Surgical procedures in the intensive care unit: a critical review

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Abstract
Introduction
Increasingly, surgical procedures are performed at bedside in the intensive care unit (ICU). Cost savings and gaining timely access to the operating room (OR) have helped to spur this trend towards more ICU-based procedures. Patient physiology and the patient transport concerns have made performing bedside procedures a more attractive option than the OR in certain settings.

Discussion
ICUs have begun to adapt to accommodate these bedside surgical procedures. Specialized personnel have been trained to facilitate and support procedures in some hospitals. Because the operating room remains the best location for most surgical procedures, there are only a few indications to perform bedside surgical procedures. These indications include lesser procedures for which the OR costs and transport risks are not justified or emergent procedures in patients are too unstable for transport to the OR. The most common procedures performed in the ICU include percutaneous tracheostomy, percutaneous endoscopic gastrostomy tube and inferior vena cava filter. Performing these procedures in the ICU is equally safe and more cost effective than performing them in the OR. Procedures of a more urgent nature can also be performed in the ICU and include laparotomy and damage control orthopaedics. Patient instability often dictates the need for these procedures to be performed in the ICU.

Conclusion
The operating room is no longer the only location that surgical procedures can be performed. The ICU is becoming a more common location where selected bedside procedures are being performed. Reasons to perform bedside procedures in the ICU rather than the operating room include cost savings, elimination of risks of transporting critically ill patients, and avoidance of OR availability concerns. The operating room remains the preferred location for almost all surgical procedures, but the ICU offers an attractive alternative for certain selected patients and procedures.

Introduction
Bedside surgical procedures performed in the intensive care unit (ICU) have become more commonplace in recent years. Much of this is because of the acceptance by surgeons and intensivists that procedures once thought to be performed exclusively in the operating room (OR) may be safely and easily performed in the ICU. In many cases, it has been demonstrated that significant cost savings can be achieved by performing these procedures in the ICU without sacrificing patient safety1-5. Additionally, difficulties gaining timely access to the OR, either because of patient instability or OR availability, have made bedside procedures an attractive alternative that often allows for more efficient care6-9. Most importantly, there are inherent risks to transport critically ill patients and some studies have demonstrated that serious adverse events, including death, can occur in up to 30%-45% of intra-hospital transports involving critically ill patients7-9. These risks can be mitigated by performing select procedures at bedside in the ICU.

Discussion
The authors have referenced some of their own studies in this review. These referenced studies have been conducted in accordance with the Declaration of Helsinki (1964) and the protocols of these studies have been approved by the relevant ethics committees related to the institution in which they were performed. All human subjects, in these referenced studies, gave informed consent to participate in these studies.

ICU as an OR
Care in the ICU mirrors that in the OR for a number of reasons. The monitoring and equipment capabilities in the ICU are nearly identical to the OR. Ventilators in most ICUs have mechanical ventilation capabilities beyond standard OR ventilators. While inhaled anaesthetics are not readily available, intravenous sedatives are routinely used and are easily accessible. Additionally, ICU personnel are analogous to OR staff. Critical care nurses, respiratory therapists and patient care assistants replace circulating nurses, anaesthetists and OR attendants. The scrub nurse, however, is a position without a natural counterpart in the ICU. Many hospitals have developed systems that bring the OR to the ICU. This typically involves an OR staff, which brings the necessary equipment and supplies from the OR to the ICU. This can be an arduous and difficult task, especially in time-sensitive situations or at inconvenient times, such as nights or weekends. At our institution, we employ the use of specialised procedure support nurses (PSNs) in our trauma and surgical ICUs10. These nurses are specially trained to set up

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Critical review

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of choice for tracheostomy placement\textsuperscript{12,13}. Bedside percutaneous tracheostomy (Figure 3) has been shown repeatedly to be a safe alternative to open surgical tracheostomy in the OR\textsuperscript{2,5,10}. Meta-analysis by Higgins showed percutaneous tracheostomy to have lower wound infection rates, less scarring and shorter case lengths when compared to open tracheostomy\textsuperscript{5}. Bedside percutaneous tracheostomy has been shown to be substantially more cost-effective than open tracheostomy performed in the OR. Studies have shown savings between $1100 and $3400 per procedure\textsuperscript{3,14,15}. The Johns Hopkins Percutaneous Tracheostomy Program Group showed that a hospital-subsidised multidisciplinary team performing bedside percutaneous tracheostomies can decrease complications and length of stay in ICU resulting in a net increase in hospital revenue\textsuperscript{4,6}. The safety of bedside percutaneous tracheostomy even in high-risk groups, such as the obese, was recently demonstrated in two large retrospective studies. Complication rates in high-risk patients in these studies were 1.0\% and 1.7\%, respectively\textsuperscript{10,16}.

**Percutaneous endoscopic gastrostomy**

Since its first description, PEG is a procedure, which was an obvious choice to be performed outside the OR\textsuperscript{17}. The combined endoscopic and percutaneous techniques have low risk and are relatively easy to perform at the bedside (Figure 4). Even in the initial cases, Ponsky and colleagues used only local and topical analgesia\textsuperscript{18}. Other techniques and devices exist for percutaneous feeding access, but the PEG remains the gold standard. Indications for PEG are related to the requirement for long-term feeding access and include severe neurological injuries, prolonged mechanical ventilation, inability to swallow (e.g., head and neck cancer, trauma, etc.), high risk of aspiration, severe facial trauma and severe malnutrition in debilitated or demented patients\textsuperscript{19}. Although few, but some potential contraindications to PEG are haemodynamic instability, recent oesophageal or gastric surgery, coagulopathy, inability to oppose the gastric wall to anterior abdominal wall, inability to pass a flexible endoscope and gastric outlet obstruction. Relative contraindica-

Figure 2: Dilation of tracheotomy using Ciaglia Blue Rhino\textsuperscript{®} during bedside percutaneous tracheostomy.

Figure 3: Standard equipment set up for bedside modified percutaneous tracheostomy using Ciaglia Blue Rhino\textsuperscript{®} kit.
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Laparotomy

Bedside laparotomy can be necessary in cases of abdominal compartment syndrome, severe abdominal trauma and specific emergency general surgical conditions. Abdominal compartment syndrome is often the result of aggressive fluid resuscitation after trauma or sepsis. The resultant bowel and interstitial oedema may lead to pulmonary compromise, diminished venous return and decreased cardiac output. The result is severe hypoventilation and combined cardiogenic and hypovolemic shocks. The profound haemodynamic and respiratory instability that can develop secondary to abdominal compartment syndrome obviates safe transport of the patients to the OR and necessitates immediate surgical intervention in the form of decompressive laparotomy.

Damage control operations with temporary abdominal closure have been well established in patients with severe torso injuries in the setting of the so-called lethal triad of hypotension, acidosis and coagulopathy. The initial operation is performed in the OR and is primarily focused on controlling haemorrhage and gaining source control of sepsis. A temporary abdominal closure system is typically applied, and the patient may be transferred to the ICU for ongoing resuscitation and stabilisation. The decision regarding when and where to re-operate is dependent on factors, such as operative complexity and patient physiology. Simple procedures, such as removal of intra-abdominal packing and fascial closure may be performed at the bedside in the ICU (Figure 5), particularly for patients with significant respiratory compromise requiring high levels of ventilator support. More complex procedures, such as restoration of bowel continuity may also be performed in the ICU provided the appropriate equipment is available (Figure 6), and can be considered on a case-by-case basis. Care must be exercised to maintain patient safety principles as would be expected in the OR setting.

While there are many diagnoses that may benefit from bedside laparotomy, there are few, if any, definite indications. Diaz reported the use of a protocol for bedside laparotomy. As defined by the protocol, the four primary clinical indications for bedside laparotomy in patients felt to be unsuitable for transport to the OR were as follows: abdominal compartment syndrome, acute haemodynamic instability caused by intra-abdominal haemorrhage, washout or closure of a previous open abdomen and intra-abdominal sepsis. Damage control laparotomies had previously been shown to carry higher rates of complications than the more traditional exploratory laparotomy, particularly intra-abdominal abscess and fistula. However, after employing the bedside laparotomy protocol, Diaz demonstrated intra-abdominal abscess and fistula rates that were equivalent to studies involving damage control laparotomies performed in the OR. Additionally, as with the previously discussed procedures, significant cost savings can be realised by avoiding transport to the OR with bedside laparotomy being shown to save as much as $5300 per case.

Damage control orthopaedic procedures

Just as the bedside laparotomy is a damage control procedure for general surgeons, orthopaedic surgeons are occasionally required to perform operative procedures at bedside. While there are sparse reports in the published literature of bedside orthopaedic procedures, they are frequently practiced at our institution in select circumstances. Indications for bedside...
orthopaedic procedures reflect those for bedside laparotomy with one additional indication. Reasons for bedside orthopaedic procedures include the following: compartment syndrome, haemorrhage control, debridement and irrigation of wounds and temporary fracture stabilisation in patients too unstable for transport to the OR. Ebrahim et al. recently reported the first series of bedside fasciotomies for compartment syndrome. Their study investigated 34 patients, who were treated with fasciotomies at the bedside using sedation and local anaesthetic. The authors observed an infection rate of 9%, similar to the published rates for fasciotomies performed in the OR and no deep infections, osteomyelitis, amputations or death were observed28. Haemorrhage control of an open or badly mangled extremity in unstable patients, with multiple injuries, is sometimes necessary, particularly in patients with moderate-to-severe traumatic brain injuries. Fluid and blood product resuscitation may at times be insufficient to keep up with the ongoing losses from a severely injured extremity. In these rare instances, bedside exploration and washout are required to prevent secondary brain injury from hypotension due to haemorrhagic shock. Traditional orthopaedic surgical principles would hold that formal irrigation and debridement should occur within six to eight hours. For patients with extended periods of instability preventing safe transport to the OR, irrigation and debridement can be performed at the bedside with relative ease.

Fracture stabilisation may be also performed at the bedside in a closed technique or with skeletal traction pins. However, stabilisation with external fixation is possible in the ICU as well, and our own orthopaedic colleagues will employ this in select cases. As with previous indications, these patients usually have multiple injuries and require significant critical care supportive measures. A typical scenario would include a patient, with multiple long bone fractures that are believed to contribute to a continued systemic inflammatory response.

Conclusion
It is important to remember that OR is still the preferred venue to perform the vast majority of surgical procedures. However, the OR is no longer the only location, in which operative procedures can be safely and effectively performed. Because of either necessity or convenience, the ICU has become an accessory theatre, in which surgical procedures are now routinely performed. In fact, there are some advantages to perform procedures in the ICU. Eliminating risks associated with transporting critically ill patients, avoiding OR availability issues and cost savings, are all advantages to perform select procedures in the ICU. Properly training the ICU personnel, including a specially trained PSN or mobile OR personnel, is essential for the safety and success of the ICU procedures. Additionally, appropriate patient and procedure selection for the ICU setting are paramount to minimise the risk of adverse outcomes.

Abbreviations list
DVT, deep venous thrombosis; ICU, intensive care unit; IVCF, inferior vena cava filter; OR, operating room; PSN, procedure support nurse.

References
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