SEDATION SOLUTIONS

Capnography In Sedation – Should it be mandatory? Can one teach a new dog old tricks? A literature review

Introduction

The use of capnography or capnometry, as a monitoring tool for conscious sedation or moderate sedation and analgesia, is neither new, nor ground-breaking.

What is novel, and the purpose of this review, is to marry this tried and tested modality, with its 'old tricks', to the current scope of modern sedation, in 'new' and innovative ways.

It is usually accepted that ASA 1 and 11 patients for sedation do not really need monitoring with capnography during the procedure. It is only currently recommended in a subset of patients, undergoing sedation i.e., the obese patient, patients with chronic obstructive lung disease that qualify for sedation outside the operation theater, patients that qualify for prolonged sedation, and paediatric sedation. While Principles of Safe Sedation Practice[1], coupled with a renewed understanding of pharmacokinetic and pharmacodynamic principles, and advanced intravenous drug delivery systems, provides a relative level of safety against adverse events, new studies of the limitations of the so called mandatory monitors, has cast some doubt on their previously steadfast trustworthiness.

There has also been a paradigm shift in the demand for sedation services, and due to the stark reality of financial pressures, an ever

increasing demand on the sedation practitioner to deal with more complex patients, procedures (especially prolonged procedures) and varying demands during such procedures.

If capnography is to be made mandatory, then one needs to evaluate the way it works, its precision in sedation specifically, if it has been previously underutilised, and what it has to offer to sedation, from increasing patient safety, to a surrogate method of depth of sedation monitoring.

Setting the Scene

“Capnography is the gold standard for the monitoring of ventilation. It is a more sensitive monitor for the adequacy of ventilation than pulse oximetry. Capnography is not mandatory, but is advisable in the obese patient and in patients with respiratory problems.”[1]

It is well known that the definition of Procedural Sedation and Analgesia (PSA) encompasses a sedation continuum of an altered state of consciousness, varying from minimal sedation/anxiolysis, moderate sedation and analgesia (conscious sedation) to deep sedation, and even the possibility of general anaesthesia”.[1] The definition of the so called sedation end-points, minimal, moderate and deep, are made by an appreciation of the sedated patients’ clinical parameters, cardiovascular and respiratory status in comparison to pre-sedation levels, and the response, or lack thereof, of the patient to verbal commands (as per UK sedation guidelines), or light, tactile stimulation.

These endpoints therefore rely on the clinical acumen of the seditionist, and their interpretation of the sedation picture, before them. Sedation scales are used to determine the level of sedation but they are subjective scales with some of them not validated for sedation. There

has been a concerted effort to define levels of sedation by objective methods. There is an array of the Depth of Anaesthesia monitors i.e., the BIS monitor, currently used widely in anaesthesia, but there have been mixed results, thus far, and no definitive solutions. The electroencephalogram signal reflects the electrical activity of the neurons in the cerebral cortex. It is thus the key to assessment of the level of hypnosis. The accurate assessment of the depth of anaesthesia or sedation (LOC), allowing a more accurate adaptation of the doses of hypnotics, is an important end point for the anaesthetist and sedation practitioner. It is a particularly crucial issue in paediatric anaesthesia or sedation.

Because PSA encompasses a continuum, the prudent sedation practitioner will appreciate that the lines between these sedation endpoints are not always clearly clinically defined, and sometimes difficult to recognize, and that any patient may progress inadvertently from one end point, to another.[2] While it is inherent that sedation practitioners must be able to 'rescue ' such patients from a level of sedation that is deeper than intended, it is surely more practical, safe and ideal, to prevent such a situation before it occurs.

The Historical Perspective of Capnography

It is a well-defined monitoring modality in general anaesthesia, and has been used clinically for more than 35 years. Originally designed in the 1940's, by Luft [2], and used primarily as a research tool in the 1950's, it was with the advent of the development of mass spectroscopy technology, that it was commercialised in the 1970's.[2] Smalhoudt and Kalenda promulgated its clinical applications and it became a routine monitor in anaesthesia in the 1970's and 1980's, until the American Society of Anaesthesiologists issued Standards for Basic Anaesthetic Monitoring, in 1999 –

“Every patient receiving general anaesthesia (also sedation) shall have adequacy of ventilation continually evaluated. Qualitative clinical signs such as chest excursion, observation of the reservoir breathing bag and auscultation of breath sounds are useful. Continual monitoring for the presence of expired carbon dioxide shall be performed unless invalidated by the nature of the patient, procedure or equipment.”[2]

The above recommendations apply principally to the intubated and ventilated patient, in the operating room, but capanography is not mandatory to monitor ventilation during sedation for procedures outside of the operating room, and it is stressed, in an article by Kodali [3], especially if these sedations are performed by non-anaesthetists.

The evolution of sedation practice has been embraced by a number of different specialities, from anaesthesia, through the American Society of Anaesthesiologists (ASA), the Association of Anaesthetists of Great Britain and Ireland (AAGBI) and the South African Society of Anaesthesiologists (SASA), to Emergency Medicine, Gastroenterology, Radiology and Paediatrics, to name just a few. While the various Societies representing those specialities have issued their own consensus documents and guidelines, there is still a lack of a single, unified body overseeing safety issues pertaining to the delivery of sedation, especially in services delivered outside of the operating room. Recently the International Sedation Task Force, one of the committees of the World Society of Intravenous Anaesthesia, has started working on safety issues relating to safe sedation practice. This is a step in the right direction and promising for future collaboration.

Kodali[3] remarks that even though this is the case, “in the last 2 years there has been a surge in understanding and recognizing the value of capnography outside of the operating rooms.”
One of the limiting factors in this exciting understanding of the role of capnography is the costs involved.

The Evolution of Sedation

The proposal that the use of capnography be mandatory in sedation could be construed as very controversial, if the proponents of its use are taken in isolation. The progression of the field of sedation, and the exponential growth in its use, by an ever expanding variety of other specialities, lends itself to the idea that capnography should maybe become mandatory, not because of previous methods of sedation, but rather because of current, future trends in sedation technology and practice i.e., longer sedation procedures and the use of combinations of different drugs.

In a succinct, but pertinent review of the history of sedation, by Robert S. Holzman[4], it is emphasised that the progression of sedation and anaesthesia, through the ages, is completely intertwined, and “induced altered states as a means of tolerating the intolerable is as old as man…”

While these ‘initial’ methods may now seem rather crude, one could argue that they do form the basis of our understanding of modern pharmacology. The ‘success’ of modern sedation techniques has come at the cost of an exponential increase in the demand for sedation services, and the provision of such services to an increasingly diverse patient population, with analogously diverse sedation requirements.

It has been previously acknowledged that sedation encompasses a clinical continuum, and practically speaking, it is incumbent on the vigilant sedition practitioner not only to ensure that the patient does not progress to a level that is deeper than intended, but that, should it occur, the sedation practitioner possess the necessary knowledge and clinical acumen to 'rescue' such a patient.[1]

Bearing this, and the points made in the previous paragraph, what about the other side of the coin? The variety of clinical procedures, now performed under sedation, mean that there may often be situations where the level of sedation is purposely increased, or decreased, depending on the nature of different intensities of stimuli, during a single sedation.

There are a variety of methods of inducing and maintaining sedation levels, but one of the most exciting, is the field of Total Intravenous Anaesthesia (TIVA). One may question this seemingly grand assertion, because by its very name, it implies anaesthesia, and not sedation. However, the principles of TIVA, with the advent of sophisticated Target Controlled Infusion (TCI) pharmaceutical delivery systems, renewed understanding of pharmacokinetic, pharmacodynamic, pharmacogentic modelling, and the availability of potent, titratable designer medications, provide an easy fit to the clinical goals of modern sedation.[5]

In a superb review of the Clinical Pharmacology of Intravenous Anaesthetics[6], Egan T.D., outlines how the provision of modern anaesthesia, as a whole, requires a unique standard of precision and accuracy, that requires one to dovetail the seemingly opposed "clinical imperatives of adequate anaesthesia (without toxicity) and rapid emergence.[5] He uses the "surfing analogy" to provide a framework in the understanding of scientifically based drug selection, and explains that

through a combination of three distinct approaches, one is able to specifically “target the upper portion of the steep part of the concentration-effect relationship.”[5] His eloquent description of these three approaches provides insight into how ‘early’ sedation practitioners and anaesthetists used such principles, relying on clinical experience, intuition, and pattern recognition, as guidance.

The recognition of pharmacogentics, as a distinct field, is where capnography may in fact prove most useful. Depth of anaesthesia monitoring is by no means an exact science, and correlation of sedation levels with current devices, remains invalidated.[15] Despite being able to computer model isobolograms of response-surface hypnotic-opioid synergism and interaction, along varying concentrations, in population groups, there remains a small sense unpredictability, in the individual patients response to a therapeutic regime, used to induce, maintain and “reanimate”[5] the patient.

While it is accepted that the number of adverse events correlates directly with deepening levels of sedation, and that respiratory patterns show a mirrored response to this increasing level of CNS depression, the answer to this problem may be as simple as accurately quantifying respiratory depth, frequency, and distortions away from the normal capnographic waveform, rather than relying on simple, and to be honest, rather crude, practitioner observation, and the inter-observer variability that that yields.

“Over-sedation can be accompanied by ventilatory depression, as demonstrated by decreased respiratory rate, apnoea, decreased minute ventilation, hypercarbia, hypoxaemia, and a decreased ventilatory response to carbon dioxide.”[9]

Capnography

- Terminology –
  - “Capnography is the non-invasive measurement of the partial pressure of carbon dioxide in exhaled breath.”[2]
  - “A capnometer is a CO2 monitor that displays a number.”[2]
  - “A capnograph is a CO2 monitor that displays a number and a waveform.”[2]
  - A capnogram is the display of the CO2 waveform, representing real time changes in the CO2 concentration during the respiratory cycle.[2]

- Methods of Measurement

Although there are numerous methods of gas concentration monitoring, from Refractometry, Mass Spectrometry and the paramagnetic gas analyser, Infrared (IR) Absorption Spectroscopy is “by far the most common and cost effective method of carbon dioxide measurement and monitoring.”[3]

It is imperative that this method has been validated, because cost will also impact on the availability of such monitors, if the decision is taken to make their use mandatory.

A detailed explanation of how IR gas analysers function, is probably beyond the scope of this text, but a short summary is worth noting, because it highlights areas, in the process, that may lead to inaccuracies, in the sampling, quantifying and therefore clinical information, provided to the individual monitoring of the capnograph.

Essentially, infrared absorption spectroscopy, works on the principle that bonds between two or more different atoms, that make up a molecule, e.g. nitrous oxide, water vapour, volatile agents or, most appropriately, carbon dioxide, absorb radiation, in the infrared (IR) spectrum, but bonds between atoms that are identical, like oxygen, do not.[7]

This process is governed by the Beer-Lambert law, which describes the amount of absorption of any radiation by any substance.

"…different polyatomic (molecule) species absorb maximally at characteristic wavelengths within the Infrared bandwidth, which means that it is possible to identify the gas molecule as well as quantify the gas concentration."[7]

No matter the actual method of quantifying the CO2 in the sample, all carbon dioxide monitors are designed in one of two configurations (2), each with their own advantages and disadvantages –

- **Main Stream** –
  The measurement of CO2 is sampled, in-line, directly from the airway, and because the sensor is connected straight to the endotracheal tube, such a configuration typically mandates an intubated patient (this is not the case with sedation practice but where a patient may be intubated for rescue purposes). An obvious advantage, because of such positioning, is that there is a reduced delay in the breath to breath measurement of CO2, while a disadvantage is that the size of the adaptor interface, interposed between the endotracheal tube and the ventilator circuit, poses bulky interference. Even though technological advancements have resulted in impressive streamlining, it would not be conducive to nasal cannula, and therefore unsuitable, for the requirements of a

typical sedation scenario.[2]

- Side Stream
  The Co2 sensor is located within the capnographic monitor itself, and the measurement is done remotely, by aspiration of a small sample, through tubing connecting the monitor to the breathing circuit. Because it involves sample aspiration, this configuration is fundamentally adaptable to both intubated and non-intubated patients, enabling the use of simple nasal cannula, as a surrogate for the circle system and used commonly in sedation, for concomitant CO2 sampling and oxygen delivery.[8]

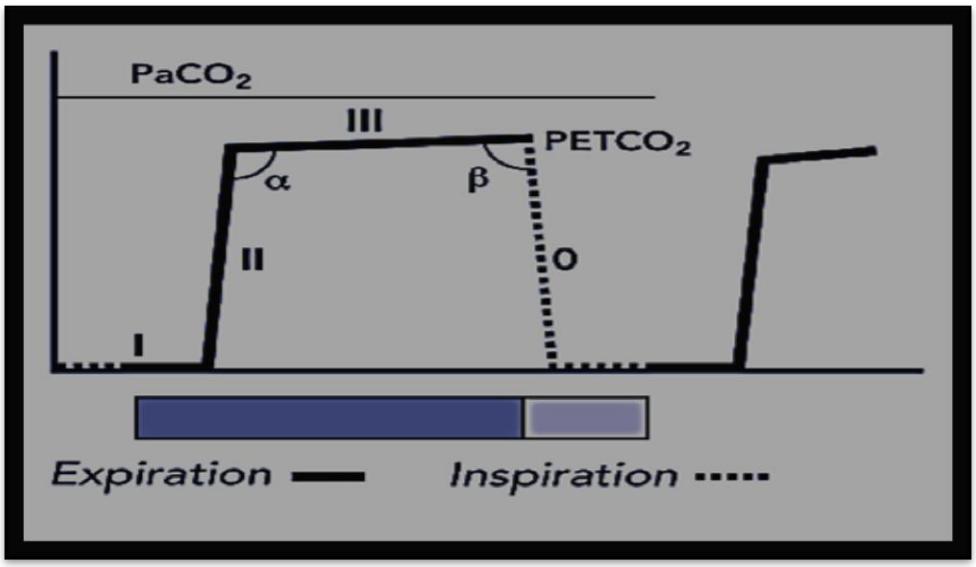
- Trans transcutaneous monitoring of carbon dioxide (AARC clinical practice guideline: Respir Care. 2012 Nov;57(11):1955-62). Sites for monitoring may be the lateral side of the abdomen, chest, buttock, inside of the upper thigh, forearm, the zygomatic bone, the ear lobe, cheeks, or the forehead. There are no documented absolute contraindications for use of transcutaneous monitoring. This configuration should be acce[ptable for monitoring of the sedated patient.

Initial, incapacitating, technical problems, retarded the clinical application of capnography exclusively to the realm of the operating theatre. However, the advent of “Micro stream Technology”, in the late 1990’s, mitigated these problems by featuring “low flow (sample) rates, reduced dead space, lack of moisture-associated occlusion problems and low power consumption”[8], and thus ensured a portable monitoring modality that could even be used under adverse conditions, remote from the often serene theatre environment.

The Capnograph and Physiology

Capnography represents a graphic, continuous measurement of the partial pressure of carbon dioxide in respiratory gas[8], and are plotted either against time (time capnogram), or expired volume (volumetric capnogram).[3]

Figure 1 (3) -



The analysis of this prototypical time capnogram provides insight into varied application in the assessment of a patient's well-being, and clinical response, during the sedation. If the requirement was simply for the detection of the presence or absence of carbon dioxide, then qualitative assessment would suffice.

The time capnogram is firstly divided into two distinct segments[3], inspiration and expiration, with these been further divided into phases, as illustrated below, and in correlation with Figure 1, and represents the evolution of PCO2 concentrations, from the lungs, during the time frame of a typical tidal volume.

- Inspiratory –
  - Phase 0 – Rapid decrease in the PCo2 concentration representing inspiration
- Expiratory –
  - Phase I – representative of the airway dead space gases, containing no PCO2
  - Phase II – Rapid rise in the PCO2, representing the shift from airway dead space gas to the gas, rich in PCO2, from the lung alveoli intimately involved in the process of respiration
  - Phase III – The alveolar plateau, a continuation of Phase II, which is seldom practically flat, and represents a dynamic picture of the individual variables of Ventilation (V) and Perfusion (Q), within the respective respiratory system, as a whole.
- PETCO2 – The maximal PCO2 at end expiration

- Angles –
  - “α Angle” – The angle between Phase II and Phase III, normally about 100°, if increased can represent airway calibre changes, indicative of an obstructive picture.

- “β Angle” – Generally 90°, represents the angle between Phase III and the Inspiratory segment, will increase in the presence of rebreathing

Although the above provides a very limited interpretation of the capnogram, it provides a window into how much clinically relevant information is immediately at hand. The validity of the given information, when divided into three distinct sources, detailed below, can be used to verify clinical suspicions.

1. The numerical value of the PETCO2 can be classified as normal, low or high, and, depending on its trend, used in the differential diagnosis of pathological conditions
2. The shape of the capnogram can be compared to known, pathognomonic changes, and through simple pattern recognition, that cause of the disturbance may be elucidated.
3. The difference between the end tidal PCO2 (PETCO2) and the arterial PCO2 (PaCO2), can be best summarised in the following statement, by Kodali[3] –

   “A changing (PaCO2-PETCO2) gradient denotes unstable circulatory haemodynamics or variable alveolar ventilation as a result of dynamic changes in compliance or resistance in the lungs. If the gradient stabilizes over the course of clinical management, it can be surmised that the stability of alveolar ventilation and perfusion has been achieved.”[3]

Even with consideration of the above, it must be stated emphatically that the capnogram is not to be used and cannot be used as a standalone

monitor, but rather in a complimentary role, with observation of the patient (clinical monitoring), at the forefront of clinical sedation assessment.

It is also obvious, from the above, that if the potential of capnography is to be truly maximised, then crude, visual interpretation of the capnographic shape, is not sufficient. Minor nuances in gradients and angles, which may have a disproportionately large clinical impact, would need computer assisted graphic analysis, somewhat analogous to pulse contour analysis for example, and is something that is currently not available.[2]

Is Capnographic Monitoring, via Nasal Cannula, Valid?

The first description of monitoring end-tidal PCO2 (PECO2) using nasal cannula, was made by Goldman, and published in the Journal of Anaesthesiology, 1987. Other reports followed, detailing modification of Goldman's technique, and this clinical pressure resulted in manufacturers formalising the production process by introducing "nasal cannula specifically designed to sample end-tidal gas."[9]

With refinement of such nasal cannula, initial investigations, in both adult and paediatric patients, demonstrated both the accuracy of the technique, and good correlation between PETCO2 vales, obtained by CO2 monitoring via nasal cannula, and PaCO2 values, obtained by arterial sampling.[9]

However, these studies more importantly identified factors, both patient and potential sampling errors, like nasal airway obstruction, mouth breathing, and the dilution of the end-tidal gas by the co-administration of oxygen, that corrected by the prudent physician, allow this method to have acceptable accuracy, and thereby a clinically useful monitor of the

ventilatory status of spontaneously breathing patients, undergoing sedation.[9]

Why add another monitor? –

In order to fully answer this question, one needs to look at the monitoring methods and modalities that are currently employed.

Consensus guidelines, issued by the respective societies, mentioned early in this review, advocate a combination of routine clinical observation, and haemodynamic monitoring, via pulse oximetry and non-invasive blood pressure. Clinical observation, which is crucial, involves direct assessment of the patient, and the use of the Ramsay and Wilson sedation scales to evaluate sedation levels, and the modified post-anaesthesia (Aldrete) recovery score. Although ventilation monitoring by clinical observation is also regarded as routine, “recent studies have questioned the sensitivity of this practice for early changes in respiratory status.” (10). The same statement may probably apply to the use of pulse oximetry which is used routinely in sedation practice, especially with the use of combinations of drugs, and more sophisticated sedation techniques. With prolonged sedation capnography is even more important to diagnose early changes in respiratory status.

Changes in oxygenation, that leads to hypoxic events, are consistently preceded by changes in ventilation, and capnography detects those ventilation changes prior to the detection of desaturation by pulse oximetry,

In an interesting article by Langhan M, the much more worrisome trend of variations in Paediatric Sedation monitoring, depending on the provider type, is highlighted.[11] She goes on to illustrate, through the

observational study, which even monitors such as the ECG, were not used universally.[11,14]

Conclusion

These are exciting times for the field of sedation and analgesia and, as through history, general anaesthesia and sedation remain inseparably intertwined, and innovation in one produces dramatic improvements in the other.

This review proposes to highlight how the mandatory use of capnography in sedation, could provide an extra margin of safety in clinical practice, and has potential benefit, for patient safety during sedation. It is recognised that such decision cannot be taken in isolation, and that the consensus statements, by the various governing bodies involved, reflects careful consideration of all factors, including cost-benefit relationships, and the practicalities in the real world. Therefore, if the tone this review implies any disrespect, it is completely unintended.

However the idea of this review is also to stimulate sedation practitioners to always look at “possible” better ways of monitoring our patients during sedation. Sedation remains one of the fastest growing areas in anaesthesia care.

The idea that sedation involves keeping the patient awake, as opposed to the conventional anaesthetist, who would be criticised for not keeping the patient asleep, often produces an uneasy feeling in the novice sedation practitioner.

Even though sedation techniques may be improved and streamlined, and our understanding expanded, the provision of sedation remains an

art form, and as the custodians of the patient, we should always strive to be the best monitor of them all.

The use of the capnograph is not yet mandatory for monitoring ventilation during sedation for ASA 1 and 11 patients. It is up to every sedation practitioner to review his scope of practice and decide whether capnography can be a valuable monitor for patient safety during sedation.

I want to acknowledge the contribution of Dr Simon Christie who is an anaesthetist and graduate in sedation and pain control.

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