Commentary on Transcutaneous Oxygen Monitor Electrode Sensor Set Point Calibration Verification

The transcutaneous oxygen monitoring system uses a two point calibration process to assess tissue oxygen values throughout the range of the monitor's measuring scale. These two points are zero mmHg (also referred to as zero current) and the barometric pressure of oxygen (approximately 159 mmHg at 1 ATA). The resulting calibration scale is in effect a straight line. If the zero set point has drifted higher the calibration slope will be deflected downwards. This would result in too high measured values at low oxygen tensions (air breathing) and too low measured values at high oxygen tensions (oxygen challenge). If the monitor's built-in barometer is defective, the calibration slope would likewise be affected, with resulting erroneous data collection and interpretation.

Zero Calibration

It makes sense, therefore, that those responsible for the operation of the monitor undertake routine checks of the accuracy of the zero set point. Radiometer, one prominent manufacturer of this product, recommends in its TCM-400 Operations Manual that such checks should be undertaken 'periodically'. Their previous recommendation had been monthly, suggesting increasing confidence in zero current stability. Radiometer also recommends that a zero calibration check be performed whenever the sensor appears to be responding poorly, if the sensor appears damaged, and whenever it has been dropped. Zero current faults can occur in the sensor's sensitive oxygen cathode if there are any micro-cracks in its surrounding glass housing.

Zero current checks were traditionally undertaken by applying several drops of a 'zero' solution directly onto the sensor while the monitor remained in its operational mode. A resulting value of 4 mmHg or lower would indicate that the electrode sensor zero calibration point was functioning effectively. Within the past decade, Radiometer has switched the testing process to one that employs a calibration gas. A pressurized cylinder of 10% carbon dioxide in a balance of nitrogen is connected to the sensor via a gas adaptor. Again, values of 4 mmHg or less indicate that the sensor electrode zero current setting is in good condition.

There are, however, several issues related to the calibration gas testing approach. First, it is a relatively expensive product to acquire and maintain, certainly when compared to the zero solution method. Further, the cylinder is not provided with a pressure gauge or other means to determine its remaining gas volume, a critical issue should the cylinder have been emptied during previous testing or because of a leak. If the cylinder has emptied one would attempt zero calibration with an empty (no reference gas) cylinder. The sensor electrode would be likely, therefore, to appear defective (readings greater than 4 mmHg) under these circumstances of no calibration gas flow. One final concern is the issue of disposing of gas cylinder that may still have contents under pressure.

The resulting cost, more complicated testing process, and uncertainty as to the amount of calibration gas volume remaining has led many to disregarding zero testing altogether. We asked Radiometer why they switched to the calibration gas method from the more simple, inexpensive and no less effective zero solution; their reply was that 'the zero solution was not economically viable'.

In practice, when a sensor appears to be defective the 'path of least resistance' is first to remembrane it. If this does not fix the problem one can then do a zero current check. If this results in a defective value (5 mmHg or higher) then the sensor electrode needs to be checked by the manufacturer. If the test determines that zero current is indeed accurate (4 mmHg or lower), then the sensor electrode will still need to be checked by the manufacturer, with a zero current set point malfunction having been ruled out. Arguably, therefore, the value of a zero current calibration check seems is in its periodic confirmation of a normally functioning sensor, particularly if it has been dropped or otherwise thought to have been damaged.

Calibration to Atmospheric Air

The second of the two calibration points for sensor electrode function is atmospheric oxygen. Calibration is accomplished by inserting the cleaned electrode sensor into the cleaned calibration chamber. The sensor must be dry. The chamber should be dried whenever it has been exposed to liquids such as when the monitor itself has been cleaned or disinfected. A soft cloth or tissue moistened with water or a mild detergent works well. If detergent is present, follow-up with a water-moistened tissue in order to remove any remaining detergent from the chamber.

Calibration to atmospheric oxygen should be undertaken prior to every patient monitoring period, whenever the electrode is changed to a new anatomic site and each time the electrode is remembraned. Radiometer recommends that if the electrode sensor has been remembraned immediately prior to calibration, leave the sensor in the chamber and calibrate a second time after a waiting period of 30 minutes. This second calibration serves to further confirm that the sensor is fully operational and ready for use. Users are also advised that if the sensor is not removed from the calibration chamber after a period of 30 minutes from the monitor's indication of 'Ready', the heat to the electrode will be automatically switched off in order to minimize drying out of the electrolyte. If this has occurred then recalibration is necessary.

Modern transcutaneous oxygen monitors incorporate a built-in barometer. Using this technology, the air calibration process automatically accounts for prevailing barometric conditions and resulting influence on oxygen pressure. The monitor's automatic calibration process does not, however, account for the relative humidity (RH) level present within the testing environment. A formula exists to calculate saturated water pressure at different temperatures, with resulting values applied to a second formula that provides the required compensation value to be subtracted from the monitor's barometric pressure-based atmospheric oxygen value. This calculation process is somewhat convoluted and the resulting correction factor does not materially affect data interpretation, as the difference between recorded and actual oxygen pressures is very small in the indoor testing setting. For example, without compensating for a room temperature of at or near 70 F and a RH of at or near 60%, the monitor's air calibration would be reading approximately 1.5% (of 2.5 mmHg) or too high, should a an uncompensated value of 159 mmHg (common with a barometric pressure of 760 mmHg) have been recorded. This difference is inconsequential at the lower end of the calibration curve, where all air breathing values are recorded. The difference is equally unimportant clinically with regard data interpretation following either a normobaric or a hyperbaric oxygen challenge. For those interested in the humidity correction calculation process, it is described in the Table, below.

As with the zero calibration set point, there is value in conducting a periodic check of the monitor's barometer. This device operates across a pressure range of 375-825 mmHg; thereby representing every possible altitude/barometric pressure that one could conceivably be required to conduct a transcutaneous oxygen tension assessment. For example, those living at 11,000 feet or 450 mmHg in the Andes of South America fall within this range, as would those living adjacent to the Dead Sea, ay 1,200 feet below sea level, or 800 mmHg.

Barometer checks are straight forward enough and require no additional equipment or supplies. One simply needs to determine local barometric pressure and there are numerous resources available in this regard. They include internet sites such as www.findlocalweather.com and www.noaa.gov as well as local television station website links, and regional airports.

Those resources accessed within the United States invariably report barometric pressure in inches. However, the monitor's display reads in either mmHg (the principal form of measurement used throughout the Americas' and several other regions) or kilopascals (preferred by a number of European countries and elsewhere).

In the US, therefore, it is necessary to convert inches into mmHg. This is accomplished by multiplying inches by a conversion factor of 25.4. This will then report the current barometric pressure in mmHg. To then determine the current oxygen partial pressure at this barometric pressure, multiply the resulting value by the oxygen percent in the atmosphere (20.93), expressed as a decimal, namely 0.2093.

Example: A barometric pressure of 29.99 inches is reported

29.99 x 25.4 x 0.2093 = 159 mmHg oxygen

Check this resulting value (159 mmHg) against the value displayed on the monitor once it has completed its self-calibration process. Radiometer advises that the barometer's built-in accuracy is +/- 5 mmHg. So, one can expect a small difference (within this 5 mmHg range) between what you calculate via the above formula and what is present on the monitor's display.

The frequency at which one should conduct barometer calibration checks has not been established by the monitor's manufacturer. It will, therefore, be a matter of individual facility policy. A monthly schedule that involves rotating staff members through this process serves to maintain team skill levels and represent what could be argued as a reasonable frequency in the absence of established guidelines.

TABLE: Humidity Correction Factor Calculation

The first step in the humidity correction factor calculation process is to multiply the standard saturated water pressure (noted below for each room temperature level likely to be encountered during the testing process) by that same testing environment's relative humidity (RH).

Saturated Water Vapor Pressure

° F	° C	mmHg	kPa
68	20	17.5	2.33
70	21	18.7	2.49
71.5	22	19.8	2.64
73	23	21.1	2.81
75	24	22.4	3.00
77	25	23.8	3.17
79	26	25.2	3.36

RH is determined with an instrument called a hygrometer. If one intends to routinely calculate the RH correction factor then a hygrometer should be permanently located in the testing environment so that its constant state of equilibrium with the surrounding environment can be assured.

So, for a room temperature of 70° F the correction factor is 18.7. As this value assumes 100% humidity (hence the title 'Saturated Water Vapor Pressure'), the next step in the correction factor process is to multiply this value by the actual room humidity level, per the previous example it will be 60%. The percent RH is also expressed as a decimal (0.6). The calculated correction factor for a 70 ° F temperature and a 60% RH is, therefore, 18.7 x 0.6, or 11.22.

This correction factor (11.22) is then subtracted from the barometric pressure previously obtained from one of the above sources. Then, one multiplies the corrected barometric pressure by the atmosphere's standard oxygen percentage (again expressed as a decimal) to arrive at the actual oxygen (calibration) pressure, in mmHg. Using a nominal barometric pressure of 760 mmHg and subtracting the correction factor of 11.22, the corrected barometric pressure would become 748.78 mmHg. Finally, multiply 748.78 by 0.2093 (the 20.93 percent oxygen in the atmosphere) and the corrected oxygen partial pressure is 156.49 mmHg.

The difference between the uncorrected and corrected calibration values is, therefore, just 1.58% (159-156.49/159 x 100). Under conditions of corrected barometric pressure, the difference between the two point calibration slope and the non-calibrated slope is clinically insignificant throughout the air breathing range during tissue oxygen assessments. Even during normobaric and hyperbaric oxygen challenges, differences will remain insignificant in terms of data interpretation.