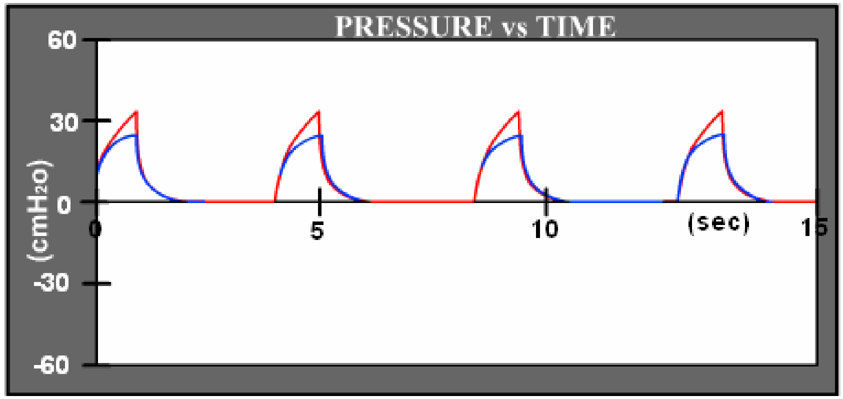




- *Resistance increases (Red)*
  - The slope of the second portion of the inspiratory support curve depends upon the resistive characteristics of the patient's respiratory system.
  - Obstructive pathologies like asthma or secretions are present, or
  - There is a decrease in the diameter of the endotracheal tube.

Peak pressures - Compliance



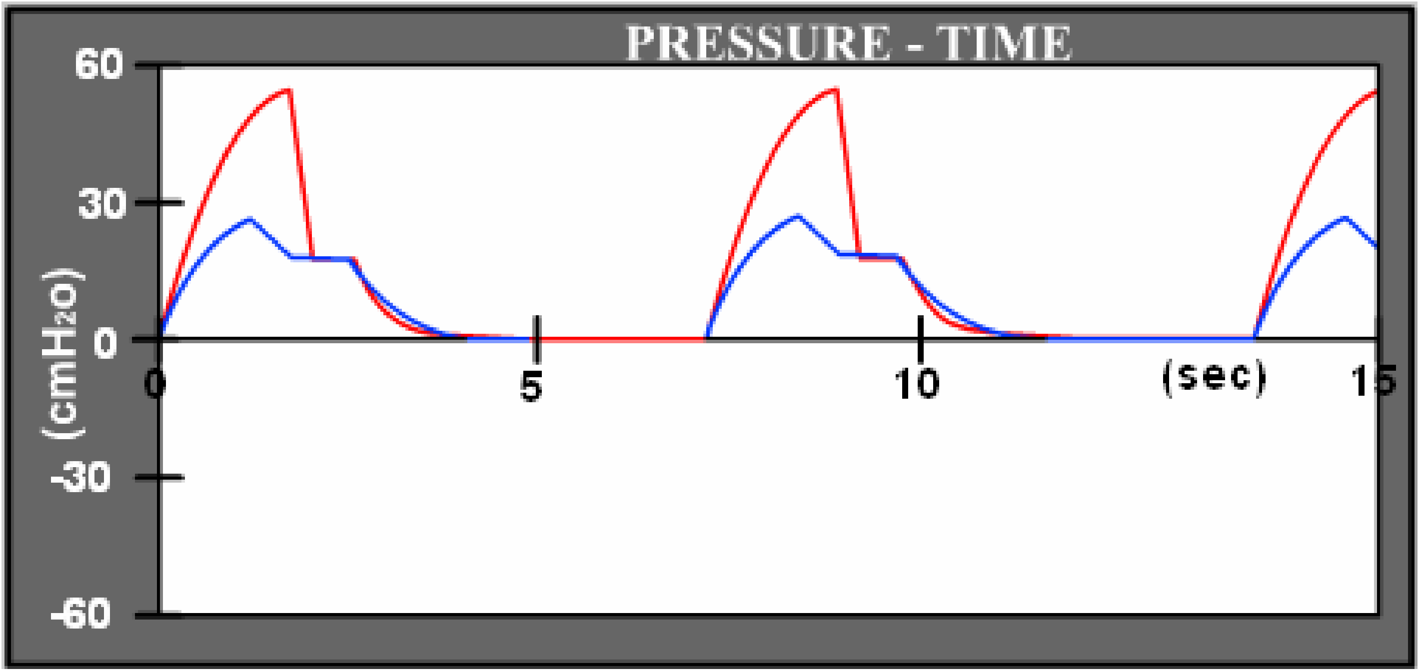


- A compliance decrease generates a pronounced increase of the slope.
- Restrictive pathologies such as pulmonary oedema or pneumothorax would cause a *decrease in compliance.*
- Peak pressure increases because of a compliance decrease but inspiratory time is not altered (Viasys).

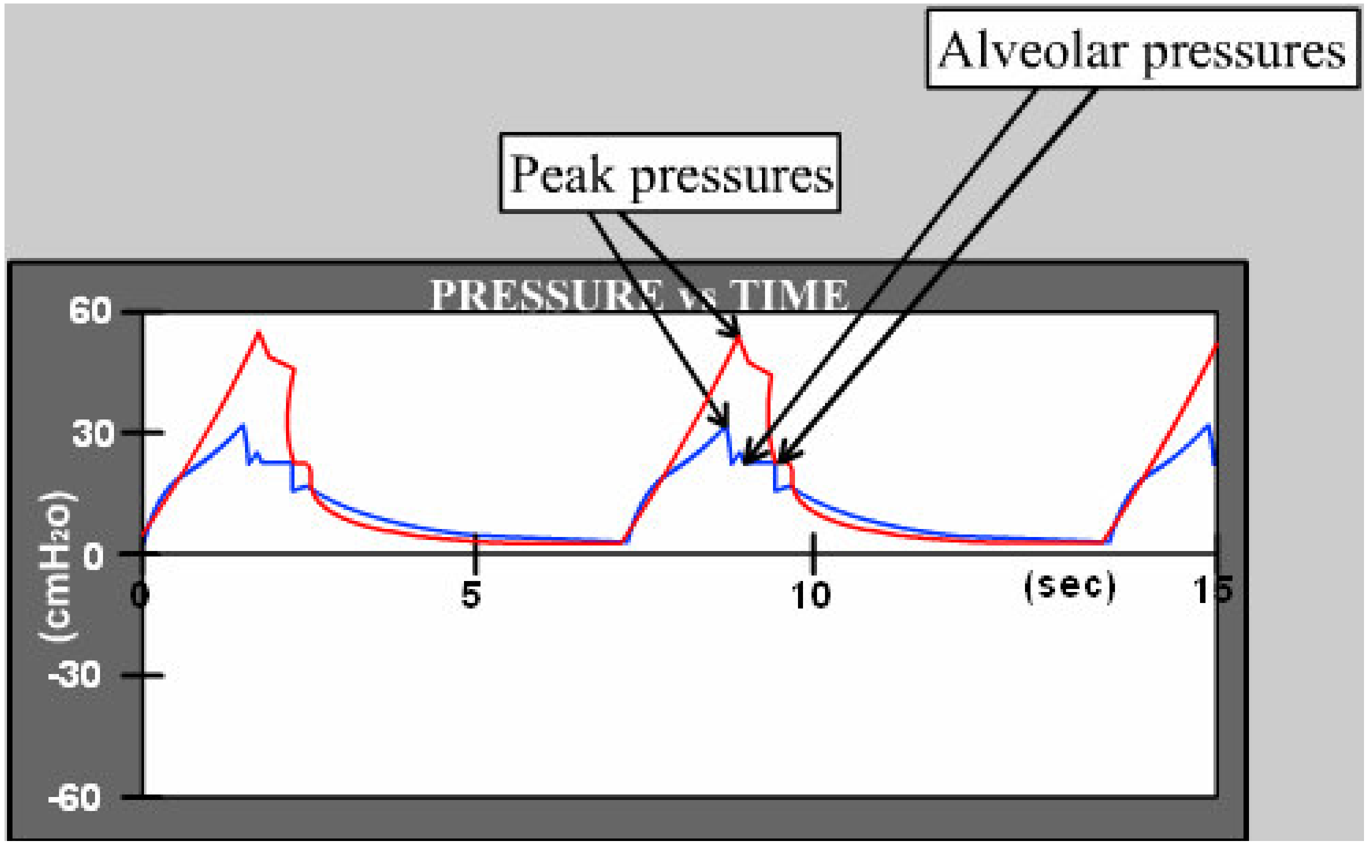
Alveolar pressure - Resistance

- Plateau pressure = the pressure required to distend the alveoli in zero flow condition, *i.e.* it represents alveolar pressure.
- Factors that generate changes in alveolar pressure
- Factors that increase peak pressures are factors that *increase resistance.* ***An increase in resistance generates an increase in PIP.*** However, plateau pressure remains unchanged. Consequently, *the difference between these two pressures shows the magnitude of the resistance.*

Alveolar pressure



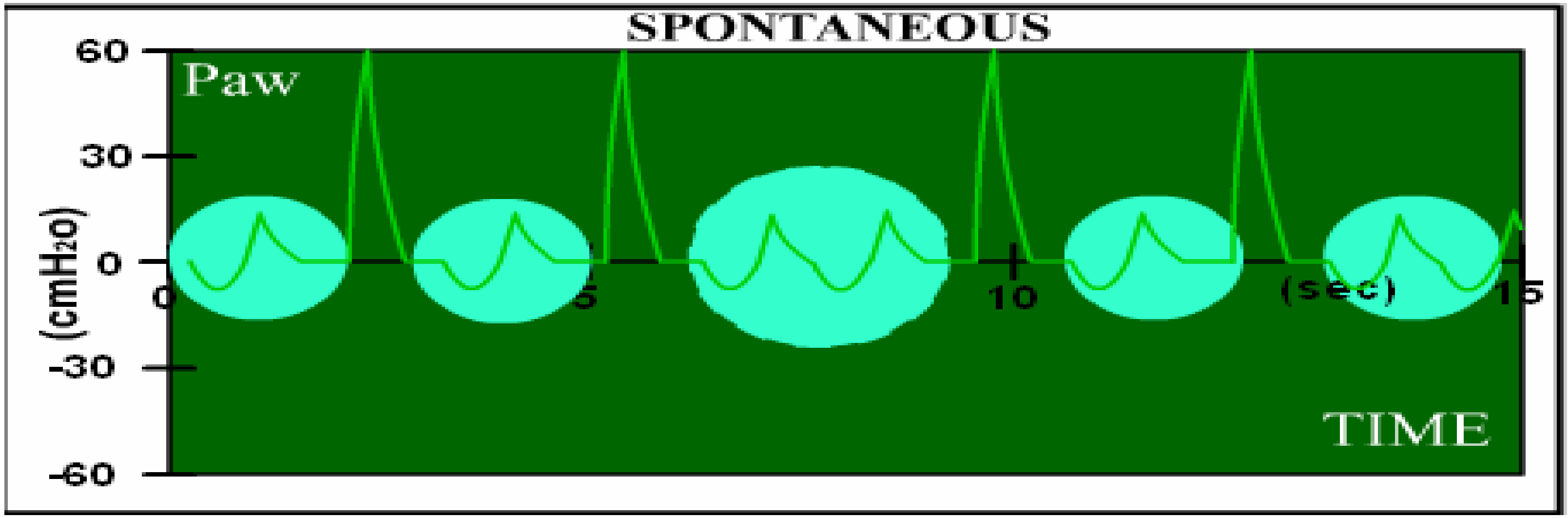
Alveolar pressure - Compliance



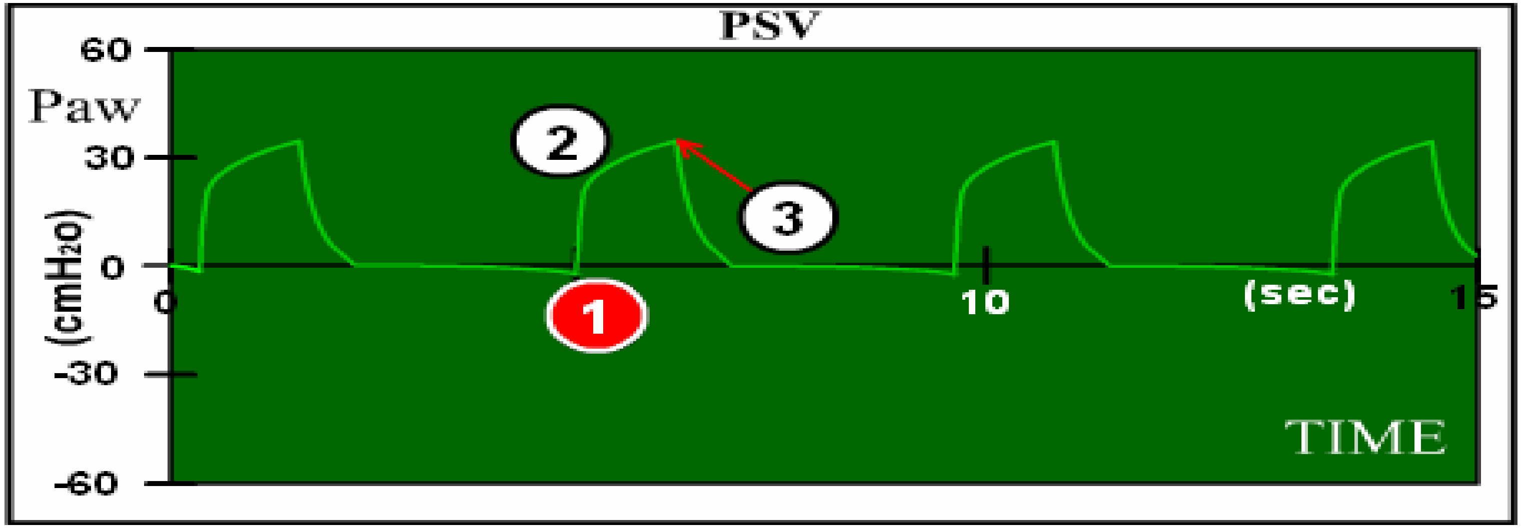
Pressure graphics during different modes of ventilation

- Spontaneous
- Pressure support
- SIMV
- Pressure controlled ventilation
- Pressure controlled ventilation & Pressure support

Spontaneous

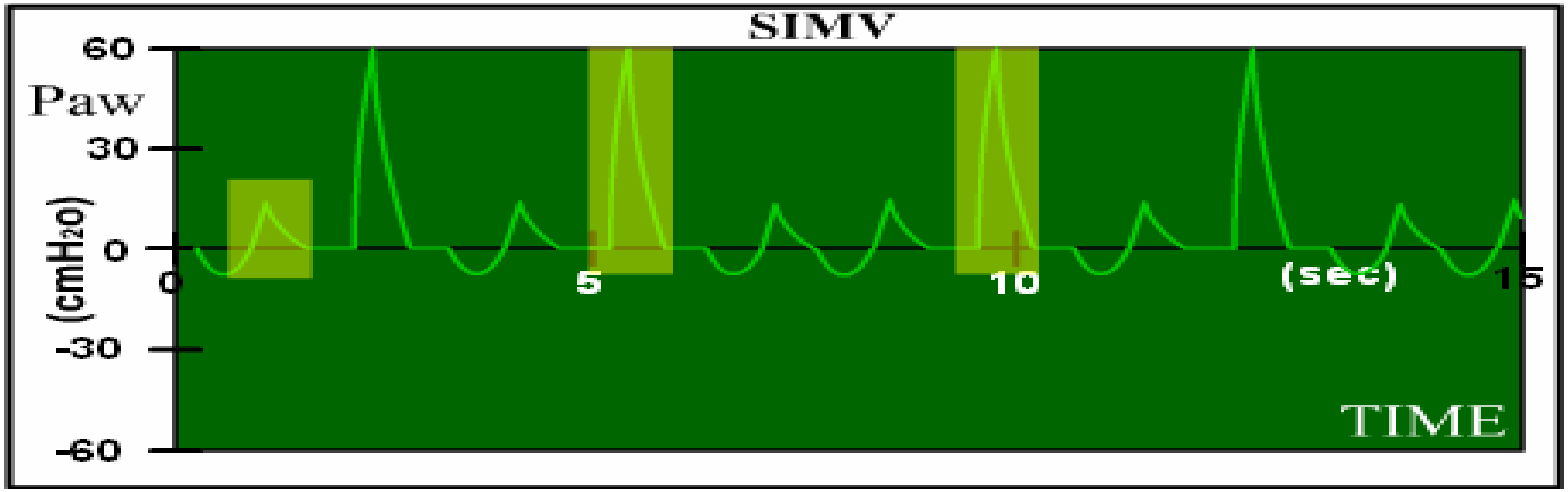


Pressure support ventilation



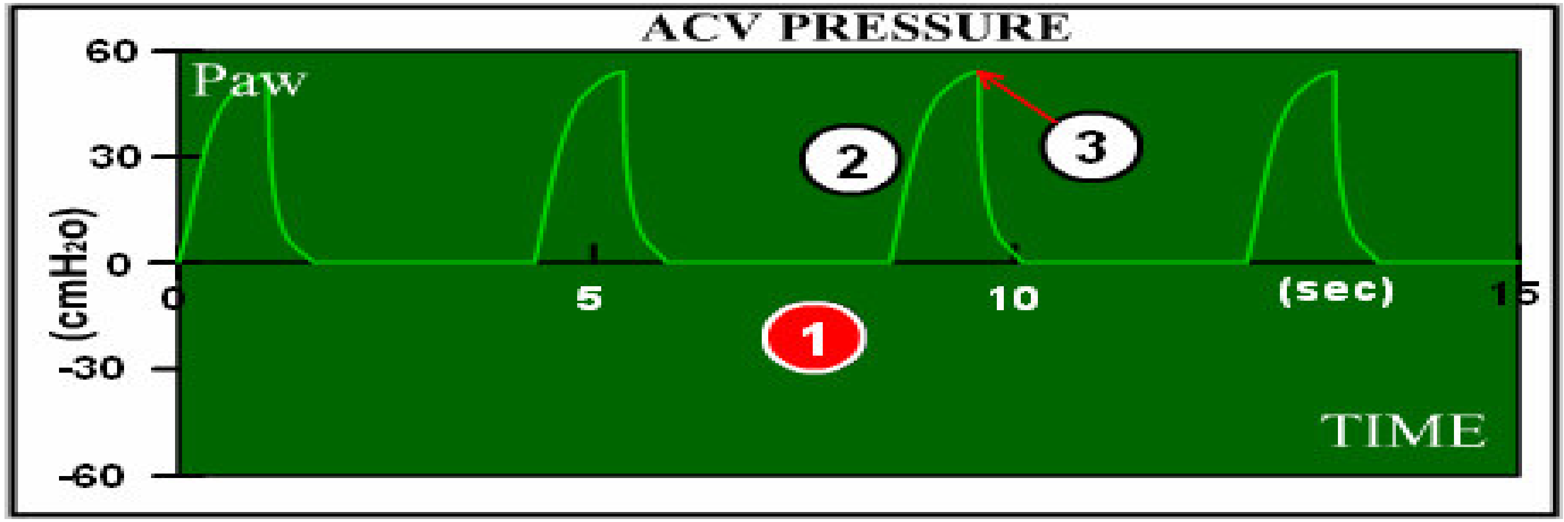
1. Trigger
2. Inspiratory support
3. Cycling

SIMV



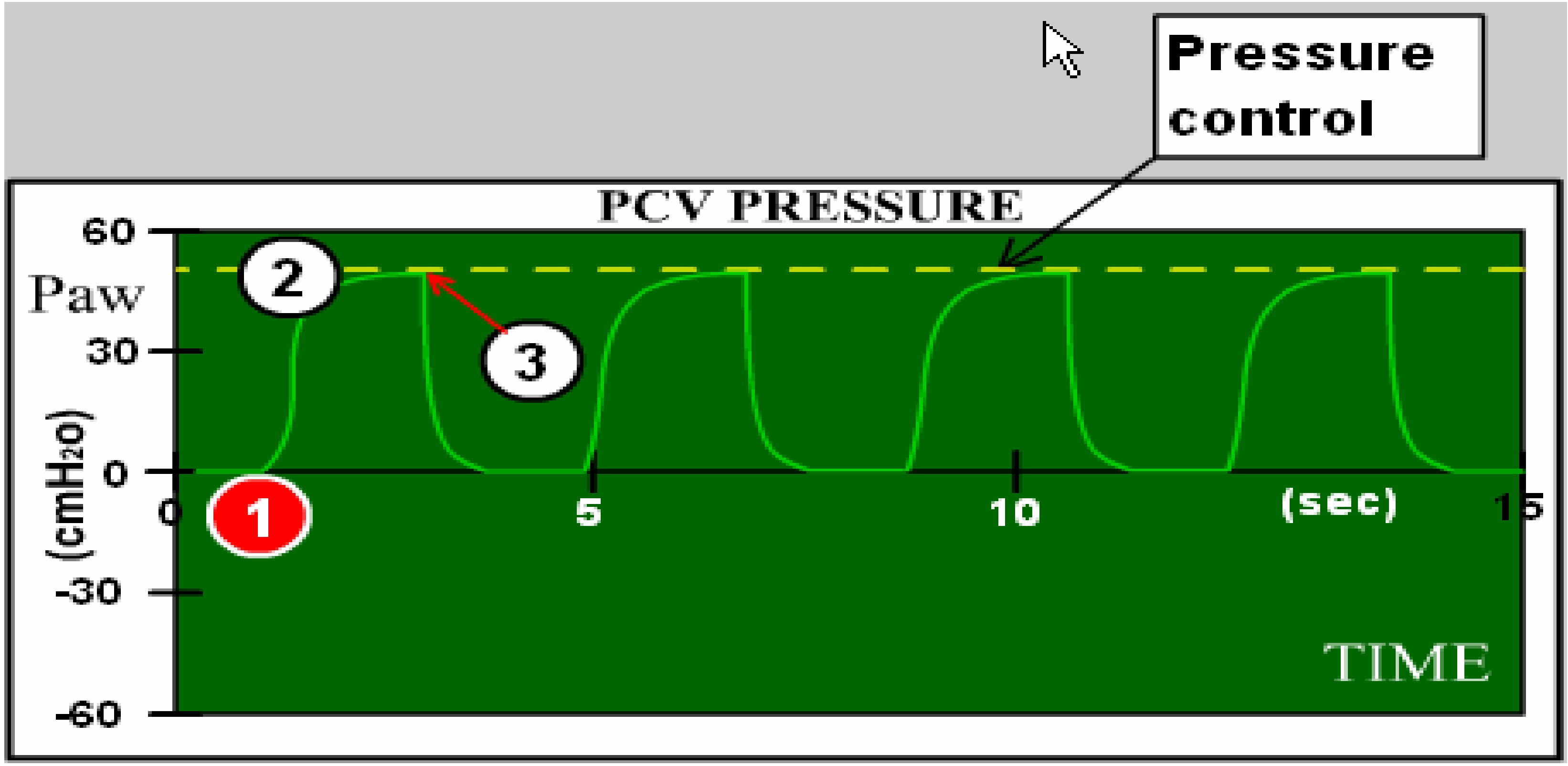
- Spontaneous ventilation: Negative deflection & low amplitude
- Assist/control ventilation: Assisted or controlled breath because of a negative deflection and amplitude

Assist/Control ventilation



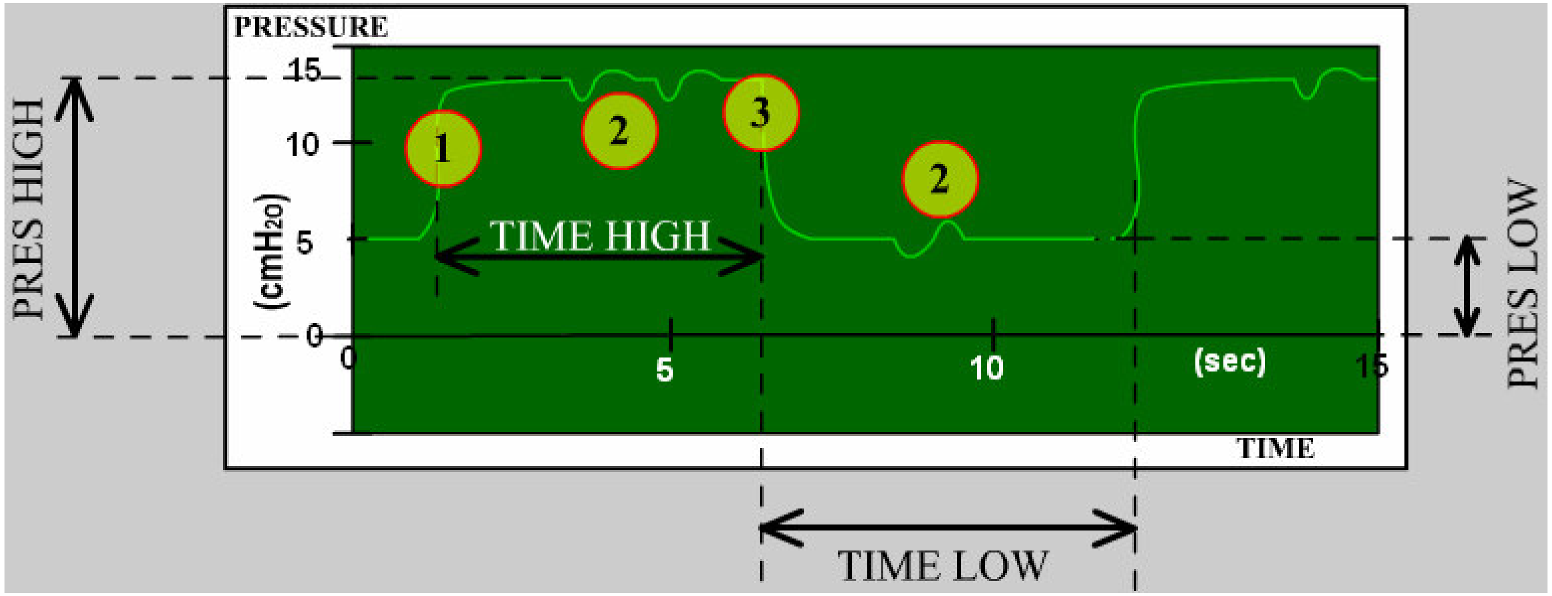
1. Trigger
2. Inspiratory phase
3. Cycling

Pressure controlled ventilation



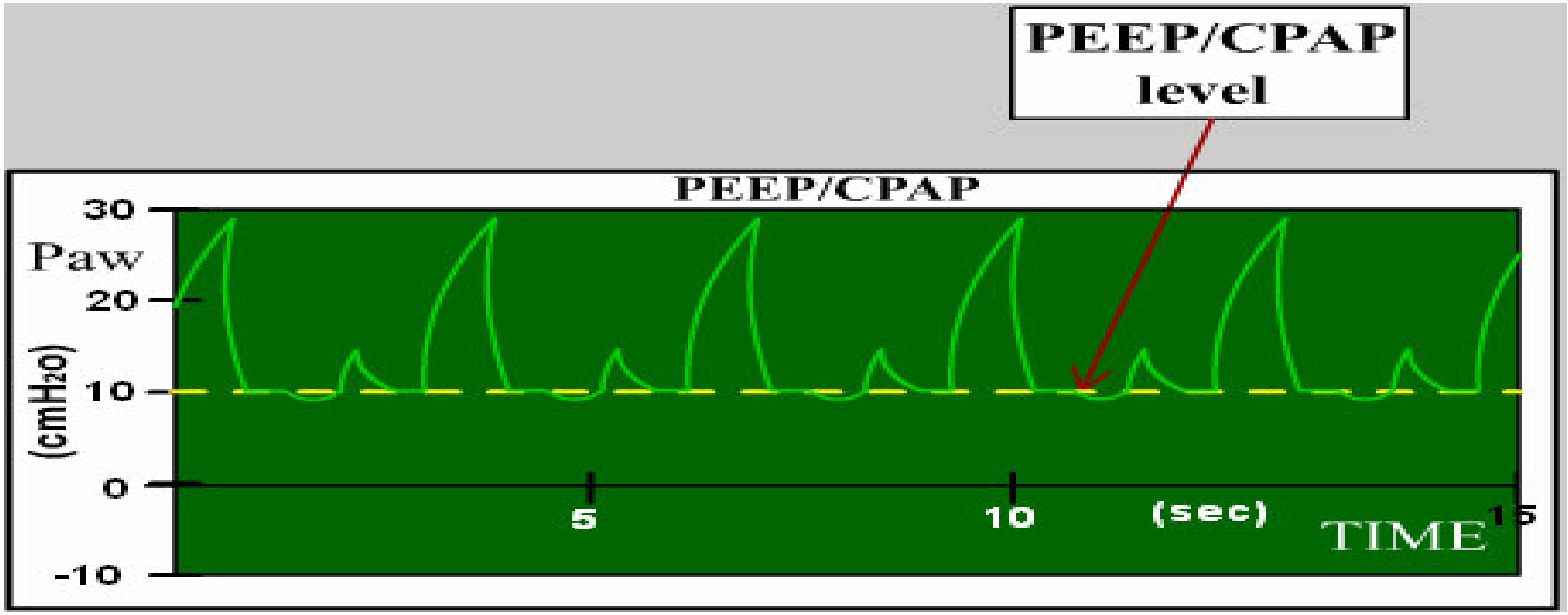
3. The pressure to be applied throughout the inspiratory phase is fixed.

BIPAP



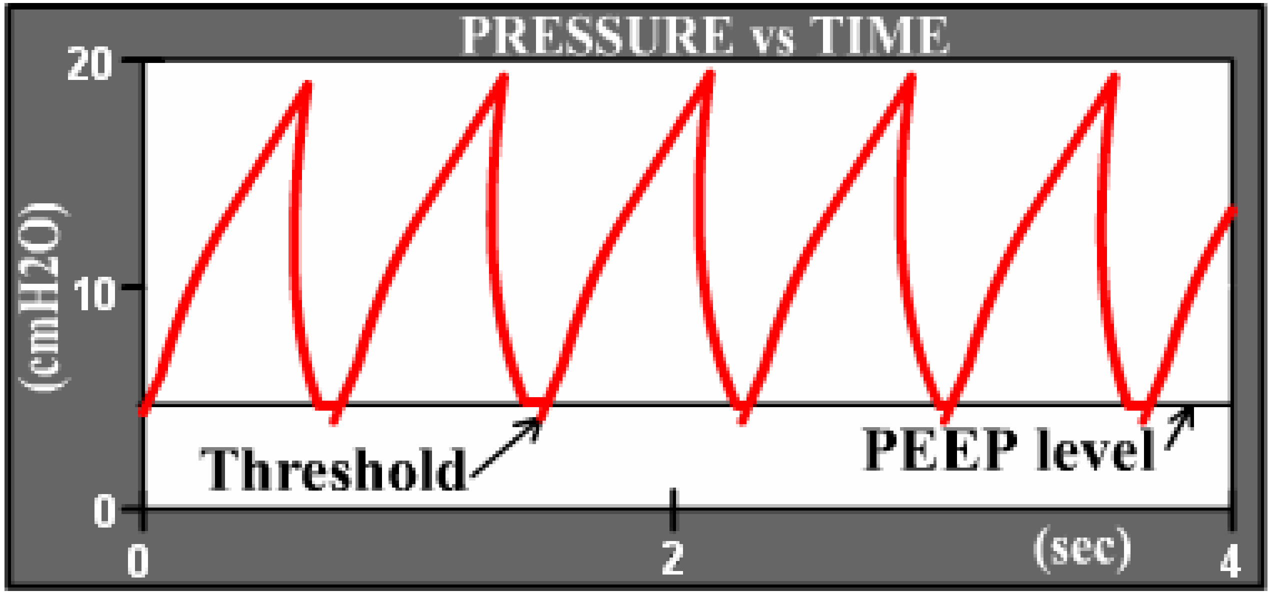
1. Rise time
2. Spontaneous breaths during BI-PHASE VENTILATION
3. BI-PHASE VENTILATION CYCLING: The moment passage from PRES HIGH to PRES LOW occurs is observed in this graph. The time spent at PRES HIGH depends on the time set by the operator (time-cycled) (Viasys).

PEEP/CPAP



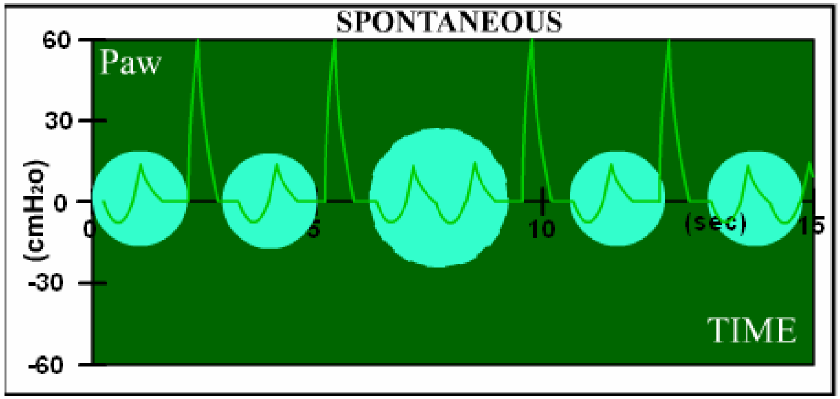
- Both PEEP and CPAP determine the presence of a pressure level different from zero in the airway.

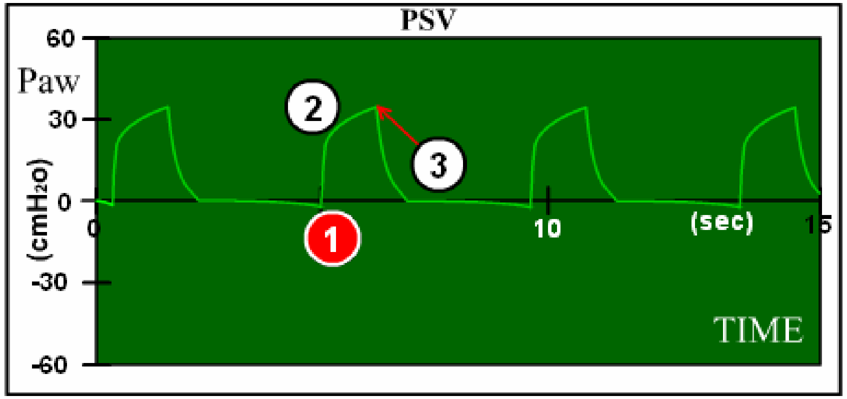
Variations: Auto cycling

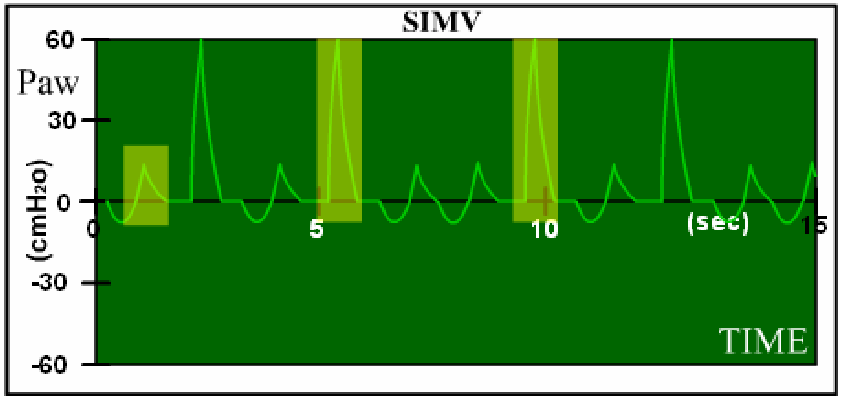


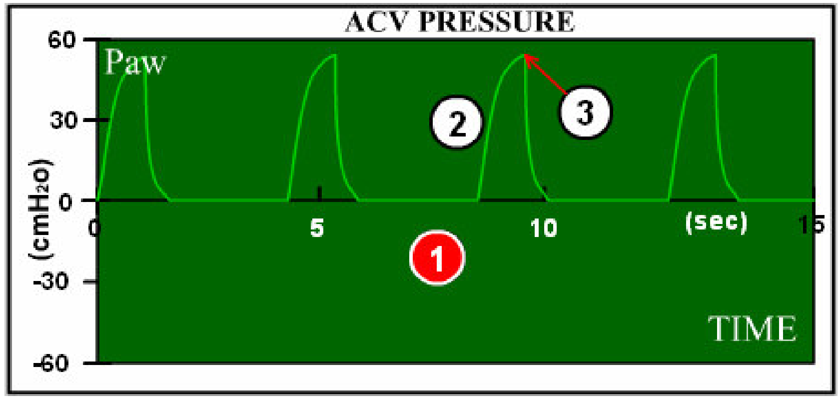
- Leak in the endotracheal tube: The pressure decrease exceeds the sensitivity threshold; the ventilator will interpret that the patient wants to inspire and will trigger continuously.
- Solved either by flow-triggering or by varying the pressure sensitivity value (Viasys).

Pressure graphics: Modes of ventilation

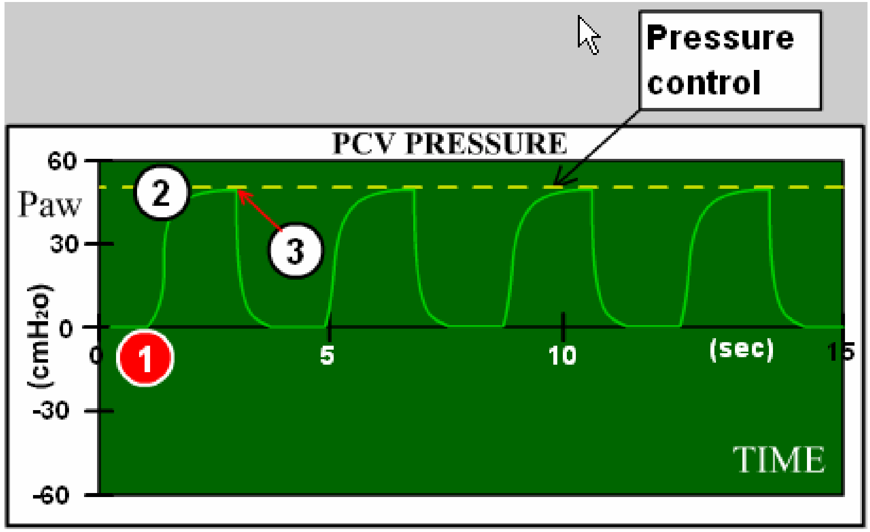


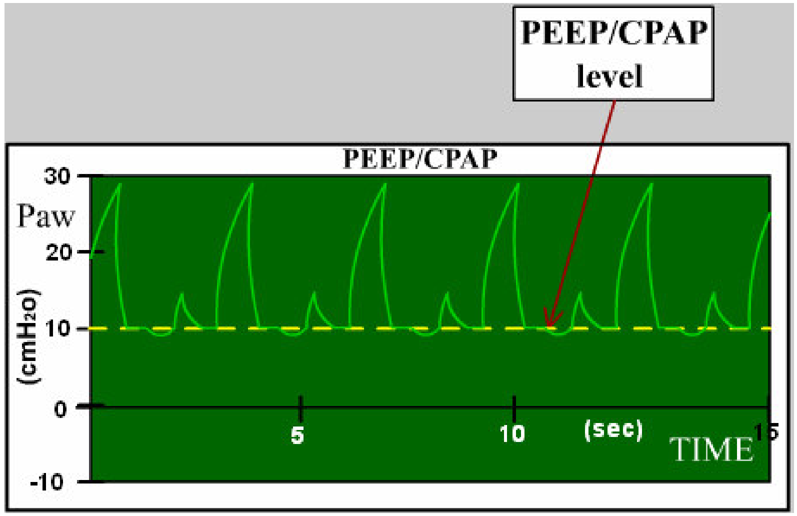


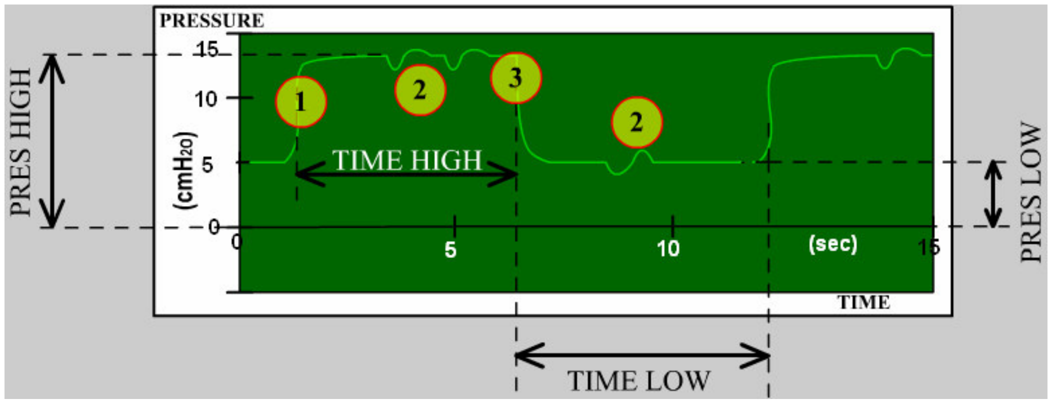


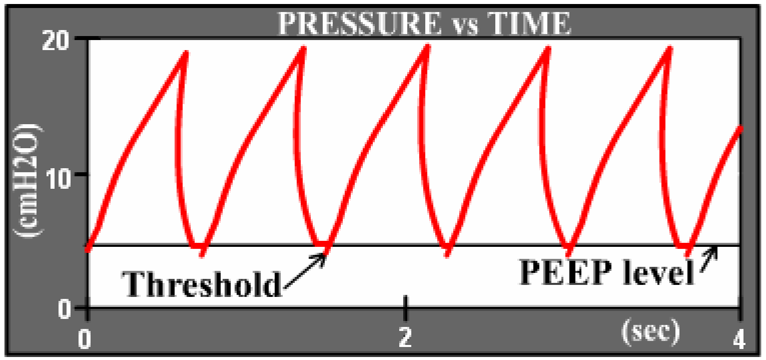


Pressure graphics: Modes of ventilation









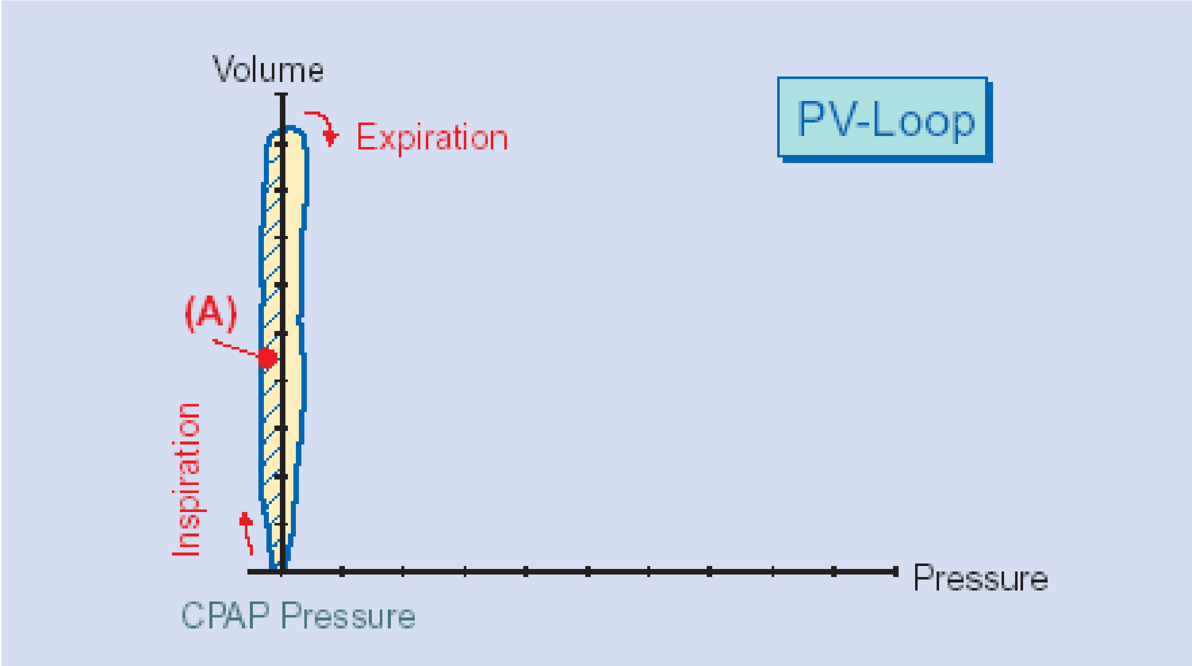
PART 4

PRESSURE-VOLUME LOOPS

Pressure-volume Loops

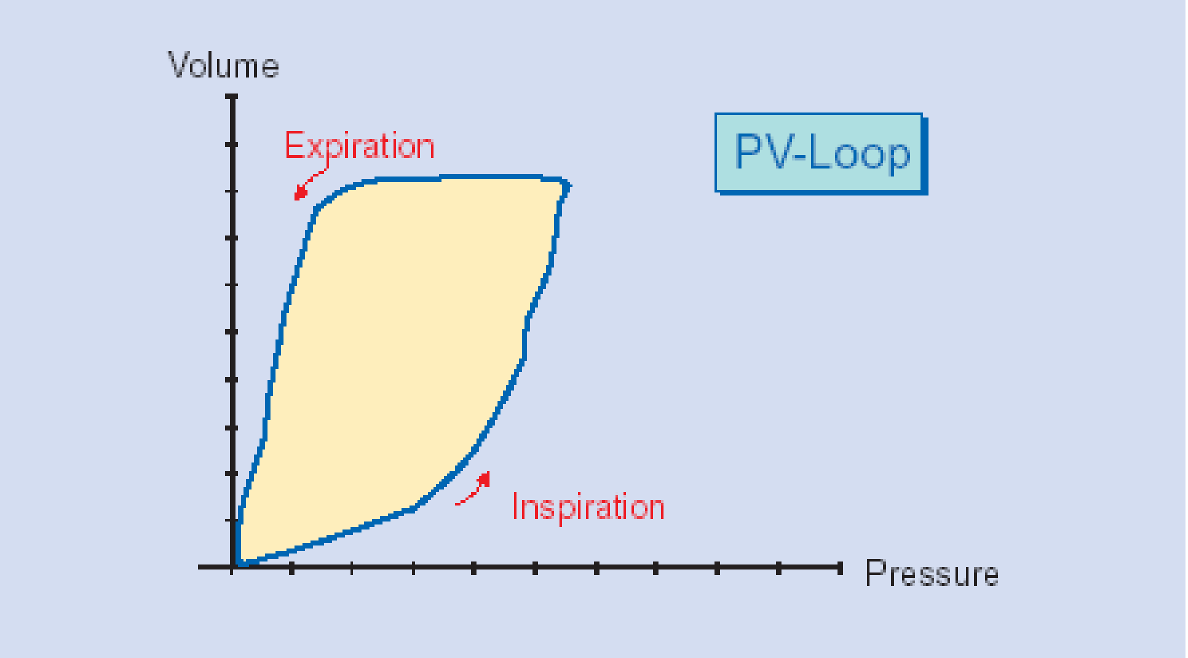
- Modes of ventilation
- Work of breathing
- Changes in respiratory mechanics
  - Compliance increase
  - Compliance decrease
  - Resistance increase
  - Resistance decrease
  - Overdistensions

SPONTANEOUS BREATH



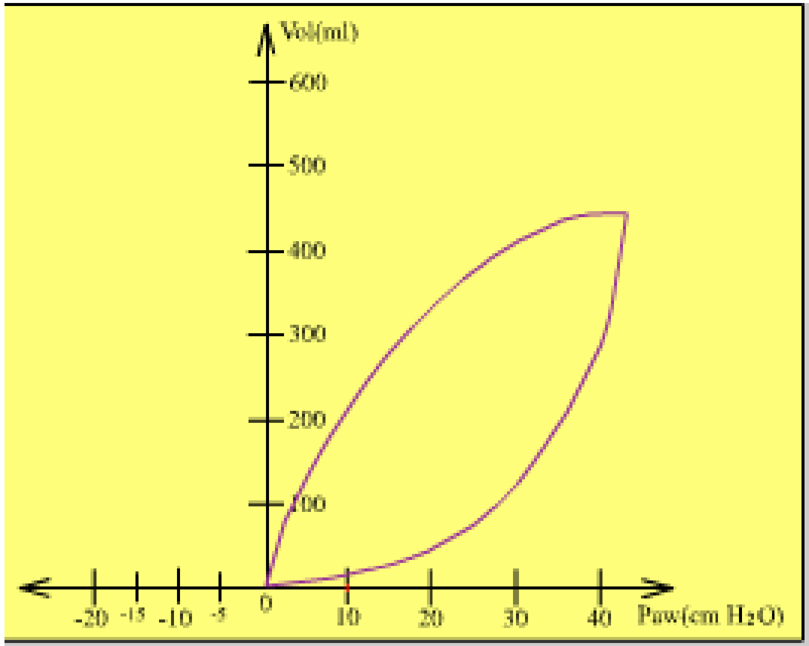
- Spontaneous breath - circulates clockwise; inspiratory phase on the side of negative pressure; the expiratory phase in the positive pressure zone.
- If PEEP/CPAP is set, the inspiratory phase will be below this value, and the expiratory phase above this value.

Volume ventilation

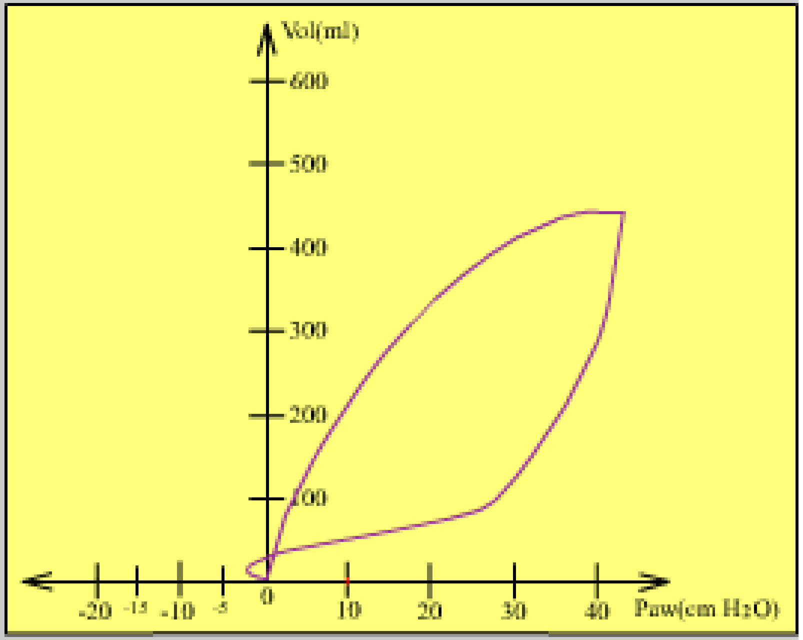


- The volume loop circulates anti-clockwise.
- An assisted breath: A negative pressure will be observed during the trigger period.
- A mechanical breath: The full extent of the loop will be in the positive pressure zone (Viasys)

Volume ventilation

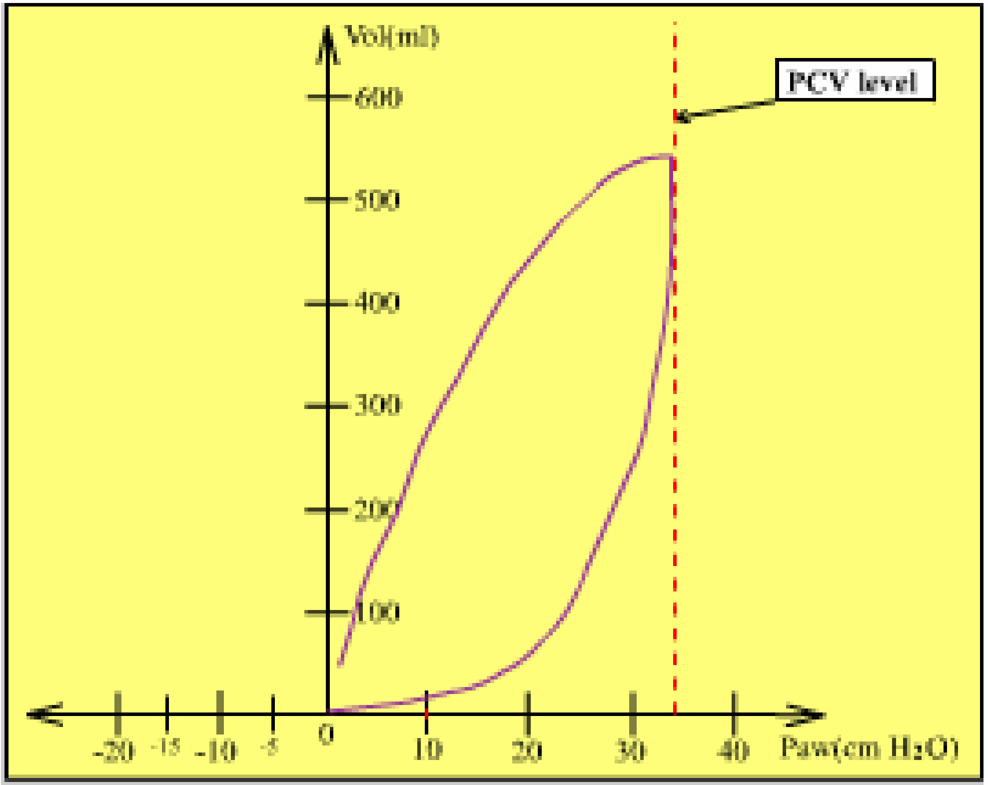


CONTROLLED



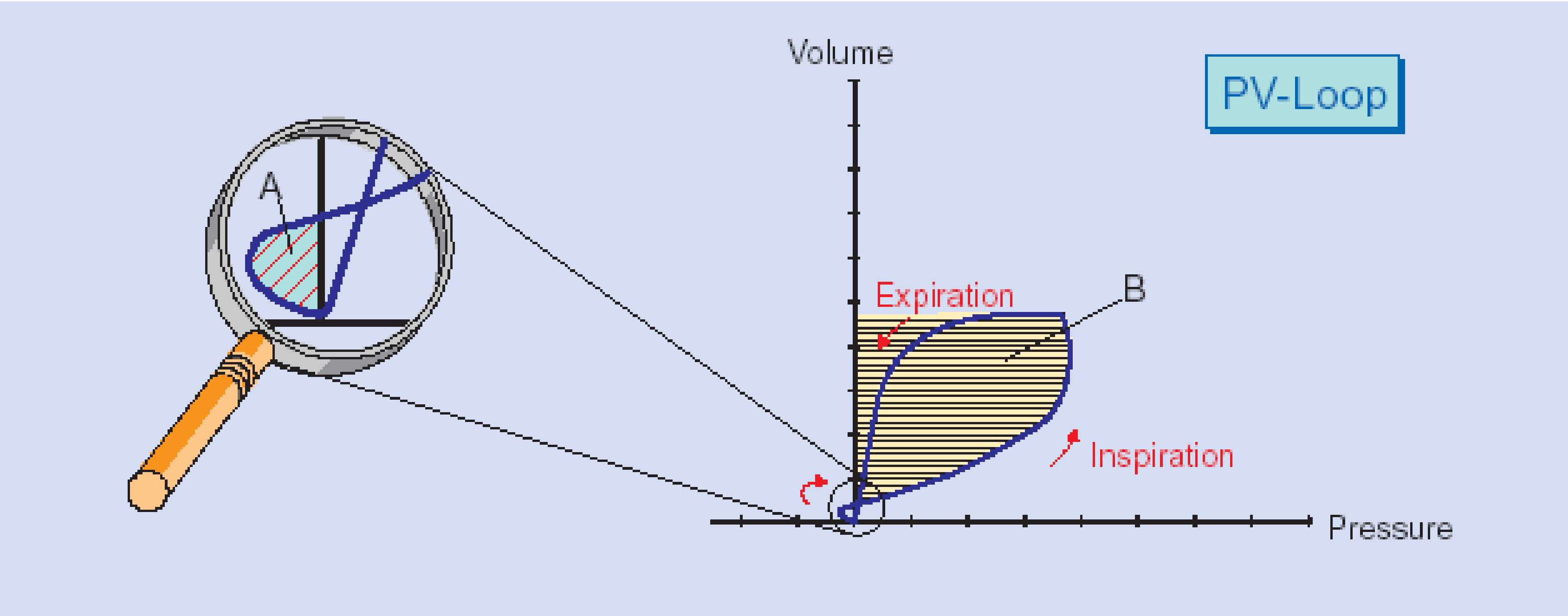
ASSISTED

Pressure controlled ventilation



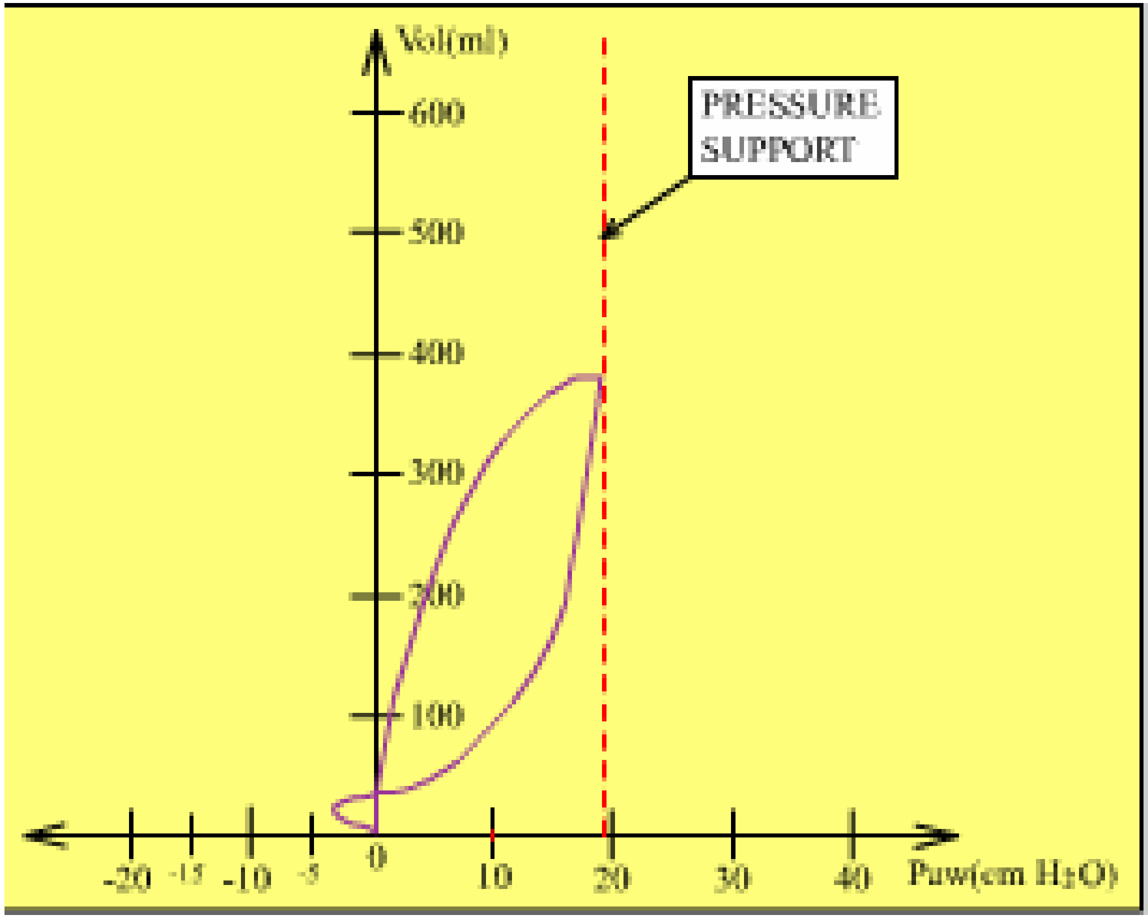
- The pressure controlled loop also circulates anti-clockwise.
- A rapid pressure increase occurs during the inspiratory phase.
- During the expiration phase the pressure decreases (Viasys).

Pressure support ventilation



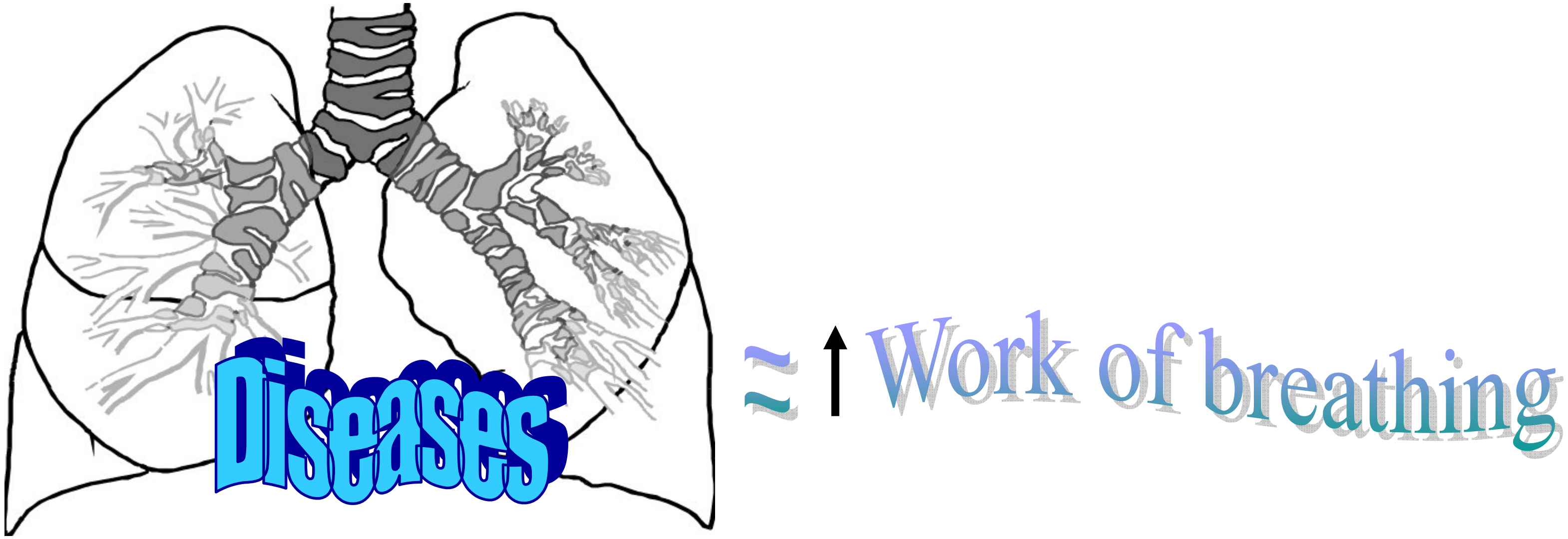
- Loop begins as a negative deflection when the patient initiates the breath.
- Ventilator delivers flow, pressure and volume.

Pressure support ventilation

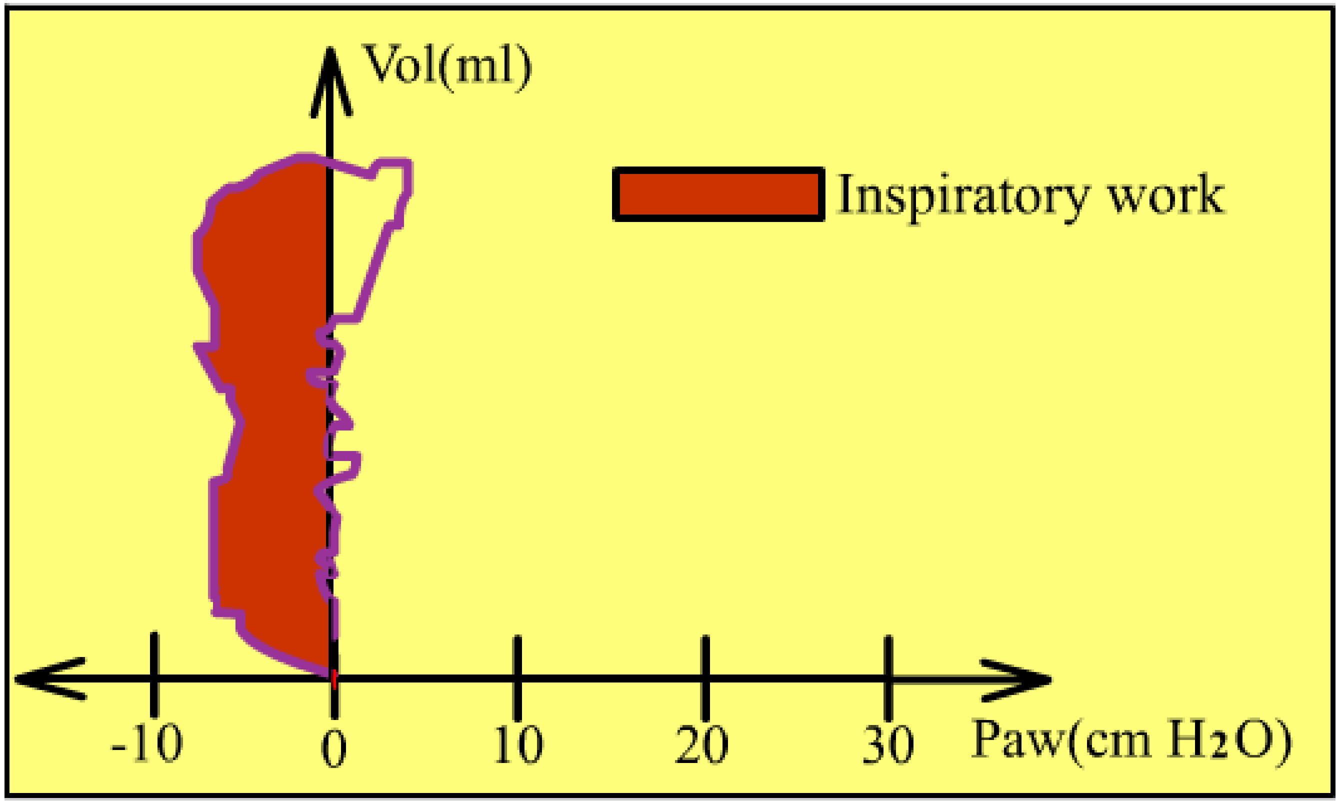


Work of breathing

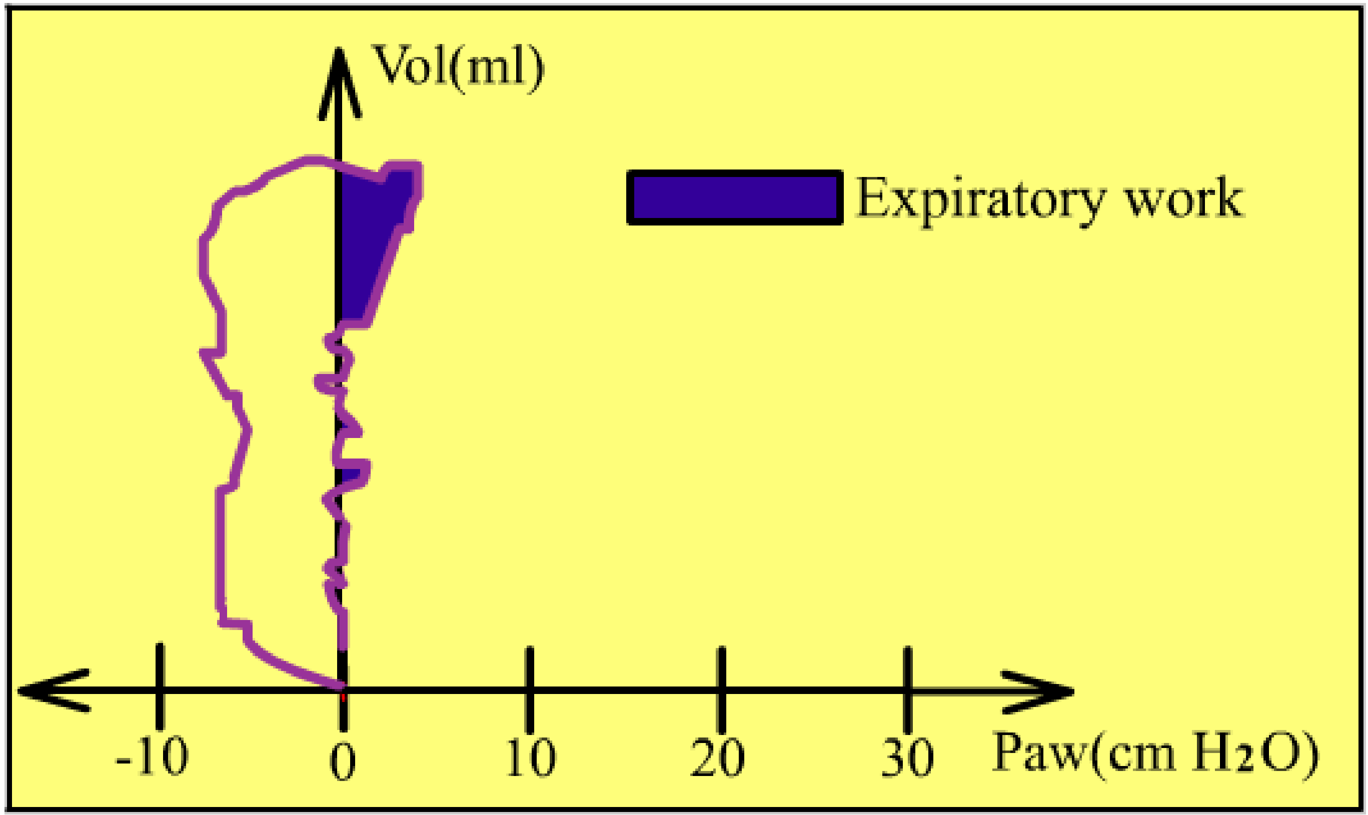
- The work performed by the respiratory muscles to enlarge the thoracic cavity



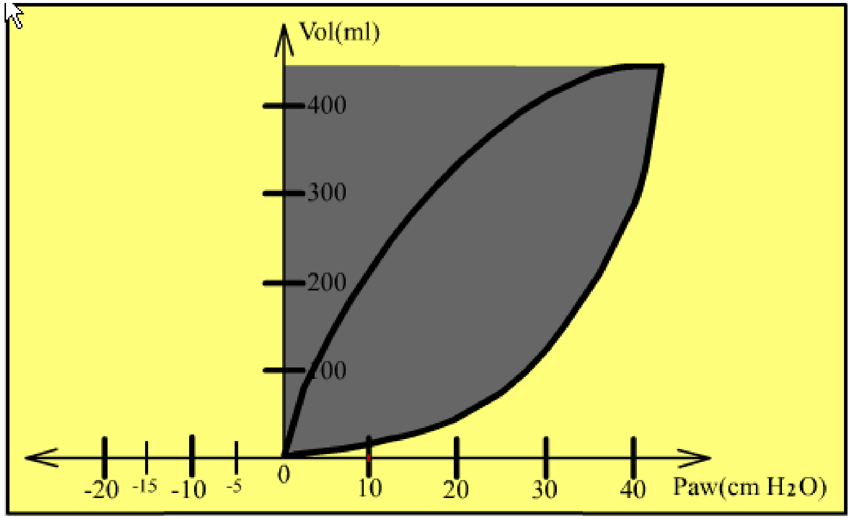
Inspiratory work during spontaneous breaths

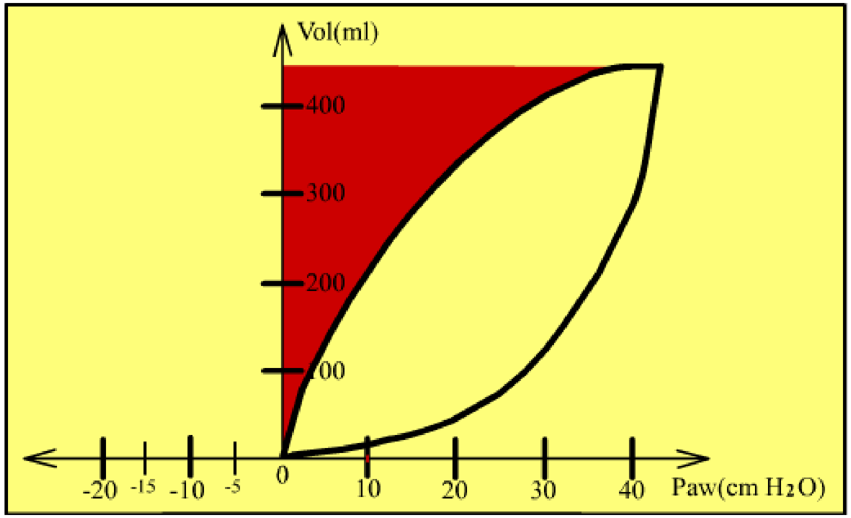


Expiratory work during spontaneous breaths



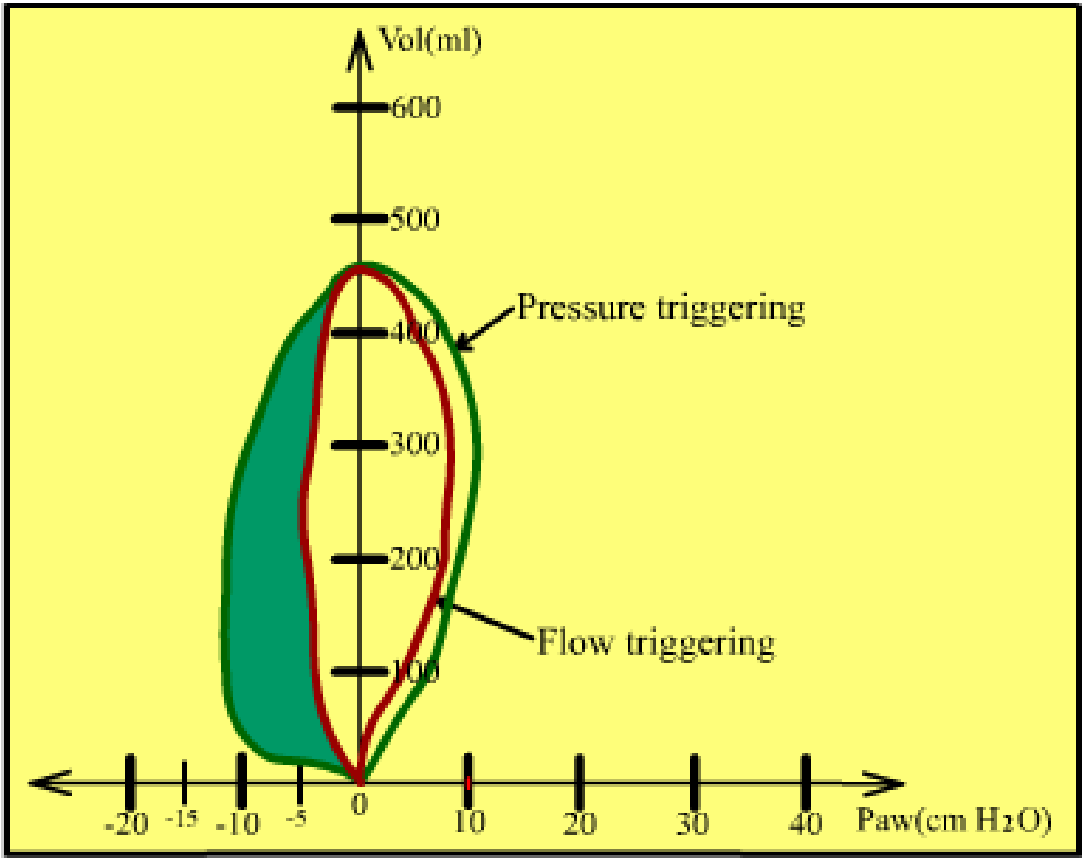
Inspiratory work during controlled breaths



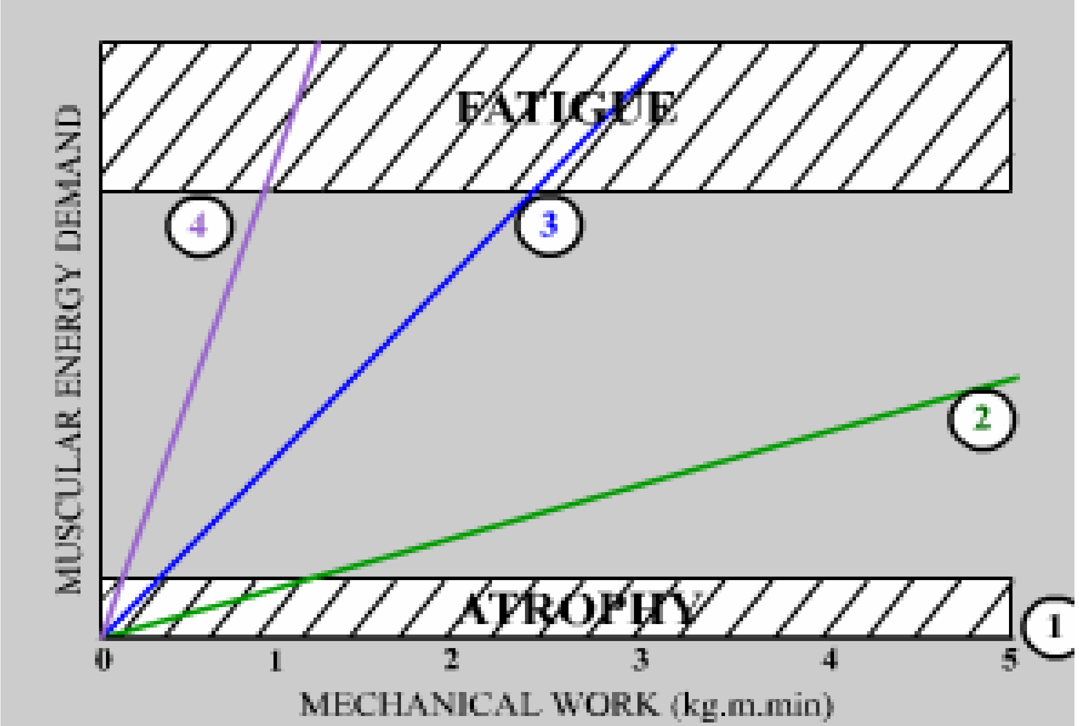


- Controlled breaths are mechanically produced and therefore create no direct work of breathing

Work of breathing



Interpreting work of breathing

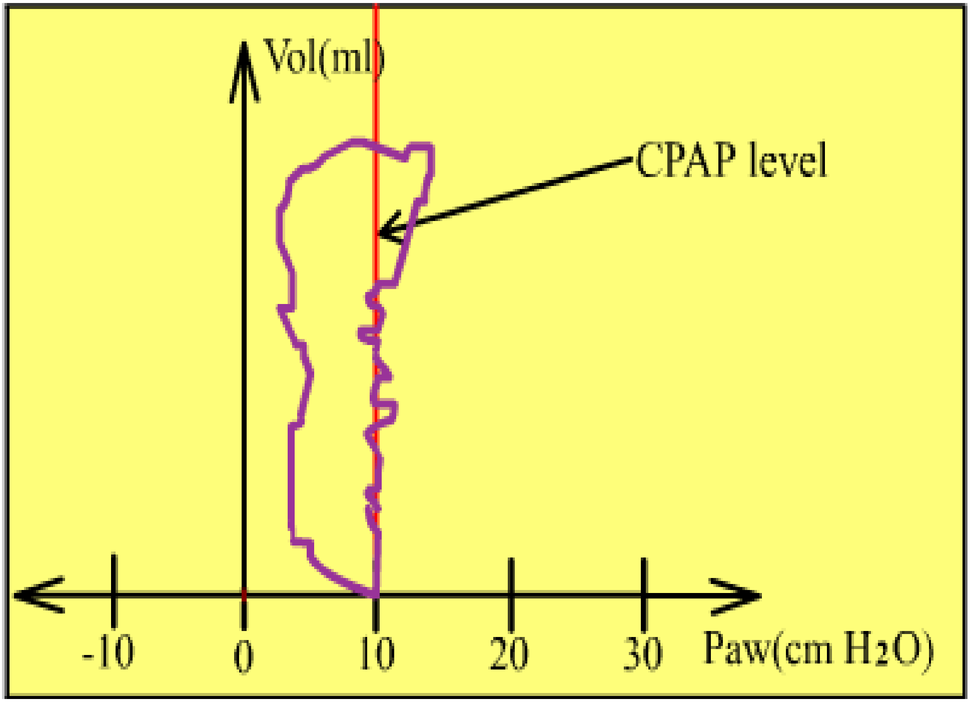


- Aim = limit the work of breathing
  - Eliminating work of breathing causes muscular atrophy.
  - *If the respiratory workload demand is too low, the energy expenditure will be as low, resulting in a high probability of developing muscular atrophy.*

Interpreting work of breathing

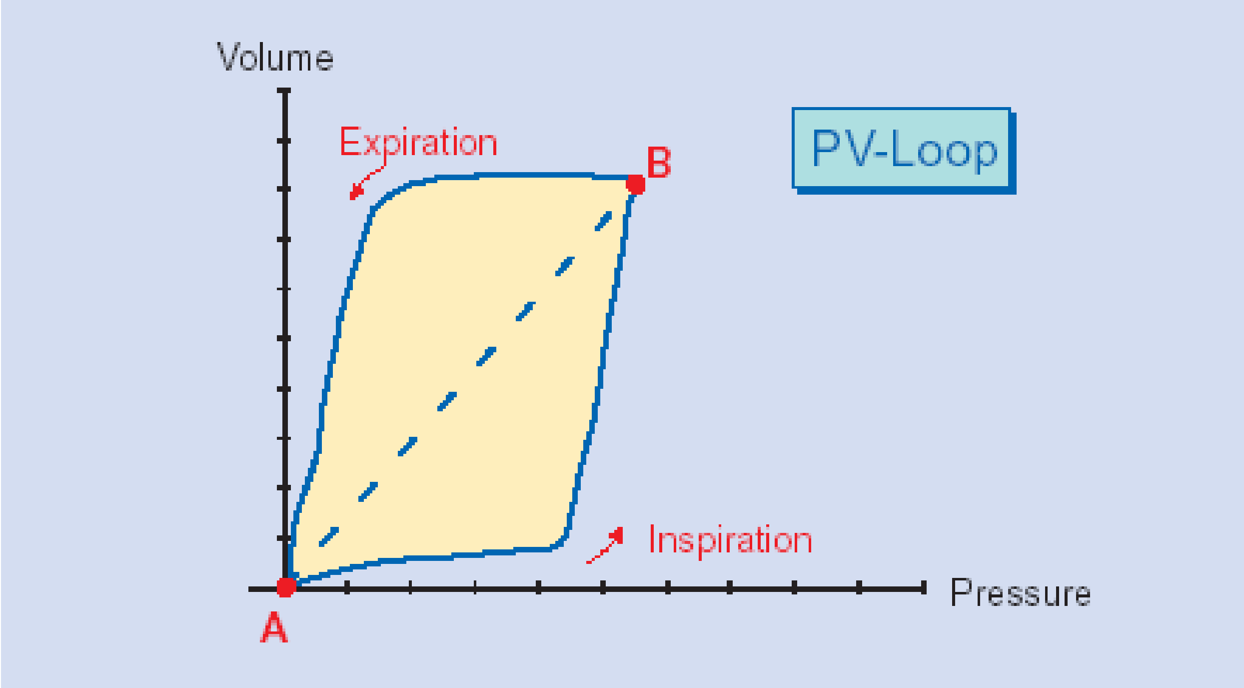
- Observe the straight line that represents mechanical work (measured kg.m.min).
- For the same workload, different energy expenditure is required according to the patient's condition. Energy demand is considered normal in straight line 2.
- In line 3, greater energy expenditure is required as a result of the deterioration of the patient's condition.
- In line 4, the patients' condition is really critical because, for the same load, the energy expenditure generates muscular fatigue (Viasys).

Interpreting work of breathing



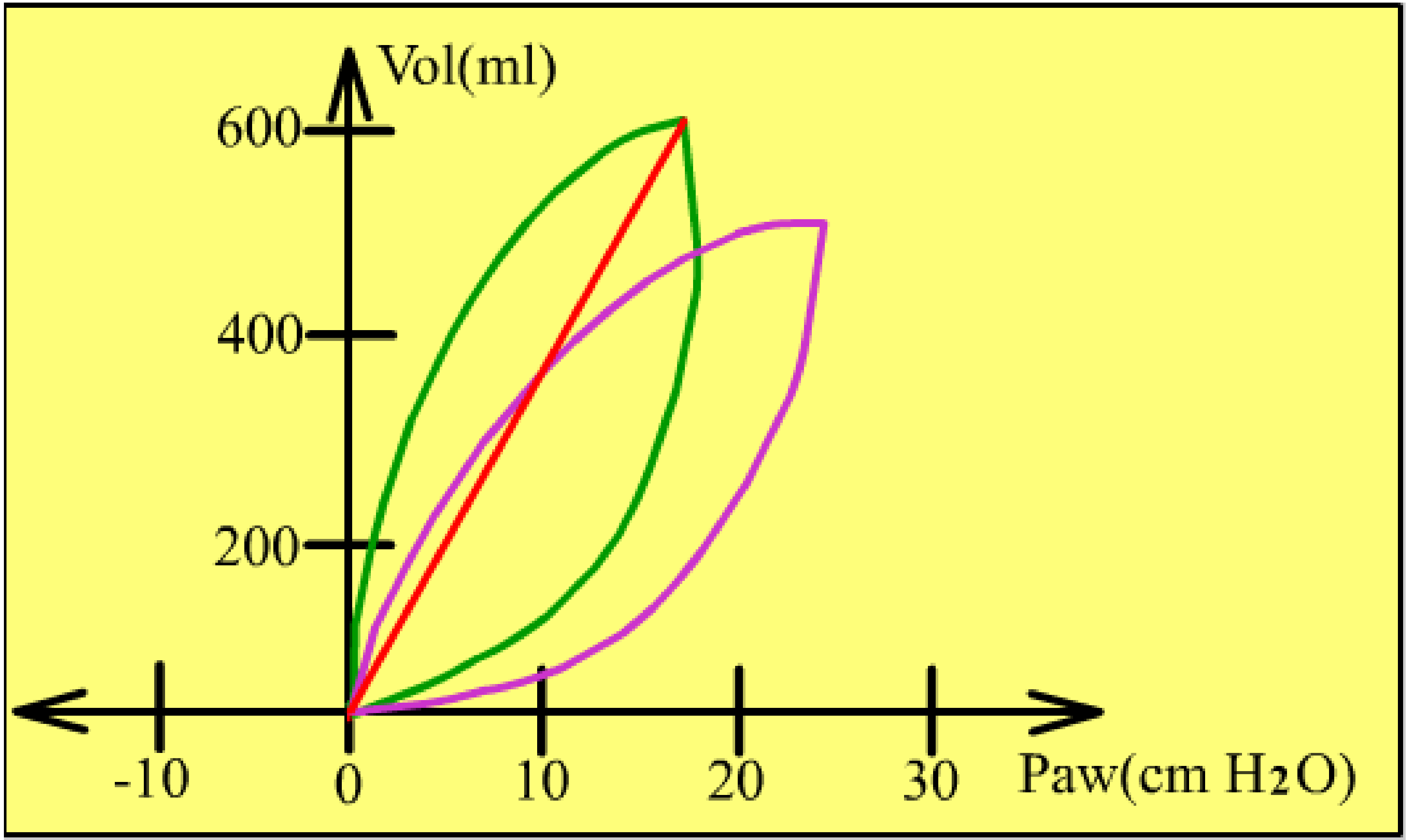
- On PEEP/CPAP the loop moves to the right (Ouellet 1997:67).
- Use a movable axis up to the PEEP/CPAP setting.
- The area to the left of the axis indicates the work of breathing (Viasys).

Slope

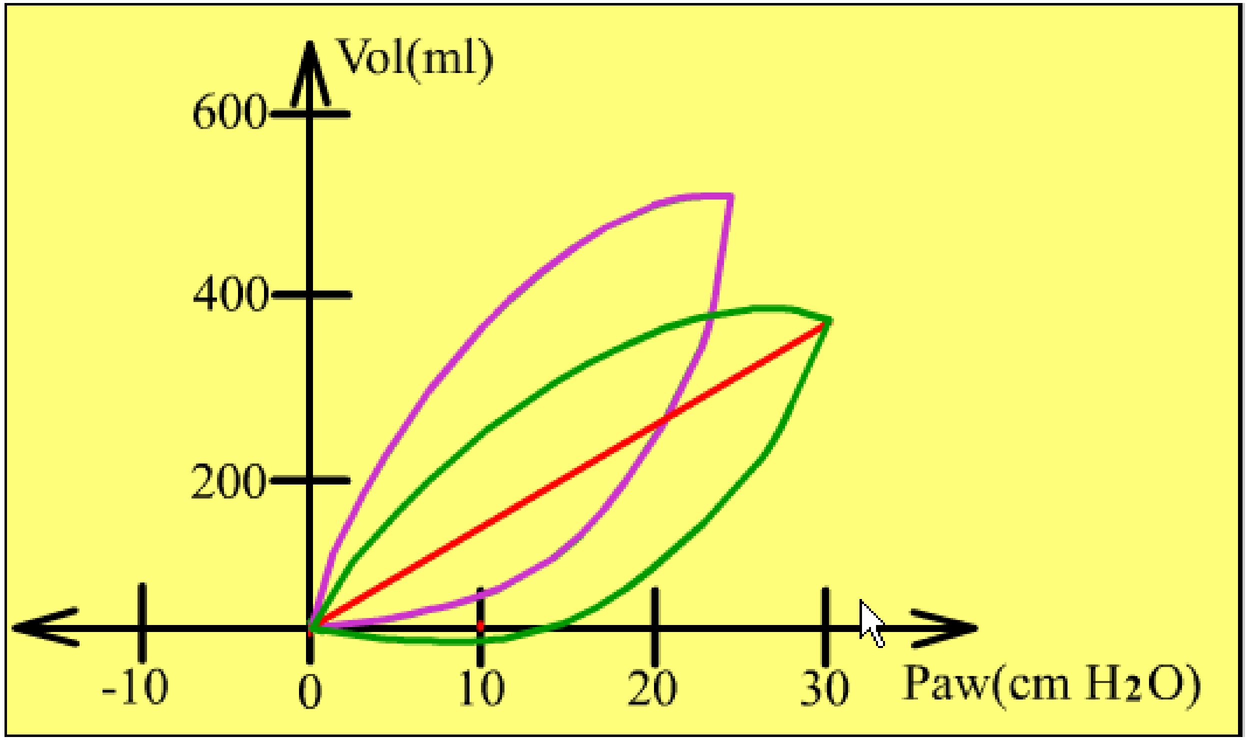


- The dotted line joining the end-inspiratory pause or pressure plateau (B) to the end-expiration point (A) indicates the slope.

Compliance increase

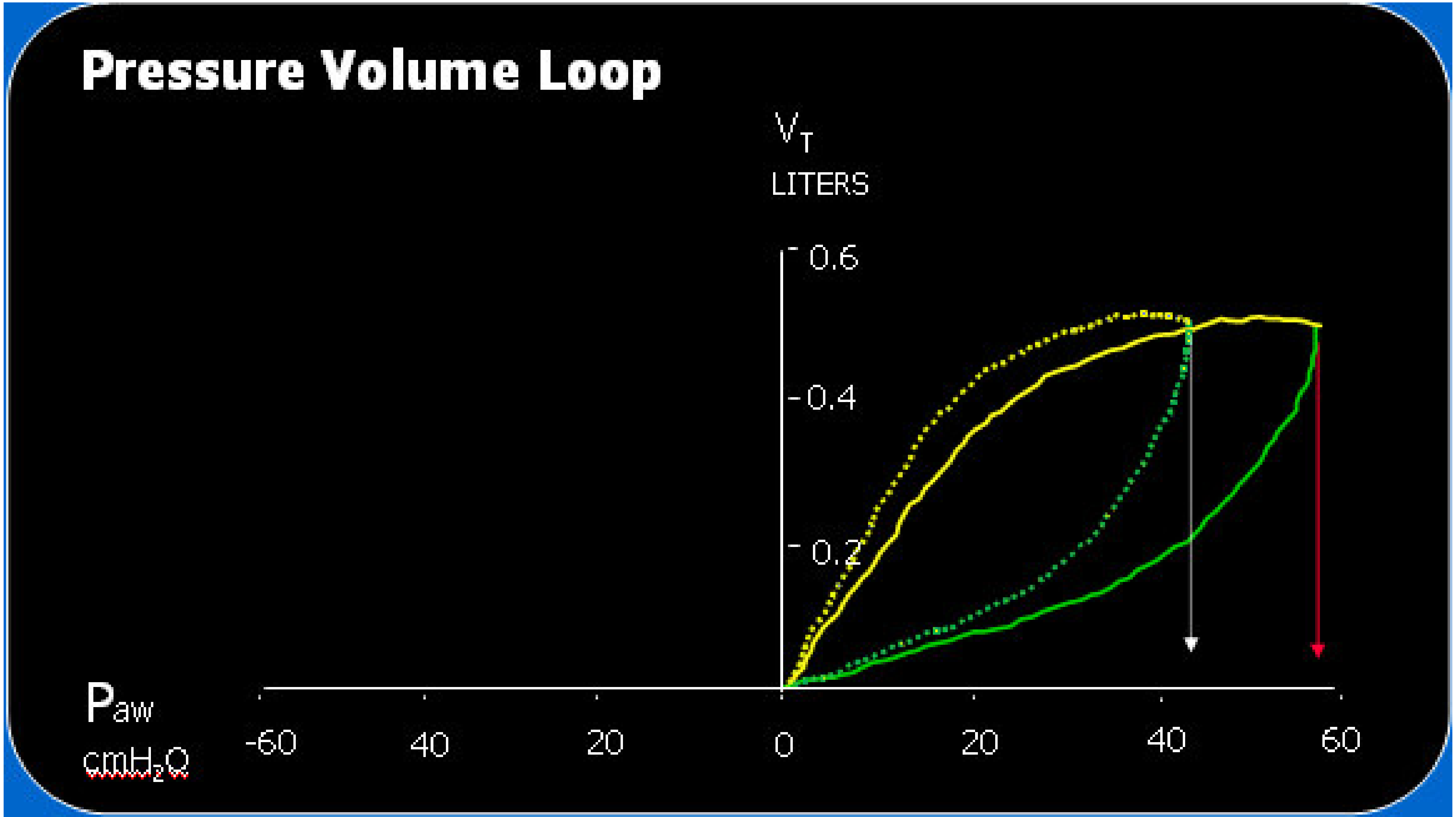


Compliance decrease

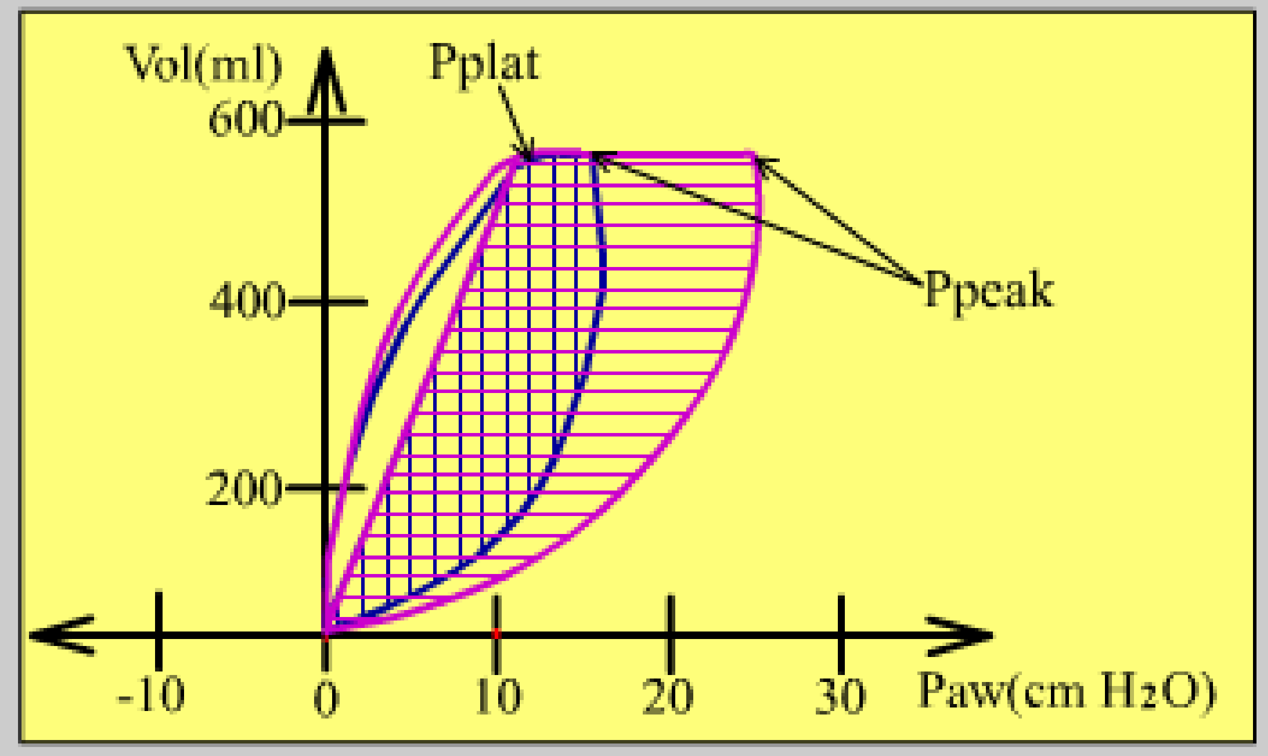


- When compliance decreases, a higher pressure is required to accommodate the same volume. The normal loop is indicated in purple, and the decreased compliance loop in green, with the slope stretching from the inspiratory pause to the end-expiration point (Viasys).

Compliance decrease

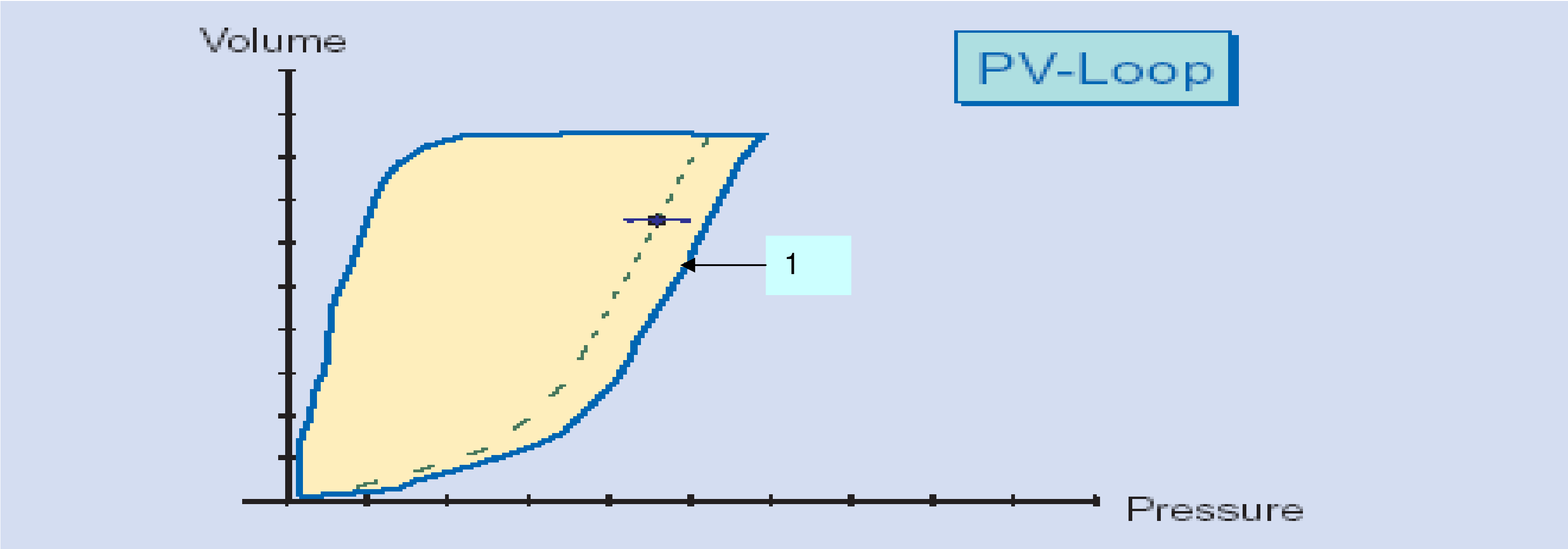


Resistance increase



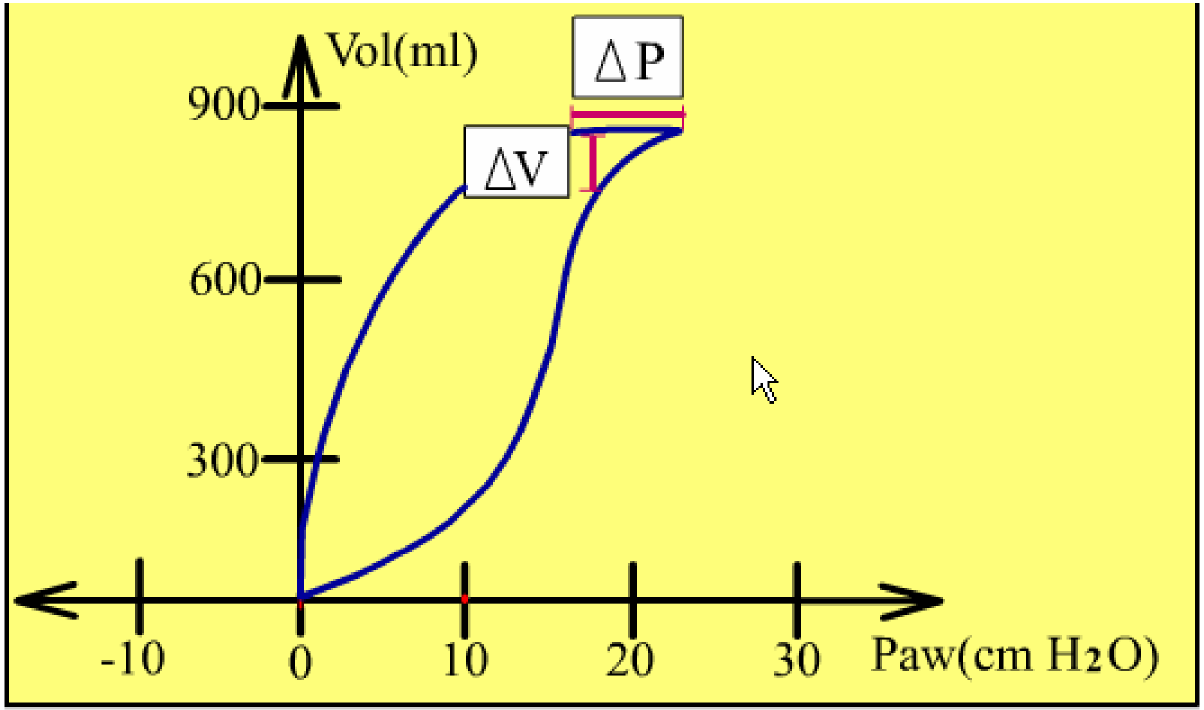
- Area lying between the slope and the inspiratory phase

Resistance decrease



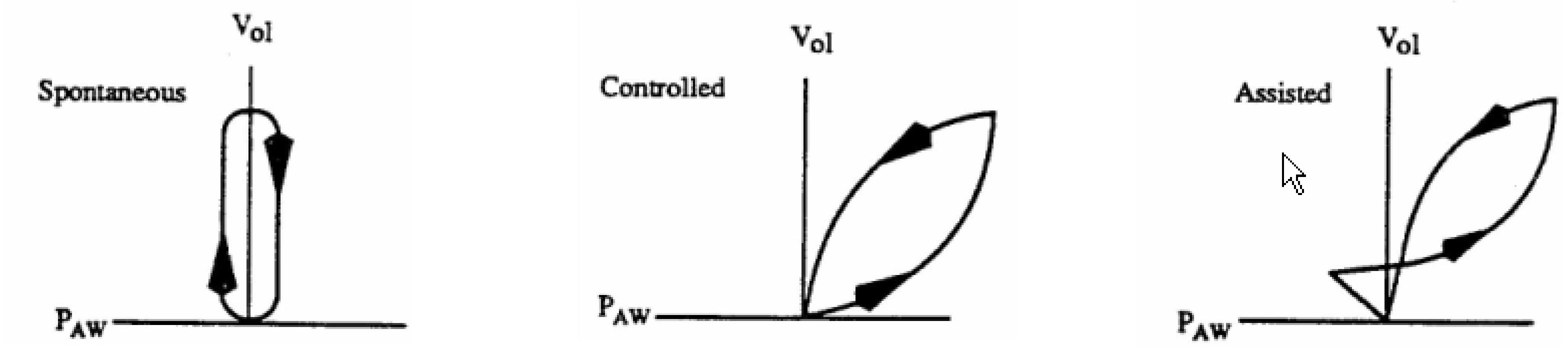
- With an increase in resistance, the slope moves to the right or toward the solid line (1), indicating a higher peak airway pressure.

Overdistension



- Bird's beak

Pressure-volume loops



- Compare the different loops during different modes of ventilation.

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PART 5

FLOW -VOLUME LOOPS

Flow-volume loops

- Modes of ventilation
- Changes in respiratory mechanics
  - Resistance increase

Flow-volume loops

- The second loop of interest is the flow-volume loop.
- The flow-volume loop has diagnostic value in diagnosing obstructive pathologies in patients that breathe spontaneously.
- In the flow-time curve, the inspired flow is considered to be positive, and the expired flow negative. In contrast, in the flow-volume loop the expired flow is considered to be positive, and the inspired flow negative for this particular model. Tidal volume is represented on the horizontal axis and the flow on the vertical axis. The loop circulates clockwise (Viasys)

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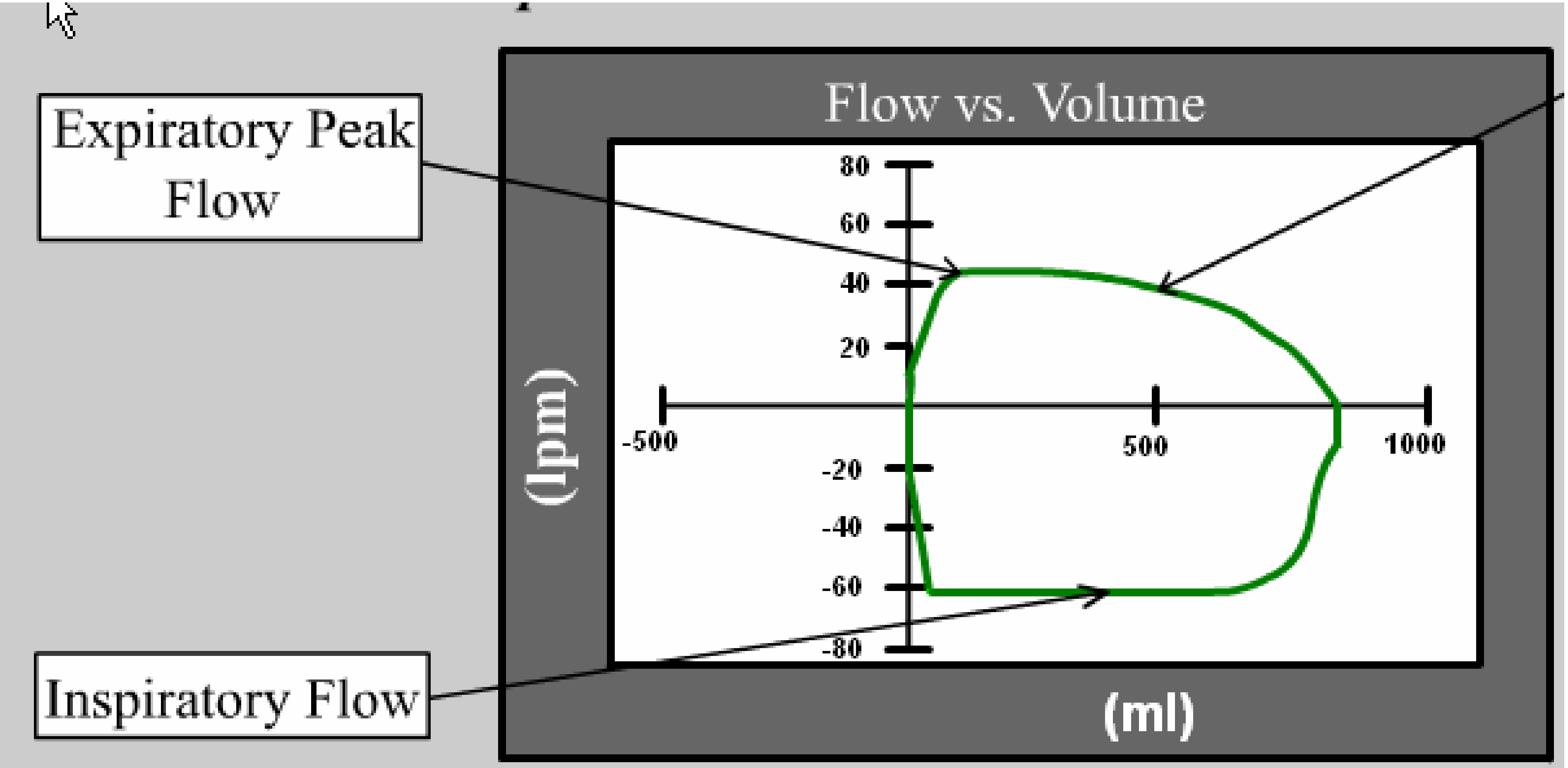
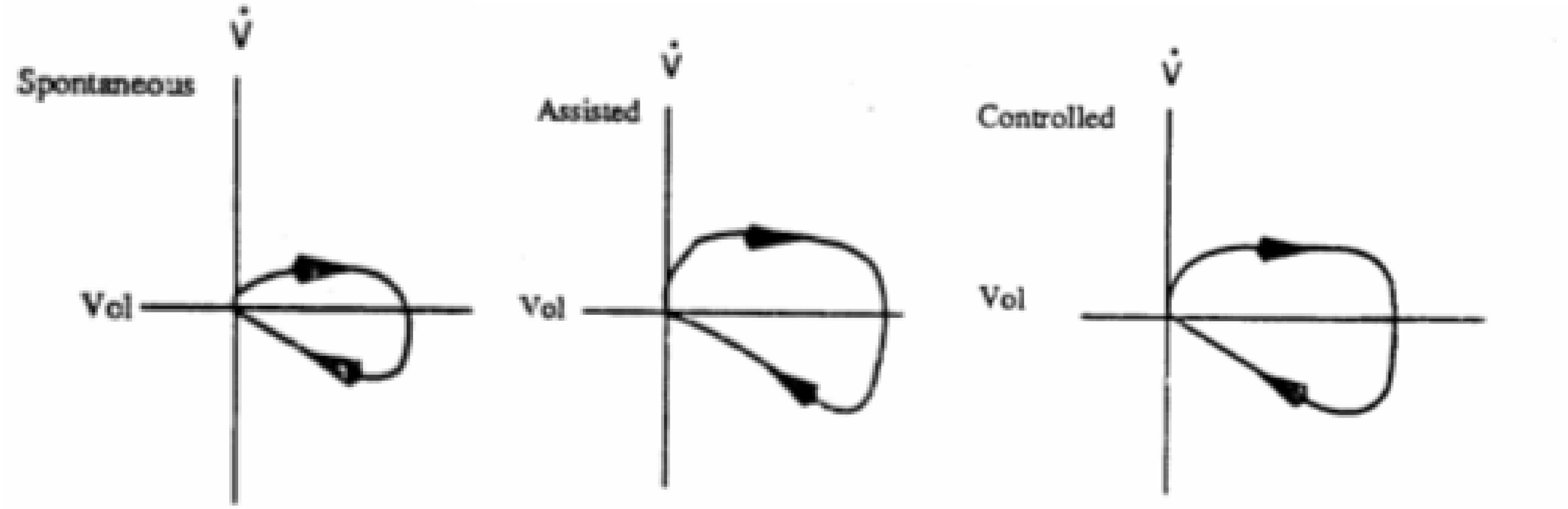
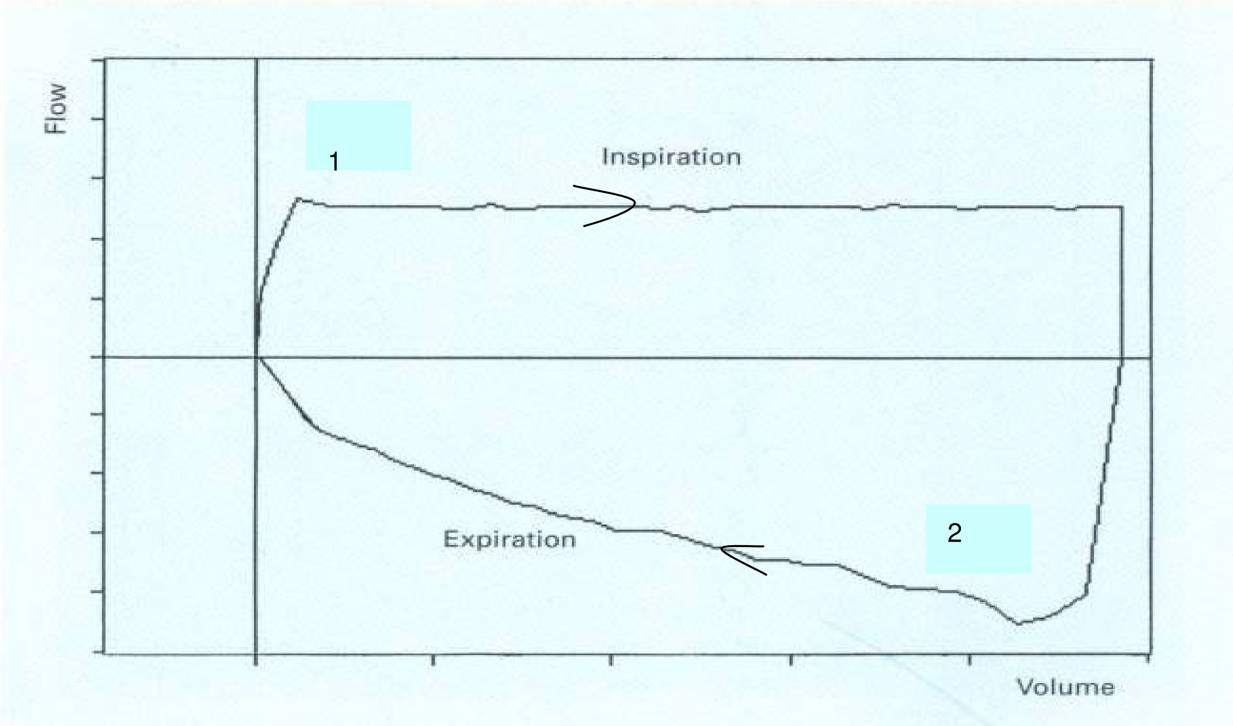
Flow-volume loops



Flow-volume loops



Constant flow mode of ventilation

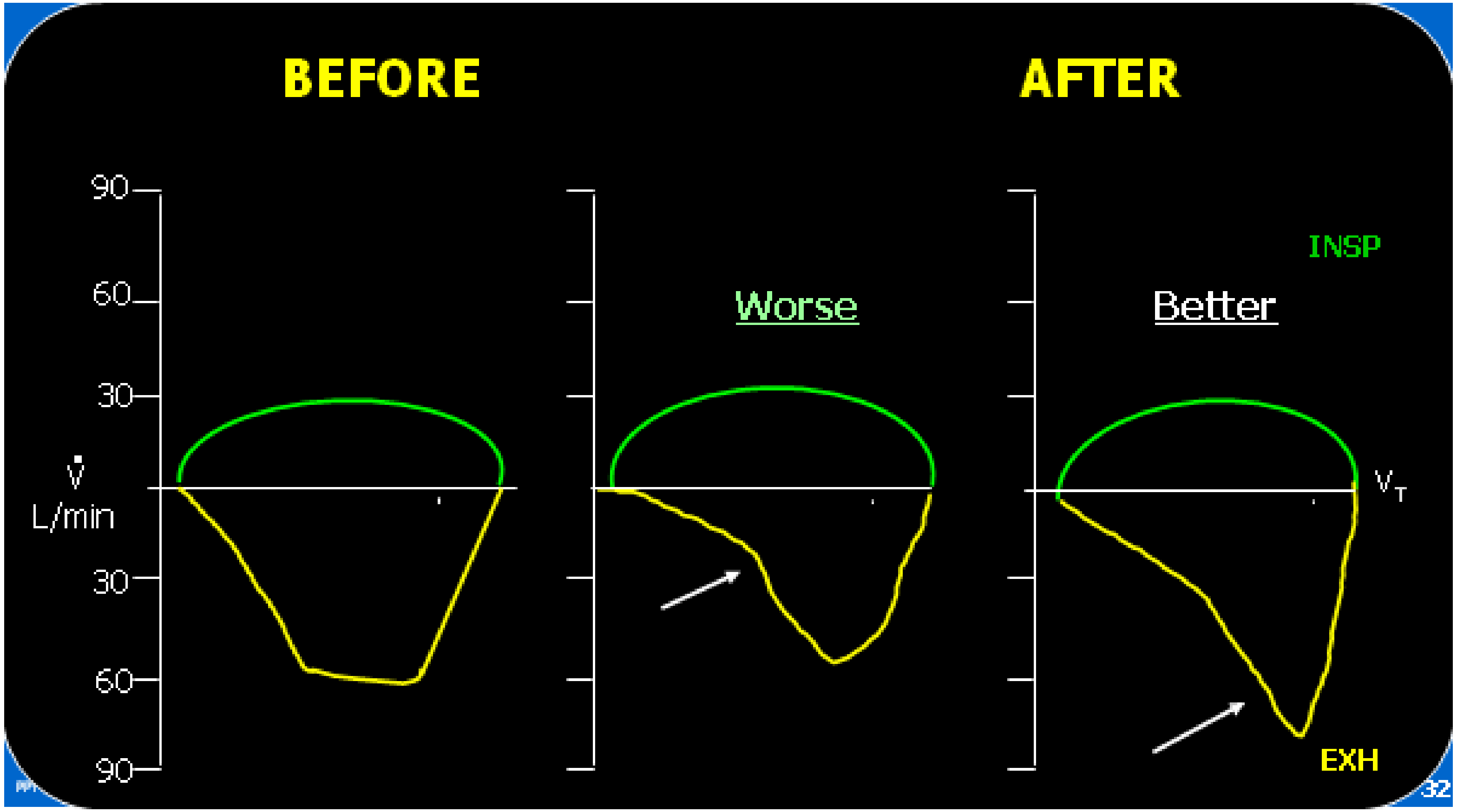


- When a constant flow mode is selected, the initial rise to inspiratory flow and decay will be rapid. The expiratory phase is started by a rapid decay to peak expiratory flow, followed by a progressive return to baseline.

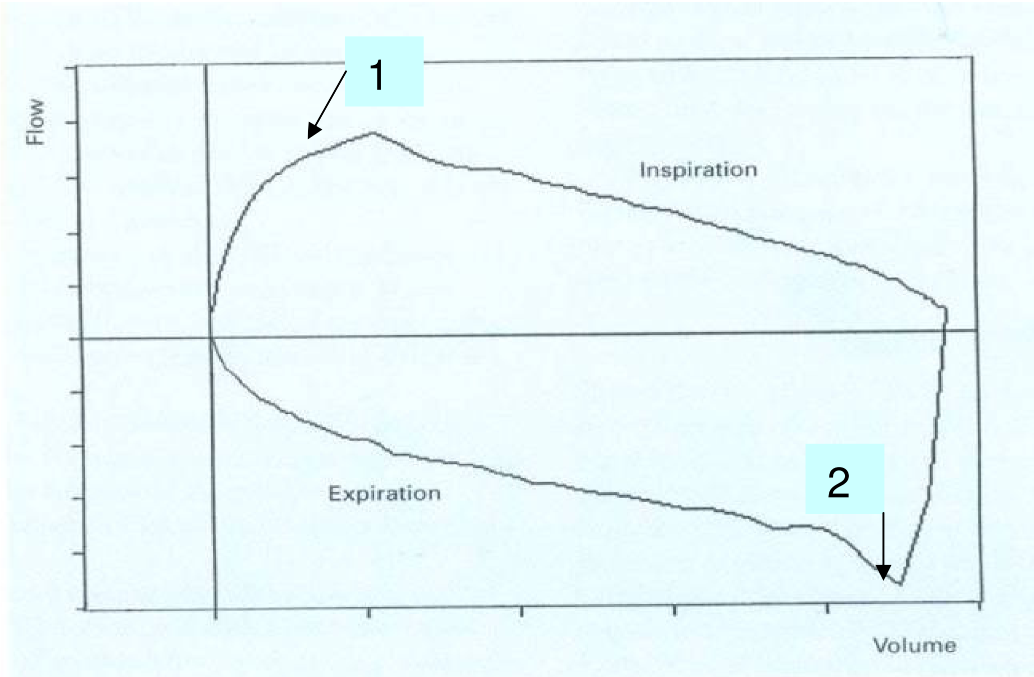
Flow-volume loops

- An airflow limitation is associated with a convex shape to the volume axis of the second phase of the expiratory profile of the loop. A fixed obstruction is associated with both decreased peak inspiratory flow and peak expiratory flow. The effect of a bronchodilator is present when the peak expiratory flow increases and the expiratory profile becomes less convex to the volume axis (Ouellet 1997:70).

Bronchodilators

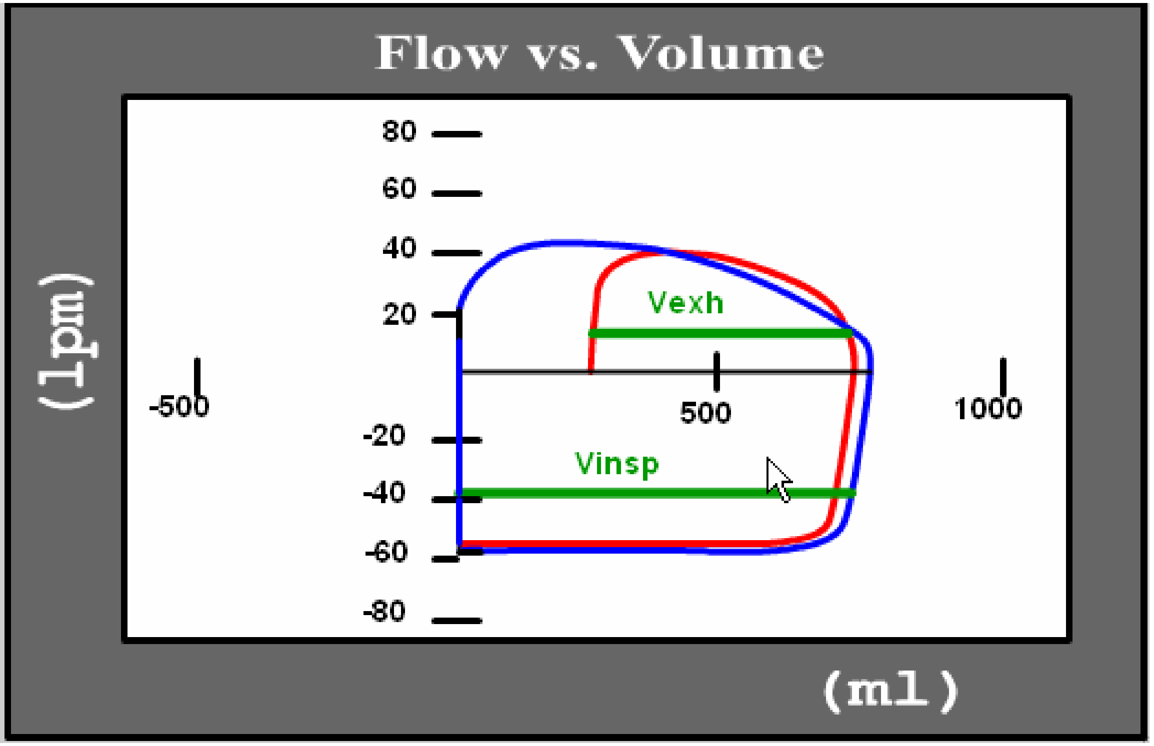


Constant pressure mode of ventilation



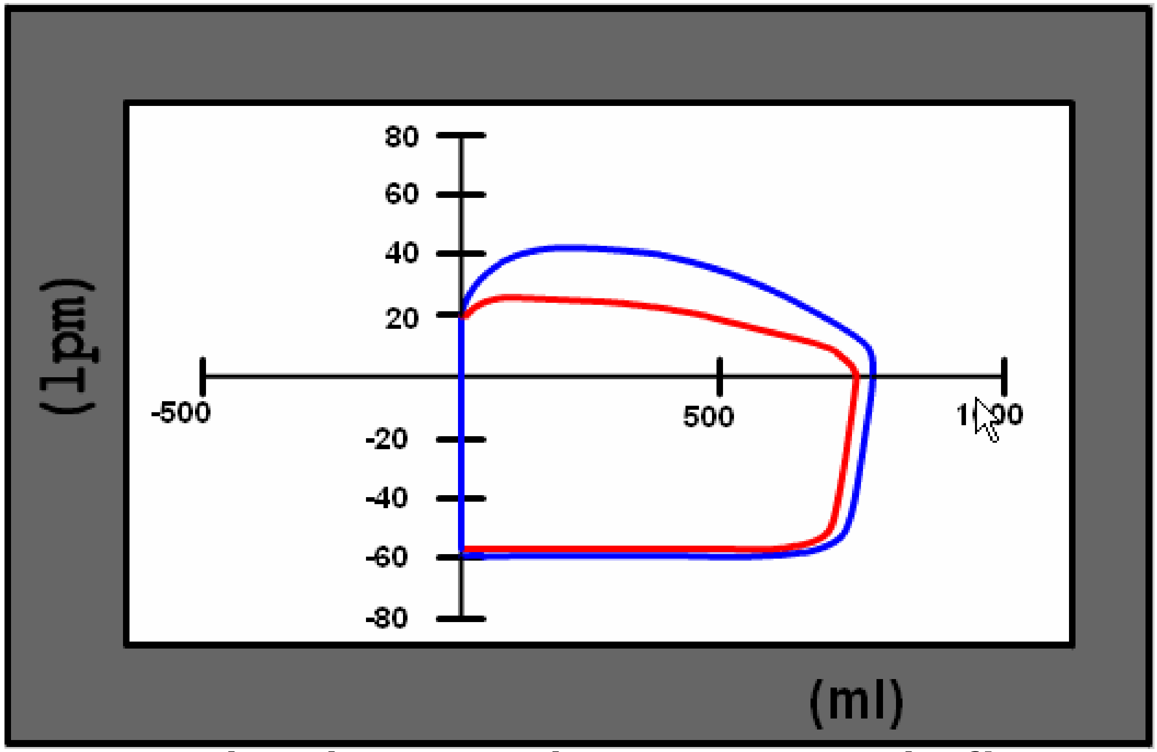
- Constant pressure loop begins with a rapid rise to peak inspiratory flow, then a decay to baseline. The expiratory phase is a reverse of the inspiratory flow with a rapid decay to peak expiratory flow, and a progressive return to baseline.

Value of flow-volume loops



- Leaks in the system (circuit or patient) can be seen when the expired volume is less than the inspired volume.

Changes in airway resistance



- A decrease in the expiratory peak flow and the slope of the flow drop indicates an increase in resistance, as illustrated by the red loop.

Conclusion

- Schaar (2003:487) states that the “future is not some place we are going, but one we are creating. The paths to it are not found but made, and the activity of making them changes both the maker and the destination”. Visser (2004) proposes the value of waves and loops in managing ventilated patients.

Conclusion

- Changes in patient condition and effects of treatment can be monitored closely. The skills that you acquire and the competence that you develop regarding ventilator graphics now will merely form the foundation of clinical nursing expertise in the future.

Conclusion

- Ouellet (1997) states: “We must never forget that the patient needs all our attention and compassion. Time spent at the bedside manipulating technology should never compromise the caring devotion for the most important person, the patient in need of critical care.”