Common errors in clinical measurement

Ming Wilson

Abstract

In modern anaesthetic practice, the use of progressively sophisticated measuring devices increases the possibility of erroneous measurements. This can potentially result in misguided decision-making and patient harm. Anaesthetists must be aware of the limitations of these devices and their sources of error. This article will discuss the errors associated with equipment used in daily anaesthetic practice including capnography, electrocardiography, invasive and non-invasive blood pressure, and pulse oximetry.

Keywords Calibration; damping; drift; error; hysteresis; natural resonant frequency

Royal College of Anaesthetists CPD Matrix: 1A03

Learning objectives

After reading this article you should be able to:

- define the different types of error and where errors may occur in the monitoring process
- describe the common causes of error in clinical monitoring
- discuss the methods of reducing common errors in clinical practice

Measurement errors

Measurement errors can be classified into two categories:

1. **Accuracy**

The accuracy of a measurement is how close the measured value is to its actual true value.

2. **Precision**

Precision is the degree to which repeated measured values are reliably reproduced using the same device.

Errors of one or both of these categories may occur within any measurement system. For example, a device may measure a parameter precisely (with little variations in the measured values) but not accurately. Alternatively, a device may be accurate (the average of the measurements are in close proximity to the true expected values) but not precise (large variation in the measured values). On the other hand, a device may be neither accurate nor precise.

Accuracy

The accuracy of a measurement system consists of three components:

1. **Bias**

Bias is a measure of the inaccuracy in the measurement system (the difference between the measured value and the actual true value).

2. **Linearity**

Linearity is a measure of how accurate the measured values are through the expected range of measurements. Linearity indicates whether the device has the same accuracy across all reference values. The output is directly proportional to input over its entire range so that the slope of a graph plotted of output versus input is a straight line.

3. **Stability**

Stability (often referred to as drift) is a measure of how well the system performs over time; the total variation obtained with a particular device, when measuring a parameter over time.

Precision

The precision of a measurement system consists of two components:

1. **Repeatability**

Repeatability is the variation observed when the same user measures the same parameter repeatedly with the same device (i.e. variation due to the measuring device).

2. **Reproducibility**

Reproducibility is the variation observed when different users measure the same parameter using the same device (i.e. variation due to the measurement system).

A measurement system consists of components in a chain of hardware and software that leads from the measured variable (measurand) to the processed data that are displayed. Figure 1 highlights the general structure of elements within a measurement system. Errors may occur at any point along the measurement chain.

Types of error

Systematic errors (also called systematic bias) are consistent, repeatable errors associated with faulty equipment. Imperfections of the measurement device (e.g. cable or connector setup), incorrect calibration, incorrect use of the device, or worn-out devices usually cause these errors. Systematic errors produce consistent errors; if the measurement is repeated, the same error occurs.

Random errors (as the name suggests) are completely random and have no pattern. They are unpredictable and cannot be replicated by repeating the measurement again.

Drift (drift error) is caused by deviations in the performance of the measurement system that occur after calibration. Drift is often caused by thermal expansion of the connecting cables. Drift may be reduced by frequent calibration as the ambient temperature changes or by maintaining a stable temperature during measurements. Drift is an indication of the loss of perfect repeatability or reproduction of a measured value by a measurement device.

Ming Wilson *MB ChB FRCA is a Consultant Anaesthetist at Salford Royal Foundation Trust, Manchester, UK. Conflicts of interest: none declared.*

Please cite this article in press as: Wilson M, Common errors in clinical measurement, Anaesthesia and intensive care medicine (2017), https://doi.org/10.1016/j.mpaic.2017.09.008

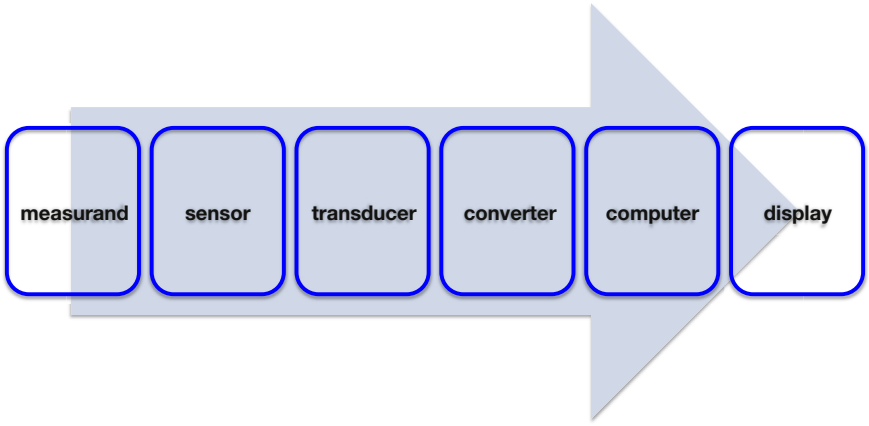

Figure 1 Elements within a measurement system.

Hysteresis can be defined as the deviation in output at any point within the device's sensing range, when first approaching this point with increasing values, and then with decreasing values. The measured values are different when a measurement device approaches a signal from opposite directions; that is the corresponding value taken down as the device moves from zero to mid-scale will be different from that between the mid-scale and full-scale reading. The reason is the appearance of stresses inside the device material due to the change of its original shape between the zero reading and the full-scale reading.

Capnography

Capnography is the graphical waveform display of end-tidal CO_2 ($EtCO_2$) concentration over time. The principle of capnography is infrared (IR) absorption by CO_2 molecules. The amount of IR absorbed is proportional to the CO_2 concentration.

There are two types of CO_2 analysers; sidestream and mainstream. Sidestream capnography involves measuring CO_2 concentrations distant from the sampling site whereas mainstream capnography measures CO_2 concentrations at the sampling site.

The use of sidestream capnography has potential for erroneous readings. Sidestream capnography involves the aspiration of a sample of gas from the breathing circuit via a long narrow sampling line at varying flow rates (ranging from 50 to 250 ml/minute). This sample is then often passed through a water trap (altering the temperature and humidity) prior to being analysed in a sample chamber. This results in a delayed response time of up to several seconds. Sampling port location varies depending on the breathing circuit used. For example, the sampling port may be positioned on the ventilator side of a heat and moisture exchanger (HME), resulting in a drier sampling tube with the inherent risk of significant distortion of the capnography trace and lower $EtCO_2$ values. It may also be placed on the patient side of the HME resulting in possible accumulation of condensate and secretions. Contaminants may partially or fully obstruct the sampling line and increase resistance to flow in these lines thus affecting the response time and accuracy of CO_2 measurement. The sampling line usually hangs free between the breathing circuit and the monitor where it is vulnerable to being kinked, occluded or damaged. With mainstream capnography, the IR analyser is located at the airway connector, resulting in a real-time capnogram display.

Gases with molecules containing two or more different atoms absorb IR. CO_2 maximally absorbs IR at wavelengths of 4.2–4.4 μm. Nitrous oxide (N_2O) maximally absorbs IR at wavelengths 4.4–4.6 μm. The measured CO_2 absorption can be affected by collision broadening and cross-interference. Collision broadening is the increased absorption of CO_2 due to the presence of N_2O. The collision of these molecules changes the way CO_2 absorbs IR resulting in a broader absorption pattern, leading to potential source of error in measurement. Modern analysers measure the amount of N_2O and O_2 in the sample mixture and use this information to correct for errors due to collision broadening. Cross-interference (the overlapping of absorption wavelengths) can occur from N_2O due to the presence of its absorption wavelengths that slightly overlap the CO_2 wavelengths. Because both CO_2 and N_2O absorb IR at similar wavelengths, narrow band filters are used in front of the detectors to measure in-wavelength signal for CO_2 and separate out-of-wavelength signal as a reference channel; thereby only a portion of the CO_2 wavelength can be selected and hence eliminates any interference from water vapour or even closer wavelengths of N_2O. The absorption of IR by CO_2 is non-linear, affected by the presence of other gases (but not O_2) and proportional to gas concentration and path length (i.e. obeys the Beer–Lambert law). The measurement system contains an algorithm that translates the detected IR signals to a CO_2 value, which is corrected for the effects of N_2O.

In sidestream analysers, the temperature of the sample gas decreases during its transit from the sample site to the sampling chamber, resulting in condensation forming on the walls of the sample tubing with a subsequent decrease in the partial pressure of water vapour from 47 mmHg to much lower values (fully saturated exhaled gas at 37°C has a water vapour pressure of 47 mmHg). This can lead to an apparent increase in $EtCO_2$. These analysers compensate with software for water vapour removed, resulting in inaccuracies, as assumed conditions may be different from actual conditions.

Sidestream analysers may not be accurate in neonatal and paediatric patients as they aspirate a significant portion of the patient's total ventilation. Therefore, mainstream analysers are more suited to neonatal and paediatric use.

Please cite this article in press as: Wilson M, Common errors in clinical measurement, Anaesthesia and intensive care medicine (2017), https://doi.org/10.1016/j.mpaic.2017.09.008