DESIGNED TO ALERT YOU TO SIGNS OF **RESPIRATORY COMPROMISE.**

Integrated Pulmonary Index™ (IPI) Algorithm

Monitoring respiratory status and alerting you to changes

Respiratory compromise may be defined as respiratory decompensation through insufficiency, failure, and/or arrest. It can be common, costly, deadly.

Respiratory compromise costs are projected to reach $37 billion annually by 2019.[1] Based on a 2011 Healthcare Cost and Utilization Project report from the Agency for Healthcare Research and Quality, respiratory compromise is among the top 10 conditions that are most rapidly increasing hospital costs.[2] Capnography monitoring is designed to potentially provide early alerts to changes in respiratory status. So you can act faster and intervene sooner.

Patients who develop respiratory compromise on the general care floor (GCF) have a mortality rate 29 times that of patients who don't.[3] Currently, there's no standardized and proven method of respiratory compromise risk assessment with appropriate monitoring of those at increased risk. This leads some to suggest risk stratification is not an acceptable alternative and all patients should be monitored.[4,5]

Respiratory compromise is the leading cause of ICU admissions,[6] and is one of the key contributing factors for code blues.[7,8] Hodgetts et al found that in primary respiratory arrests:

- 64% were classified potentially avoidable; of these, all had inadequate treatment prior to the event[9]
- 67% failed to respond to abnormal laboratory findings[9]

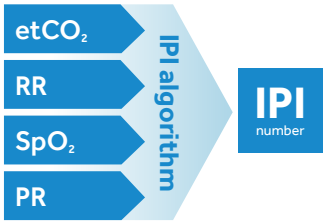
A survey of physicians and nurses found[10]:

- 92% agree continuous monitoring of patients who are at higher risk or in early stages of respiratory compromise can lead to earlier interventions, preventing further deterioration
- 84% agree respiratory compromise monitoring can save money by preventing the need for more complex, costlier levels of care (e.g., ICU admissions, ventilation)

For more information on respiratory compromise, visit medtronic.com/covidien/clinical-solutions/respiratory-compromise.

You might face tremendous challenges in monitoring multiple patients simultaneously. The IPI algorithm was developed to help you more easily monitor a patient's complete respiratory status. It incorporates into a single number four real-time respiratory measurements:

- End-tidal CO_2 ($etCO_2$)
- Respiratory rate (RR)
- Pulse oximetry (SpO_2)
- Pulse rate (PR)



The IPI algorithm number is displayed on a scale from 1 to 10, with 10 indicating a normal respiratory status. The monitor home screen displays the IPI algorithm trend to:

- Help you monitor patients at risk of developing respiratory compromise
- Provide early indication that may not be indicated by the current value of any of these four parameters individually

IPI* number	Patient status
10	Normal
8–9	Within normal range
7	Close to normal range; requires attention
5–6	Requires attention and may require intervention
3–4	Requires intervention
1–2	Requires immediate intervention

*To aid in monitoring patients over time, IPI number is captured and available to show upward and downward trends.

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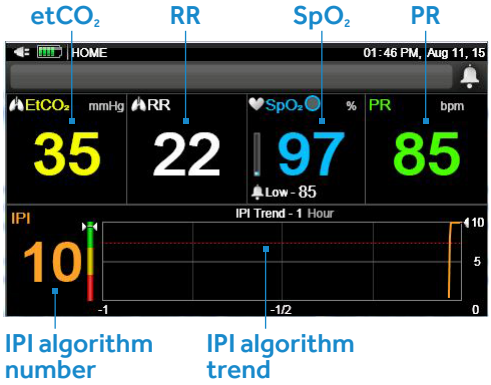

A number of papers have evaluated the clinical value of the IPI algorithm in the PACU, postoperative GCF, ICU, pediatrics, emergency department, obstetrics, and outpatient care environments. Other papers have evaluated the clinical value of IPI algorithm for alarm management and during procedural sedation and sleep testing. The results are summarized below.

General validity

- The validity of the index was tested in a retrospective analysis of continuous SpO_2, RR, PR, and $PetCO_2$ readings obtained from 523 patients in a variety of clinical settings. IPI algorithm correlated well with expert interpretation of the continuous respiratory data ($R = 0.83$, $p < 0.001$), with agreement of -0.5 ± 1.4. Receiver operating curves analysis resulted in high levels of sensitivity (0.83 to 1.00) and corresponding specificity (0.96 to 0.74), based on IPI algorithm thresholds 3–6. The IPI algorithm reliably interpreted the respiratory status of patients in multiple areas of care using off-line continuous respiratory data.[11]
- The IPI algorithm incorporated expert's knowledge into a fuzzy-logic inference. IPI algorithm number presents one value demonstrating real-time respiratory status based on RR, heart rate, SpO_2%, and $etCO_2$.[12]

Postoperative monitoring

- Code blue events were compared to the previous 20 months on each patient care unit prior to implementation as the primary outcome measure. Capnographic monitoring of patients at high risk for respiratory compromise on three surgical care floors was implemented with the IPI algorithm in September 2013. This resulted in a 65% reduction in code blue events over the following 24 months. No code blue events with high risk patients occurred since the program began. This led clinicians at the facility to consider capnography monitoring for other areas of the hospital to continue reducing code blues.[13]
- After general surgery, the incidence of respiratory adverse events (RAE) was 7% for postoperative patients with high risk of hypoventilation at PACU. IPI algorithm on admission to PACU can predict onset of RAE better than SpO_2 alone. This result suggests the necessity to measure noninvasive $etCO_2$ in addition to pulse oximetry in high-risk patients in a PACU.[14]
- The IPI algorithm number has been shown to correlate with the respiratory status of adult patients after surgery under general anesthesia. Since it's displayed as a single value, it may simplify the monitoring of patients in a busy PACU.[15,16]

Procedural sedation

- Thirty-one clinical respiratory depression events occurred in 15 patients (mean duration of clinical respiratory depression 61.4 s; 30–190). IPI algorithm detected all the clinical respiratory depression events (31/31 events), but pulse oximetry detected only 12.9% (4/ 31 events; $P<0.01$ compared with IPI algorithm).[17]
- IPI algorithm alerted all apnea episodes and hypoxia episodes, whereas pulse oximetry captured only the hypoxia episodes (IPI algorithm sensitivity = 1, specificity 0.98, positive predictive value 0.95).[18]
- IPI algorithm has been shown to correlate well with the respiratory status of pediatric patients for procedures under deep sedation. The simple display of the IPI measurement as a numeric value may be useful for nonexpert personnel monitoring patients undergoing or recovering from procedures requiring sedation. In these cases a simple tool informing the practitioner of the patient's ventilatory status and possibly promoting early awareness to changes is particularly valuable. The display was found to be clear and simple. Alarm utility, alarm thresholds, and trend display were found to be useful.[19]
- IPI algorithm monitoring adds to patient safety during endoscopic procedures in children.[20]
- IPI algorithm[21,22]:
  - Provides a measure of patient ventilation that correlates well with assessments made by GI physicians familiar with advanced patient monitoring
  - Provides relatively conservative patient assessments
  - May represent a safe and useful tool for all GI providers interested in adopting capnography into their procedure units

Alarm management

The IPI algorithm is engineered to alert clinicians to pre-defined severe or clinically significant events. This may help reduce alarm fatigue because clinicians can respond to those patients requiring immediate attention. In one study, the number of alarms was reduced significantly (by 66%) without losing sensitivity (0.999 vs. 1). Hence IPI algorithm can be used safely and may reduce alarm fatigue and the desensitization effect.[23]

Mechanical and noninvasive ventilation

- These findings indicate that in healthy subjects undergoing noninvasive positive-pressure ventilation (NPPV), IPI algorithm appears to allow detection of abnormal breathing events caused by overventilation, rapid shallow breathing, and bradypnea. These abnormal events were not identified by pulse oximetry and may not have been recognized with traditional capnography.[24]
- On this group of Medical-Surgical ICU patients, the IPI number was consistent with the interpretation of the respiratory status reflected by the ABG values.[25]
- IPI algorithm number demonstrates reasonable agreement with clinical evaluation of spontaneous breathing tests (SBTs) by respiratory therapy (RT) staff. It may be useful in predicting readiness to discontinue mechanical ventilation.[26]
- In postoperative coronary artery bypass grafting patients, IPI number demonstrates reasonable agreement with clinical evaluation of SBTs by RT staff and may be useful in predicting readiness to discontinue mechanical ventilation.[27]

Trauma

The IPI algorithm provides a measure of patient ventilation that correlates excellently with prospective definitions of clinically significant events requiring intervention. This tool may therefore simplify the monitoring of prehospital trauma patients and has value as a decision support tool.[28]

Cardiorespiratory arrest

Cumulative IPI algorithm data may be able to differentiate between patients who will eventually require intubations for critical deterioration and those who will improve without intubation.[29]

Labor and delivery

In the labor setting when remifentanil is administered, pulse oximetry is often viewed as the superior monitor for respiratory depression. However, pulse oximetry was observed to have the worst performance in detecting apnea in this setting. Measurement of RR, used through bedside assessment or as a component of capnography, may be more effective. The addition of IPI algorithm, an integrated alarm for RR, may be more effective than RR as the false alarm rate is lower.[30]

Sleep medicine

This simple composite derived from capnography and oximetry may provide a useful tool for simple assessment of the presence and severity of sleep apnea. The within-night variability of these physiologic parameters (IPI_{SD}) is the most predictive although mean composite score (IPI_{mean}) is also highly predictive.[31]

IPI algorithm under changing conditions
(gas composition, delivered flow rates, and mouth position)

The IPI algorithm variable was unaffected by the gas compositions, delivered flow rates, and mouth positions used with this adult sample during resting breathing. The most influential measured variables on IPI algorithm under these conditions were $etCO_2$, RR, and SpO_2. A single, reliable variable for respiratory status has potential clinical implications for faster assessment and response.[32]

Chronic obstructive pulmonary disease screening

In this study, IPI algorithm identified patients with poor lung function, possibly in need of intervention. IPI algorithm may have a role to screen for unrecognized pulmonary disorders and monitor outcomes of pulmonary care.[33]

Important notes on IPI alogrithm

- The IPI algorithm value is generated every second from the average of the last 15 seconds on the basis of the SpO_2, PR, RR, and $etCO_2$ parameters. By averaging the values, the IPI value is stabilized from the effects of artifact on the individual parameter values. The exceptions are a no breath alarm or when SpO_2 is "very low" (< 85%), which will immediately drop the IPI value to 1.
- IPI algorithm is available for pediatric patients (1–3 years, 3–6 years, and 6–12 years), and for adult patients. It's not available for patients up to the age of one year, and thus won't appear on screens for neonatal/infant patients.
- The IPI algorithm trend display can be set on the home screen to 1 hour (default), 2 hours, or 4 hours.
- Trend views for all parameters and IPI algorithm value can be set to 1 (default), 2, 4, 8, or 12 hours for up to 48 hours (depending on the resolution set for trend sampling) in the trend menu.
- IPI algorithm has no effect on any of the existing parameters or alarms.
- If one or more of the component parameters become invalid, the IPI algorithm value ceases to be displayed and an error "---" is displayed

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