Common errors in clinical measurement

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Abstract

Inaccurate clinical measurement may lead to patient harm or sub-optimal care. As monitors become more complex the possibility of measurement error increases. Clinicians need to understand the causes of errors to avoid and correct them.

In this article we will discuss errors associated with equipment commonly used in anaesthesia including pulse oximetry, capnography, ECG, non-invasive and invasive blood pressure, central venous pressure, gas flow and cardiac output measurement.

Keywords Accuracy; artifact; calibration; interference; measurement error; precision; random error; systematic error

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Learning objectives

After reading this article you should be able to:

- describe the different types of error and where errors might occur in the monitoring process
- discuss common causes of error in clinical monitoring
- identify ways to reduce the most common errors

Introduction

Measurement is a process to acquire new information about a physiological parameter. A measurement system must be accurate and precise; however real measurements will always contain errors of varying magnitude. **Accuracy** is the absence of error — that is, the degree to which the measured value reflects the actual value. **Precision** is the reproducibility of a measurement.

Measurement error (Δx) is the difference between the measured value (x_r) and true value (x_t).

$$\Delta x = x_r - x_t$$

A monitor/measuring process typically consists of a number of components, as shown in Figure 1.

Errors may occur at any stage, and may be defined as systematic or random (Figure 2). **Systematic error (bias)** is consistent error across the measurement range. It will affect the mean measured value. It can be prevented by accurate **calibration**: the process by which a measuring system is aligned against a known standard or reference. **Random error** causes scattering of measured values around a mean value. This will have little effect on the mean value, as individual inaccuracies will tend to cancel one another out. Precision is the inverse of random error.

Sources of error include poor discrimination and non-linearity. **Discrimination** is the ability of the system to detect small changes in measurands. Poor discrimination may occur due to inadequate sampling resolution and/or frequency. A transducer should produce an output which is proportional to the input over the specified operating range — that is, a graph of input against output should be a straight line. **Non-linearity** describes the degree of deviation from this ideal straight line relationship, expressed as a percentage. Non-linearity may occur due to:

- improper calibration
- errors at extremes of range
- worn equipment
- internal design problem (e.g. choice of electronic components)
- drift
- hysteresis.

Drift is a slow change in the response of the system, often caused by build-up of heat over time; or deterioration in chemical reagents (e.g. oxygen cell). This is not usually a problem with short calibration cycles. **Hysteresis** (Gk. 'deficiency') is a phenomenon whereby the output of a system depends not only on the value of its current input, but also on the history (e.g. direction of change) of previous inputs; and occurs widely in electricity, magnetism, thermodynamics, and mechanics. Hysteresis occurs during elastic deformation — hence the familiar form of a lung compliance (pressure—volume) loop, which shows different values on inspiration versus expiration. A **Schmitt trigger** is a simple electronic circuit that utilizes hysteresis and positive feedback to provide clean switching at a given threshold.

Pulse oximetry

The algorithms used in pulse oximeters are based on experiments in healthy volunteers breathing hypoxic mixtures. For this reason, values of SpO_2 below 80% are extrapolated and hence inaccurate.

There is probe—probe variability in measured SpO_2. The exact wavelength emitted by individual light-emitting diodes (LEDs) varies due to manufacturing tolerances; however, trends in SpO_2 remain accurate. Devices are now available that enable internal correction of this effect.

Signal artifacts are the most common sources of error in pulse oximetry. Sensor displacement and patient movement are common causes. The photodetectors in the probe cannot differentiate between the (red and infrared) light from the LEDs, and other sources of ambient light, leading to poor signal.

The output of a pulse oximeter is based on a time-averaged sample over a period of 10—20 seconds. This reduces the effect of random artifacts, but results in a delayed response time. The delay is less in ear probes (10—15 seconds) compared to finger

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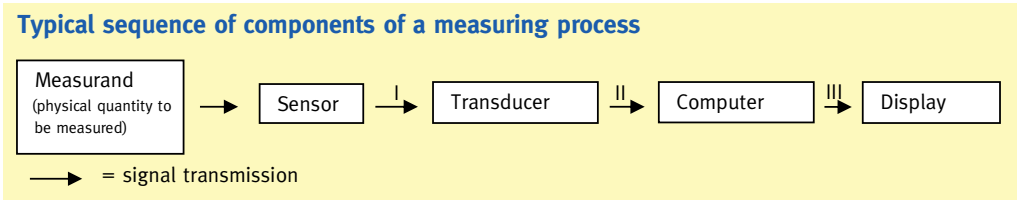
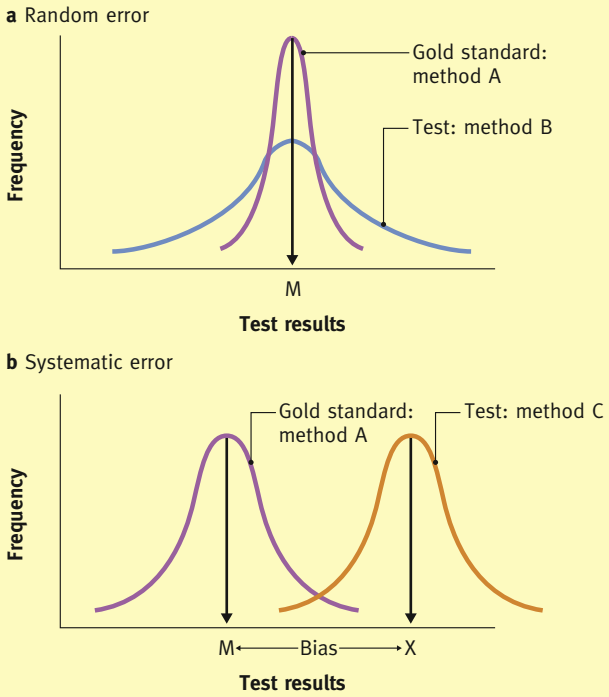


Figure 1

probes (>60 seconds). The response time is further increased by poor tissue perfusion due to, for example, hypotension, vasoconstriction and hypothermia. Atrial fibrillation and arterial disease may also cause measurement errors. Table 1 shows sources of error in pulse oximetry due to abnormal haemoglobins or dyes used in medical therapies.

Capnography

Gas molecules with at least two dissimilar atoms absorb infrared light. This property is used in clinical practice to measure carbon dioxide (CO_2), nitrous oxide (N_2O) and volatile agents.



a Test method B suffers from random error when compared with the gold standard, method A. The distribution of the test results is more widespread, but the mean difference of the results from the gold standard result (M) is zero. Test method A is just as accurate as the gold standard method, but less precise. **b** Test method C suffers from a systematic error or bias when compared with the gold standard, method A. The mean difference of the test (method C) results from the gold standard result (M) is significantly large. The difference between X and M is the bias. Test method C is less accurate than the gold standard, but has similar precision

Figure 2

There is an overlap in the absorption spectrum of infrared light between CO_2 and N_2O (CO_2: 4.2–4.4 μm, N_2O: 4.4–4.6 μm). Therefore N_2O absorbs some of the infrared energy within the CO_2 bandwidth resulting in erroneously high readings of CO_2. Clinical analysers contain narrow-band filters to increase the accuracy of multiple gas analysis. A phenomenon known as **collision broadening** may also elevate the reading of CO_2. Here, the absorption peaks of carbon dioxide are widened in the presence of other gases such as N_2O and nitrogen. For example, in the presence of 70% nitrous oxide the actual CO_2 value is 90% of that recorded. Electronic compensation reduces this error.

As infrared analysers measure the partial pressure of gases, atmospheric pressure also affects readings (the **Ram-gas effect**). Similarly, any drop in pressure across a sampling line (e.g. partial blockage) will lead to underestimation of the true value.

Water vapour absorbs infrared light and contamination of the sample with water can lead to high CO_2 readings. The use of sidestream analysers reduces this effect, as water condenses in the tubing and water trap.

Contamination of the sample with room air or fresh gas leads to erroneous results. In patients with a high respiratory rate and low volumes (e.g. neonates) the gas-sampling rate exceeds the expiratory gas flow rate, diluting the patient's tidal breath with fresh gas. The presence of a leak around the endotracheal tube may result in room air being entrained into the sample, causing errors in measurement. Monitors are calibrated using a standard gas mixture and any internal leaks will lead to room air being drawn into the sample, causing calibration errors to occur.

ECG

The electrical potential from a surface ECG is approximately 0.5–4 mV. Being such a small value, the ECG is prone to noise, interference, or artifact. This could originate from the patient, electrodes, and leads; or the operating room environment.

Patient

To reduce high-frequency interference from electrical potentials generated by muscular activity (shivering or patient movement) electrodes can be placed over bony prominences, and low-pass filters used. Removing excess hair, cleaning and de-greasing the skin can improve electrode contact and reduce impedance.

Electrodes and leads

ECG electrodes contain a silver/silver chloride gel to reduce impedance. Old or incorrectly stored electrodes may dry out and