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REVIEW

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Safe paediatric intensive care

Part 1: Does more medical care lead to improved outcome?

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Abstract Neonatal and paediatric intensive care has improved the prognosis for seriously sick infants and children. This has happened because of a pragmatic approach focused on stabilisation of vital functions and immense technological advances in diagnostic and therapeutic procedures. However, the belief that more medical care must inevitably lead to improved health is increasingly being questioned. This issue is especially relevant in developing countries where the introduction of highly specialised paediatric intensive care may not lead to an overall fall in child mortality. Even in developed countries, the complexity and availability of therapeutics and invasive procedures may put seriously ill children at additional risk. In both developing and industrialised countries the use of safe and simple procedures for appropriate periods, particular attention to drug prescription patterns and selection of appropriate aims and modes of therapy, including non-invasive methods, may minimise the risks of paediatric intensive care.

Keywords Paediatrics · Safety · Critical incidents · Organisation

Introduction

Does more medical care lead to improved outcome in the context of critically ill children? In rural Papua New Guinea, the introduction of oxygen for the treatment of severe pneumonia resulted in a major decrease in childhood mortality [1]. In developing countries the introduction of highly specialised paediatric intensive care may not lead to a drop in child mortality if scarce financial and human resources are thereby channelled away from improved quality of paediatric care in rural and district hospitals [2, 3].

Even within developed countries, the "law of diminishing returns" suggests that, after a certain point, additional inputs may provide decreasing additional benefit and that there may be a point at which additional growth will actually cause harm [4]. The paediatric intensivist has the choice of an increasing range of diagnostic and therapeutic techniques, both invasive and non-invasive. While increased diagnostic capacity may improve patient care, it may cause harm by: identifying abnormalities that are not actually causing problems; pressurising clinicians to treat conditions that are asymptomatic; confusing clinicians by the complexity of the diagnoses and by channelling resources away from other clinically relevant issues. Likewise, while increased therapeutic capacity may improve patient care, it may also be associated with increased iatrogenic disease and inappropriate utilisation of scarce resources. Increased complexity of care alone may be responsible for increased numbers of critical incidents, as physicians are more likely to miss important issues and the system becomes more liable to error. Neonatal and paediatric intensive care is especially vulnerable in regard to unintended consequences of care because the wide range of diseases and ages makes standardised care difficult. Anonymous, voluntary critical incident monitoring has shown the dimension of the problem [5] and in paediatric intensive care patients receiving the most intensive and invasive care are especially prone to critical incidents [5].

From the early days of paediatric and neonatal intensive care serious side effects were associated with new invasive therapies. In 1967 Northway et al. [6] described a new "pulmonary disease following respirator therapy" in neonates, which was later called bronchopulmonary dysplasia. Oxygen toxicity and baro- or volu-trauma associated with mechanical ventilation were shown to aggravate lung injury [7], partly related to the therapeutic goal of "normal" levels of oxygenation and ventilation.

Even generally accepted therapies have been shown to be harmful. Exchange transfusions for a bilirubin of more than 20 mg/dl were routinely undertaken in neonatal units until the practice was reviewed [8]. Steroid treatment for chronic lung disease of the newborn was almost routine until recent associations with neurodevelopmental outcome [9]. Even routine postoperative fluid management may be deleterious [10]. The "normal" fluid maintenance volumes used in many paediatric units are based on Holliday and Segar's work [11] and these volumes may be inappropriately high in sick children who have much lower caloric intake, lower urinary excretion rates and decreased insensible losses.

The use of invasive monitoring has facilitated the development of paediatric and neonatal intensive care. However, there are problems in assessing the exact risk-benefit ratio of many invasive interventions, e.g. pulmonary artery catheters [12]. Invasive monitoring may be inappropriate and actually harm patients. In a paediatric intensive care unit, routine use of invasive monitoring of infants with respiratory syncytial virus disease was associated with increased laboratory testing, over-treatment and significant increases in costs and morbidity without improvement in outcome [13]. Similarly, Earle et al. [14] showed that tracheal intubation and the use of central venous catheters were associated with poor outcome for low-risk patient groups in six ICUs in Central and South America. In an adult intensive care unit, the presence of an arterial line led to increased blood drawing [15] and in a neonatal intensive care unit the presence of arterial catheters increased the frequency of blood transfusions, thereby exposing neonates to, probably, unnecessary risk [16].

Even "safety systems" may add to risks: the increasing number of alarm systems in intensive care may be problematic. It has been shown that over 94% of alarms triggered in a paediatric intensive care unit are not clinically important and may distract care givers from real problems [17].

The clinical examples given above illustrate the possibility of harm from increased medical care. Problems in system structure may also cause harm as reflected by medication errors, which are a leading cause of iatrogenic complications in neonatal and paediatric intensive care [18]. The risks of neonatal and paediatric intensive care may be minimised using several approaches, as discussed below.

Use of safe and simple procedures for appropriate periods

Most of the success of neonatal and paediatric intensive care is based on an uncompromising, resolute approach to the child with overt or potential respiratory, circulatory or central nervous system failure. The first goal of this pragmatic approach is to stabilise the vital parameters of the seriously ill child according to the ABC concept (A: airway, B: breathing, C: circulation) [19].

Some questions still remain with this pragmatic approach: Should oxygen be used for the resuscitation of neonates [20]? What is the end point for volume resuscitation in children with trauma and potential bleeding? Recent experimental data challenge the approach of providing aggressive blood pressure support under these circumstances [21]. Although intubation is said to be the gold standard for airway control in children with head trauma, there is data to suggest that urgent prehospital intubation does not improve outcome and may lead to complications [22, 23].

Diagnostic and therapeutic methods must be as safe, simple, standardised and effective as possible. The procedures should be performed by suitably trained and experienced personnel. Adult data have shown that the risks of central venous access are substantially increased if the operator has less personal experience of the technique [24]. This is likely to be true in children, too.

Once invasive techniques have been instituted, they should be terminated as soon as possible. The evidence in favour of such an approach has been shown for tracheal intubation and central venous catheterisation. Complications of endotracheal intubation and mechanical ventilation in infants and children are related to duration [25]. The fact that 47–78% of neonatal and paediatric patients who have had unplanned extubations do not require reintubation [25, 26, 27, 28, 29, 30] suggests that ventilation is frequently being prolonged unnecessarily. This may be partly due to the association of failed extubation with subsequent prolonged mechanical ventilation [31]. With the use of central venous lines, vascular thrombosis [32] and line-related infections [33] are major complications that are related to the duration of placement.

Particular attention to medication prescription patterns

Clinicians have become increasingly aware of unnecessary medication and the potential to harm patients. This has been clearly shown for antibiotic use in neonatal and paediatric intensive care [34]. In addition to the danger to the patient to whom they are given, unnecessary antibiotics are potentially dangerous to other patients because of the development of multi-resistant organisms.

The number of medications given to a patient simultaneously has to be restricted because drug/drug-interactions are not foreseeable even when relatively few medications are prescribed. Furthermore, there is potential to treat side effects of drugs with the application of more drugs.

In paediatric intensive care, drug therapy is especially prone to incidents [18, 35, 36, 37, 38, 39, 40, 41], but amenable to organisational measures for improvement. The drug delivery process comprises three stages and errors may occur at each stage: prescription (wrongly or illegibly prescribed or incorrectly transcribed onto the medication chart, calculation errors and confusions of units), preparation and administration. In administration of the drug there may be problems with interpretation of wrong or misleading drug labels or packaging [35]. The following error types may then occur: dose too high or too low, drug omitted or given too frequently, wrong route of administration and wrong drug [35].

In this multi-stage process, interception plays an important role [35]. In order to improve their controlling function, nurses should have drug booklets and perform double checks on selected drugs. Furthermore, involving pharmacists in reviewing drug orders has been shown to significantly reduce the potential harm resulting from errant medication orders [38, 42]. Computerised physician order entry with clinical decision support systems has been shown to reduce the rate of errors [43, 44]. Prescriptions written on a computer can be forced to be legible and complete and applications can force constraints on clinicians' choices regarding the (weight-dependent) dose or route of administration. Using such a system, a physician cannot enter an order for a lethal overdose of a drug.

Given the number of drugs and the number of doses administered to critically ill patients, error limits will have to be considerably below 1% to avoid significant numbers of daily errors. That requires a very well structured and monitored system.

Selection of appropriate aims of therapy

One of the problems of therapy has been the delineation of the required end point and the cost of reaching that end point. In paediatric cardiac surgery there has been an evolution away from maintaining blood pressure to optimising cardiac output and decreasing cardiac work. It is likely that that sort of issue will arise in many other areas of paediatric intensive care.

Physiological (healing) processes should be integrated in treatment plans. In neonatal ICU the "minimal handling" concept has been shown to be more successful than more aggressive approaches [45]. Whenever possible, natural organ functions should be maintained. Enteral feeding is considerably safer (and cheaper) than intravenous alimentation [46]. Spontaneous breathing is preferable to muscle relaxation/fully mechanical respiratory support whenever possible. The drawbacks of neuromuscular blocking agents include a fall in lung compliance and functional residual capacity, a rise in airways resistance [47], a reduction of joint mobility in premature infants [48] and an association with the so-called critical illness neuropathy [49].

The maintenance of normal body temperature has often been an end point for the use of paracetamol. Some studies now suggest that fever may have a beneficial role in infection [50], and the World Health Organisation recommends that antipyretics be withheld in bacterial sepsis [50].

Selection of appropriate modes of therapy including non-invasive therapeutic and diagnostic methods

The application of early continuous positive airway pressure (CPAP) by nasal prongs in babies with respiratory distress syndrome (RDS) has been associated with a reduction in the requirement for mechanical ventilation and in its complications [51], although the technique does not improve the outcome with respect to mortality [52].

The World Health Organisation recommends the use of nasal prongs and nasopharyngeal catheters as a safe and efficient means of oxygen administration [53]. It has been shown that these methods, applied to infants with oxygen flows of 0.5–1.0 l/min, produce PEEP of up to 4 cmH_2O [54, 55]. These levels of PEEP are safe (although gastric distension is a potential complication if the oxygen is poorly administered [56]) and a welcome by-product because they may contribute to an improvement in oxygenation by altering the viscoelastic properties of the lung. The attributes "safe" and "efficient" are especially important in countries with limited resources for patient monitoring, equipment and supplies, such as medical oxygen. However, safe and simple methods are equally useful in the industrialised world as they have the potential to reduce the risks of therapy.

Gentler modes of ventilation have been successfully introduced. With conventional ventilation, a high-PEEP-small-tidal-volume-strategy has shown reduced mortality due to acute respiratory distress syndrome in adults [57, 58]. High frequency ventilation, the extreme of small tidal volume ventilation, has been shown to be effective in preventing chronic lung disease in preterm infants suffering from neonatal respiratory distress syndrome [59, 60]. Non-invasive positive pressure ventilation by either a nasal or oral-nasal mask is increasingly used in children with acute respiratory failure [61]. However, it has not been established whether non-invasive positive pressure ventilation can significantly decrease mortality or the incidence of endotracheal intubation in paediatric patients [61]. Non-invasive negative pressure ventilation is not widely used, because of lack of portability and limited physical access for nursing care [61].

Advances in medical technology have made it possible to replace an increasing number of invasive, and thus potentially harmful, monitoring devices by non-invasive methods: pulse oximetry, transcutaneous PO_2 and PCO_2, capnography, continuous electrocardiography to monitor heart rate and inductance respiratory plethysmography to monitor respiratory rate, oscillometric blood pressure measurement (Dinamap) and cerebral function monitoring (continuous EEG with a reduced number of electrodes and combined with a slow chart recorder [62]). Still in the research stage and not yet used in daily clinical practice are: near-infrared spectroscopy to calculate cerebral blood flow [63] and transesophageal Doppler ultrasonography to measure cardiac output [64]. Advances in bedside laboratory equipment enable us to investigate an increasing number of parameters in minimal blood volumes. As an example, capillary whole blood lactate measurements (amperometric lactate biosensor, blood volume 0.04 ml) in healthy and sick newborn babies agree excellently with arterial values [65]. Therefore, even in very small newborn infants, reliable lactate values can be easily obtained.

Pulse oximetry has become one of the most valuable monitoring techniques in intensive care, anaesthesia and emergency medicine for continuous evaluation of arterial haemoglobin oxygen saturation. In addition, it measures pulse rate, thus providing a non-electrical assessment of the patient's heart rate [66], which may be important when monitoring a pacemaker-dependent child who is at risk of respiratory failure or loss of pacemaker capture. In addition to the above-mentioned parameters, the amplitude of the plethysmograph waveform may reflect the adequacy of peripheral perfusion [67] and the amplitude of the plethysmographic respiratory wave reflects variation in intrathoracic pressure and can thus be used for continuous, non-invasive monitoring of pulsus paradoxus [68]. In infants and children at risk of pericardial tamponade, continuous monitoring of the plethysmographic pulse oximeter wave may alert the clinician when increasing respiratory-dependent fluctuations occur [69].

Appropriate staffing

Despite all the advantages of non-invasive monitoring delineated above, one has to ask the question: what is the evidence that the use of all the technology is any better than trained clinical monitoring? An indication of the importance of the presence of appropriately trained nursing and medical staff who frequently and thoroughly examine patients, has been given in critical incident monitoring. The most important method of critical incident detection was patient inspection; the rate of alarms drawing staff's attention to a critical incident was astonishingly low in view of the high numbers of monitors in use (percentage of critical incidents detected by alarms: 10% in [5] and 8% in [70]).

In resource-rich, and resource-constrained communities, there may be a tendency to try and use equipment as a means to limit expenditure on personnel. There is no evidence that ICU equipment can replace trained staff and increasing evidence that understaffing is associated with poor outcome.

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