**Table S1.** Challenges and solutions for improved environmental monitoring of temperature, pH, dissolved oxygen (O2), and dissolved carbon dioxide (CO2) live-cell culture systems.

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| **Parameter** | **Challenges** | **Advantages** | **Solutions for improved environmental monitoring** |
| **Temperature** | Commercially available thermometers can give inaccurate readings (± 1 oC error). | A stable thermal environment ensures accurate control of dissolved gases and acid-base chemistry.Low cost, but accurate measurements. | Traceable thermometers and temperature logging systems calibrated by an ISO [International Standards Organization] certified laboratory ensure accurate and precise temperature readings. ISO-certified thermometers are widely available at low cost (< US $100). |
| **pH/ acid-base chemistry** | Changes in media pH are commonly assessed using pH indicator dye. However, media color assessments that are done “by eye” may produce inaccurate readings. | Simple to measure with electrodes or *indicator dyes*.Cost-effective and accurate measurements. | pH sensors calibrated with traceable buffer solutions (e.g.primary standards set by NIST [National Institute of Standards and Technology]) ensure highly accurate and precise pH readings.pH meters and sensors are widely available at low to moderate costs (between US $300 -$1000). Traceable standard buffer solutions available at low cost (< US $100). Sensors compatible with sterilization and autoclaving are available.pH sensing technologies are available for non-invasive measurements in cell cultures.Color assessments of pH indicator dyes via absorbance spectrum analysis provide accurate measurements when calibrated with traceable standard buffer solutions.  |
| **Dissolved O2** | Gaseous calibrations may be required (typically a two-point calibration of 100% air saturation, and 0% O2). | Accurate tracking of O2 regimes (e.g. hypoxic exposure).Cost-effective and accurate measurements. | Dissolved O2 meters and sensors are widely available at low to moderate costs (between US $400- $2000). Dissolved O2 meters that compensate for temperature, altitude (pressure), and salinity are available. Dissolved O2 sensors compatible with sterilization and autoclaving are available.Dissolved O2 sensing technologies are available for non-invasive measurements in cell cultures.Simple calibration protocols for most sensors, typically involving air and N2 gas (100% saturation, and 0% O2, respectively). |
| **Dissolved CO2** | High-cost sensing systems.Manufacturer calibrations may be required. | Permits tracing of CO2 regimes in culture, independent of pH (and acid-base regulation). | CO2 meters and sensors can achieve accurate and precise CO2 readings. Dissolved CO2 sensors compatible with sterilization and autoclaving are available.Dissolved CO2 sensing technologies are available for non-invasive measurements in cell cultures, but some commercially available technologies are in the prototype phase. |
| **Agitation**  | Agitation rates (e.g. impeller speed in bioreactor set-ups) control shear force affecting cell experimental responses.  | Stable rates of agitation ensure accurate control of gas/atmosphere equilibration and uniform environmental conditions (i.e. prevent gradient from the air-medium interface to the cell layer). | Report rates of agitation/ flow. |
| **Relative humidity** | Variations in relative humidity are common. Affects osmolarity as well as solute and gas concentrations, that in turn, affect diffusion. | Adequate levels and control of humidity prevent changes in medium viscosity, concentrations of salts and ions, gas solubility and osmolarity.  | Low-cost sensors are available to monitor relative humidity levels inside incubators. Thermoset polymer based capacitive humidity sensors are fast, linear and are stable long-term. They also compatible with internal incubator conditions and available for in-line set-ups.Advanced control systems for relative humidity are also available, including direct steam humidification and bidirectional humidity control.  |